CeBE Centre for the Built Environment

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The Coheating Test: The value of a number

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Introduction

Climate change, fuel poverty and energy security are significant drivers to the reduction in energy required to heat our homes. The European Energy Performance of Buildings Directive (Directive 31/10/EU) requires the participating countries to reduce the energy needed to heat and cool buildings. The performance targets are determined by each member state and should provide as a minimum a cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building (Directive 31/10/EU). Achieving significant reductions is also necessary to meet the 20% reduction in green-house emissions, with respect to 1990 levels, agreed at Kyoto (UN, 1998).

The building industry is being made to consider building practices by the use of legislative instruments and in some cases, by customer demand. In the UK, Building Regulations will require increasingly stringent thermal performance between now and 2016, when the "zero carbon" design standard will be required. However, occupied dwellings are observed to consume more energy than the models predict at design stage. The difference results because the models do not accurately represent the reality with respect to the users' behaviour, and the performance of the dwellings and its systems are lower than expected in the design.

The development of suitable test methodologies, to understand whether buildings are performing as designed and where failings occur, is required in order to achieve the necessary improvement in thermal performance. Leeds Metropolitan University CeBE group have used the coheating methodology, as part of suite of tests, to understand the heat loss mechanisms within a dwelling. First used by the group as part of the York Demonstration project in 1991-1992 (Bell and Lowe, 1998), CeBE will have completed over 40 tests by the end of the winter 2012 (Johnston, 2012). Over this period, the method has been developed and refined from that laid out by Everett (1985) and Lowe & Gibbons (1988) to the form described by Wingfield (2011) and Johnson (2012). The availability of better, more affordable equipment over the intervening years has supported the development of the test methodology.

The coheating test: theory and methodology

Equation 1 shows the heat balance of the dwelling. Heat loss occurs as fabric and ventilation losses. The rate of heat loss through the fabric is proportional to the temperature difference between inside and out. Heat energy input to the dwelling comes from electrical input to the heaters, and casual gains from other electrical equipment and solar gains.

$$Q_{input} + Q_{solar\ gain} = \left[\{U * A\} + \frac{1}{3}nV\right]\Delta T$$

Equation 1

Where

Q_{input} is the power supplied by the electrical resistance heater (and additional incidental heat input) (W)

Q_{solar} is the solar gain (W)

U is mean u value of the fabric ($Wm^{-2}K^{-1}$).

A is the surface area of the fabric, at the insulation/air barrier boundary (m^2)

n is the air change rate (derived from the pressure test using rule of thumb

V is volume of the dwelling, within the thermal envelope. (m^3)

ΔT is the difference between mean internal and mean external temperature (K)

The coheating test is designed to determine the heat loss coefficient (HLC) ($\{U * A\} + \frac{1}{3}nV$) by measuring the other factors. The temperature difference, ΔT, is determined by measuring internal and external temperatures and taking daily averages. A constant temperature is achieved throughout the test dwelling using thermostatically controlled electrical resistance heaters; fans are used achieve even heat distribution preventing thermal stratification. Temperature is monitored in several locations within the property and used to give a mean internal temperature. External temperature, irradiance and wind speed is measured using a weather station. The heat input, using the heaters is measured using kilowatt-hour meters and used to give an average power input. The contribution to the heat input from solar gains reduce that required from the heaters; this is accounted for in the analysis using solar irradiance data collected using pyranometer. A regression and correction for wind speed is also applied.

There are two methods used to calculate the heat loss coefficient. The main difference between them is how they account for solar gains to the property. The test measures irradiance at the weather station. Some of the irradiance falling on the dwelling is absorbed by the fabric of the dwelling and some passes through the windows and raises internal temperature, reducing the heat demands.

In order to correct for these gains Leeds Met University undertake a linear regression, relating the heat input, temperature difference and irradiance. The regression analysis gives a value for the solar aperture and describes the required correction to the heat input. This average daily power input is plotted against the temperature difference, as shown in figure 1. The gradient of the line represents the heat loss coefficient. In houses built as part of the typical United Kingdom housing stock the correction is in the order of 10% however, for passive house, which are designed to maximise solar gains the correction can much larger.

