Analysis Example – Identifying the benefits of Programmable Radiator Control Valves and Wood Burning Stoves on Domestic Heating Oil Consumption

Introduction

The following example demonstrates the process of data analysis. This is an example based on the author's own home and identifies the benefit of fitting programmable radiator valves and lighting a wood burning stove to reduce heating oil consumption.

The author lives in a rural property heated by oil (28 sec Kerosene). The hydronic heating system boiler is a Worcester (Bosch) Heatslave 20/25 which includes a small potable hot water cylinder to give 'combination' type, 'on demand' water heating. The house is detached, rebuilt to 1996 building standards, but is in a relatively exposed position at approximately 245m elevation on the East slope of one of the Clwydian hills in North East Wales, UK. The house is occupied on most days of the year with family members at home during the day.

Over the last four years the oil consumption at the property has been measured by dipping of the oil tank at various periods to record around 30 measurements per year - more in the winter than the summer. Each measurement has been recorded with additional comments on the weather, activities (visitors, etc) and whether/how often a wood burning stove was lit. The stove provides room heat only.

In March 2011, some of the radiators in the property were fitted with Pegler Yorkshire terrier i-temp programmable radiator valves (i35 horizontal models). Prior to fitting five of these valves, the radiators were fitted with good quality Thermostatic Radiator Valves (TRVs) which were adjusted for comfort and economy. The new valves were used to 'zone' the principal radiators in the living room (x2) and three bedrooms. However, two of the bedrooms only get used occasionally so like the

previous TRVs, they essentially provided a 'setback' temperature control, such that only three of the valves actively control zones most of the time. For the main bedroom and living room a control strategy was programmed into the valves so that the living room is at setback temperature (17C) during the morning heating period whilst the bedroom is set for 'occupied' (21 C) during the morning. Throughout the afternoon and evening up to 9pm, the bedroom is set to the setback temperature and the living room to the

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occupied temperature. Finally, from 9pm in the evening both the living room and bedroom are set to the occupied temperature. The remaining radiators in the property are controlled for approximately 21C room temperature by ordinary TRVs. This simple strategy avoids wasting heat at various times in areas which are unlikely to be occupied and also ensures that more heat is available to quickly heat up the occupied areas to the set-point temperature when the boiler is operating. In addition to savings from zone/time control, the rapid response and accurate temperature control offered by the programmable valves should also provide savings compared to TRVs.

It is fair to say that the use of these five valves represents only partial coverage of the home heating system, particularly as two of the valves are mainly acting as setback temperature controllers for the majority of the time. The savings that can be expected due to the fitting of the valves are likely to be less that the savings that may be achieved in a house with more occupancy and with more valves fitted.

In addition to the effect of fitting programmable radiator valves, the author also wanted to identify the benefits of lighting a wood burning stove (simple room heat output only) to show how the stove offsets oil consumption during the coldest periods. Oil consumption records (dip height) also show when the stove was lit although actual wood consumption is not recorded.

The raw data

The raw data covers the last four years, including one of the coldest winters experienced in the last 50 years. To identify the actual temperatures (and other weather data) during each oil consumption measurement period, a small weather station was installed at the property but unfortunately this proved unreliable leaving too many 'holes' in the temperature records. To obtain a reasonable proxy for outdoor temperature at the property, weather data from West Cheshire College in Chester was downloaded from their website (see http://www.west-cheshire.ac.uk/weather and go to the 'Archive' tab). Chester is approximately 20 miles from the property and typically a couple of degrees warmer (being an urban area close to sea level), but is likely to be a reasonably good proxy for temperature at the property. Although West Cheshire College's weather data is an excellent source of free weather data, in common with many such weather stations the raw data records require careful 'cleaning' and analysis to compensate for missing data and changes in recording formats (thirty minutes and ten minute periods are used at different times). The oil data (average daily consumption) and daily temperatures are shown in the chart below.

