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Measuring thermal performance in steady-state conditions at each stage of a full fabric retrofit to a solid wall dwelling

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ABSTRACT

The methodology used for measuring the thermal performance of fabric retrofit systems which were applied to a solid wall UK Victorian house situated within an environmental chamber is explored in detail. The work describes how steady-state boundary conditions were approximated, then repeated at the Salford Energy House test facility. How established methods of measuring the fabric thermal performance of buildings *in situ* were adapted to test the effectiveness of retrofit measures within a steady-state environment. The results presented show that steady-state boundary conditions enable the change in fabric heat loss resulting from the retrofit of a whole house or individual element to be measured to a level of accuracy and precision that is unlikely to be achieved in the field. The test environment enabled identification of heat loss phenomena difficult to detect in the field. However, undertaking tests in an environment devoid of wind underestimates the potential reduction in ventilation heat loss resulting from an improvement in airtightness, and hides the susceptibility of retrofit measures to various heat loss mechanisms, such as wind washing. The strengths and weaknesses of the methods employed, the Energy House test facility, and a steady-state environment, for characterising retrofit building fabric thermal performance are demonstrated.

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1. Introduction

Table 1 – Nomenclature

Term	Symbol	Unit
Whole building heat transfer coefficient	HTC	W/K
Ventilation heat transfer coefficient	$HTC_{(V)}$	W/K
Thermal transmittance	U-value (U)	W/m^2K
Target retrofit thermal transmittance	U_t	W/m^2K
Thermal conductivity	λ	W/mK
Thermal resistance	R-value (R)	m^2K/W
Internal surface thermal resistance	R_{si}	m^2K/W
External surface thermal resistance	R_{se}	m^2K/W
Measured baseline thermal resistance	R_b	m^2K/W
Thermal resistance of retrofit materials	R_m	m^2K/W
Power input	Q	W
Heat flux density	q	W/m^2
Internal air to external (chamber) air temperature difference	ΔT	K
Air permeability at 50 Pa	q_{50}	$m^3.h^{-1}.m^2$ @ 50 Pa
Air change rate at 50 Pa	n_{50}	h^{-1} @ 50 Pa
Background ventilation rate	n	h^{-1}
Internal surface area	A	m^2

"Improving the energy efficiency of the existing [UK housing] stock is a long-term, sustainable way of ensuring multiple gains, including environmental, health and social gains." [1]. Pre-1919 homes are ripe to yield the aforementioned gains as they comprise 21% of England's housing stock and have the lowest average energy performance rating [2]. However, these homes typically have solid wall construction [3] and it is not currently considered economically viable to the apply solid wall insulation required to make them energy efficient [4].

The incentive to perform retrofit is further diminished as the anticipated reductions in energy use are often not realised [5]. This has been attributed to incorrect assumptions regarding occupant energy use behaviour pre-retrofit [6] and post-retrofit [7]. Evidence is also growing to suggest that assumptions regarding heat loss from a home pre- and post-retrofit are incorrect. UK Government schemes to incentivise retrofit such as the Energy Company Obligation (ECO) [8] and the now defunct Green Deal [9] calculate baseline thermal performance using the Reduced Data Standard Assessment Procedure (RdSAP) [10]. The average measured heat loss from solid walls has been found to be substantially less than the standard values used by the RdSAP calculation [11,12], meaning the baseline heat loss prediction could be overestimated. A performance gap between the measured and predicated reduction in heat loss from fabric retrofit measures has also been observed [13,14]. Thus, it can be argued that more measurements should be undertaken pre- and post-retrofit to understand the nature of the prediction and performance gaps in retrofit.

The effectiveness of a thermal retrofit can be assessed at a whole building level by measuring the change in heat transfer coefficient (HTC). ISO 13789 defines the HTC as the "heat flow rate divided by temperature difference between two environments" [15]. It represents the steady-state aggregate total fabric and ventilation heat transfer coefficient ($HTC_{(V)}$) from the entire thermal envelope in Watts, per kelvin of temperature difference (ΔT) between the internal and external environments, and is expressed in W/K. The coheating test has been shown to be reliable a reliable method of determining the HTC of a building [16]. The improvement in HTC resulting from retrofit has been measured using coheating tests by Miles-Shenton et al. [14] and Rhee-Duverne and Baker [17]. In both instances the baseline HTC measured was lower than that predicted using RdSAP, which highlights the importance of calculating potential improvements in thermal performance from a measured baseline. Miles-Shenton et al. found performance gaps between the measured and predicted HTC reduction at each stage of the retrofit process. However, HTC measurements are not targeted enough to explain the cause of a performance gap.

The thermal transmittance of a building element (U-value) is defined in ISO 7345 as the "Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on both sides of a flat uniform system" [18]. Measurement of *in situ* U-values is typically undertaken in accordance with ISO 9869 [19]. Doran [13] and Miles-Shenton et al. [14] both measured U-value performance gaps for retrofitted cavity wall insulation (CWI). Miles-Shenton et al. found that U-value performance gaps measured for the CWI retrofit and for the subsequent external wall insulation (EWI) retrofit were sufficient enough to account for the discrepancy between the measured and predicted HTC reduction following each retrofit.

Work undertaken by Everett [20] and Stamp et al. [21,22] investigating the coheating test method uncovered a number of variables that not only increase the complexity of the data analysis, but can also result in greater uncertainty. Variables identified include: inaccurate estimation of solar gains, delayed release of stored solar gains from the thermal mass, variation in air infiltration (background ventilation rate (n)) caused by a change in wind velocity and/or direction, thermal lag caused by external temperature variation, long-wave radiative heat exchange with the sky, solid ground floor heat loss not directly driven by the internal air-to-external air ΔT, and inter-dwelling heat transfer across a party wall. Many of these variables are also known to increase the uncertainty of *in situ* U-value measurements. The variables listed are all caused by variations in the external boundary conditions and, with the exception of inter-dwelling heat transfer, cannot be practically controlled. The effects of solar radiation on the building fabric mean that it is recommended that coheating tests are only undertaken during the winter months.

As a consequence, it is accepted that when measuring the thermal performance of an unoccupied house, the main sources of uncertainty result from variations in the external boundary conditions. This problem is compounded when attempting to measure the improvement in thermal performance resulting from thermal retrofit, due to the uncertainty associated with both the pre- and the post-retrofit measurements. Coheating test accuracy is estimated to be ±8–10% [16]. The uncertainty of *in situ* U-value measurements undertaken in accordance with ISO 9869 is quoted as ±14% [19]. The uncertainty of air permeability (q_{50}) measurements using a blower door is highly dependent upon the wind velocity, with the uncertainty ranging from <±2% in calm conditions and ±15% at a velocity of 6 m/s [23], the maximum velocity in which measurements can be undertaken in accordance with ATTMA Technical Standard L1 [24].