MEASURING THE HEAT LOSSES AND SOLAR GAINS OF BUILDINGS VIA A NOVEL ANALYSIS OF THE DATA

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1. Abstract

The work was prompted by published results for Passive Houses, showing that the Total Heat from the heating system is much less than the Gross Heat Loss, as calculated with a steady-state thermal design procedure. (Feist, 2006). Solar gains account for most of the difference but would be extremely difficult to measure directly. Other gains come from electrical appliances and lighting and from the occupants, which are easy to determine from electricity meter readings and known metabolic rates. Direct measurement of the Gross Heat Loss is also impractical, since days with zero solar gain – i.e. heavily overcast - are very rare. The paper describes a method of determining the Heat Losses and hence the solar gains from the Total Heats supplied by a gas-fired central heating system with auxiliary electricity input. The novel analysis is based on the observation that days with high solar gains are associated with large Outside Temperature Swings – the differences between the maximum and minimum - and assumes that they are proportional. Total Heat values inherently vary, so the method uses data sets for extended periods, such as a year. The Total Heat, Outside Temperature and Temperature Swing values are fitted by a plane surface, so that extrapolation to zero Temperature Swing and solar gain gives the Heat Loss line over the range of Outside Temperatures. Adding the electrical and metabolic gains gives the Gross Heat Losses. For the test house, which faces near-south but has no special solar features, the solar gains over a typical year were about 20% of the Gross Heat Losses.

The method should be applicable to all new and existing buildings, including those with group or district heating. These may use heat-only boilers or co-generated heat, from fossil fuels or renewable energy from e.g. solar, wind or biomass. Indeed it should be even easier to apply in these cases, since the heat supplied is often already metered and logged, as are the outside temperatures. Also, by using the method before and after, it enables the experimental determination of the effectiveness of insulation and air-change measures in place. Since most existing buildings will remain in use for many decades, such a method for determining their gross and net heat demands will help to meet the challenges of fossil fuel depletion and climate change.

2. Introduction

The work was prompted by published results for Passive Houses, showing that the Total Heat from the heating system is much less than the Gross Heat Loss, as calculated with a steady-state thermal design procedure. (Feist, 2006). Solar gains account for most of the difference but would be extremely difficult to measure directly. Other gains come from electrical appliances and lighting and from the occupants, which are easy to determine from electricity meter readings and known metabolic rates.

The cost of gas and electricity for the present test house will soon be about £ 1100 a year and energy in buildings accounts for around half of all UK final energy, which costs many billions of pounds a year. Moreover, from 2016, the UK Building Regulations for Low Carbon Homes are to be based not on 'as designed' but on 'as built'. This will require not the estimation - as hitherto - but the measurement of Heat Losses and Solar and other Gains.

2.1. The HWB Method

Determining the Heat Losses and Solar Gains of the Linford houses in Milton Keynes in the 1980s was described in Everett et al, 1985. Page 1.4 shows the test results as the 'fabric heat loss excluding floor' and 'the solar aperture'. The method is creditted to Siviour, 1981. However, it is a heat balance method that treats the house as a flat plate solar collector and uses a transformation of the Hottel-Whillier-Bliss analysis. (Duffie and Beckman, 1974). The analysis is sometimes elaborated, with separate terms for the floor heat loss and the ventilation loss. (Everett et al, 1985, Pages 1.4 and 8.2). It requires a solarimeter to relate the heat input to insolation, then extrapolates to zero insolation and hence zero solar gains. As used by the Open University Energy Research Group, the HWB method requires relatively little equipment – a solarimeter and data logger plus gas and electricity meters. To experience a good range of insolation, it should be carried out in Spring or Autumn. It requires e.g. 13 days but should not be carried out while the house is occupied.

2.2. The Co-heating Method

A test to determine the Heat Loss of the first active solar house in the UK was carried out by the Built Environment Research Group at the Polytechnic of Central London. It is a heat balance method, using the inbuilt heating system to establish a range of inside-outside temperature differences for periods of about 8 hours per test. The insolation and the ventilation rate were also measured, in order to determine the fabric loss coefficient. These were used in monthly energy balances. (Horton et al, 1979).

A very similar procedure, termed the 'Co-heating method' was developed by the Centre for the Built Environment at Leeds Metropolitan University. It is a also heat balance method, but uses temporary electric fan heaters to establish a range of inside-outside temperature differences. Initially the windows were shuttered during the test. (Bell and Lowe, 1998). Later the electric heat inputs were corrected for solar gains. This was via a regression equation of the mean daily electric input power versus the mean daily insolation measured on a vertical surface and the mean daily inside-outside temperature difference. The building Heat Loss Coefficient (input power over temperature difference) was then determined by extrapolation to zero insolation. The Co-heating method requires relatively little equipment - electric heaters, fans and meter, a solarimeter and a data logger. For adequate inside to outside temperature differences, it should be carried out in the Winter half year. It requires about 3 days pre-heating, followed by a test period of at least 7 days, but should not be carried out while the house is occupied. (Wingfield et al, 2006 and Wingfield et al, 2010).