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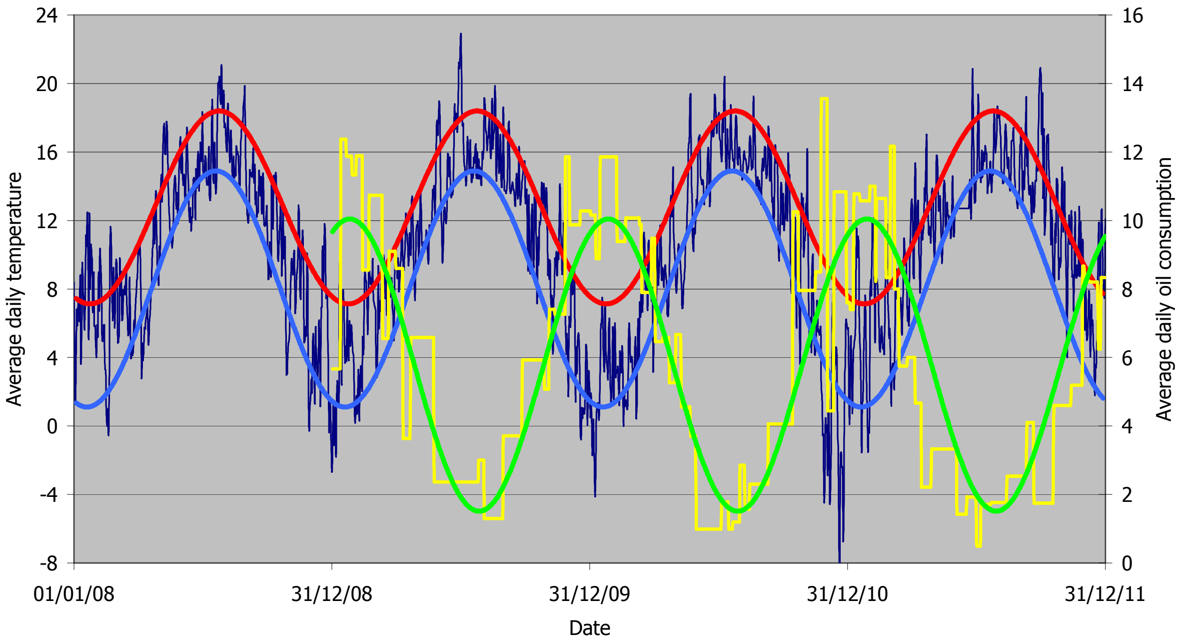
Average daily (24hr) temperature Chester UK and average period heating oil consumption at Ty Cerrig



Dark blue data points show the daily temperatures and clearly demonstrate how cold the winter of 2010/11 was with average daily temperatures (24hrs) dipping to -8C in late December. The red and light blue curves show a minimum variance fit ('least squares') of a sinusoid to the maximum and minimum daily temperatures respectively over seven days to clearly show the annual variations and to highlight extremes of temperature. The yellow points show the oil consumption per day – these are the average daily oil consumption throughout the preceding period. The green minimum variance sinusoidal fit is to the oil consumption and clearly shows (as expected) that the oil consumption is a maximum when temperatures are a minimum (180 degrees out of phase with the sinusoidal fit to temperature).

Oil data for 2008 has been rejected as the record included a long period stretching from summer into winter when only one unreliable consumption record was available due to building work which included replacing the oil tank.

It is tempting to look at the raw data and see an obvious correlation between oil consumption and how cold it is, then further to see that oil consumption during the first half of the 2011/12 winter appears to have reduced compared to previous years – possibly due to the fitting of the programmable valves in March 2010. However, such simple observations cannot identify whether any true benefit has occurred.

