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The as-built thermal quality of building components: characterising non-stationary phenomena through inverse modelling

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Abstract

The thermal resistance of building components is typically seen as a stationary parameter, although in reality, the quantity is often time varying. Several phenomena can lie at the origin of this: some of them are bound to the heat conduction mechanisms in building materials and cannot be prevented from occurring, while others are induced by external factors that can and should be avoided. Poor workmanship issues, for instance, can induce phenomena such as buoyancy driven air flows or wind washing. These phenomena interact with the regular heat transfer mechanisms in building components and can affect their thermal performance. In this paper, it is examined whether the technique of stochastic grey-box modelling holds the ability to characterise a variable thermal resistance indicator quantifying the thermal impact of such phenomena. This is investigated for the specific scenario of an insulated cavity wall that suffers from rotational air looping around its hard insulation boards.

Keywords: thermal resistance characterisation; rotational air looping; stochastic grey-box modelling

1. Introduction

In the current evolution towards energy efficient buildings, the thermal quality of a building's envelope plays an important role. This is reflected in the EPB Directives which impose increasingly stringent specifications to the thermal performance of building envelopes: among others, minimum performance levels are imposed to building components of new and highly renovated buildings. Currently, these performance levels are assessed in the design phase, neglecting the way building components are actually implemented in the construction. In reality, many *as-built* aspects might influence the thermal performance of building components in a negative way. In some cases, even the typical heat

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transfer mechanisms of building components might be disturbed. This is, for instance, the case when wind driven air flows enter roof constructions and move through or under the insulation, due to an unsatisfactory airtightness of the construction [1,2]. Or, when natural convection causes air looping around hard insulation boards in cavity walls, due to a poor installation of the latter [3,4].

In this paper, it is examined whether the impact of such phenomena can be quantified from local, on-site measurements. Therefore, the technique of stochastic grey-box modelling is used. This method is selected because of its *physical* model structure, easily allowing to describe heat transfer phenomena in building components and because of its many possibilities for model validation and pinpointing model deficiencies. More specifically, this paper examines whether stochastic grey-box modelling holds the ability to characterise a variable thermal resistance indicator quantifying the thermal impact of buoyancy driven air flows on the thermal resistance of the affected component. This is investigated for the specific scenario of an insulated cavity wall that suffers from rotational air looping around its hard insulation boards, due to a poor installation of the latter.

2. Methodology

Typically, the heat flux through a cavity wall with hard insulation boards is one dimensional and equal at every position on the wall. This picture drastically changes when air starts flowing around the insulation. Such air flows can be induced by natural convection when small air cavities are present at both sides of the insulation. Due to temperature differences across the insulation, pressure differences are created in the flanking air layers, constituting a driving force for the air to loop around the insulation. The flanking air will, however, only actually loop when apertures are present at the top and bottom joints of the hard insulation boards.

In order to study the impact of rotational air looping on the thermal performance of cavity walls, a test wall has been built in the Vliet test building of the KU Leuven (Leuven, Belgium) [5]. The wall is constructed with *poor workmanship*, meaning that air gaps are included around some of the insulation boards. Figure 1 represents the cross section of the constructed wall and the location of the measurement sensors. Figure 2 shows a picture of the wall taken before the brick façade was built. Note that the wall has an insulation board of 1.48 m high that is deliberately shifted towards the exterior so that residual air cavities of 0.01 m are present behind the insulation and at the top and bottom joints. This is done by placing wooden strips behind and between the separate insulation panels. An infrared picture of the wall (Figure 3) demonstrates that rotational air looping is indeed occurring. The temperature gradient that is seen on the exterior face of the brick façade visualises the warm air that enters the exterior cavity and that flows downwards as it cools down. Conversely, at the interior face, the cold air entering and rising in the interior cavity is visualised.

Based on the thermal properties of the wall's construction materials, a theoretical *reference* resistance of 5.31 $Wm^{-2}K^{-1}$ is computed, assuming that no rotational air looping occurs.

The surface temperatures and interior heat flux of the test wall are measured at three positions over the height of the shifted insulation panel: near the top (at 1.30 m), at the center (at 0.75 m) and near the bottom (at 0.19 m). These measurements will be used to determine the wall's *local, apparent* thermal resistances. Therefore, a measurement period of 8 days, from 06/02/2016 up till 13/02/2016, is selected. During this period, the indoor environment of the test building was maintained at a constant temperature of ±18.4°C. Figure 4 represents the heat flux and temperature measurements for the three positions on the wall, as well as the surface temperature differences. Note that these differences are mainly positive. Furthermore, two-hourly averaged data will be used for the analyses.

The goal of this paper is to characterise the impact of rotational air looping on the thermal resistance of the studied cavity wall. This will be done by characterising *local, apparent* thermal resistances at the three selected positions on the wall. These values are calculated in the same way as *stationary* resistances, notably by dividing the measured interior heat flux by the measured surface temperature difference across the component. Yet, the obtained values cannot be interpreted in the traditional way: a local, apparent R-value is no unique, constant value, but it is a varying property, depending on the location of the measured data as well as on the temperature difference over the wall. Therefore, this quantity is further denoted as R_{app}.

In a first stage, the behaviour of such *local, apparent* thermal resistances is studied. This is done by assessing stationary simulations of a cavity wall suffering from rotational air looping. From these simulations, temperature