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Heat-flow variability of suspended timber ground floors: Implications for in-situ heat-flux measuring

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ABSTRACT

Reducing space heating energy demand supports the UK's legislated carbon emission reduction targets and requires the effective characterisation of the UK's existing housing stock to facilitate retrofitting decision-making. Approximately 6.6 million UK dwellings pre-date 1919 and are predominantly of suspended timber ground floor construction, the thermal performance of which has not been extensively investigated. This paper examines suspended timber ground floor heat-flow by presenting high resolution in-situ heat-flux measurements undertaken in a case study house at 15 point locations on the floor. The results highlight significant variability in observed heat-flow: point U-values range from 0.56 ± 0.05 to 1.18 ± 0.11 $\mathrm{W m^{-2} K^{-1}}$. This highlights that observing only a few measurements is unlikely to be representative of the whole floor heat-flow and the extrapolation from such point values to whole floor U-value estimates could lead to its over- or under- estimation. Floor U-value models appear to underestimate the actual measured floor U-value in this case study. This paper highlights the care with which in-situ heat-flux measuring must be undertaken to enable comparison with models, literature and between studies and the findings support the unique, high-resolution in-situ monitoring methodology used in this study for further research in this area.

1. Introduction

The UK has committed to reduce CO_2, or equivalent, emissions by 80% from 1990 levels by 2050 in the Climate Change Act 2008 [1]. Deep cuts in CO_2 emissions associated with the residential sector, which is responsible for approximately 30% of the UK's total emissions [2], are required. Reducing carbon emissions associated with domestic space heating, which accounts for around 13% of the UK's emissions [3], is a key aspect of the UK's planned transition to a low carbon economy [3,4].

There are approximately 27 million dwellings in the UK, the majority of which are not well insulated [4]. An estimated 4.9 million dwellings were built pre-1919 in England alone [5] and 6.6 million in the UK [6]; seventy to eighty-five percent of existing UK housing is expected to still be in use in 2050 [7–9]. Dwellings of the pre-1919 period are predominantly of solid wall [10–12] and suspended timber floor construction [10]. They tend to have larger floor areas [5] and are predicted to have a 40% greater energy demand per metre floor area compared to newer dwellings built post-1990 [13]. A large proportion of this pre-1919 dwelling typology is also classified as hard to treat (HTT) [5,6], due to the relatively high cost of retrofit options, disruption and difficulty to upgrade [14–16]. It is estimated that at least 50% of energy demand in pre-1919 housing is for space-heating [5,17–19]; much of this heat is lost through un-insulated walls and insufficiently insulated roofs [20]. The proportion of total dwelling heat loss from un-insulated ground floors depends on the overall dwelling fabric efficiency standard and is estimated between 10% in un-insulated dwellings [20] and 25% in otherwise well insulated dwellings where the ground floor remains uninsulated [21]. Addressing this challenging typology presents an opportunity to deliver significant carbon reductions and increased occupant thermal comfort from improved building fabric performance [22,23]. However, this carbon reduction challenge is intensified by the underperformance of many

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Nomenclature

U, U_{mean}, U_p, U_{wf}	Thermal transmittance or U-value, $Wm^{-2}K^{-1}$; U_{mean} is the estimated in-situ U-value obtained from a mean of ratios of point U-values (U_p). U_p is a point U-value and is the term used as a generic description of the small area-based in-situ U-value measurement on a certain location on the floor. U_{wf} is the in-situ estimated whole floor U-value derived from U_p-values
HF1, HF2,...	Heat-flux sensor location 1, 2,...
T_{Si}, T_{ea}	Internal surface air temperature and external air temperature respectively
q	In-situ measured heat-flow rate, Wm^{-2}
R_{si}	Internal surface thermal resistance, taken to be $0.17\,m^2KW^{-1}$ for downward heat-flow through floors

interventions [24–27] and the low rate of refurbishment [28–30]. Just four percent of solid walls in the UK's pre-1919 properties are insulated [31] and it is unknown how many pre-1919 ground floors are insulated.