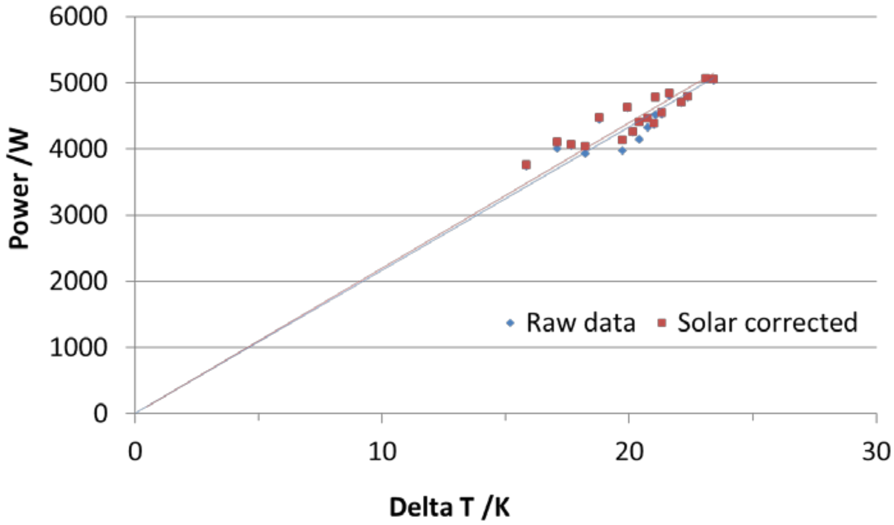


Figure 1: Graph showing coheating test results

The second method as described by Siviour (Everett et al., 1985) uses normalised power and irradiance data, normalised to temperature difference, as shown in Figure 2. When a straight line is plotted through the points; the gradient is the solar aperture and intercept is the heat loss coefficient.

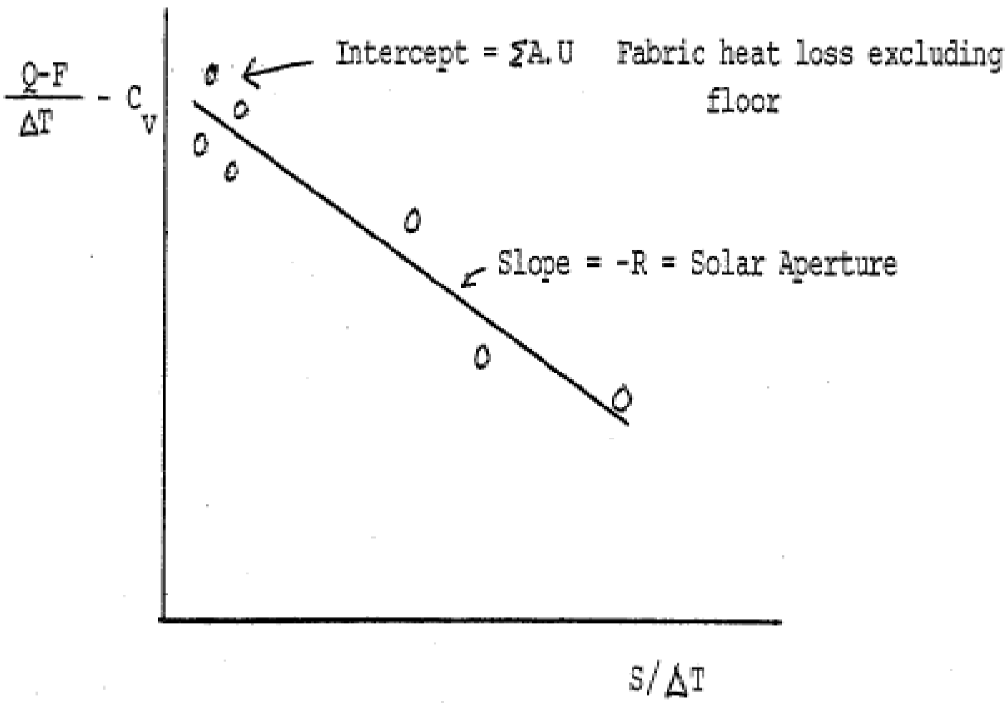


Figure 2: Example of a siviour plot (taken from Everett (1985))

By using daily average values the thermal lag, where internal temperatures are buffered by thermal mass in the dwelling absorbing and releasing heat more slowly than the air, is accounted for. By analysing from midnight to midnight, it is assumed that any solar gains stored by the mass of the building during the day are released before the next day.