2.3. Convergence

Example data from a Co-heating test – input power, inside-outside temperature difference and insolation – gave a Heat Loss Coefficient of 132.9 W/K. (Wingfield, 2011). When subjected to the HWB (Siviour) analysis, it gave the essentially identical value of 133.5 W/K. This is because the HWB and Co-heating analyses are transforms of each other.

3. Present Work

3.1. The Test House

Fig. 1: The test house.

The test building is a two-storey, 4-bedroom, detached house with a floor area of about 100 m2. (Fig. 1). The ground floor is a concrete slab, with no insulation. The walls are of brick, with nominal 50 mm cavities, filled with Urea Formaldehyde foam. The outside doors and windows are double-glazed, with frames of uPVC. The roof is tiled, with about 150 mm of fibreglass mat between the horizontal rafters. During the test period, an additional 170 mm of fibreglass mat was laid over the rafters.

The test house has only natural ventilation, so the air change loss depends on the Inside-Outside temperature difference - the 'stack' effect – and on the wind speed and direction. (Everett, R. et al., 1985. Section 9.4). However, according to a simple thermal model of the test house, the air change loss is only about 10 to 20% of the total. So with the windows kept closed, the Heat Loss line should be reasonably consistent.

The Gross Heat Loss line is an attribute of the building at a given Inside Temperature. It should be independent of location, orientation and the climate. So it should apply reproducibly to the given building design - assuming that it is built as designed. However, even a reproducible building shell, with consistent fabric and air change losses, is not sufficient to ensure that - as built - a building performs as designed, with the declared energy (fuel) consumption and CO2/GHG emissions. It is also necessary to have heating equipment and controls that ensure the designed heating system performance and efficiency. Only then could buildings be comparable to cars and their engines, which are designed, built and sample tested to this end.

3.2. Heating System and Controls

Field trials – notably of novel heating systems, such as heat pumps and micro-chp units - have shown that the heating equipment often fails to perform as expected. (Anon, 2010). This usually reduces the thermal efficiency and increases the energy (fuel) consumption and CO2/GHG emissions. Moreover, Solar Gains depend upon the orientation and geometry of the house - causing shading - and on the properties of the windows. Hence determination of the Heat Loss line requires subtraction of the Solar Gains. However, the Heat Losses also depend on the Inside Temperature and would be affected by overheating in the presence of solar and other gains. So the heating system controls should maximise the use of these and minimise overheating.

In the present case, the heating was 'on' continuously, to maximise thermal comfort and boiler efficiency. Temperature control was via an 'outside temperature compensator' built into the boiler control and thermostatic radiator valves on every radiator. These allowed different target temperatures in the various rooms and minimised overheating by reducing the radiator outputs of those receiving solar and other gains.

3.3. Instrumentation and Data Logging

Fig. 2: 1 Boiler, 2 Rain Gauge, 3 Electricity sub-meter, 4 Heat Meter-Boiler, 5 Heat Meter-DHW, 6 Screen of Data Logger PC.

To determine the boiler efficiency and the outputs to space and water heating, instruments have been installed – a data feed from the existing gas meter, a rain gauge to measure condensate, an electricity sub-meter, and two 'certified' heat and flow meters. (Fig. 2). Of these last, one is set across the boiler and the other across the DHW storage cylinder. These measure 8 flowrates (counts), which – with 14 temperatures (thermocouples) - have been logged on a PC at one-minute intervals for over 10 years.

Data logged at one-minute intervals has proved very suitable for studying the operation of a gas boiler, which often fires intermittently, and for calculating the gas heat and efficiency. The monitoring - and subsequent adjustments - has enabled the consistent achievement – with radiators – of annual average boiler efficiencies of about 96% on the Higher Heat Value basis. This is significantly higher than the SEDBUK value for the boiler - of about 90%.

3.4. The Taylor Method

The Taylor Method is also a heat balance method, and uses the inbuilt heating system to provide the inside-outside temperature differences. One purpose is to determine the Heat Losses and Solar Gains with greater precision than is possible in short-term tests. Due to the large number of data points, this should be achieved even with ‘random’ factors such as wind and rain. This also overcomes the limited resolution of some measurements – e.g. 1 kWh for the electricity sub-meter and for the two heat meters and about 0.31 kWh for the gas meter. However, the results still depend upon the measurements and calculations being free from systematic errors.

3.5. Measurement of Data

In the present work, the data was acquired by the above instrumentation and data logger. When logging over extended periods - months to years - it is very hard to avoid data loss. (Ebel et al, 2003). One reason is power cuts. Several have occurred in the 10+ years and were usually less than an hour. However the logfile was spoilt, so the day's data was lost. Another reason was failures of the logger PC - which have all been old - in continuous operation. They were usually less than a day, though sometimes longer if a change of PC was needed. Also the data would not be valid if the boiler failed by 'locking out'. This was due to limitations of the controller when adjusted to maximise thermal efficiency and was corrected by ‘resetting’. They too were usually less than a day. However, all the above could cause data losses of several days if the house was unoccupied. For some analyses data could be restored by interpolation, but this was not done in this case.

