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# Wind-driven rain as a boundary condition for HAM simulations: Analysis of simplified modelling approaches

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## Abstract

While the numerical simulation of moisture transfer inside building components is currently undergoing standardisation, the modelling of the atmospheric boundary conditions has received far less attention.

This article analyses the modelling of the wind-driven-rain load on building facades by partial simplification of a complex CFD-based method along the lines of the European Standard method. The results indicate that the directional dependence of the wind-driven-rain coefficient is not of substantial importance. A constant wind-driven-rain coefficient appears to be an oversimplification though: the full variability with the perpendicular wind speed and horizontal rain intensity should be preserved, where feasible, for improved estimations of the moisture transfer in building components.

In the concluding section, it is moreover shown that the dependence of the surface moisture transfer coefficient on wind speed has an equally important influence on the moisture transfer in building components.


*Keywords:* HAM; Wind-driven rain; Driving rain; Evaporation; Surface moisture transfer coefficient

## 1. Introduction

Knowledge of the hygric behaviour of building components is of serious importance for different building physics issues. Insight into a building component's hygric behaviour is evidently needed when analysing durability problems of existing components, or when assessing the expected performances of newly developed components. The moisture transfer inside building components also affects the interior climate though, and hence plays a role in interior air quality and energy performance. The moisture transfer inside the building components moreover determines the moisture regime at the exterior surface, and thus influences esthetical appearance, by playing a part in soiling phenomena and algae formation.

Until recently, the Glaser method was accepted as the standard [1] calculation tool for such evaluation of building components' hygric behaviour, but its restrictions—stationary, no liquid transfer, no air transfer—make it only rarely reliably applicable. Presently, application of hygrothermal simulation programmes for the evaluation [2,3] or optimisation [4,5] of the hygric performance of building components is becoming general practice.

Currently, numerical simulation of moisture transfer in building components is undergoing standardisation [6], to which a quality assessment methodology was recently added [7]. Both are restricted though to moisture and heat transfer inside permeable building components, and do not thoroughly discuss the atmospheric boundary conditions. The dependability of hygrothermal simulations under atmospheric excitation cannot be guaranteed, however, without an accurate modelling of these phenomena. This article concentrates on the atmospheric moisture load, presumed the largest and most important uncertainty.

The ensuing study reveals that wind-driven rain is the main moisture source for permeable building facades and

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investigates the required level of detail in implementations of wind-driven rain as a boundary condition in hygrothermal simulations. This study focuses on the long-term 'moisture response' of building facades, which is represented by the variation of average and surface moisture contents over the course of a year. The yearly wind-driven rain and evaporative drying amounts are, however, also incorporated in the comparison. Other 'shorter-term' wind-driven rain-related phenomena, such as run off and water penetration, are discussed only secondarily.

This analysis, based on hygrothermal simulations of building components, piecewise simplifies a complex CFD-based formulation [8] for wind-driven rain along the concepts of the European Standard on wind-driven rain [9], in order to evaluate the acceptability of the differing features of both approaches. More specifically, this article investigates the significance of the dependency of the wind-driven-rain coefficients on rain intensity, wind speed and wind direction. In the final paragraph, the resulting conclusions are put into a larger perspective, by sketching the effect of the surface moisture transfer coefficients on evaporative drying, the primary moisture removal mechanism for permeable building facades.

## 2. Numerical simulation of moisture and heat transfer in building components

All results presented in this article are achieved by numerical solution of the standard partial differential equations for coupled moisture and heat transfer in porous building materials, combined with the complete formulations for the atmospheric hygrothermal boundary conditions. Air transfer and the consequent advective transfer of moisture and heat are not included in this analysis. Further details on the numerical simulation model can be found in [10]. In this article, the formulations for the atmospheric moisture load are concisely repeated.

