report FAGO 98.62.K; article submitted to Building & Environment

Measurements of driving rain by a new gauge with a wiper

Fabien J.R. van Mook

Building Physics group (FAGO)

Faculty of Architecture, Building and Planning

Eindhoven University of Technology (TUE)

Postbus 513, NL–5600 MB Eindhoven

phone: +31–40 247 5790, fax: +31–40 243 8595

e-mail: famo@fago.bwk.tue.nl

15-7-1998

Abstract

Since December 1997 measurements of wind and driving rain are carried out at the Eindhoven University of Technology. Driving rain is measured by two types of driving-rain gauges which are located adjacent to each other on the west facade of the Main Building of the campus.

One gauge is a traditional driving-rain gauge, the other one is equipped with a wiper. The main conclusion of the measurements is that the gauge with the wiper measures approximately two times more driving rain than the gauge without wiper.

1 Introduction

Many factors determine the deterioration of building envelopes. Heat and moisture transfer, dry and wet deposition of chemical substances, design deficiencies and imperfections affect the performance and durability of facades, and the costs of maintenance.

To design good buildings with regard to deterioration, knowlegde of the exposure to the local outdoor climate is primordial. One of the parameters is driving rain, defined as rain that is carried by wind and driven onto the building envelope.

Only in the UK there is a standard method for building designers to estimate driving-rain quantities (BS 8104 [1]). Also for reseach on moisture transport in e.g. brick walls, more knowledge of driving rain is useful, as driving rain is a major boundary condition.

For these reasons, reseach on driving rain is taken up at the Eindhoven University of Technology (TUE). This research implies full-scale measurements and simulations by computational fluid dynamics (c.f.d.). In [10] we presented some preliminary computer simulations using an approach which is useful for the understanding of the distribution of the impingments of raindrops on building envelopes, and for the estimation of driving-rain intensities.

In this article we show the first results of full-scale measurements of driving rain. Since December 1997 we measure driving-rain intensities by two types of driving-rain gauges, installed adjacent to each other on the facade of the Main

Building of the TUE. The difference between the two driving-rain gauges is that one is equipped with a wiper and the other one is not.

2 Measuring driving rain

Driving rain has been the subject of research for many years. Main surveys can be found in [6], [4], [8] and in [2]. Details of the used equipment for the measurement of driving rain are not often given; Frank [4], Flori [3] and Osmond [7] are the exceptions known to us. We did not find any reference on a comparison of different types of driving-rain gauges, and no reference dealing with the systematical error of a given driving-rain gauge type.

The most widely used driving-rain gauge consists of:

- a collector (a shallow tray) fixed to the wall of a building. The drops hit the tray, drip downwards and are collected by:
- a drainage channel, that directs the collected rain water to:
- a reservoir or a water flux gauge. A water flux gauge enables the measurement of the instantaneous driving-rain intensity.

It is obvious that the catch efficiency (and thus the measurement error) of a gauge depends on size, shape and finish of the gauge surfaces. One should prevent that drops remain on the collector or in the drainage channel and evaporate, that drops splash out of the gauge, and that the shape of the gauge causes extra wind disturbances.

It is very difficult, sometimes practically impossible, to find realistic tests for evaluation of these error factors. We concentrate on the limitation of remaining and evaporating drops. This idea was brought about by our observation at the facade of the Main Building of the TUE that much of the drops simply stick on the window glass, and do not drip downwards during many driving rains.

The design of our driving-rain gauges is based on the following requirements:

1. driving-rain intensity range: 0.05 ... $\geq$ 2.0 mm/h,
2. sampling rate: 1 per min,
3. catchment area: 0.5 ... 1 m^2;
4. the reservoir should be able to contain a minimal collected driving-rain sum of 3 consecutive days: 5 mm,
5. all impinged drops should be directed into the reservoir,
6. the wind should not blow into the reservoir and influence the desired flow of the drops into the reservoir (e.g. due to wind suction).

The first and fourth requirement are estimations obtained from hourly meteorological data of the main weather station of the Royal Netherlands Meteorologic Institute (KNMI) at De Bilt. The driving-rain intensity range was calculated according to the principle of [6] and [1].

The first three requirements imply that the minimal amount of water, measurable within a minute for a driving-rain intensity of 0.05 mm/h and through a catchment area of 0.5 m^2, will be 0.5 ml. We decided to use a balance, by which one can easily and accurately measure such small quantities.

The fourth requirement implies that, if the catchment area is 0.5 m^2, the driving-rain gauge reservoir will collect at most 2.5 litres in three consecutive days.

Figures 1 and 2 show the two types of driving-rain gauges which we use for our measurements. Both types consist of a collector, a so-called wind deflector (to satisfy requirement 6), a reservoir and a balance (for the actual detection of the amount of water). Also for both types, all the inner sides have been coated with teflon (to comply with requirement 5). The main difference is that driving-rain gauge *II* is equipped with a wiper and driving-rain gauge *I* is not. The wiper is a standard windscreen wiper for cars, and is automatically switched on by a rain indicator. The speed is about 1 rotation per 2 seconds; after every 5 seconds the wiper rests during 5 s to reduce wear and tear.

