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Brick masonry response to wind driven rain

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ABSTRACT

This study develops an innovative wind tunnel testing methodology for assessing the hygro-mechanical response of brick masonry to wind driven rain. The results highlight that such response depends largely on material properties, rain load characteristics, saturation level and wetting history. Additionally, rain penetration, even during milder rainfall events, induces the degradation in mechanical properties, stress redistribution and curtailing of damage and failure stress thresholds in bricks. Finally, synergies with additional adverse conditions, such as temperature and salts, produce a combined damaging action that can undermine the structural integrity of building elements. Within the research framework, future work is also proposed.

1. Introduction

Wind driven rain (WDR) represents one of the most significant sources of moisture in buildings [1,2]. It is the result of the interaction between airflow and rainfall and it can be simply described as rain that is given a horizontal velocity component by wind [3]. Rain penetration can be defined as water ingress through the exposed surface of building components induced by the interplay between material properties and conditions, raindrop velocity and wind forces. Brick degradation due to moisture can raise a series of issues ranging from inadequate usability to material durability and structural integrity. In combination with other factors, it may significantly decrease safety in buildings and lead to defects or sudden failures [4]. There exists a vast amount of research concentrating on moisture movement in masonry and its effects on buildings. In particular, moisture-related problems deriving from damp conditions have been closely investigated in relation to the durability of the material [5,6], occupants' health and structural issues [7,8]. The influence on moisture transport in masonry of material properties [9], interfaces between units and mortar joints [10] and workmanship quality [11] has been thoroughly analysed. Considerable effort has been put also in the study of wind driven rain simulation concentrating mainly on the raindrop size and rain intensity distributions, the deposition rate and impinging patterns on physical models and the effects on buildings in terms of rain penetration and induced damages. For example, studies by Flower and Lawson [12] and by Rayment and Hilton [13] have focussed on the analysis of raindrop trajectories and rain. The ability to reproduce in laboratory the effects of natural rain has also been explored in past research [14–16] providing particular insights on the characteristics of the simulated WDR including investigation of raindrop size distribution [17] and spatial uniformity of rain as a function of nozzle positioning [18]. In an unpublished report, Blocken et al. have tested the effects of WDR on full-size buildings, concentrating on the calibration of the wind tunnel for rain simulation as well as on the measurement of the impinging rain on building models. Finally, another interesting research [19] has produced data on wind driven rain intrusion and interior damages on single-storey residential buildings. The assessment of water penetration into a wall assembly is of vital importance to predict the vulnerability of the components prior to construction. This is usually done observing the performance of the wall assembly exposed to wind driven rain till its failure i.e. when leakage occurs on the back side. Although several testing standards for water ingress assessment are available [20–22], these employ test parameters, such as the spray rate and the pressure differences across the wall assembly, which are not representative of the weather characteristics at a specific location. Methods for a far more realistic and suitable rain simulation, proposed by Sahal and Lacasse [23], aim at adjusting the testing conditions to local driving rain intensities and wind pressures. This is based on the Straube and Burnett approach [24] to estimate the quantities of rainfall deposited on the wall assembly and on Choi method [25] to calculate the short duration driving rain intensity and driving rain wind pressures.

Although past research uncovers basic theoretical clues related to WDR testing and monitoring of the response of building components to rain penetration, many practical challenges still remain to be addressed. Evaluation methods commonly employed in this field are too general and often based on simple failure assessment (e.g. building component passing or failing a water penetration test). WDR simulations require the introduction of standardised calibration procedures as well as the development of consistent testing criteria and protocol. Moisture measurement necessitates repeatable, minimally invasive and

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inexpensive solutions with regulated data gathering and processing practices. The lack of appropriate and sustainable methodologies for assessing the performance of brick masonry components postulates that experimental data necessary for further validating theoretical studies and field observations are insufficient. These are strongly required for the sake of generating innovative outcomes and ground-breaking research advancements in this field.

This study attempts a systematic analysis of brick masonry constructions which undergo continuous moisture loading from wind driven rain. The primary aim is to develop a comprehensive testing methodology for assessing the response of brick masonry to wind driven rain and to evaluate appropriately the results in terms of the hygric and mechanical behaviour of different brick types. More specifically, the objectives of the research include the following:

- To establish an adequate testing strategy for the investigation of wind driven rain penetration in masonry elements.
- To study a suitable methodology for monitoring the response of masonry specimens subjected to wind driven rain loads.
- To establish the characteristics of the impact of wind driven rain on the hygric and mechanical behaviour of brick masonry.

The paper presents the following structure: the first part describes the methods used in the study; the second part outlines the experimental investigation with insights on the test wall and set-up; the following section summarizes the main findings of the research while the conclusive section presents suggestions for future work.