The analyses give a value for heat loss from the whole dwelling (the heat loss coefficient) expressed as Watts per degree Kelvin (W/K) and solar aperture. By using a blower door to determine the ventilation losses, the fabric heat loss is determined to be the remainder.

The following sections discuss what can be understood from these values and some of the difficulties of comparing the results from different tests. From this a number of suggestions for how results should be presented to enable comparison are given. The limitation of the heat loss values derived from the test are that the values described the performance of the house and not of individual elements. The use of additional testing during the coheating test can both support the description of the heat loss mechanisms by investigation of the behaviour of individual elements exploring large scale effects.

The heat loss coefficient

The heat loss coefficient (HLC) is the value that is extracted from the coheating test data and describes the rate of heat loss from the whole dwelling. This value is often used in comparison with the as-designed data to assess whether the fabric performs as designed.

Using the heat loss coefficient during the stepped improvement of a property enables the magnitude of each action to be understood and compared. However, the value is sensitive to dwelling size: larger dwellings with the same design performance would be expected to have a larger heat loss. As such, comparisons of test results which are often between buildings of different sizes are difficult to assess.

In order to improve the comparability of tests between dwellings of a number of descriptors have been devised. These are described in the following sections. So that the impact of each of the descriptors can be better displayed, graphs showing the test result from CeBE testing are shown. In each graph the results from a test undertaken at Elm Tree Mews, York (Wingfield et al, 2008) are highlighted against the other results, and it’s ranking within the results is shown above.

Figure 3 shows the heat loss coefficient results.

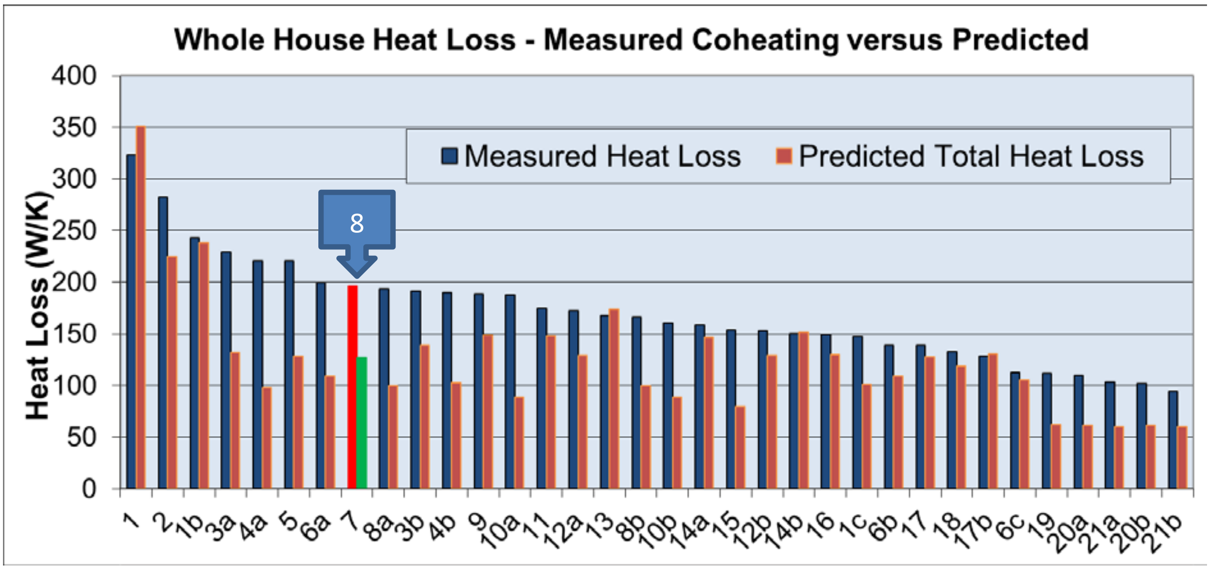


Figure 3: Predicted and measured heat loss coefficient:

Performance gap

Often, it is the difference between the expected and the actual thermal performance, the performance gap that is of interest. By presenting the difference as a percentage, the scale to which buildings underperform compared with their design: the "performance gap" has been highlighted (figure 4). The performance gap, as a concept, has been accepted and understood across the industry with groups such as the Good Homes Alliance (GHA, 2012) and the Zero Carbon Hub (2010) who have adopted and used it to influence Government and possible to persuade many important groups within the industry and government that significant attention should be given to whether dwellings actually perform, so that the industry can learn to produce dwellings that perform as expected. There is a need to develop methods of construction that will deliver performance within a known tolerance.