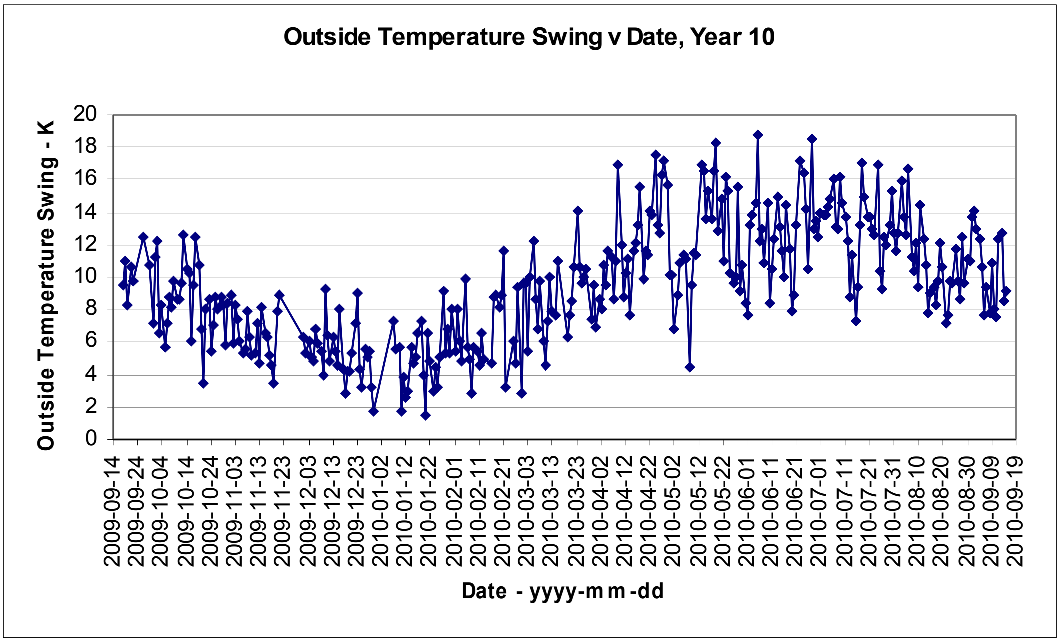

Fig. 3: Plot of Outside Temperature Swing vs Date, Year 10.

The Temperature Swing varies sharply from day to day. (Fig. 3). This is due to rapidly varying cloudiness and means that data losses cannot usefully be restored by interpolation.

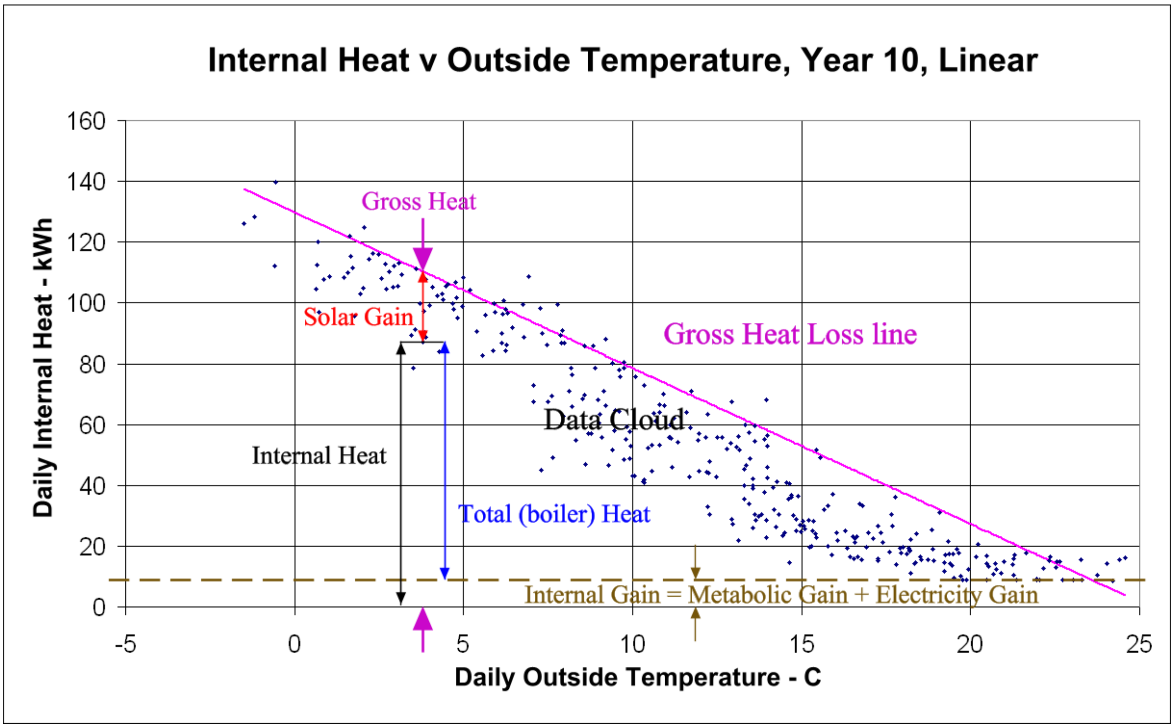

Fig. 4: Explanatory Diagram of Heat Flows vs Outside Temperature for a building.

