Heating Data Readme 5 Gordon Taylor 2011-08-24

Introduction

A key test in science is whether another worker or group can reproduce the results. My long-term research on the heating of buildings is independent and self-funded. As each body of work is published, I intend to put my data and calculations (spreadsheets etc) on line. I welcome the examination of these and am prepared to answer any reasonable questions.

This explanatory note applies to the determination of the Heat Losses and Solar Gains of a Test House (my own) from the heating data acquired with a data logger and a dedicated PC. This records 8 flows (pulse counts) and 14 temperatures (thermocouples), scanned at one-minute intervals, and has run for over 10 years. However, there have been some data losses, due to power cuts, failures of the logger PC and 'lockouts' of the boiler. These last were caused by limitations of the boiler controller when adjusted for best efficiency. More details and the principal results are in 'Measuring the Heat Losses and Solar Gains of Buildings via a Novel Analysis of the Data', Gordon Taylor, 2011. This was delivered at the Solar World Congress 2011, Kassel, on 2011-09-01, and is available in the Proceedings.

Notes

The 'years' start on September 16 and end on September 15. This is simply the date in the year 2000, from which 'good' data was obtained from all the instruments connected to the logger.

Each of the 'year' folders contains all the 'good' raw data files for that year. These are CSV files ending in .wl (for Windmill Logger). The 'bad' raw data files have been removed. These were only incomplete fragments, caused by power cuts or PC failures. Although 24 hours x 60 minutes/hour = 1440 minutes, the raw data files were accepted as 'good' if they had from 1439 to 1441 data lines. The long and short files arose because the (later) logger software starts the scan at clock times with 0 seconds, which sometimes miscounted. This usually came right in subsequent scans, but not always immediately. So a long file, with 1441 data lines, might be followed by several with 1440, before one with 1439.

Most raw data files are about 186 kB, and include the date in column A, as well as the time in column B. However, a significant number of data files lacked the date, so were of only about 173 kB. This was because – following a failure - the logger software had been set up wrongly. Nevertheless, the data files were still 'good' because the date is always included in the file header/title area, rows 1 to 6. For the first few data files of Year 6, which were acquired with a previous version of the logger software, the raw data files were numbered sequentially – e.g. 'therp361'. However, most of the data files used a later version of the logger software, which included the date in the filename – e.g. Therq_05100200.wl. All the raw data files were grouped into folders by year – in the present work Year 06, Year 09 and Year 10.

Most stages of the data reduction were done in Excel. This was preferred over e.g. OpenOffice Calc, due to the more polished appearance of the charts. The work started in 2000 and was done using Excel 97. The recent work started in 2011 and was done using Excel 2003. This was necessary to accommodate the ever-larger spreadsheets used for data reduction and analysis. There appears to be a difference between Excel 97 and Excel 2003 in holding information about the display of dates. When dates are transferred from one spreadsheet to another, if some are from Excel 97 and others are from Excel 2003, they may be displayed in different formats, and cannot be 'forced' to display in a single, uniform format. However, this does not cause any error, since all the dates are held internally in the same format.

1) The first stage is the production of 'day' files, which are then stored in the folder for that year. These are Excel spreadsheets with filenames ending in .xls. Rather than 'carrying forward' the extra data line through several data files, it was decided to accept files with 1439 to 1441 data lines as valid for the day. The error in flow (count) parameters was only 1 in 1440 = 0.07 %. The temperature parameters – averages for the day – were corrected by dividing the totals by the appropriate number of data lines –

1439, 1440, or 1441 – as counted in the 'day' spreadsheet, so are correct. The daily outside Temperature Swing is defined as the daily maximum Outside Temperature minus the daily minimum Outside Temperature. In addition, the times of the daily maximum and minimum Outside Temperatures were determined as checks and for use in possible future analyses.

The procedure for transferring the raw data to the 'day' files was as follows:

- Having been created earlier, an existing 'day' file (*.xls) was opened in Excel.
- The data file area from A1 to X1447 was selected and the contents cleared (with Delete).
- The raw data file (*.wl) was dragged to the 'day' file icon on the Task Bar, causing it to open in a new Excel spreadsheet.
- The valid (non-zero) data file area from A1 to X1447 (usually) or X1446 or X1448 (occasionally) was selected, then copied and pasted into the 'day' file at A1. However, where the raw data file lacked the date, the valid (non-zero) data file area was from A1 to W1447 or W1446 or W1448, and was pasted into the 'day' file at B1. The chart of the Space Heating temperatures versus Time of day at A1450 is an excellent check on the completeness and validity of the 'days' data.
- The 'day' file was then saved with a name including the date, usually the same filename as the original data file, but as a spreadsheet – e.g. Therq_05100200.xls.