Initiatives such as the UK government's Green Deal and Energy Company Obligations (ECO) policies, which were preceded by the Community Energy Saving Programme (CESP) and the Carbon Emissions Reduction Target (CERT), aimed to increase the rate of retrofit [32,33]. One of several drivers for energy-efficiency measures is the cost-benefit of interventions [34]. The Green Deal for example allowed building occupants to take out a pay-as-you-save loan to finance certain energy efficiency improvements, assuming the loan could be paid back from the predicted energy savings [35,36]. However, the actual carbon reductions and cost-effectiveness of retrofit interventions is contingent upon the delivered improvement in thermal performance. Recently, potential disparities between predicted and actual performance of existing construction elements have been identified [37,38]. For example, in-situ measurement of U-values in solid walls were found to be lower than those predicted [37,39,40], which affects the predicted energy savings and payback. However, while insulation of suspended timber ground floors was a Green Deal approved intervention measure [41], the heat-flow through this element, both uninsulated and insulated, is not well characterised at present, hindering retrofitting decision-making. Few in-situ measurements of floor heat loss have been undertaken and there is a need to understand the implications of the physical heat loss patterns on in-situ measuring methodology, such as location and spread of sensors across the floor, prior to undertaking larger scale field measurements.

This paper presents an investigation into the spatial variation in U-values derived from measurements at points on a suspended timber ground floor, and how this variation can affect the estimated whole floor U-value. This study presents the results of high-resolution in-situ measurements of the thermal characteristics of a suspended ground floor in a controlled environment in the Energy House (EH) a pre-1919 semi-detached house reconstructed in an environmental chamber at the University of Salford (UK). The potentially large variation in whole floor U-value estimates from low resolution measurement campaigns is illustrated and wider implications for the method of U-value estimation of floors are discussed.

Firstly, the research method is discussed, which includes a description of the Salford Energy House, instrumentation, in-situ measuring method and uncertainty. Subsequently, results and discussion are presented, focusing on wider applicability of implications arising from the findings, such as implications for future in-situ measuring techniques in the field and comparison difficulties with models and other published in-situ U-values.

2. Method

A 5-day monitoring programme was undertaken in the Salford Energy House (EH) in 2013. The EH is a reconstructed 1919 two bedroom semi-detached dwelling in a large environmental chamber at the University of Salford. The house is separated on one side with a solid brick party wall from another smaller house in the thermal chamber, referred to in this paper as the neighbouring house. The EH ground floor is of suspended timber construction, with timber floorboards in the living area and tiled floor finish in the kitchen. Its total ground floor measures 28 m^2, with an exposed perimeter (measured externally) of 16 m. The suspended floor is ventilated through air-bricks with a total ventilation opening area per metre of exposed perimeter of approximately 0.00077 m^2/m (calculated in accordance with ISO 13370 [42]) excluding an airbrick opening to the neighbouring house. Given that the EH is a reconstructed dwelling there are some differences with an actual house: (a.) it sits on a 280 mm thick concrete slab, which sits on top of an insulated ground floor slab (the slab of the building which houses the chamber) – collectively referred to as the concrete substructure; (b.) atypically, floor void ventilation occurs in between both houses and there are no airbricks on the back facade; (c.) joists run from gable wall to party wall and there is only a 50–70 mm gap under the 190 mm joists and the concrete oversite slab, likely reducing free airflow in the void (see Fig. 2); (d.) the floor finish is tongued and grooved floorboards, apart from ten floorboards, which have gaps between them; this hybrid is atypical of floors of this kind.

While the EH structure and climatic conditions are a simulation of the actual environment, the EH can be used to investigate in detail some aspects of the variability of heat-flow across a construction element and report on the implications for in-situ measuring techniques of floors. For example, the EH enabled high-resolution monitoring (i.e. many points across the surface) and the control of the variables which actual houses are subject to in monitoring campaigns, such as the exclusion of occupant interference, a controlled internal and external environment and exclusion of solar gain and wind effects. Additionally, the steady-state conditions and isolation of dependent effects facilitated repeated measurement of the physical variables, leading to reduced measurement time and small instrument measurement uncertainties derived from statistical error propagation techniques. Further advantages of using the EH included monitoring under conditions which were not otherwise possible in occupied dwellings, such as heating the neighbouring house to a constant 18 °C and the ability to electrically space heat to control for the influence of uninsulated radiator pipes in the floor void affecting heat-flow measurements and instead enabling to study of the spatial variation of the floor heat-flow.

This research is based on in-situ measuring of a case-study floor and as such the numerical results are not representative of the wider pre-1919 housing population. However, as outlined above there are significant advantages of research in a controlled environment to isolate physical effects and the physical insight and qualitative results may be used to highlight potential trends and wider methodological implications [43]. This study aims to provide such broader insight, as undertaken elsewhere, such as the broadly applicable cavity wall heat loss mechanism identified by Lowe et al. in a case study [44].