The shapes of the catchment area are different because driving-rain gauge *I* was designed well before gauge *II*, which has been designed as an improved version of gauge *I*. We do not expect that this difference will significantly affect the results.

The wiper serves to improve the collection efficiency: drops on the collector are forced to coagulate and drip down. Furthermore the wiper keeps the surface of the driving-rain gauge clean. In our laboratory the driving-rain collectors were tested for their efficiency of the transport of impinged drops into the reservoir. By a plant sprayer drops were sprayed onto the collector and the collected amount of water and the sprayed amount of water were measured. Also the time of spraying was measured. Results of this test (figure 3) show mainly that wiping decreases significantly the dependence of the collection efficiency to the total sprayed amount *and* the spray intensity. The real effect of wiping can only be found by full-scale measurements; the drop spectrum of the used spray is different from raindrop spectra.

Details of the driving-rain gauges can be found in [9].

3 Site and measurement configuration

The driving-rain measurements are carried out on the west facade of the Main Building, on the campus of the Eindhoven University of Technology (figure 4).

The dimensions of the Main Building are: (height) 45 m, (width) 167 m and (depth) 20 m. The Auditorium is 14 m high and is located at 72 m from the west facade of the Main Building. The reference wind velocity is measured at 45 m height (from ground level) on a mast on the Auditorium (figure 5). The reference horizontal rain intensity is measured by two tipping-bucket rain gauges on the roof of the Auditorium at positions `P2` and `P3`. See figures 4 and 5, and table 1 for the instrumentation. Figure 6 shows a picture of the two driving-rain gauges, which are mounted in two adjacent window frames. The distance between the centers of the gauges is 1.25 m.

A weather station for air temperature, relative humidity and solar irradiation is situated on the roof of the Main Building, at position `P0`. The data of this station can be combined with the wind and driving rain data to obtain a weather series of the microclimate at the Main Building.

The site is suited because the prevailing direction for wind and rain is between south and west. There are no large obstacles in south-west to west direction. The fetch in this direction is rough (roughness height of 1 ± 0.4 m [5]), and consists mainly of trees over a distance of 400 m. The nearest high-rise building in this direction is 500 m away.

The wind characteristics of the site have already been subject of study, see [5]. Details of the measurement configuration, data acquisition system and data processing can be found in [9].

4 Measurements

The results presented here are of the period of 1-12-1997 to 31-5-1998. Much rain and strong winds occurred from 25-12-1997 till 9-1-1998 and from 27-2-1998 till 9-3-1998. These periods were ideal to test the measurement set-up and to compare the two different driving-rain gauges.

Figure 7 shows the reference horizontal wind direction and speed (hourly averaged). (Note that a wind direction of 0° is due north; 270° is west.) Figure 8 shows the reference horizontal rain sum S_h at position `P2`.

The results of driving-rain gauge *I* (at position `P4`) and driving-rain gauge *II* (`P5`) are depicted in figure 9. It clearly shows that driving-rain gauge *I* without wiper measures much more rain than the driving-rain gauge *II* with wiper. A comparison of the two gauge results for every 10-min clock period shows (figure 10) that in general the gauge with wiper collects two times more driving rain than the gauge without wiper.

Figure 11 shows the ratio of the 10-min driving-rain sums S_{dr} of gauge *II* as a function of the horizontal wind speed and direction. The data has not been selected. Remark the general large scatter, and the large number of data points scattered over the wind velocity range with zero driving rain and nonzero horizontal rain.

The same data of figure 11 is plotted again in figure 12, but as function of the reference wind velocity component normal to the facade U_n:

$$U_n = U_h \times \cos(\Phi - 270°), \qquad (1)$$

with U_h = the reference horizontal wind speed at position `P1` (Auditorium) and Φ = the reference horizontal wind direction at the same position. Only the positive values (i.e. wind from 180°–360°) are taken into account.

Despite this correction the graph still shows a relatively large scatter, which might be caused by wind turbulence and variation in raindrop size distributions. A selection from the original data for reference wind directions of 250°–290° and for reference horizontal rain sums $S_h > 0.6$ mm/h, yields figure 13, which again shows scatter.

Finally, we reuse the original data (figure 12), define intervals of 1 m s^{-1} for the corrected horizontal wind speed U_n and subsequently we calculate a total driving-rain ratio per wind speed interval:

$$\frac{\sum S_{dr}}{\sum S_h}, \tag{2}$$

with $\sum S_{dr}$ and $\sum S_h$ = the summation of all driving-rain sums and respectively the summation of all horizontal rain sums for a wind speed interval.

The result is displayed in figure 14 and it gives an average relationship between the driving-rain ratio and reference wind speed.