The Data Model

In analyses of this type, it is essential to have some form of model for the expected performance under varying conditions and parameters. At a relatively simple level, one would expect the heating requirements of a home to vary linearly with temperature as the heat loss through the walls and roof is directly proportional to the temperature difference between the inside and outside of the house. Combined with this characteristic, one would also expect a relatively constant 'base' level of consumption for water heating. In a more comprehensive analysis one would also

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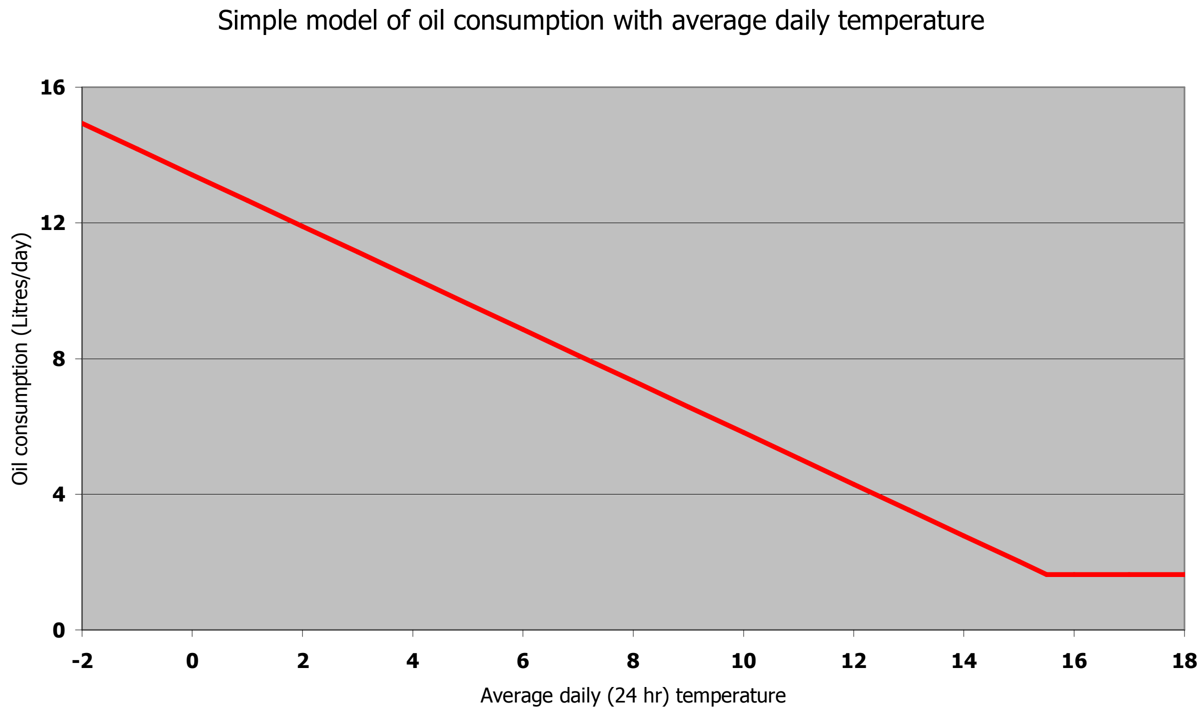
need to take account of wind speed which causes additional ventilation heat loss and solar gain which can influence oil consumption on bright but cold winter days.

A simple view of the data can be obtained by considering the degree-days Vs annual oil consumption. From the data the following were extracted:

Year	Annual oil consumption (Litres)	Annual degree days (15.5 C base)	Consumption per d-d
2009	2270	1945	1.17
2010	2258	2352	0.96
2011	1788	1690	1.06

This simple 'top level' analysis shows relatively constant oil consumption at around 1 Litre/d-d, i.e. for every degree average daily temperature below 15.5 C, the household typically consumes 1 litre of heating oil. For example, if the average daily temperature was 5 C, then the expectation is that ~10.5 Litres of oil will be consumed. However, a proportion of the oil consumption relates to water heating, which should be relatively independent of outdoor temperature. So allowing for (say) 200 Litres of water to be heated each day by 60 degrees with a boiler efficiency of 80%, suggests that approximately 1.64 Litres/day of oil will be used for water heating (based on GCV 10.7kWh/Litre for heating oil). The model can then be split into a constant daily consumption of 1.64 Litres per day and a variable of ~0.76 Litres/d-d, to give the characteristic below:



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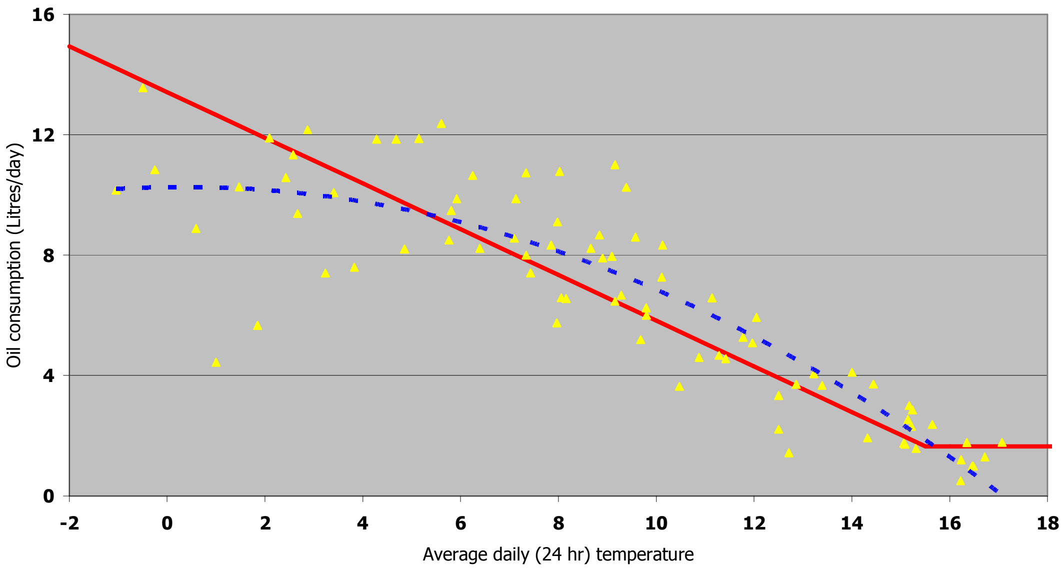
To see whether the actual daily data fits this simple model, the measured average daily oil consumption (2009 - 2011) and the average daily temperature over the corresponding periods have been added to the chart as shown below:

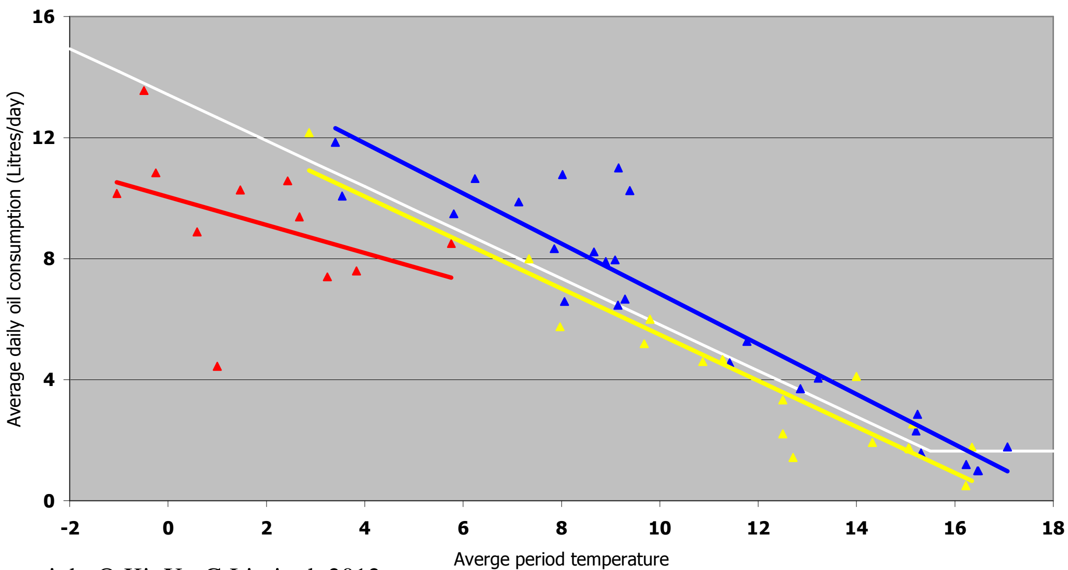
Average daily oil consumption with average daily temperature over period



Cleary the underlying model is a reasonable starting point, but the total data over three years shows a considerable spread, indicating that much of the 'mid range' consumption is generally higher than the annual analysis would suggest and some of the 'high range' consumption (at the lowest temperatures) is lower than the annual analysis suggests. This is highlighted by the simple 2nd order polynomial trend characteristic in blue.

