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Investigation of a simple approach to predict rainscreen wall ventilation rates for hygrothermal simulation purposes

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ABSTRACT

Hygrothermal simulation programs are commonly used by design engineers to analyse moisture performance of building envelopes. For ventilated assemblies, programs typically require the user to enter cavity ventilation rates. If such input data are not prepared on physical grounds, it can impair the quality of the simulation results. In earlier papers: (1) estimations of ventilation rates in experimental walls based on cavity air velocity measurements; (2) comparative calculations based on monthly and annual tabular climate data, a simple driving force model and models of cavity airflow and heat balance, have been presented. In this study, the models and hourly climate field data were used to perform calculations of transient cavity ventilation rates for comparison with previous experimental results. For 13 different time periods extending from 24 to 91 h, the calculated average ventilation rates were within or very close to the experimentally estimated limits for the ventilation rate. Additionally, the calculations captured the temporal variability and the physical cause of ventilation airflow in the cavities reasonably well. The applied calculation methodology can be developed into a user friendly approach to estimate realistic ventilation rate input data for hygrothermal purposes. Limitations and possible improvements of the methodology are discussed. The influence of the accuracy and resolution of the ventilation rate input data in simulations is demonstrated in a case study.

1. Introduction

Ventilated cavities are incorporated in building envelops with the overall purpose to enhance moisture safety. Notwithstanding the long practical experience of outdoor ventilated assemblies in both walls and roofs, there are increasing needs in the design of new buildings to quantify that the moisture performance of such components meet specific requirements. For example, the Swedish building regulations [1] have recently been clarified and revised and now explicitly demand that moisture safety issues in the building process should be systematically quantified and documented, both in the design and the construction phase. Usually, design engineers use different types of simulation programs to perform hygrothermal analyses in order to predict the risk of mould growth, chemical emissions and moisture induced material deterioration. However, simulation of heat and moisture conditions in ventilated building components introduces the challenge of quantifying the size of cavity ventilation since the programs typically require the user to provide this input. According to the authors' experience, the prevailing praxis amongst design engineers is that the ventilation rate is chosen to some different fixed levels without knowing what is realistic with respect to the climatic conditions and the geometry of the cavity. This approach to the issue clearly indicates a knowledge gap and it is probable that the results from hygrothermal calculations in many cases could be improved if the ventilation rate input data were based on physical grounds. In investigations performed by Refs. [2,3], it has been shown that a correct assumption of the cavity ventilation rate is vital for accurate simulations of temperature and moisture conditions in wood frame walls and thus for reliable assessments of the risk for moisture damage and mould growth.

In a previous paper [4], the following was presented: (1) field measurements of air velocities in experimental wall cavities; (2) a cavity airflow model; (3) estimations of the average air change rate per hour (ACH) for a 5 month period. In a subsequent paper [5], the investigation was expanded with: (4) a cavity heat balance model; (5) a driving force model which accounts for buoyancy pressures due to differences in temperature between the cavity air and the outdoor air during daytime and wind pressures during night-time; (6) calculations of the 5 month average ACH by application of the

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mentioned models and monthly and annual tabular climate data. The ACH calculated with the low-resolution climate data was in good accordance with the experimental findings, indicating that the simple driving force model was an acceptable approach for predicting the average cavity ventilation in the walls. However, comparative ventilation rate calculations based on the actual climatic conditions during the velocity measurements were excluded from the analysis since wind but no solar radiation data was collected in the experimental set-up. Thus, it was not confirmed that the simple driving force model actually captured the physical cause of the cavity airflow.

In the present study, high-resolution radiation and wind speed field data is used to perform calculations of ventilation rates in the experimental walls for comparison with the measurement based results reported in Ref. [4]. In the calculations, radiation data collected by Ref. [6] at the time of the cavity air velocity measurements is utilised. To facilitate the conversion of extensive amount of field data into cavity ventilation rates, the airflow and heat balance models are used to express the ventilation rate as function of wind speed and radiation, respectively. For general application, the demonstrated calculation methodology can be developed into a user friendly approach for estimation of realistic rainscreen wall ventilation rate data for hygrothermal simulation purposes.

In the further parts of the study, transient ventilation rate data for the experimental wall cavities is modelled using hourly values of solar radiation and wind speed from the Swedish Meteorological and Hydrological Institute (SMHI) and compared with the experimental results. Calculations with the well-established hygrothermal simulation program WUFI [7] are performed to investigate differences in drying out time of excess moisture in the exterior sheathing of a typical rainscreen wall assembly with respect to the accuracy and resolution of the ventilation rate input data.

