Experimental and numerical analysis of the hygrothermal response of walls to wind-driven rain

Citation for published version (APA):
Abuku, M., Blocken, B. J. E., & Roels, S. (2008). Experimental and numerical analysis of the hygrothermal response of walls to wind-driven rain. In S. Roels, G. Vermeir, & D. Saelens (Eds.), *Proceedings of the Building Physics Symposium in honour of Professor Hugo L.S.C. Hens, 29-31 October 2008, Leuven, Belgium* (pp. 211-214). Katholieke Universiteit Leuven.

Document status and date:
Published: 01/01/2008

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 16. Nov. 2023

Experimental and numerical analysis of the hygrothermal response of walls to wind-driven rain

M. Abuku[1], B. Blocken[2] and S. Roels[1]

(1) Laboratory of Building Physics, Katholieke Universiteit Leuven, Leuven, Belgium

(2) Building Physics and Systems, Eindhoven University of Technology, Eindhoven, the Netherlands

Keywords: moisture, driving rain, absorption, evaporation, field measurement, validation

Summary

To investigate the validity of the traditional approach to implement wind-driven rain (WDR) in hygrothermal building envelope models, under real atmospheric conditions, a new set-up was developed at a test building. Reference wind speed and direction, WDR intensity, outdoor air temperature and relative humidity and the resulting moisture response of the wall to these environmental conditions (both hygroscopic loading and WDR) were simultaneously measured. The whole measurement data set was used for validation. Large differences between the measurement and simulation results were found and possible causes discussed. It is concluded that many influencing parameters interact, and that therefore precisely predicting the hygrothermal response of walls to wind-driven rain is very difficult.

1. Experimental set-up at the vliet test building

Wind-driven rain (WDR) is one of the most important moisture sources when analysing the hygrothermal behaviour of building envelopes and thus of great concern in the field of building physics[1-4]. Without splashing, bouncing, and runoff of raindrops, the moisture flux at the outside wall surface g_m (kg/m^{2}s) is generally expressed as[5-7]

$$g_m = -\beta_e\left(p_e - p_{s,e}\right) - I_{WDR} \tag{1}$$

where β_e is the moisture transfer coefficient (s/m), p_e and $p_{s,e}$ are the vapour pressures (Pa) of the outdoor air and at the outside wall surface respectively and I_{WDR} is the WDR intensity (kg/m^{2}s).

To investigate the validity of Eq. (1), a new set-up was developed at the VLIET test building[8] (Fig. 1 (a)) located at K.U.Leuven, Belgium. The test building itself was constructed for the comprehensive study of the hygrothermal behaviour of building components under "real" climatic conditions. Apart from the building itself, in which the new test set-up is situated, the building is equipped with a meteorological mast and rain gauge in the free field[9]. With one ultrasonic anemometer at the mast the wind speed U_{10} and wind direction φ_{10} at 10 m above the ground are recorded.

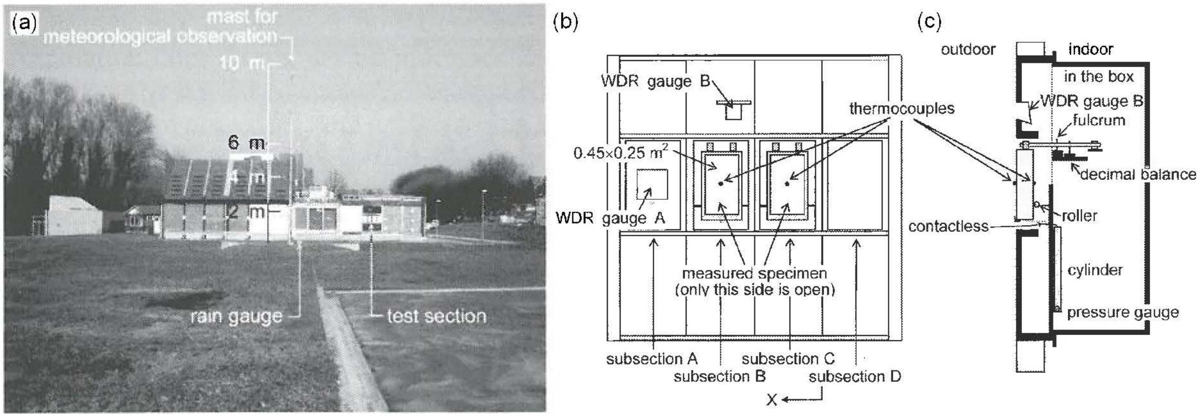

Fig. 1. (a) VLIET test building and the surrounding environment (view from south-west) and the schematic diagrams of (b) the elevation and (c) X-intersection of the test section and the new set-up.