Presenting the performance gap as a percentage disguises the carbon and energy consumption impact of the shortfall in performance. As such 25% underperformance may be presented as the same for a passiv haus as for a house designed to meet Building Regulations whereas the actual impact of in annual energy consumption for heating could vary significantly.

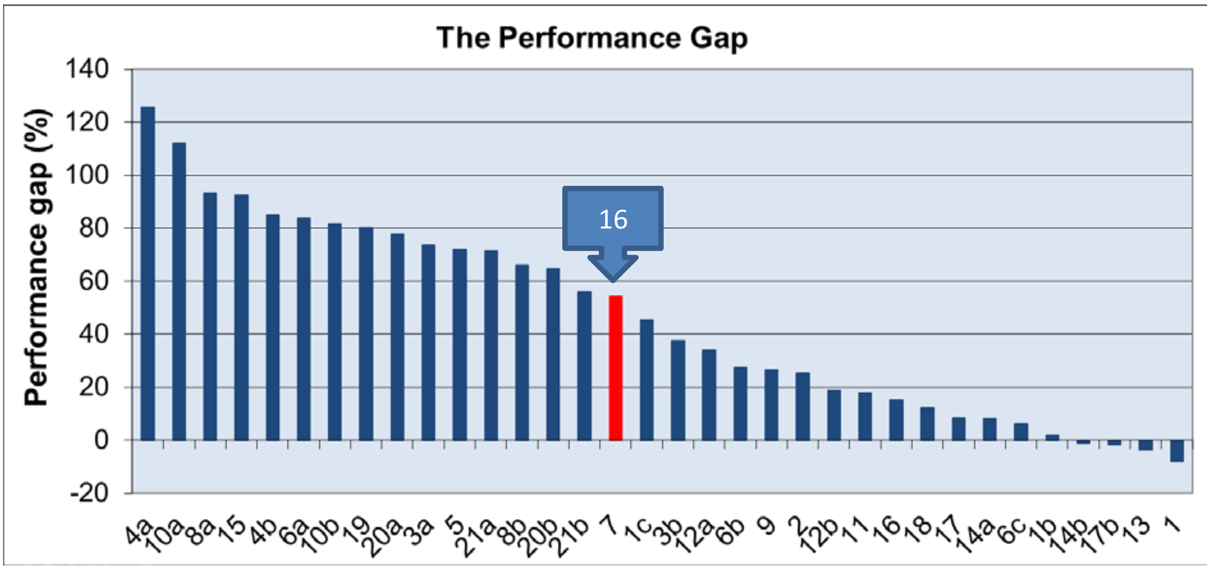


Figure 4: The performance gap

Heat Loss Parameter

To enable the more direct comparison of dwellings the HLC is normalised. By normalising values with respect to floor area or to the total surface area of the fabric enables the comparison of performance between dwellings on a more equal basis.