Historically, a considerable amount of research has been made regarding cavity ventilation and its effect on moisture performance of rainscreen walls. Since cavity airflow is analogous to fluid flow in closed conduits, many works [8–16] have used equations from the field of fluid mechanics to model flow characteristics of wall cavities. For investigating cavity ventilation under field conditions, researchers have conducted in situ measurements of cavity air velocities on several occasions. Results from such measurements performed until the mid 2000s have been summarised by Refs. [17–19]. Studies of ventilation drying have been carried out as theoretical analyses [9,12,15,20,21], climate chamber tests [22–25], physical demonstration experiments [21,26] and full scale field investigations [27–34]. Findings tend to show that cavity ventilation has the potential to assist in the drying process of rainscreen walls but also highlight that ventilation drying is greatly influenced by the: (1) exterior climate conditions, (2) size and physical position of moisture concentrations, (3) geometry of cavity flow paths and (4) moisture mechanical properties of individual material layers in the wall.

Notwithstanding that modelling of the relationship between airflow rates and driving force for cavities is fairly well described in the literature, procedures that can be used to predict driving forces and cavity ventilation rates under field conditions are less well developed and rarely discussed. However, Ref. [12] suggests a methodology to estimate the ventilation potential for different types of ventilated cladding systems. In the recommended procedure, average wind forces driving cavity ventilation are calculated based on annual average wind speeds and a zonal model of wall pressure coefficient distributions whereas average buoyancy forces are estimated by applying a constant temperature difference between the outdoor air and the cavity air. Depending on the angle between the considered wall and the primary wind direction, the ventilation potential is calculated assuming the wind-induced force to either assist or counteract the buoyancy-induced force. Compared to the approach presented in this study, the methodology suggested by Ref. [12] is more detailed regarding wind effects while buoyancy effects are treated with less attention.

2. Experimental walls and earlier reported field measurements

To provide relevant background information, this section briefly presents the experimental walls and the earlier performed field measurements. For more specific information on the experimental set-ups, see Refs. [4] and [6].

2.1. Experimental walls

The experimental walls were south oriented and arranged in a test house in Lund, situated in the southernmost part of Sweden (55°42′ N, 13°12′ E). On the roof of the house, 5 m above the ground level, a local weather station logged the air temperature and the wind conditions every 10 min. The rainscreen cladding consisted of cementitious carrier boards, completed with lime-cement render and a dark red finishing layer. The walls included four separate cavities measuring 2150 mm × 390 mm × 25 mm ($h \times w \times d$), see Fig. 1. The only difference between the cavities was the batten configuration: vertical wooden battens in cavity 1 and three different types of vented metal battens with horizontal alignment in cavity 2–4. The vented metal battens in cavity 2 had a very small flow area and the air velocity was found to be close to zero. This cavity is therefore excluded from the presentation in this paper. The geometries and flow areas of the horizontal metal battens that were used in cavity 3 and 4 are shown in Fig. 2.

2.2. Cavity air velocity measurements and ACH estimations

The air velocity was point measured with single hot-wire sensor, placed at mid-depth and mid-height in the vertical centre axis of each cavity. Only one sensor was used and it was moved between cavity 1, 3 and 4 in the implementation of the measurements. The velocity was generally registered with an interval of 10 or 20 s and the total measuring time was about 2400 h, distributed over 36 individual time periods from October to February. Due to the hot-wire technique, the measurement data were absolute with no information about the direction of the airflow. Considering the non-uniform shape of the velocity profile across the cavity depth, the sensor measured the maximum velocity u_{max} (m s^{-1}). To convert it into average velocity u_m (m s^{-1}) across the cavity depth, findings from laboratory experiments regarding the ratio of average to maximum velocity was used [4]. In the analysis of the measurement data, it was estimated that a direct transformation of the absolute average velocities u_m (m s^{-1}) to ACH resulted in overestimations in the range of 5–40% due to frequent changes in direction of wind-induced cavity airflow. Based on this, the true average ACH during October–February was estimated to be: 230–310 in cavity 1, 75–100 in cavity 3 and 95–130 in cavity 4.

2.3. Radiation measurements

On the roof of the test house, horizontal global and diffuse radiation was measured hourly with a sunshine sensor. From the data, it is possible to convert the solar radiation values for the horizontal surface to the corresponding amount of global radiation on the experimental walls including the reflected radiation from