The newly developed set-up at the test section is illustrated in Fig. 1 (b) and (c). The new set-up consists of a device to measure the weight change w_{mea} of the specimen, PMMA WDR gauges[9] on the wall, temperature sensors at the material surface, and a collector gauge for the runoff water. With a data logger the weight change, the surface temperature of the specimen, the amount of the runoff water and the WDR intensity next to the specimen are measured simultaneously. The principle of leverage was used for measuring w_{mea}, achieving a resolution of 5 mg. To prevent horizontal disturbance by the wind without disturbing the material movement in the vertical direction, a roller supports the material at the back side (see Fig. 1(c)).

2. Measurement results

Fig. 2 shows results of measurements performed during two periods in 2007: November 29, 0:00 - December 2, 0:00 and December 3, 20:00 - December 12, 15:00. In all measurements described in the current paper, a specimen of calcium silicate (0.25 m × 0.45 m × 0.09 m) was used because of its very high capillary moisture content (803 kg/m^3) and water absorption coefficient (1.22 kg/m^{2}s$^{0.5}$)[10]. Fig. 2 (a) and (b) show the weight change w_{mea} of the specimen from the initial value at the test subsection B (see Fig. 1 (b)), the cumulative amount $S_{WDR,mea}$ of WDR and the WDR intensity $I_{WDR,mea}$ at test subsection A. The figures show that w_{mea} increased during WDR and decreased due to evaporation afterwards. Furthermore the temperatures at the centre of the exterior and interior surfaces of the specimen and the outdoor air temperature and vapour pressure near the specimen (Fig. 2 (c) and (d)) were simultaneously measured, as well as U_{10} and φ_{10} (Fig. 2 (e) and (f)). The adhesion-water evaporation error[9] of $I_{WDR,mea}$ is estimated at 3 % for the current rain events.

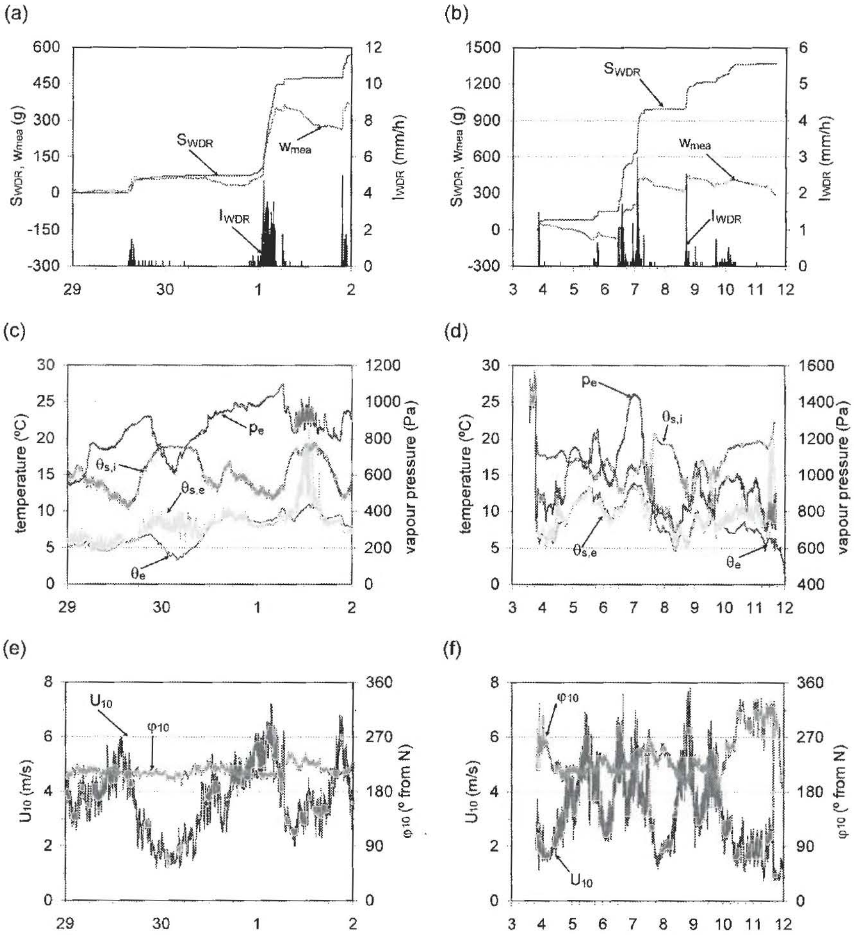

Fig. 2. Measurement results of (a,c,e) November 29 - December 2, 2007 and (b,d,f) December 3 -12, 2007. (a,b) weight change of the specimen w_{mea}, cumulative amount $S_{WDR,mea}$ and intensity $I_{WDR,mea}$ of wind-driven rain; (c,d) outdoor temperature θ_e, outdoor vapour pressure p_e, and temperatures at the inside and outside material surfaces $\theta_{s,e}$ and $\theta_{s,i}$; (e,f) wind speed U_{10} and wind direction φ_{10} (10 m above the ground level).

