A status report of wind-driven rain research at the Laboratory of Building Physics, K.U.Leuven

Masaru Abuku a, Bert Blocken a,b, Jan Carmeliet a,b, Staf Roels a

a Laboratory of Building Physics, Katholieke Universiteit Leuven, Kasteelpark Arenberg 40, Leuven, Belgium
b Building Physics and Systems, Technical University Eindhoven, P.O. box 513, Eindhoven, the Netherlands

ABSTRACT: This paper reports on past and ongoing wind-driven rain (WDR) research at the Laboratory of Building Physics, K.U.Leuven. It is based on the philosophy that WDR research consists of two main parts: (1) The assessment of the amount and intensity of WDR impinging on the building facade and (2) The assessment of the contact and surface phenomena that occur after impact of raindrops: splashing, evaporation, adhesion, absorption, runoff. The paper provides a brief overview of research in terms of full-scale measurements and CFD simulations of WDR on the VLIET test building and full-scale measurements with a newly developed test set-up for contact and surface phenomena.

KEYWORDS: wind-driven rain, driving rain, validation data, full-scale measurements, contact and surface phenomena

1 INTRODUCTION

Since 1936, wind-driven rain (WDR) has been an active research subject in Building Physics. The study of WDR consists of two main parts, namely (1) the quantification of WDR loads on vertical building walls and (2) the determination of the response of building walls to these loads. The quantity of WDR impinging on building walls is governed by a diversity of parameters: building geometry, environment topology, position on the building facade, wind speed, wind direction, turbulence intensity, rainfall intensity, raindrop-size distribution and rain-event duration. The large number of parameters and their variability make the quantification of WDR a highly complex problem. Three approaches are available: experimental quantification, semi-empirical quantification and numerical quantification. The result of WDR quantification is the WDR intensity or amount that hits the building wall. The determination of the response of the building wall to WDR comprises surface phenomena such as splashing, adhesion, runoff, evaporation, absorption and the distribution of the moisture in the wall. The response of the wall to WDR is also determined by a diversity of parameters: the intensity and raindrop-size distribution of the WDR, the diameter and impact angle of each individual drop constituting the WDR, material-surface characteristics such as wall roughness, surface tension, and material characteristics such as moisture permeability and moisture-retention curve, etc.

The majority of research efforts in the past has focused on the first part of WDR research, as described in a recent review paper on WDR [Blocken and Carmeliet]. Significantly less attention has been given to the second part, i.e. contact and surface phenomena that determine in what way and how much of the impinging WDR actually adds to the moisture content of the exposed building components. Also at the Laboratory of Building Physics, K.U.Leuven, past research was mainly concentrated on WDR impact assessment. Recently however, a new full-scale measurement set-up for WDR was developed to measure contact and surface phenomena. The
aim of this set-up is to provide detailed validation data for the numerical simulation of heat and moisture transfer in building components. This paper is a brief status report of past and ongoing research at the Laboratory of Building Physics. In section 2, the past research in terms of WDR impact assessment is summarized. Section 3 describes the newly developed measurement set-up for contact and surface phenomena and provides some measurement results.

2 ASSESSMENT OF WIND-DRIVEN RAIN IMPACT

Three methods can be distinguished to quantify the WDR impact. Experimental methods provide a direct indication of the actual WDR load but they are time-consuming and often difficult in practice. Semi-empirical methods are easy-to-use but require long WDR measurement series for a large number of buildings with various configurations. Numerical methods based on Computational Fluid Dynamics (CFD) are also time-consuming and put high demands on computer performance but can provide very specific information for buildings with any configuration. In addition to intensive WDR research in other countries, full-scale measurements of wind, rain and WDR were also made at the VLIET test building of the Laboratory of Building Physics (Fig. 1). This set-up has been described in detail earlier [Blocken and Carmeliet2]. It comprises a pyrheliometer and thermohygrometer for outdoor temperature and relative humidity, a meteorological mast with cup anemometers at 2, 4, and 6 m above ground level and an ultrasonic anemometer at 10 m height, a rain gauge for the reference horizontal rainfall intensity and 23 WDR gauges situated at different positions of the building facade. These measurements were used to validate the CFD methodology for WDR developed by Choi3 that was extended into the time domain by Blocken and Carmeliet4. This CFD methodology consists of 5 main steps: (1) calculating the wind-flow pattern around the building; (2) determining raindrop trajectories in the wind-flow pattern; (3) calculating the specific catch ratio and (4) the catch ratio based on the configuration of the raindrop trajectories and (5) combining the catch-ratio data with meteorological data records at the appropriate time scale. Some simulation results are given in Figure 2.

