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Obtaining the heat loss coefficient of a dwelling using its heating system (integrated coheating)

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ABSTRACT

This paper presents the methodology, along with some of the initial findings and observations from tests performed on two dwellings, of differing construction and form, in which a coheating test was performed using the dwelling's central heating system; this method is referred to as *integrated* coheating. Data obtained during the integrated coheating tests using a dwelling's heating system have been compared with data obtained during electric coheating of the same dwelling. In one instance, integrated coheating test data from one dwelling was compared to a similar adjoining control dwelling that was simultaneously subject to an electric coheating test. The results show a good agreement between the heat loss coefficients (HLC) obtained using a dwelling's own heating system and those obtained through electrical coheating. Initial analysis suggests the HLC estimate obtained from integrated coheating is likely to be more representative of how a dwelling performs in-use. The findings question the appropriateness of comparing current steady-state HLC predictions to those derived from in-use monitoring data. Integrated coheating has the potential to provide a more cost-effective and informative indication of whole house heat loss than electric coheating, as it enables *in situ* quantification of both fabric and heating system performance.

1. Introduction

EU [1] and UK [2] regulations are progressively increasing the building fabric energy efficiency standard of new and existing dwellings driven by the requirement to reduce CO_2 emissions and the increasing cost of the energy required to heat dwellings. A body of evidence has been amassed which highlights a discrepancy between the predicted and as-built thermal performance of the building fabric which threatens to reduce the desired impact of these regulatory measures (Stafford et al. [3] and Johnston et al. [4]). This underperformance is commonly referred to as the '*performance gap*'. In order for the thermal performance of buildings to be quantified a metric is required: the heat loss coefficient (HLC) is one such metric. The HLC is the rate of heat loss in Watts from the entire thermal envelope of a building per Kelvin of temperature differential between the internal and external environments (ΔT) and is expressed in W/K. Obtaining an estimate of a building's HLC *in situ* enables a comparison to be made between the realised performance and predicted performance and enables feedback to the occupier, building management system and to other stakeholders regarding the thermal performance of the dwelling.

Comparable metrics to the HLC can be obtained from in-use monitoring data using linear regression based energy signature analysis techniques (Hammarsten [5], Sjogren et al. [6]). As many of these models rely on assumptions regarding occupant behaviours, their accuracy must be questioned. Complex dynamic statistical models are also being identified which aim to isolate the effect of occupant behaviour, enabling identification of the HLC and other parameters from in-use monitoring data (Bacher and Madsen [7]). Although these methods could enable a HLC to be isolated from smart metering of an occupied dwelling; validation of their output parameters against measured baseline values is required to establish their reliability.

The uncertainties associated with occupant behaviour when estimating the HLC *in situ* can be removed by physical measurement of an unoccupied dwelling. Physical measurement techniques can be separated into two distinct categories: disaggregate and aggregate. To estimate the HLC of a building using disaggregate techniques, the *U*-value of all thermal elements must be measured (commonly using heat flux plates), along with the background ventilation rate of the building (pressurisation testing or tracer gas methods), and linear thermal bridging (Taylor et al. [8]).

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Estimating the HLC using a combination of disaggregate methods has the advantage of providing multiple parameters relating to the building fabric which can potentially isolate the cause of any potential performance gap. However the veracity of the HLC estimate is questionable as it is difficult to ensure that the *U*-values measured *in situ* are representative of the entire element (especially ground floors and bridging layers), and measurement of linear thermal bridging is highly complex in a dynamic environment. Although aggregate methods yield less information regarding individual parameters of the building envelope, they capture the thermal bridging component of the HLC and can obtain an estimate of the HLC with a lower level of complexity; one such method is electric coheating.

Electric coheating is a recognised test method for obtaining an estimate of the *in situ* HLC of a building. A coheating test involves heating the internal environment of a building to an elevated, homogenous, and constant temperature with electric resistance heaters and then maintaining that temperature over a number of days (typically 10–21 days). The power input to the dwelling, as well as the internal and external environmental conditions, is monitored throughout the test.

Electric coheating has existed in various forms since the late 1970s. It was originally performed overnight as a test to measure the efficiency of heating systems that cannot be measured directly, such as fireplaces and furnaces (Sonderegger and Modera [9] and Sonderegger et al. [10]). These early tests found that heating a building solely with electric resistance heaters meant that the building's HLC could also be measured. Future development of the coheating test in the 1980s in the UK (Siviour [11], Everett et al. [12] and Everett [13]) focused upon measurement of the HLC. These works increased the length and complexity of the test and analysis to better accommodate for the dynamic external environment in which coheating tests take place.