3. Numerical analysIs and discussion

3.1 Numerical analysis

In this section, the measurement data of the hygrothermal response of the specimen to the WDR loads are compared to the results of one-dimensional numerical calculations with the traditional approach (Eq. (1)) for WDR. For windward facades, which are those exposed to WDR, Janssen et al.[6] described the moisture transfer coefficient with the following equation:

$$\beta_e = 7.7\times10^{-9}\left(3.06U_{10}+5.44\right) \qquad (2)$$

In the current study, three simulations were carried out with different β_e equations based on Eq. (2) to check the adequacy of β_e for the given conditions. The first is Eq. (2), another is the half of Eq. (2) (Eq. (2) / 2), and the other is the double of Eq. (2) (Eq. (2) × 2). For the heat transfer analysis, the measured temperatures at the centre of the exterior and interior surfaces of the specimen are used as boundary conditions. The initial conditions were determined based on the measurement data.

Fig. 3 compares the measurement and simulation results for the two periods. In general, although qualitative trends of the measurement results of absorption and evaporation of WDR are well predicted by the numerical simulations, important differences can be observed. These differences are discussed from several points of view in the next section.

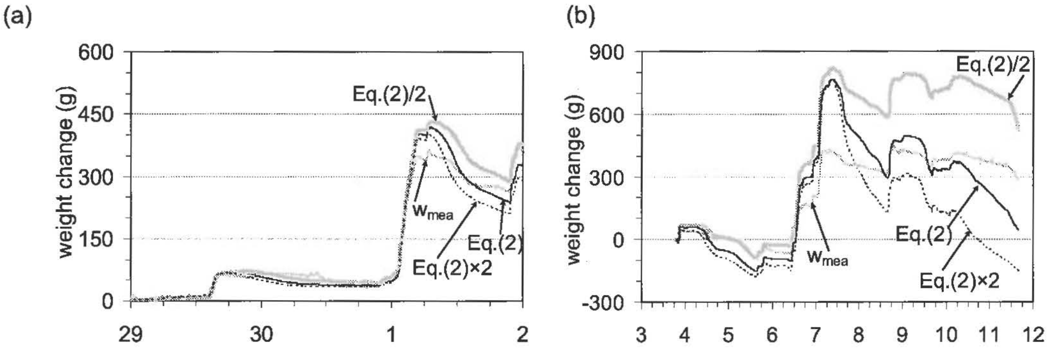

Fig.3. Simulated weight changes $w_{sim}(I_{WDR,mea})$ of the specimen compared to measured ones w_{mea} for the two periods. (a) 29/11/2007 - 2/12/2007 and (b) 3/12/2007 - 11/12/2007.

3.2 Discussion

In Fig. 3, the results of the simulations with three different β_e equations are compared to the corresponding measurements for each period. This comparison shows that, although the results are significantly influenced by β_e, the differences between w_{mea} and $w_{sim}(I_{WDR,mea})$ are mainly caused during rain. Therefore, it seems that β_e is not the main reason that caused the differences. Also Eq. (2) / 2 seems to be more appropriate for the current cases than the other two β_e equations, when looking at the evaporation rates during drying processes. Note, however, that the overestimated drying rate in the simulations is not only caused by the applied equation for the surface coefficient, but also due to an overestimation of the moisture uptake during WDR.

From the above discussion, the differences between w_{mea} and $w_{sim}(I_{WDR,mea})$ presented in the previous section may be attributed to other errors. Conceivable errors are: (1) the averaging error[11] and the splashing/bouncing error[12]. The traditional approach of modeling WDR uptake (Eq. (1)) is a simplification of the real discrete and random impingement, uptake and evaporation of raindrops. It presents a spatially and temporally averaging approach which can cause considerable errors[11]. The splashing/bouncing error refers to possible surface phenomena at raindrop impact. Due to splashing and/or bouncing of raindrops, part of these raindrops may not contribute to the moisture load on the facade.