The total data shown above contains both consumption with and without fire lighting (a good reason for lower consumption than expected at low temperatures) and consumption with and without the programmable radiator valves. As the periods when the fire was lit for all or some of the time are identified in the oil consumption records, the data can now be sub-divided to show the characteristics with and without the fire lit and to show the consumption with and without the programmable radiator valves. The chart below shows the divided data and simple linear trend plots for each set.

Oil consumption with temperature by categories



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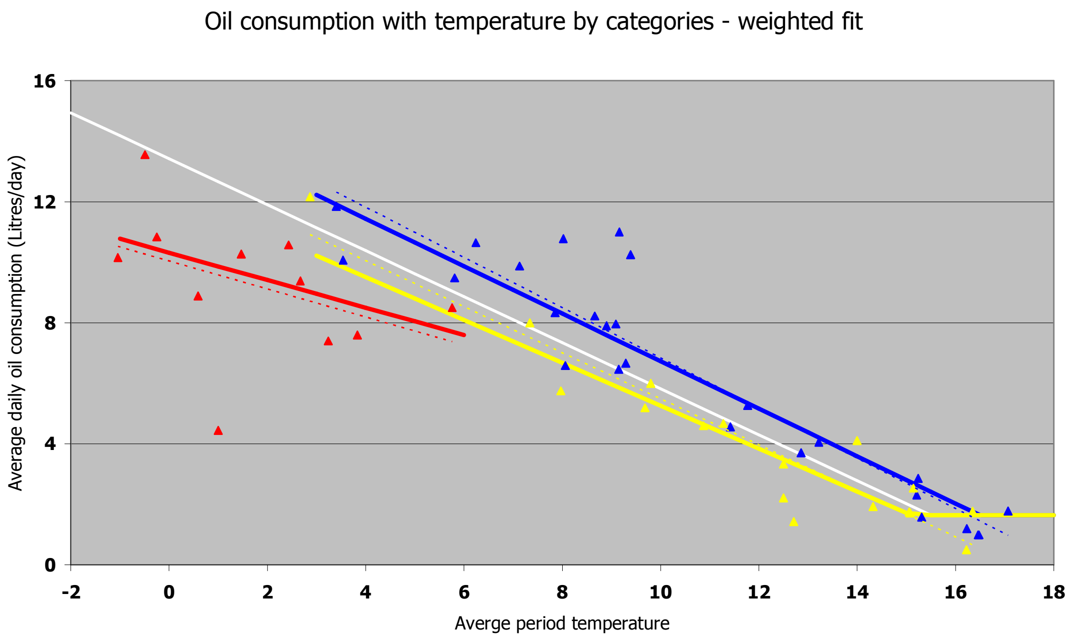
In the above chart, the blue data and trend show the characteristic during 2010 and early 2011, before the programmable valves are fitted and excluding periods when the stove was lit. The red data and trend shows the characteristic before the programmable valves were fitted for periods when the stove was lit all or some of the time. The yellow data and trend shows the characteristic for the period after the programmable radiator valves were fitted (March 2011 onwards), but excluding a couple of periods when the stove was lit. Finally the white characteristic shows the characteristic from the previous graphs based on annual consumption.

The simple trend analysis shows that the programmable radiator valves clearly save energy compared to simple TRVs, and that lighting the wood burning stove clearly reduces the consumption of oil at lower temperatures. It is tempting to simply take the trend equations and apply them to the raw temperature data to conclude the analysis by comparing the consumption that would have resulted with and without programmable radiator valves and with and without lighting the wood burning stove. However, the various data points each relate to different measurement periods and are subject to errors; some consumption data points have already been combined to account for periods when the oil is below freezing such that any water in the bottom of the tank may be frozen so giving a false result. Dipping is an imprecise measurement at the best of times, so data relating to short measurement periods is less valid than longer periods, particularly when temperatures between measurements vary considerably such that oil expansion is an issue. The simple trend analysis will also predict very low or even negative consumption during high temperature periods, whereas in reality the consumption defaults to water heating only at higher temperatures.