Figure 1. VLIET test building and the surrounding environment (view from south-west, March 18, 2006)

Figure 2. CFD simulation of wind-flow pattern and raindrop trajectories for the VLIET test building (wind speed $U_{10}$ at 10 m above ground level is 10 m/s. The wind direction is south-west. (a) Mesh on the surface of the VLIET test building and the ground around it. (b) Wind speed (m/s) distribution (3 m above ground level). (c) Trajectories of 1 mm diameter drops. (d) Trajectories of 5 mm diameter drops.
3 ASSESSMENT OF CONTACT AND SURFACE PHENOMENA

3.1 Measurement set-up

The traditional approach of implementing WDR in numerical models of Heat, Air and Moisture (HAM) transfer in building components, even if the amount of WDR impinging on the building component is known, is very simplified: the total amount of impinging WDR is implemented as an averaged moisture flux per surface area. This approach, however, needs to be experimentally validated and, if necessary, improved. The difficulty of such validation studies is that they require very precise measurements of each of the contact and surface phenomena of WDR and hence a specialised and very accurate measurement set-up. The new set-up to measure WDR contact and surface phenomena is concentrated in one specific part of the south-west facade of the VLIET test building, as indicated in Figure 1. A schematic overview is given in Figure 3. The set-up consists of boxes with material samples with an exposed surface of 0.45x0.25 m² and a thickness of 0.09 m, cantilever systems to measure the material weight change, WDR gauges, anemometers near the material sample surfaces, temperature sensors near and at these surfaces and collectors for runoff water from the exposed surface of each of the samples separately. The measurement system has a resolution of 5 mg of water uptake/removal, irrespective of the weight of the sample. To prevent the horizontal disturbance by the wind, a roller to support the material was placed behind the sample (Fig. 3) without disturbing the material movement in the vertical direction. Different material samples are tested, including calcium silicate (CaSi) which is an interesting material because of its very high capillary absorption coefficient (1.2 kg/m²s¹/²) and capillary moisture content (800 kg/m³) [Roels et al.4].

Figure 3. Schematic overview of the new set-up. (a) View from south-west. (b) X-intersection.

3.2 Measurement results

Measurement results for two days between March 24 and March 26, 2006, are presented in Figure 4a and 4b. Figure 4a shows the reference wind speed and wind direction measured at 10 m height during this period. Figure 4b shows the WDR intensity, the cumulative amount of WDR...
and the corresponding weight change per unit volume of the calcium silicate (CaSi) sample starting from the initial value. The material is in section B (Fig. 3a). The cumulative amount and the intensity of WDR were measured by the WDR gauge at section A. Figure 4b clearly shows the weight increase due to WDR uptake and the decrease due to evaporation. To provide the data for the validation of numerical simulations, the temperatures at the material surface, the outdoor air temperature, the vapour pressure in the outdoor air, the horizontal rainfall intensity, and the amount of runoff water were measured as well. The amount of runoff water was under the measurable range, because of the very high capillary absorption coefficient and capillary moisture content of the material and because the intensity of WDR was not strong (Fig. 4b). These measurements and measurements with other material samples will be used to analyse the precision of the common modelling assumption for WDR in HAM models.

![Figure 4. Measurement results (March 24, 2006 ~ March 26, 2006). (a) Wind speed and direction (horizontal component, 10 m above ground level). (b) Material weight change, cumulative amount and intensity of WDR.](image)

4 CONCLUSION

In the past decades, wind-driven rain (WDR) has been an active research subject at building research institutes and universities all over the world. This paper has presented part of past and ongoing WDR research at the Laboratory of Building Physics, K.U.Leuven. Following earlier research efforts on the assessment of the WDR impact on buildings, current research at the Laboratory is focusing on the measurement of contact and surface phenomena. For this purpose, a new measurement set-up was installed in which different material samples are exposed to the outdoor climate. The data set obtained in these and ongoing measurements will be used for the validation of numerical modelling of WDR in HAM models.

5 REFERENCES