So each of the 'year' folders should contain all the valid raw data files for the year, plus an equal number of matching 'day' files. However, there are a few extra raw data files (*.wl) that have not been used to date. They look 'bad' but have been kept in case it is possible later to use them to produce 'day' files.

2) The second stage in reducing the heating data was to assemble all the valid 'day' data into a 'year' file. In practice, the latter included more than one year, to enable the results for different years to be compared both numerically and in charts. The 'year' Summary files are spreadsheets containing the algorithms necessary to calculate the final results for each day. These include the electricity input (to the boiler etc), the gas input (as energy) and the gas (boiler) thermal efficiency. The sum of the first and the product of the last two (the gas heat) is here defined as the 'Total Heat' for the day. With the daily average Outside Temperature and the daily Outside Temperature Swing, as transferred from the 'day' files, the Total Heat is the third parameter of the 3D data arrays used in the Taylor Method.

The procedure for transferring the 'day' results to the 'year' files was as follows:

- Having been previously created, an existing 'year' Summary spreadsheet was opened in Excel.
- Starting with that for September 15 or the first valid one thereafter, each 'day' file was also opened in Excel.
- In the 'day' file, the results line, A1448 to AC1448, (highlighted in Turquoise), was selected and copied into the 'year' file, at columns A to AC at the bottom of the sheet, usually below that for the previous day. With the results for up to 365 days (less 'lost' days) to be transferred, this can take two days to carry out. Clearly it would be very helpful if this process could be 'automated' with the use of 'macros' or even programming in VBA. However, this has not yet been explored. Moreover, handling the case of 'lost' day files may present problems. Meanwhile, where data for one or more days were 'lost', the results for the following day were highlighted (in Rose).

The 'year' Summary file thus contains all the 'day' results for all three years. Charts of all the values of daily average Total Heat plotted versus the daily average Outside Temperature are at DG35, DG380 and DG694. These show that – for the Heat Losses to be represented as a single straight line – the data must exclude those days for which the Space Heating is zero and the Total Heat is only for DHW (tap water) Heating. This was done by truncating the data set at an Outside Temperature of 20 C.

However, the 'year' Summary file was originally developed for analysing the boiler and electricity input very extensively, which work has not yet been published. Therefore this file will only be published after this work. In the meantime, the values for the daily average Outside Temperature, the outside Temperature Swing and the Total Heat in the 'year' Array spreadsheet will have to be taken on trust.

Even so, this data may still be used to examine and validate the crucial surface fitting stage of the Taylor Method.

Furthermore, since the raw and 'daily' files are provided, those who would like to validate the above derived values would still have the option of doing so for themselves. To that end, I intend to provide the necessary information about the Higher Heat Value of the gas, the correction of gas volume readings for temperature and pressure and the calibrations (per count) of the gas meter, the rain gauge (used to measure the condensate) and the electricity sub-meter.

From the 'year' Summary file, columns O, AD, and AQ were copied to columns A, B and C of a new 'year' Array spreadsheet. This allowed the day results lines for each year to be sorted on daily average Outside Temperature (column A), and days with Outside Temperatures greater than 20 C discarded.

3) The third stage and the core of the Taylor Method is the fitting of a surface to the array of 3D data – the daily average Outside Temperature, OT, the daily outside Temperature Swing, TS and the daily Total Heat, TH. The time period was usually one year (less 'lost' and discarded days).

Time periods of a half-year were also explored, often with start dates other than September 15 (or as soon as possible thereafter). For example, to ensure that the Outside Temperature range for the half-year was as large as possible, the start date was chosen as that of the highest Outside Temperature for the year. If 'day' results were available for only one year, but those for a second half-year were wanted for comparison, the latter was completed by adding those for the unused portion of the first half-year. In other words, to enable the creation of two complete half-years with an arbitrary start date, the data results were 'wrapped around'. This was originally done using data for Year 10 that had been reduced by a slightly different procedure, which had resulted in several fewer days of 'good' data. However, although included in the paper, the description and files from this work have been omitted to avoid confusion.