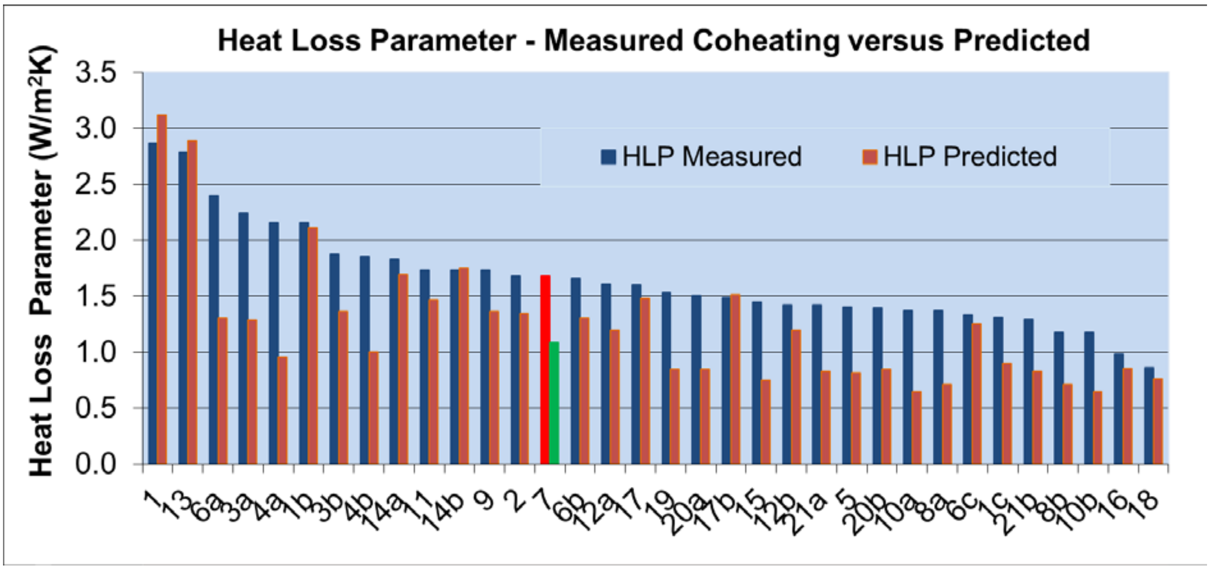


Figure 5 Predicted and measured performance shown as heat loss paramter.

By normalising to floor area, the heat loss parameter (HLP) in W/m^2K is produced; results presented as HLP are shown figure 5. This reduces the influence of the size of the property. This value enables households to compare the heating requirements of dwellings. However, for the building industry considering the performance of the fabric, the use of the floor area

may be misleading. In many cases, the relationship between floor area and fabric area is not linear. Building form affects the surface area to floor area ratio. Box shaped buildings maximise the volume to surface area*.
Where buildings move away from box shapes to more complex forms, the ratio increases, as shown in Table 1; so for similar sized dwelling the fabric performance could appear to be less effective for the same design and actual performance.
Furthermore, increasing the number of storeys within a dwelling reduces the ratio; for each additional storey to a building, the ceiling and floor fabric is shared out; this is shown in Table 2.

* In fact, a sphere maximising the volume to surface area ratio .

Table 1: Relationship between form and surface area.

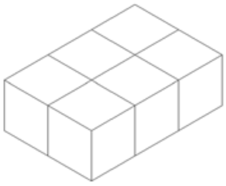
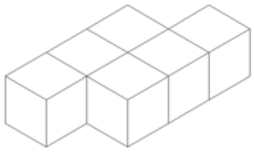
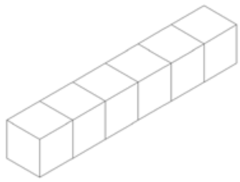
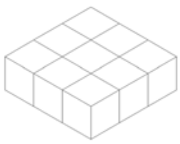
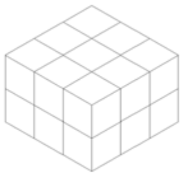
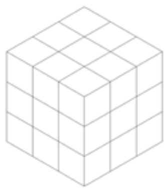
	Block	Offset	Line
Surface Area	22	24	28
Surface Area/ floor area	3.6	4	4.6
			

Table 2: Relationship between size and surface area.

	1 storey	2 storeys	3 Storeys
Surface Area	30	42	54
Floor Area	9	18	27
Surface Area/ floor area	3.3	2.3	2.0
			

Conversely, having floor areas and ceilings as a large portion of the total fabric surface area may improve performance. The understanding required to construct these elements so that they have high thermal efficiency is relatively well understood and easy to manage on site. The impact of poorly performing elements can be compensated, or hidden, by the good performance of these elements.

Mean U-value

A key strength of the coheating test is the delivery whole fabric performance which cannot be achieved by many other methods of testing. Often only representative values for the material performance are given, in methods such as collecting heat flux data. The mean u-value is the fabric loss component of the heat loss coefficient normalised to the surface area of the fabric envelope. The CeBE method calculates the value using the area of the entire envelope, including the floor.