For the test house, the Daily Total Heat was plotted against the Daily Average Outside Temperature for a year at a time, similar to Fig. 4. This is sometimes called an 'Energy Signature'. (Day, A. 2006). To determine the building Heat Losses as a linear function of the 24-hour average Outside Temperature, the data of days with no space heating but only DHW heating must be omitted from the analysis. In this case, this was done by discarding the data of days with average Outside Temperatures greater than 20 C.

A straight line at around the upper edge of the truncated data cloud would be the Heat Loss line, with the vertical difference between this and the data points of the daily Total Heat values being due to Solar Gains. (Feist, 2006). The slope of the Heat Loss line is the Heat Loss Coefficient.

The electricity consumption for appliances and lighting may vary over the year, yet this was only available from quarterly bills. The annual Electricity Gain was about 2400 kWh, less the electricity input to the heating system of about 100 kWh, hence a daily value of 2300/365 = 6.3 kWh. The Metabolic Gain for one adult was taken as 100 W = 2.4 kWh per day. The Electricity Gain plus the Metabolic Gain – the Internal Gain - was taken as constant over the year. When added to the daily Total (boiler) Heat and Heat Loss, this gives the daily Internal Heat and the Gross Heat Loss. Fig. 4 shows daily Internal Heats and the Gross Heat Loss line.

The Gross Heat Loss at a given Outside Temperature depends on the building fabric and air change rate and the Inside Temperature. It should be independent of the weather and consistent between years with no change – e.g. in insulation level. However, the Heat Loss Coefficient allows buildings to be compared independent of the Inside Temperature and the Internal Gain. The Taylor method usually requires data for times periods of a year, but this would often be needed in any case, to determine the energy performance and efficiency of the heating system.

The measurements have not included the insolation, so the Solar Gains could not be determined directly. As it happens, this would be particularly problematic for the test house since - of the south-facing windows – that of the Study has a roof overhang, that of the Lounge has a flanking wall, and all such windows, including that of the Hall and two for Bedroom 1, are affected by the presence of a cherry tree, which gains and loses leaves over the year. Other buildings might also be subject to shading from neighbouring buildings, which – due to the motion of the sun - again would change over the year.

Initially the Heat Loss line was positioned relative to the data cloud 'by eye'. Days with Total (boiler) Heat values on this line have zero Solar Gains. However, some values were above the line, implying heat losses higher than for 'steady state'. This could be due to winds causing higher air change losses or to the house warming up after a long interruption in heating. However these days were not many in a year and for these the daily Total Heat was taken as the Heat Loss for that Outside Temperature. The Heat Loss line then gave the daily Heat Losses and – by subtracting the Total Heats – the Solar Gains. Although this gave plausible values for the Heat Losses and Solar Gains, an objective, 'science-based' method was sought.

The Taylor method uses a novel analysis based on the observation that the daily insolation is related to the daily Outside Temperature Swing – the difference between the minimum and maximum Outside Temperatures. Both upward swings in OT during the day and downward swings in OT at night are related to the clarity (the opposite of the cloudiness) of the sky. Hence the daily Temperature Swing is greatest when the sky is clear and least when it is heavily overcast and is assumed to be a direct function of the daily Solar Gain. So after fitting a 3D surface to the data set (x = Daily Average Outside Temperature, y = Daily Temperature Swing, z = Daily Total Heat), extrapolation of the Temperature Swing to zero should give the Heat Loss line, where the Solar Gains are zero and the Outside Temperature is constant over the 24 hours, much as Fig. 4.

If daily insolation data was available, it could be used instead of the daily outside Temperature Swing. The solarimeter should preferably be located nearby, as in the HWB method, and ideally installed vertically, parallel to the south-facing windows of the test building, as in the Co-heating method. In such a case, a 3D surface could be fitted to the data set (x = Daily Average Outside Temperature, y = Daily Insolation, z = Daily Total Heat), and extrapolation of the daily Insolation to zero should also give the Heat Loss line, where the Solar Gains are zero and the Outside Temperature is constant over the 24 hours, much as Fig. 4. Compared with the 2D regressions used in the HWB and Co-heating methods, this variant of the Taylor method would still have the advantages of a larger data set obtained while the building was occupied.

The numbers of days with data and days with OTs less than 20 C for Years 6, 9 and 10 are given in Tab. 1.

Tab. 1: Days with Data and Days with Average Outside Temperatures less than 20 C, for Years 6, 9 and 10.

Time Period	Days with Data	Days with OT < 20 C
Year 6	307	274
Year 9	329	297
Year 10	336	301

3.7. The 3D Software

Various 3D surfaces were fitted to the data sets. (Tab. 1). The 3D surfaces (functions) were found and the coefficients calculated using a very powerful software package, available online and for free. (http://www.zunzun.com). It would have been far too tedious to use Excel as a 'function finder', since each function would have to be set up individually. However, once suitable function types were found, the coefficients can be calculated in Excel, using the LINEST function.

3.8. Fitting the 3D Surface to the Data

For this paper, the type of 3D surface chosen was a plane, termed 'Linear'. This has the form:

$TH = a + b \times OT + c \times TS$

Example values of the coefficients are given below. (Tab. 2).

Tab. 2: Coefficients of 'Linear' Surface fitted to 3D data.