When seeking software capable of 'finding functions' that fitted such 3D data, that available online at www.zunzun.com was found. This is at least comparable to software packages costing several hundred dollars, but can be used online for free. As well as the coefficients for the chosen function, together with 'fit' parameters, such as R2, this package can output all the results in a pdf document. Moreover, it can also output a VRML file showing the 3D data points and the fitted surface. This may be viewed in a suitable viewer, such as the Cortona plug-in that is available for the Microsoft Internet Explorer and Mozilla Firefox browsers. (www.cortona3d.com). Such a viewer allows the data points and fitted surface to be viewed interactively from any direction, so allowing their relative positions to be judged. Hence the zunzun 3D software was used for most of the present work analysing and modelling the Heat Losses and Solar Gains of buildings. For the present work, the surface chosen was a plane, known as a 'linear' function.

Once a suitable surface (function) had been found, it was possible to fit the 3D data in Excel, using the LINEST function. However, Excel works with fewer significant figures than the zunzun package and cannot produce a VRML file of the data points and surface. For the only case compared to date, the fewer significant figures do not materially affect the final results – the Heat Losses and Heat Loss Coefficients and the Solar Gains.

The procedure for determining first the 3D function and then later just the coefficients of the chosen surface was as follows:
- From the 'year' Array file, the reduced (truncated) arrays of the daily average Outside Temperatures, OT (as X), the daily outside Temperature Swings, TS (as Y) and the daily Total Heats, TH (as Z) for each year were saved as .csv files.
- The zunzun package was accessed at http://www.zunzun.com
- The 3D surface function type was chosen. For the present work, it was the 'linear' (plane) function, which has the form Z = a + b*X + c*Y.

- The data axis labels were set to X = OT, Y = TS, and Z = TH as short forms suitable for reference in the results and in the VRML files.
- The number format was set from Scientific Notation On (the default) to Off.
- The 3D data set as a .csv file was opened e.g. in a browser window, then copied and pasted into the data entry window of the zunzun 3D package.
- The processing time was usually short, whereupon the results could be saved. The most convenient form is as a .pdf document, which includes every possible plot of the variables, together with the 'fit' statistics, including R2, and a fixed 2D view of the 3D data points and fitted surface. There is also the option to save a VRML file of the data points and fitted surface. With a suitable viewer, such as the Cortona plug-in for Microsoft Internet Explorer and Mozilla Firefox mentioned above, this may be viewed interactively from any direction.

The input and output files for this stage are in the Surface Fitting folders for each year.

4) The fourth stage was the production of the final results. The procedure was as follows:
- the equation and coefficients 'a', 'b' and 'c' were read from the zunzun .pdf documents and entered into the 'year' Array and Results spreadsheet at Column D (i.e. D9 for Year 6, D327 for Year 10 and D675 for Year 9). These equations were copied down the length of the array for each year.
- The value of Y – i.e. the Temperature Swing was set equal to zero to represent extrapolation to zero Solar Gains. (In practice, some of the equations seemed to be indeterminate with Y = 0, so Y was instead set = 0.001. Since the units are Kelvin, this was near enough for the purpose).
- The values of Total Heat for each Outside Temperature so extrapolated were here defined to be the Heat Losses and the resulting line to be the Heat Loss line.

For the present work, the Metabolic Gain was taken as that for one adult present at all times. The metabolic rate was taken as 100 W, giving a daily Metabolic Gain of 2.4 kWh. For the present work, the Electricity consumption was taken from quarterly bills, totalling 2400 kWh for a year. The Electricity Input to the boiler etc was measured by the sub-meter and data logger as about 100 kWh for a year. Hence the Electricity Gain was taken as 2300 kWh for a year – i.e. 6.3 kWh a day. The sum of the daily Total Heat, the Metabolic Gain and the Electricity Gain was defined to be the Internal Heat. Then for each 'day' point, the difference between the Heat Loss and the corresponding Total Heat (i.e. the Gross Heat Loss and the corresponding Internal Heat) was defined to be the Solar Gain for that day.

In the 'year' Array and Results spreadsheet, the Heat Loss was shown in column D, the Internal Heat in E, the Gross Heat Loss in F, and the Solar Gain in G.