### 2.1. Atmospheric moisture load

As long as the building facade's exterior surface does not reach capillary saturation, the moisture exchange with the atmosphere $\mathbf{g_{es}}$ comprises wind-driven rain $R_{\mathrm{wdr}}$ and vapour exchange $E_{\mathrm{e}}$ (all in kg/m$^2$s):

$$\mathbf{g_{es}} = R_{\mathrm{wdr}} + E_{\mathrm{e}}. \tag{1}$$

In this numerical model, wind-driven rain is calculated from the wind-driven-rain index, the product of reference wind speed $U$ (m/s)—at 10 m height in the upstream undisturbed flow—and horizontal rainfall intensity $R_{\mathrm{h}}$ (kg/m$^2$s)—through a horizontal plane—by use of the wind-driven-rain coefficient $\alpha$ (s/m) [11]:

$$R_{\mathrm{wdr}} = \alpha U R_{\mathrm{h}}. \tag{2}$$

All arriving wind-driven rain is assumed to be retained by the surface, splash-off is thus neglected. When the exterior surface reaches capillary saturation though, the moisture flow supplied to the surface may exceed the possible inflow into the component: the excess is assumed to be discarded from the system as runoff.

Evaporative exchange $E_{\mathrm{e}}$ is described by:

$$E_{\mathrm{e}} = h_{\mathrm{m,e}}(p_{\mathrm{v,e}} - p_{\mathrm{v,es}}), \tag{3}$$

where $h_{\mathrm{m,e}}$ is the surface moisture transfer coefficient (s/m), and $p_{\mathrm{v,e}}$ and $p_{\mathrm{v,es}}$ are the air and surface vapour pressure (both in Pa), respectively.

### 2.2. Wind-driven-rain coefficients

All wind-driven-rain coefficients used in this study are adapted from the CFD simulations in [12]. The numerical methodology to obtain these coefficients was validated by comparison with full-scale measurements by Blocken and Carmeliet [8].

Blocken and Carmeliet applied a three-step approach to compute the wind-driven-rain coefficients:

1. *Steady-state wind flow pattern*
   The steady-state wind flow patterns around the buildings are simulated with CFD, for wind speeds from 0 to 10 m/s and for deviations between wind direction $\theta$ and the surface normal $\varphi$ (both in degrees from north) of 0°, 22°, 45° and 67°. The Reynolds averaged Navier–Stokes equations and continuity equation are solved applying the control volume method (with commercial code Fluent 5.4). Closure is obtained by the use of realizable $k$–$\varepsilon$ turbulence model. Results are numerical values for wind speeds, pressure and the turbulence quantities at the centre of each volume.
2. *Raindrop trajectories*
   With the obtained wind flow patterns, raindrop trajectories are calculated for raindrop diameters from 0.5 to 6 mm. Rain drops are injected from a horizontal plane located in the upstream-undisturbed wind flow, high above the ground: its location must allow injected raindrops to reach the terminal fall velocity (vertical) and wind velocity (horizontal) before entering the flow pattern disturbed by the presence of the building and its surroundings.
3. *Specific and integrated catch ratio, and wind-driven-rain coefficient*
   Comparison of the horizontal rain drop density with the density of wind-driven dropsarriving at the building facade defines the specific (for a rain-drop diameter $d$) catch ratio's $\eta_{\mathrm{d},\theta} = R_{\mathrm{wdr,d}}/R_{\mathrm{h,d}}$. The global catch ratio $\eta_\theta$ ($= R_{\mathrm{wdr}}/R_{\mathrm{h}}$) is obtained by integration over the raindrop spectrum. Division of $\eta_\theta$ by wind speed $U$ yields the wind-driven rain coefficient $\alpha_\theta$.

The resulting $\alpha_\theta(R_{\mathrm{h}},U,\theta\text{–}\varphi)$ relations are depicted in Fig. 1, for the left top corner and centre of a cubic ($10 \times 10 \times 10\,\mathrm{m}^3$) building's facade. It is apparent that $\alpha_\theta$