Coefficient	Example Values (for Year 10, Linear)
a	1.2108487031717381E+02
b	-5.1268724669712418E+00
c	-1.7279661588663637E+00

The ‘zunzun’ 3D software package can generate VRML files of the data points and fitted surfaces that may be viewed interactively from any direction. (Fig. 5).

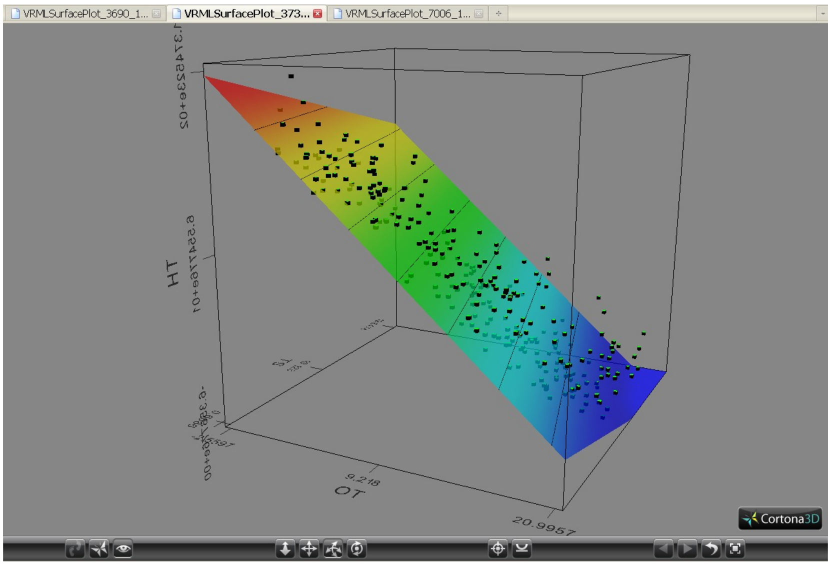

Fig. 5: Still of VRML file for 3D surface, Year 10, Linear.

Relative to the fitted surface, the individual data points have 'offsets' above and below. This could be due to varying cloudiness. However it could also be due to the house fabric and contents storing and releasing heat, carrying energy from one day to the next. Moreover heat may move between the floor slab and the ground, which – compared with the walls and roof - is less tightly coupled to the outside air. No attempt was made to correct for this, unlike in the HWB method. (Everett, 1985, p 1.4). However, where the HWB method uses data from about 13 days and the Co-heating method from at least 7 days, the Taylor method uses data from 365 less 'lost' and 'discarded' days, so all such effects should be averaged out far better.

4. Results using the Taylor Method

4.1. Time Period – Year and Half-year

The Heat Loss lines for Year 10, half-year 10A and half-year 10B were compared (Fig. 6).

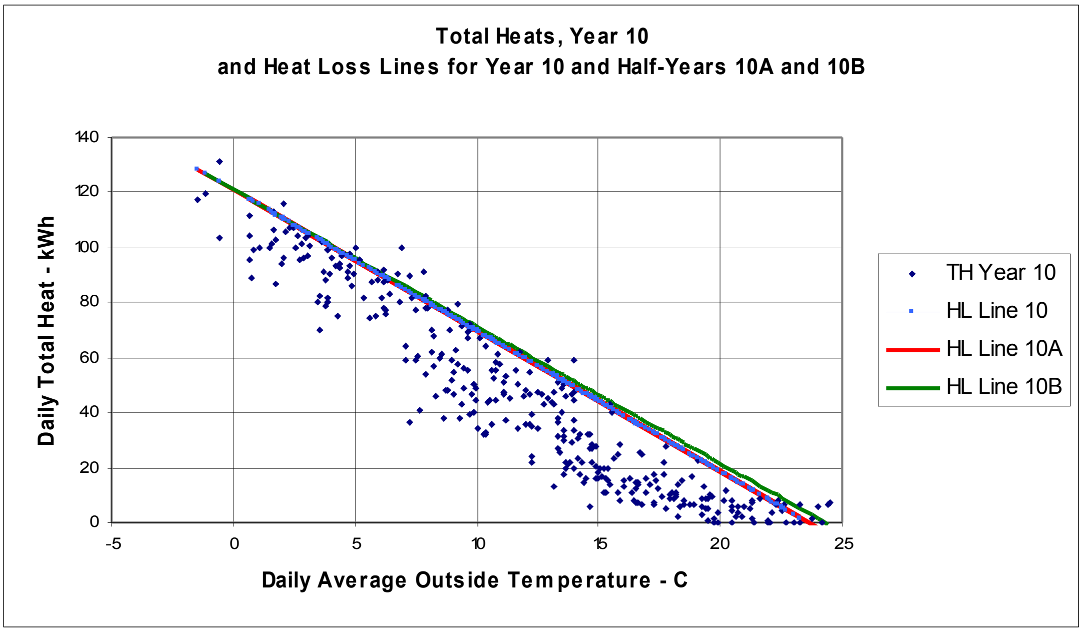

Fig. 6: Daily Total Heats, Year 10 and Heat Loss lines for Year 10, half-year 10A and half-year 10B.

Tab. 3: Heat Losses and Heat Loss Coefficients for Year 10, half-year 10A and half-year 10B.