To accommodate the above issues, the consumption characteristics have been re-fitted to the data sets with the number of days in each period acting as a weighting factor; the error squared at each data point is multiplied by the number of days in the period when evaluating the minimum variance fit. In addition, the characteristics are both truncated to a default minimum of 1.64 Litres/day for water heating. With this improved fit, the following characteristics are derived (simple trends shown as dashed lines):



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The weighted fits show that the characteristics with TRVs and the programmable valves but without fire lighting have slightly lower consumption than predicted by the simple trend analysis, whereas the characteristic for TRVs with the stove lit has slightly higher consumption than that predicted by the simple trend analysis.

Oil Consumption Savings

The weighted characteristics represent the 'best' model of consumption as a function of temperature that can be extracted from the current data set. From these characteristics, the 'goodness of fit' can now be tested by running the characteristics against the temperature data to compare with actual oil consumption. The characteristics can also be applied to evaluate the savings achieved by the programmable valves and by lighting the stove, but sadly not the benefit of lighting the stove with the programmable valves. The actual data records when fires were lit either continuously, often or occasionally, but cannot describe when fires were not lit on very cold days or were lit on warmer days when some overheating is likely to have occurred. The only way to deal with fire lighting is to choose that the blue characteristic is followed unless the temperature drops below 5.8C when it then follows the red characteristic. The point at which the characteristics are swapped is based on the highest actual temperature point in the 'stove lit' data set.

Applying the above characteristics to weather data from 2009 to 2011 gives the following results:

Year	Actual consumption	Predicted consumption	% diff
2009	2270	2136	-5.9%
2010	2258	2280	1.0%
2011	1788	1707	-4.5%

This table shows the comparison between the actual consumption in each of the three years and that predicted by the models, including a change to the yellow characteristic (with programmable valves) in March 2011. The agreement is remarkably good considering that the actual stove lighting did not necessarily take place whenever the average daily temperature dipped below 5.8C! The best agreement occurs in 2010 which is not surprising as the stove lighting data was all taken from that year. From this comparison we can conclude that the models are sufficiently accurate to be used to enumerate the benefits of the programmable radiator valves and stove lighting as presented in the next table.

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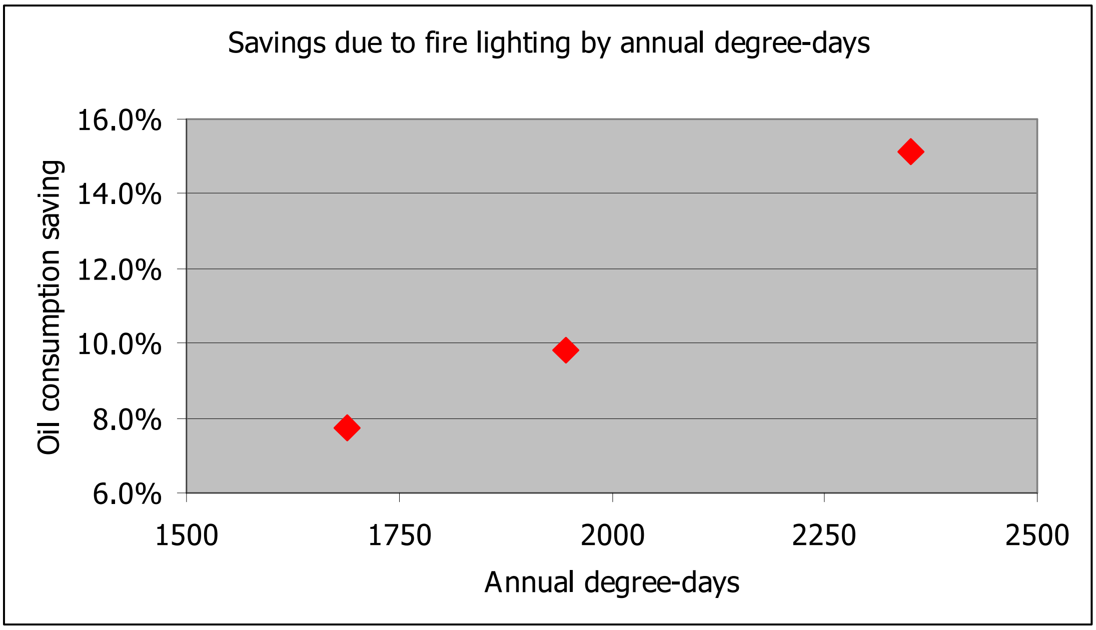
Year	Predicted without fires, TRVs	Predicted without fires, new valves	Saving due to new valves	Predicted with fires, TRVs	Saving due to fire lighting
2009	2369	1881	**20.6%**	2136	**9.8%**
2010	2687	2165	**19.4%**	2280	**15.1%**
2011	2178	1702	**21.9%**	2009	**7.8%**