Although it is "almost" impossible to perform a detailed three-dimensional simulation of individual raindrops[11] for the current study due to the limitation of computer capacity, the differences are considered to be largely attributable to the averaging error as demonstrated by Abuku et al.[11].

Furthermore, given the limited data available on oblique water drop impact on porous building materials, it is not possible to quantify the splashing/bouncing error at this moment. The differences are also considered to be partly attributable to the splashing/bouncing error.

4. Conclusions

A new measurement set-up was developed to validate the traditional approach to implement wind-driven rain (WDR) in hygrothermal building envelope models, under real atmospheric conditions. The material weight change (hygrothermal response of walls) and WDR loads as well as other environmental conditions were simultaneously measured for two rain events. The measurement results were compared to those of numerical simulations with the traditional approach. The simulations significantly overestimated the average moisture in the specimen during rain. Whereas it was shown that the results of the simulations depend on the value of the moisture transfer coefficient especially during drying periods, differences between the simulated and measured responses of walls mainly occurred during rain. Therefore it seems that the moisture transfer coefficient is not the main reason of the differences. Although it is not possible at this moment to quantify the averaging error and the splashing/bouncing error described in the previous section, it is concluded that the reliable prediction of the response of walls to WDR loads is a very difficult task.

ACKNOWLEDGEMENTS

The results in this paper have been obtained within KUL OT/04/28, 'Towards a reliable prediction of the moisture stress on building enclosures', funded by the K.U.Leuven and IWT 050154, 'Heat, air and moisture performance engineering: a whole building approach', funded by the Flemish Government. This financial support is gratefully acknowledged.

The authors are especially grateful to Prof. Hugo Hens, for his continuous support throughout the years. As one of his many achievements, the VLIET building has become an indispensable tool for Building Physics research at K.U.Leuven and other universities.

REFERENCES

[1] C.Sanders. 1996. Heat, air and moisture transfer in insulated envelope parts. IEA Annex 24, Final report – Vol. 2, Task 2: Environmental conditions, Leuven: Acco Leuven.

[2] H.M.Künzel, K.Kiessl. 1997. Calculation of heat and moisture transfer in exposed building components, International Journal of Heat and Mass Transfer, 40(1), pp.159-167.

[3] B. Blocken, J.Carmeliet. 2004. A review of wind-driven rain research in building science, Journal of Wind Engineering and Industrial Aerodynamics, 92(13), pp.1079-1130.

[4] M.Abuku, H.Janssen, S.Roels. 2008. Impact of wind-driven rain on historic brick wall buildings in a moderately cold and humid climate: numerical analyses of mould growth risk, indoor climate and energy consumption, Energy and Buildings, in press, doi:10.1016/j.enbuild.2008.07.011.

[5] H.Janssen, B.Blocken, J.Carmeliet. 2007. Conservative modelling of the moisture and heat transfer in building components under atmospheric excitation, International Journal of Heat and Mass Transfer, 50, pp.1128-1140.

[6] H.Janssen, B.Blocken, S.Roels, J.Carmeliet. 2007. Wind-driven rain as a boundary condition for HAM simulations: analysis of simplified modelling approaches, Building and Environment, 42, pp.1555-1567.

[7] B.Blocken, S.Roels, J.Carmeliet. 2007. A combined CFD-HAM approach for wind-driven rain building facades, Journal of Wind Engineering and Industrial Aerodynamics, 95(7), pp.585-607.

[8] H.Hens, A.Janssens, R.Zheng. 2003. Zinc roofs: an evaluation based on test house measurements, Building and Environment, 38(6), pp.795-806.

[9] B.Blocken, J.Carmeliet. 2005. High-resolution wind-driven rain measurements on a low-rise building-experimental data for model development and model validation, Journal of Wind Engineering and Industrial Aerodynamics, 93(12), pp.905-928

[10] S.Roels, J.Carmeliet, H.Hens, O.Adan, H.Brocken, R.Cerny, Z.Pavlik, H.Hall, K.Kumaran, L.Pel, R.Plagge. 2004. Interlaboratory comparison of hygric properties of porous building materials, Journal of thermal envelope and building science, 27(4), pp.307-325.

[11] M.Abuku, H.Janssen, J.Poesen, S.Roels. 2009. Impact, absorption and evaporation of raindrops on building facades, Building and Environment, 44, pp.113-124.

[12] M.Abuku, B.Blocken, J.Poesen, S.Roels. 2008. Surface phenomena of raindrop impact on porous building materials for pollutant deposition and detachment studies, Atmospheric Environment, in review.