Time Period	Daily Heat Loss at 0 C – kWh	H. L. Coefficient - W/K
Year 10	121	213
Half-Year 10A	121	213
Half-Year 10B	121	207

4.2. Heat Losses and X-intercepts

The 3D data sets for Years 6, 9 and 10 were fitted with ‘Linear’ surfaces, with R^2 values as in Tab. 4.

Tab. 4: R^2 Values for Linear Surfaces fitted to 3D data for Years 6, 9 and 10

Time Period	R^2 Value for Linear Surface
Year 6 (Before added insulation)	0.9258
Year 9 (After added insulation)	0.9244
Year 10 (After added insulation)	0.9205

The daily Internal Heat values for Year 10 were plotted versus the daily average Outside Temperature, together with the Gross Heat Loss Lines for Years 6, 9 and 10. (Fig. 7).

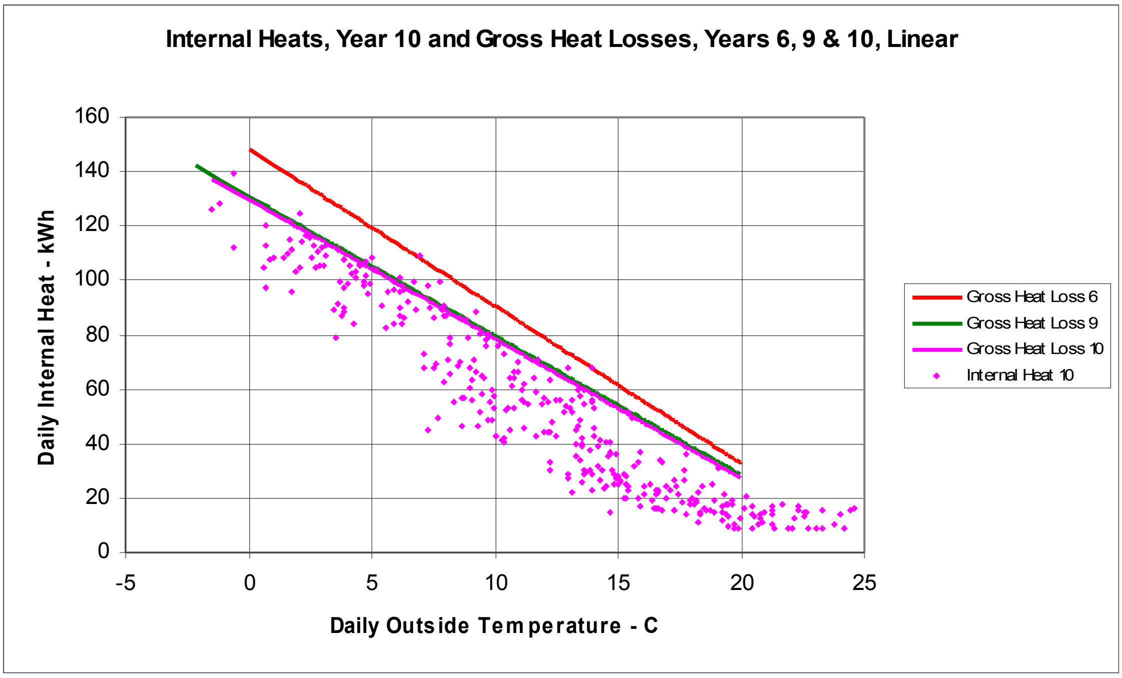

Fig. 7: Daily Internal Heats for Year 10, with Gross Heat Loss lines for Years 6, 9, and 10.

The Linear surfaces fitted to the data for Years 6, 9 and 10 were extrapolated to zero TS to give the Gross Heat Losses at 0 C and Heat Loss Coefficients (Tab. 5), together with the X-intercepts (Tab. 6).

Tab. 5: Gross Heat Losses and Heat Loss Coefficients for Years 6, 9 and 10.

Time Period	Daily Gross Heat Loss at 0 C– kWh	H. L. Coefficient - W/K
Year 6 (Before added insulation)	148	241
Year 9 (After added insulation)	131	213
Year 10 (After added insulation)	130	214

Tab. 6: X-intercepts for Years 6, 9 and 10.

Time Period	X-intercept - C
Year 6 (Before added insulation)	25.6
Year 9 (After added insulation)	25.6
Year 10 (After added insulation)	25.3

In the 10+ years of data logging, there was one change to the test house that should have affected the Heat Losses – increasing the thickness of insulation in the loft (roof space) from 150 to 320 mm in Year 7.

Between Years 9 and 10 (both After) for the Linear surfaces, the Gross Heat Losses at 0 C differ by only 0.7% and the Heat Loss Coefficients by less than 0.5%. (Tab. 5).

Between Year 6 (Before) and Years 9 and 10 (After) for the Linear surfaces, due to the added insulation, the reduction in Gross Heat Loss at 0 C is about 12% and in the Heat Loss Coefficient about 13%. (Tab. 5).

4.3. Solar Gains

Some days have suffered data loss and days with Outside Temperatures above 20 C were discarded. (Tab. 1). However such days account for very little heat, of which almost all is for DHW heating, which does not benefit from Solar Gains. Hence it is possible to estimate the Solar Fraction as the total Solar Gains divided by the total of the Gross Heat Losses for the truncated data set. (Tab. 7). Although based on less than 365 days, the data sets are large and the same for Solar Gains and Gross Heat Losses.