2. Research methodology

This research concentrates on three fundamental aspects related to rain penetration testing of brick masonry components: (1) how to test – the feasibility of wind driven rain simulation in the climatic wind tunnel is investigated and a correct testing procedure and test wall specifications are established; (2) how to measure rain penetration – the changes in moisture distribution inside brick masonry components is measured by employing an electrical resistance-based moisture monitoring system and a procedure is developed to convert the results to moisture content values; (3) how to evaluate the response – the impact of rain penetration on the hygric and mechanical behaviour of brick masonry is analysed using gravimetric methods and mechanical testing of brick specimens. Methods employed in this research are further described in the sections below.

2.1. Climatic wind tunnel simulation

In this study the Vincenc Strouhal climatic tunnel located in the Centre of Excellence Telč, Czech Republic is used (Fig. 1). It is a small scale tunnel intended for civil engineering purposes, designed as a closed circuit composed of two sections, the climatic and the aerodynamic one. For the experimental investigation presented in this research the former section has been used (Fig. 2). This presents a rectangular cross section 2.5 m × 3.9 m with length of 9 m. Different weather conditions with combinations of wind, rain, snow, freeze and radiant heat can be reproduced. Wind speed can vary between 0.02 m/s and 20 m/s. A radiation system with four infrared lamps with total power of 8 kW and a maximal incidence of 60° to the floor is available. The sprinkler system consists of a 2.3 m × 4.2 m moveable panel (functioning also as the ceiling of this section) to which a spray rack is connected. The rack features three longitudinal lines of sprinklers with a set spacing of 0.65 m. Individual sprinkler supports can be located and fixed by means of screws at different distances along such lines depending on the density of spraying required during testing. The system allows a maximum of 40 sprinklers to be activated.

The simulation of wind driven rain in the wind tunnel should ensure a realistic representation of rainfall events in a laboratory environment. It necessitates understanding how the governing input parameters of the tunnel relate to its outputs. In this perspective, a preliminary assessment should be carried out in order to grant the reproduction of a homogeneous volume of rainwater and a natural raindrop size distribution. The assessment performed concentrates mainly on the calibration of wind speed and rainwater intensity inside the tunnel: the first is obtained by measuring with a vane anemometer wind speed against different engine power of the wind generating fan in kW; the second is achieved by monitoring the variation in parameters of the sprinkler system, such as pressure at the nozzle tip (assessed by internal sensors), nozzle type, number of sprinklers active, spray rate and spacing between nozzles, in relation to the rain intensity simulated and its distribution inside the tunnel (mapped using a laser precipitation monitor and a tipping bucket rain gauge). Based on the results of this assessment, it is possible to transform the rainfall characteristics provided by weather data, such as rain intensity and wind speed, into input parameters for the tunnel, such as number of active sprinklers, spacing, pressure, fan power etc. Wind driven rain simulation in the wind tunnel is usually carried out in rain pulses i.e. by activating cyclically the sprinkler system for a determined duration of time. In this perspective, it is suggested to maintain the magnitude of such rain pulses constant throughout the tests while varying only their distribution and density in time. This permits to reproduce a wide range of rain intensities while keeping the same sprinkler layout (i.e. nozzle type, number of

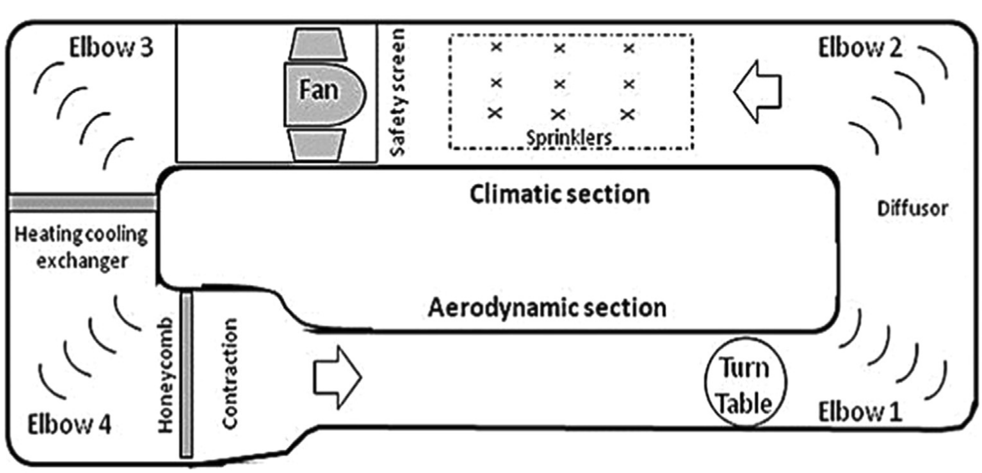

Fig. 1. Plan Vincenc Strouhal climatic tunnel.