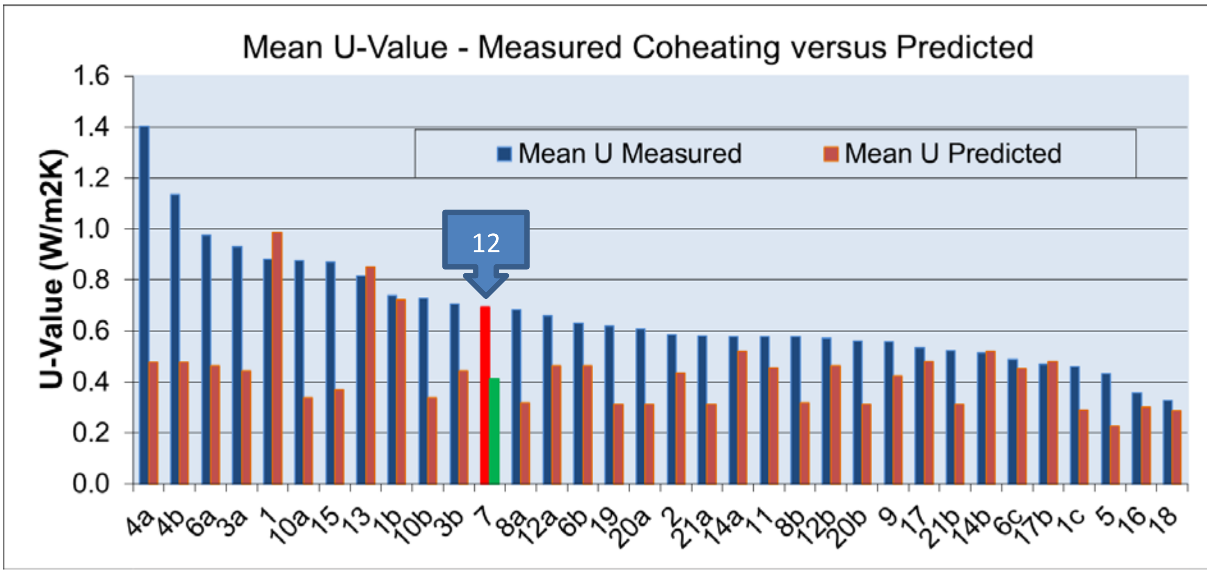


Figure 6 Predicted and measured mean u-value.

Limitations of the test

The GHA report (2012) describes the coheating test methods “to identify and highlight detailing and/or construction issues that may exist in their test properties”. However, the coheating test as described above will only provide value which describes the heat loss of the dwelling as a whole. The test only describes heat loss as fabric and ventilation losses and does not describe the thermal behaviour of individual elements. However, additional testing can be undertaken which enables a closing the loop exercise to be undertaken. Additional testing can include thermal imaging using an infrared camera, heat flux measurement, measurement of surface and cavity temperatures.

During the coheating test, the raised internal temperature drives heat transfer from inside outside, this can be used to determine rates of heat flow through the fabric and determine apparent u-values. This testing must be undertaken on elements least effected by solar gains, which affect heat transfer.

The coheating method is a valuable test method for indicating the performance of the envelope as a whole. As dwellings are constructed with smaller with more efficient performance or get closer to performing as designed, the size of the gap will become smaller. Eventually the gap will be undetectable with respect to the limit how accurately the coheating test can measure the variation between design and actual performance. The limits of the test and how to improve them need to be explored.

Conclusions

The coheating test is a valuable method to give a measured value whole house heat loss, which can be described in terms of fabric and ventilation losses heat losses. Interpretation of the results of the test, especially for comparisons with other dwellings must be undertaken with information relating to the dwelling and the test conditions. Construction material, dwelling form and floor area all affect the dwellings response to the test procedure. Reporting the dates and location of the test with details of any correction and statistical confidence is required.

Coheating test is insufficient to understand the root causes behind any additional heat loss, however, it creates conditions suitable (heat saturated fabric) for valuable data to be collected using other methods. Undertaking this additional testing allows heat loss mechanism to be understood. The coheating test also enables before and after performance measures to be calculated enabling their direct comparison.

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