Tab. 7: Solar Fractions of the Gross Heat Losses for Years 6, 9 and 10.

Time Period	Solar Fraction
Year 6	0.196
Year 9	0.208
Year 10	0.214

So the Solar Gains as a fraction of the Gross Heat Losses for all the valid days with Average Outside Temperatures of less than 20 C is about 0.2 or 20%.

5. Discussion

To determine Heat Losses and Solar Gains of buildings, the HWB and Co-heating methods require only one or two weeks. However, the energy performance of buildings depends also on the efficiency of the heating system. Only direct electric heaters and district heating have efficiencies of 100%, relative to that metered. With combustion heaters, such as boilers or air heaters, and micro-generators, such as heat pumps and micro-chp units, this varies significantly with load and/or outside temperature. The Taylor method may require more instruments - gas meter, rain gauge, electricity sub-meter, and two heat meters, but no solarimeter – and would require a test period of a year or maybe a half-year. It can be used while the house is occupied but, like all such tests, requires a consistent heating and ventilating regime, with no window opening. This may be easier for a single occupant than for a family - except in a Passive House, which usually has Mechanical Ventilation with Heat Recovery.

The comparison of the HWB, Co-heating and Taylor Methods is summarized in Tab. 8.

Tab. 8: Comparison of the HWB, Co-heating and Taylor Methods for Measuring the Heat Losses and Solar Gains of Buildings.

Criterion	HWB (Siviour) Method	Co-heating Method	Taylor Method
Heating by:	Inbuilt system.	Electric fan heaters.	Inbuilt system.
Time Required:	Short, e.g. 13 days.	Short, at least 7 days.	Long, one year or half-year.
Time of Year:	Spring or Autumn.	Winter half of year.	Any or months 1-6 or 7-12.
Heat measured by:	Gas meter, El. meter.	Electricity meter.	Gas & El. meters, rain gauge.
Solarimeter:	Yes, serving whole site.	Yes, aligned to windows.	No.
House Occupied:	No	No	Yes
Heating Efficiency:	No	No	Yes

Hence the Taylor method may be used to determine the Heat Losses and Solar Gains of the building and - at the same time - the efficiency, fuel consumption - and thus the CO_2/GHG emissions - of the heating system.

5.1. Time Period – Year and Half-year.

The widest OT range occurs over a full year, but it may also occur over a half year, provided that this starts at about the date of the lowest or highest OT. Compared to the Heat Loss line for the full Year 10, that for Half-year 10A is virtually identical, and that for Half-year 10B is very close, and identical at 0 C. (Fig. 6). The Heat Loss Coefficients for 10 and 10A are identical, and that for 10B is within 3%. (Tab. 3). Since the analysis removes the Solar Gains to determine the Heat Loss line, it should not matter if they differ during the two halves of the year. However, 10B could have been affected by the differing state of the cherry tree. Moreover, considering Winter and Summer half-years not only reduced the OT ranges, but also gave Heat Loss lines that differed appreciably both from each other and from that for the full year.

5.2. Heat Losses and X-intercepts.

Daily Heat Losses at 0 C and Heat Loss Coefficients are shown in Tabs 3 and 5. (The Year 10 data set in Tab. 5 was re-processed, recovering five formerly 'lost' days). Tab. 3 shows the former as daily Heat Losses, excluding the Internal Gains. Tab 5. shows them as daily Gross Heat Losses, including the Internal Gains. Except for Year 6, the daily Heat Losses at 0 C – after allowing for the daily Internal Gains of about 9 kWh between Tab.3 and Tab. 5 - are within 0.9%. Also, except for Year 6, the Heat Loss Coefficients, which are independent of the Inside Temperature and Internal Gain - are within 3%. If that for Half-Year 10B is excluded, this becomes 0.2%. As expected, both parameters are significantly higher for Year 6, since this was before more insulation was added. So for all other years and half-years, both parameters are highly consistent and thus very suitable for comparison with those from detailed thermal models.

Both the German Passive House Planning Package (PHPP) and the UK Standard Assessment Procedure (SAP) use the building steady state Heat Loss Coefficient multiplied by degree-days, with internal and solar gains subtracted, to estimate the annual energy. (Reason and Clarke, No Date).

For the Rychenburgstrasse multi-family Passive House, the 'Heizkennlinie' would intercept the x-axis at about 24 C. (Guetermann, A. 2002). Furthermore, the Passive Houses at Hoerbranz had an average daily inside temperature of about 23 C. (Feist, 2005). As average daily inside temperatures, these are very close. For the Passive Houses at Kranichstein, the 'Heizgerade' line intercepts the X-axis at 15 C. (Feist, 2006). This is far below any likely daily inside temperature. However, another Heat Loss line could be positioned relative to the given 'data cloud' that would give a more likely value of the X-intercept.

For the present test house, the Gross Heat Loss line, including the daily Internal Gains, obtained using the Taylor method with the plane 'Linear' surface, intercepts the X-axis at about 25.5 C. (Tab. 6). This is fairly close to the highest target room temperature – that of the Lounge at 23 C. Also, a line through the data cloud - i.e. including the daily Solar and Internal Gains - for Year 10 would give a Balance Temperature of about 22 C. (Fig. 7).