The use of coheating increased in the UK following its uptake and development by Leeds Metropolitan University (now known as Leeds Beckett University); notably during the Stamford Brook Project. Coheating tests during the Stamford Brook Project identified a substantial performance gap in new dwellings, and helped quantify the party wall bypass heat loss mechanism (Lowe et al. [14]). Following the Stamford Brook Project, the electric coheating test method was further refined and developed by Leeds Metropolitan University, resulting in the 2010 version of LeedsMet's Whole House Heat Loss Test Method (Wingfield et al. [15]). This version became recognised as an established test method in the UK when it was incorporated within the Post Construction and Initial Occupation studies undertaken under the Technology Strategy Boards (now Innovate UK's) Building Performance Evaluation Programme [16]. The 2010 version of the test method was significantly revised in 2013 (Johnston et al. [17]).

In recent years, research efforts have primarily been concentrated on coheating test data analysis and the identification of sources of uncertainty, rather than the experimental setup or the testing methodology. *In situ* coheating tests and computer simulations found measurement uncertainty to be greatest during periods of high solar gain and also for dwellings with high thermal mass (Bauwens et al. [18] and Stamp et al. [19]). Most recently, a state-of-the-art review of the coheating test and the methods used to analyse test data proposes that the most sensible analysis method to adopt is multiple linear regression (Bauwens and Roels [20]).

Unlike the fan pressurisation test method, which is used to establish the air permeability of dwellings, the coheating test has not been widely-adopted as a procedure for either regulatory compliance or quality control purposes. Instead, it remains the preserve of a few academic institutions and specialist consultancy services (Zero Carbon Hub [21]). There are numerous reasons why the coheating test has seen limited application, which include: reluctance from the construction industry to acknowledge and research the performance gap; criticism regarding the precision and accuracy of the coheating test (Butler and Dengle [22]); the duration of the test with no guarantee of obtaining a confident estimate of the HLC in the limited time available; the test's restriction to the heating season (October–March in the UK); the lack of a recognised, standardised test and analysis method; a lack of experienced testers; and, the time and financial costs associated with undertaking the test (Taylor et al. [8]).

Nomenclature

HLC	Heat loss coefficient, W/K
ΔT	Total measured power input from space heating, K
Q	Total measured power input from space heating, W
R	Solar aperture coefficient, m^2
S	Solar irradiance, W/m^2
ΣU.A	Total transmission heat loss, W
C_v	Background ventilation heat loss, W
ρ	Density of the heat transfer medium, kg/m^3
V	Volume flow rate, m^3/s
c_p	Specific heat capacity at constant pressure, kJ/kgK
t_f	Temperature of the liquid in the flow pipework, K
t_r	Temperature of the liquid in the return pipework, K
Qhm	Heat input to the dwelling measured by the heat meter, W
Q_p	Heat gain from the heat generation plant, W

The financial cost of a coheating test can be disaggregated into costs associated with the time for which a dwelling must remain unoccupied, as well as the personnel, equipment and energy costs. Dynamic whole house heat loss test methods exist that are far shorter in duration than the coheating test. These include: ISABELE (Bouchié et al. [23]), the Quick *U*-value of Buildings (QUB) method (Mangematin et al. [24]) and the Primary and Secondary Terms-Analysis and Renormalization (PSTAR) method (Subbaro [25], Subbaro et al. [26]). However, the nature of the HLC estimation obtained by PSTAR was questioned when compared with that measured by a coheating test on the same dwelling (Palmer et al. [27]). The robustness of methods currently under development (the QUB and the ISABELE method) is yet to be established for dwellings in the field. Other financial costs could be significantly reduced by substituting the dwelling's heating system for the portable electric heaters that are commonly used to provide the heat input during whole house heat loss tests.

This paper provides details of the methodology and early analysis of the data obtained from experiments performed on two dwellings where coheating tests were undertaken using the dwelling's own hydronic central heating system to provide heat input; a method referred to as *integrated* coheating. It also compares the results obtained to the same dwellings undergoing electric coheating in accordance with LeedsMet's 2010 coheating method (referred to henceforth as LeedsMet coheating).

2. Estimation of the HLC from a coheating test

Following an initial period during which the building fabric reaches thermal capacitance, a coheating test assumes the following whole house energy balance (adapted from Siviour [11]):

$$Q + R.S = (\Sigma \text{U.A} + C_v).\Delta T \tag{1}$$

where: Q is the total measured power input from space heating (W), R is the solar aperture of the house (m^2), S is the Solar irradiance (W/m^2), ΣU.A is the total fabric transmission heat loss (W), C_v is