Charts of the Total Heat v Outside Temperature, together with the Heat Loss line, for Year 6 were shown at H9, for Year 10 at H327 and for Year 9 at H675.

Charts of the Internal Heat v Outside Temperature, together with the Gross Heat Loss line, for Year 6 were shown at H53, for Year 10 at H372 and for Year 9 at H720.

Charts of the Total Heat v Outside Temperature for Year 10, together with the Heat Loss lines for Years 6 and 10 were shown at H416, and for Years 9 and 10 at H765.

Charts of the Internal Heat v Outside Temperature for Year 10, together with the Gross Heat Loss lines for Years 6 and 10, were shown at H461, and for Years 9 and 10 at H810.

A chart of the Internal Heat v Outside Temperature for Year 10, together with the Gross Heat Loss lines for Years 6, 9 and 10, was shown at H507. In this last chart, the equations of the three Gross Heat Loss lines were also shown. (These result from the equations input at D9, D675 and D327 plus the Internal Gains of 8.7). These were used to determine the daily Gross Heat Losses at an Outside Temperature of 0 C. Also, multiplying these by 1000/24 and dividing by the X-intercepts gave the Heat Loss Coefficients.

E.g. for Year 10, with the Gross Heat Loss line having the equation Y = - 5.1269 * X + 129.78, the Gross Heat Loss at 0 C = 129.78 or about 130 kWh per day. Also, the X-intercept = 129.78/5.1269 = 25.3 C and the Heat Loss Coefficient = 129.78 * 1000 /(24 * 25.3) = 213.7 W/K or about 214 W/K.

As noted in the above-mentioned paper, Year 6 was before the only thermally significant change to the house - the addition of more insulation in Year 7 - while Years 9 and 10 were both after. Comparing the results of Year 6 (Before) with those of Year 10 (After), the additional insulation reduced the Gross Heat Loss at 0 C by about 12% and the Heat Loss Coefficient by about 13%. Comparing the results of Year 10 (After), for Year 9 (After) the Gross Heat Loss at 0 C was only about 0.7% greater and the Heat Loss Coefficient only about 0.5% less. These suggest that the additional insulation was effective and that the Heat Losses determined by the Taylor Method are notably consistent from year to year.

The Solar Fraction is here defined as the total Solar Gains divided by the total Gross Heat Losses. In this work, these results are determined for each year. Although the data for some days were 'lost' and discarded (as OT > 20 C) in each year, this affected both totals. Also, such discarded days account for little or no Solar Gains, since the latter cannot contribute to DHW (tapwater) heating, which accounts for almost all the Total Heat load when the daily average Outside Temperature > 20 C.

The Solar Fraction for Year 6 was 0.196, for Year 9, 0.208 and for Year 10, 0.214. Hence the average value for the Test House is about 21%. However, Year 6 was before more insulation was added, whereas Years 9 and 10 were after. While the annual insolation can vary, these results suggest that adding more insulation increased the Solar Fraction.

Like the Solar Gains, the Internal Gains (Metabolic and Electricity) cannot contribute to DHW (tapwater) heating, which accounts for almost all the Total Heat load when the daily average Outside Temperature > 20 C. Therefore, in these conditions, the daily Internal Heat = the daily Total Heat. So in the Heating Array and Results spreadsheet, in all the charts of Internal Heat v Outside Temperature, the data points for daily average Outside Temperatures > 20 C are shown too high by 8.7 kWh/d. However, they play no part in determining the Heat Losses or the Solar Gains.

Finally

I would welcome the application of the Taylor Method of determining the Heat Losses and Solar Gains of buildings to your data. Since this need not include the insolation, but only the Outside Temperature (to determine the average daily Outside Temperature and the daily Outside Temperature Swing (= OT max – OT min) with the daily Total Heat (from the boiler or other heating equipment), there should be plenty of existing data. All group and district heating schemes that use heat meters should have access to the daily Total Heat and may well have access to suitable Outside Temperature data. Otherwise, nearby weather stations should be able to provide Outside Temperature data at say hourly if not minute intervals.

I would also like to see more consideration of the physics behind the Taylor Method – both meteorological and of (building) heat transfer. This would guide and explain the choice of the 'best' surface (function) to be fitted to the 3D data.

If you think that this explanatory document could be improved, or you have comments and questions about the data and the Taylor Method, please contact me by email at: gordon@energypolicy.co.uk

Gordon Taylor, 2011-08-24.