These results for the test house are for the 3D data fitted with plane 'Linear' surfaces. However, other 3D surfaces are possible, which give slightly different values for the Heat Loss Coefficient and the X-intercept.

5.3. Effects of insulation and air-change measures.

The Taylor method allows the determination of the Heat Losses and Heat Loss Coefficient with high consistency, even with some data loss. So it is very suitable for determining the effects of insulation and air change measures and for comparison with those from detailed thermal models.

5.4. Wider application of the Taylor Method

The Taylor method should be applicable in field trials of all innovative buildings, including Passive Houses, which have very consistent air change losses even in family occupation. These are often monitored for comparison with detailed thermal models. With no need to measure insolation, it should also be applicable to all new and existing buildings, including those with group and district heating. Energy suppliers could analyse existing customer data and report the results to them. The energy use - hence Heat Losses – the Heat Loss Coefficients and the Solar Gains could show the savings to be made by reducing Inside Temperature and by installing additional insulation and air change loss reduction measures. Such results should also be of particular interest to Energy Service Companies and for informing energy policy at all levels.

6. Conclusions

The HWB and Co-heating methods generate the same types of data and the two analyses are equivalent – being transforms of each other. The tests take only about 10 days or so, and are thus compatible with both refurbishment and new construction. However, they can determine only the Heat Loss Coefficient and the Solar Gains during the test, whereas the annual Solar and Internal Gains and the performance and efficiency of the heating system also affect the energy and CO2/GHG emission performance of buildings.

The Taylor method was developed using data originally obtained to determine the efficiency and outputs of a heating system – specifically one with a gas condensing boiler. It requires no insolation measurements but the Heat Losses and Solar Gains are determined from the daily outside Temperature Swing, which is extrapolated to zero. Even with some data loss, it can determine Heat Losses to within less than 1%. The short-term methods can correct for Solar Gains with insolation measurements during the test. However, to determine the annual Solar Gains where there is shading by other buildings and trees requires testing over a full year. So too does the determination of the Internal Gains and the heating system performance and efficiency. Thus the short-term HWB and Co-heating methods and the long-term Taylor method are essentially complementary.

The Taylor method enables the energy performances of the building and the heating system to be separated, when assessing energy and fuel consumptions and CO2/GHG emissions. This could inform all field trials, including of Passive Houses, which are often monitored. It should also be applicable to all new and existing buildings, including those with group and district heating. These may use heat-only boilers or co-generated heat, from fossil fuels or renewable energy from e.g. solar, wind or biomass. Indeed it should be even easier to apply in these cases, since the heat supplied is often metered and logged, as are the outside temperatures. Energy suppliers could analyse existing customer data, to advise them of their energy saving options. Also, by using the method before and after, the effectiveness of insulation and air-change measures may be measured 'as built'. Such findings should also inform energy policy at all levels. Since most existing buildings will remain in use for many decades, such a method for determining their gross and net heat demands will help to meet the challenges of fossil fuel depletion and climate change.

7. Glossary

Balance Temperature – X-intercept of line through the data cloud, taking account of Solar Gains.
Co-heating Method – Procedure and analysis for measuring the Heat Losses and Solar Gains of buildings.
Data cloud – a cluster of data points on a plot, here usually of daily Heat versus Outside Temperature.
Degree-days – parameter multiplied by Heat Loss Coefficient of building to estimate annual energy use.
DHW - Domestic Hot Water (i.e. hot tap water).
Electricity Gain - here taken as all that for lights and appliances, less Electricity Input to the boiler etc.
Electricity Input – energy to boiler controller, fan, pumps and diverter valve.
Gas Heat = Gas Input x Gas Efficiency (on the Higher Heat Value basis).
Gas Input – energy calculated from gas meter readings and the declared Higher Heat Value of the gas.
GHG – Greenhouse Gas.
GHL - Gross Heat Loss = Internal Heat + Solar Gain
Heat Loss Coefficient of building - here taken as (Gross Heat Loss at 0 C)/X-intercept
Higher Heat Value – Gross Calorific Value of the gas used in the boiler.
HL – Heat Loss = Total (boiler) Heat + Solar Gain
HWB Method - Hottel-Whillier-Bliss analysis and Procedure for measuring Heat Losses and Solar Gains.
Internal Heat = Total (boiler) Heat + Internal Gain
Internal Gain = Metabolic Gain + Electricity Gain
Metabolic Gain - here taken as 100 W for one adult.
OT - Daily Average Outside Temperature.
Taylor Method – Test Procedure and analysis for measuring the Heat Losses and Solar Gains of buildings.
TH - Total (boiler) Heat = Gas Heat + Electricity Input (to boiler etc).
TS - Daily Outside Temperature Swing = Daily Maximum Temperature – Daily Minimum Temperature.
SEDBUK - Seasonal Efficiency of Domestic Boilers on the UK Market.
X-intercept – here of Gross Heat Loss line on plot of daily Heat Loss vs daily average Outside Temperature.

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The data and spreadsheets used in this paper are available at: http://www.energypolicy.co.uk

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