This table shows scenarios to enumerate the savings that will occur due to installing the programmable valves and lighting the stove. For each of the three years the Blue characteristic was applied to the data to give the predicted consumption if the stove had been lit and only TRVs were used on radiators. This was compared to the predicted consumption if the yellow characteristic was followed for the house with some programmable radiator valves but no stove lighting. Although there are small variations (the benefit is slightly better for milder years), it is reasonable to conclude that fitting the programmable valves saves around 20~21% pa. With heating oil costing 63p/litre at the time of writing, this gives a saving in this property of around £300 a year, compared to valve costs of less than £30 each – a very worthwhile cost saving measure.

The first set of predictions was then compared to predictions based on following the blue characteristic if the average temperature was greater than 5.8C, otherwise the red characteristic – this is the same as the first table predictions for 2009 and 2010, but different for 2011 as the programmable valves are not incorporated. The resulting savings are due to stove lighting only and show variation according to the 'coldness' of the winter. As one would expect, greater benefit occurs during colder winters as the stove is more likely to be lit. To illustrate this, see the chart below comparing the savings due to stove lighting against annual degree-days.



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For the simple stove providing room heat only in this example, the analysis shows that lighting the stove on the coldest days of the winter typically saves around 10% of the oil consumption (2000 d-d), but may be considerably more during very cold winters. Although not the subject of this analysis, the FHT Stove technology developed by KinXerG Limited enables stoves to be lit comfortably on roughly twice as many days of the year, showing the clear potential to save at least twice as much oil compared to a room heat only stove.

Sadly the data contained too little information about oil consumption when the stove was lit with the programmable radiator valves, so no sensible analysis was possible. However, the accurate temperature control and fast response of such valves is likely to have resulted in radiators in the stove heated room responding more quickly to the stove output compared to TRVs, so resulting in further savings.

Conclusions

Subject to caveats concerning the quality of data available, the following conclusions can be drawn for this property:

- Fitting programmable radiator valves to the main radiators in the home can result in significant savings. With only three programmable radiator valves actively controlling zones/temperatures for the majority of the time, **a saving of ~20% was achieved**.

- For the oil heated home in this study, the fitting of a limited number of programmable radiator valves **saved around £300 pa** oil consumption and gave a simple **payback of less than six months**.

- The programmable radiator valves typically save around **1.3 tonnes of CO_2** emissions per year at this property.

- Provided the programmable valves are used as intended, it is likely that greater savings would have resulted if more valves were used and the home had greater occupancy.

- Lighting a simple room heat output stove during the coldest days of the year is likely to **save around 10%** of the annual oil consumption during a typical year (2000 degree-days, 2009), and more during colder years.

- The cost effectiveness of lighting a stove is difficult to assess as wood costs vary considerably from source to source, but in this instance the typical annual saving on oil consumption is **worth around £150**.

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