Lacy [6] and BS 8104 [1] assume the following relationship between S_{dr}/S_h and the reference wind speed:

$$\frac{S_{dr}}{S_h^b} = \kappa\, \alpha\, U_n, \tag{3}$$

with κ = the driving-rain catch ratio [-] depending on building geometry, α = the free driving-rain catch ratio [s m^{-1} mm^{-b} h^{b}], with a constant value of 0.22 [6], and b = a constant, which according to [6] equals to 0.88, here we assume $b = 1$.

In figure 14 we have also plotted the line according to (3), with $\kappa = 0.1$. This line does not fit well our measurements by gauge *II*.

5 Conclusions

The main conclusion of the measurements so far, is that a driving-rain gauge with wiper catches substantially more rain than a driving-rain gauge without wiper. We found a factor 2. The laboratory tests (spraying water on the driving-rain collector) showed that wiping decreases significantly the dependence of the collection efficiency to the total sprayed amount and the spray intensity.

Consequently, the measurements also show that only making the surface of the driving-rain collector more hydrophobic (e.g. teflon coating) is not adequate enough.

A plot of the driving-rain ratio S_{dr}/S_h as function of the reference wind speed shows a large scatter, which might be caused by wind turbulence and variation in raindrop size distributions.

The linear relationship between S_{dr}/S_h and the reference wind speed, assumed by Lacy [6], does not fit well to our measurements.

Acknowledgements

This research is a joint project of the Faculty of Architecture, Planning and Building and of the Faculty of Technical Physics, at the TUE. The project is partly funded by the common TUE programme on 'Technology for Sustainable Development'.

References

[1] BSI. *BS 8104: Code of practice for assessing exposure of walls to wind-driven rain*, 1992.

[2] J.-P. Flori. Conditions de mouillage et de séchage des façades verticales: Étude bibliographique. Technical Report EN-CLI 88-17 L, Centre Scientifique et Technique du Bâtiment, Nantes, 1988.

[3] J.-P. Flori. Mouillage et séchage d'une façade verticale: analyse expérimentale. Technical Report EN-CLI 90.2 L, Centre Scientifique et Technique du Bâtiment, Nantes, 1990.

[4] W. Frank. Einwirkung von Regen und Wind auf Gebaüdefassaden. In *Berichte aus der Bauforschung*, volume H. 86, pages 3–13. Wilhelm Ernst & Sohn, Berlin, 1973.

[5] C.P.W. Geurts. *Wind induced pressure fluctuations on building facades.* PhD thesis, Eindhoven University of Technology, 1997.

[6] R.E. Lacy. Driving-rain maps and the onslaught of rain on buildings. In *RILEM/CIB Symposium on Moisture in Buildings, Helsinki (SF)*, 1965.

[7] S.D. Osmond. Assessment of the full scale micro-climate around buildings. Technical Report N47/95, Building Research Establishment, 1995.

[8] M.J. Prior. Directional driving rain indices for the United Kingdom — computation and mapping, Background to BSI Draft for Development DD93. Building Research Establishment Report, 1985.

[9] F.J.R. van Mook. Description of the measurement set-up for wind and driving rain at the TUE. Technical Report FAGO 98.04.K, Building Physics group, Eindhoven University of Technology, 1998.

[10] F.J.R. van Mook, M.H. de Wit, and J.A. Wisse. Computer simulation of driving rain on building envelopes. In *Proceedings of the 2nd European and*

African Conference on Wind Engineering, 22-26 June 1997, Genova (IT), pages 1059–1066, 1997.

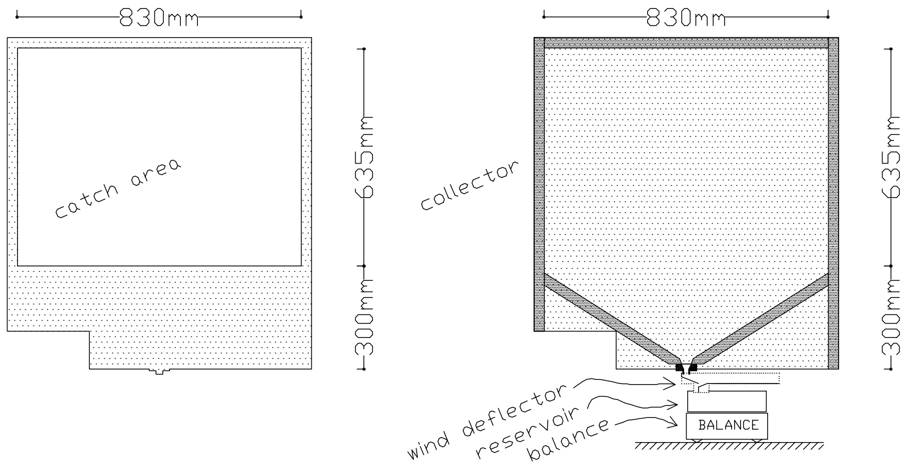

Figure 1: Driving-rain gauge, with driving-rain collector I, wind deflector, reservoir (2 litres) and balance. Left: foreplate with the rectangular catchment area (0.527 m^2). Right: backplate and the inside.

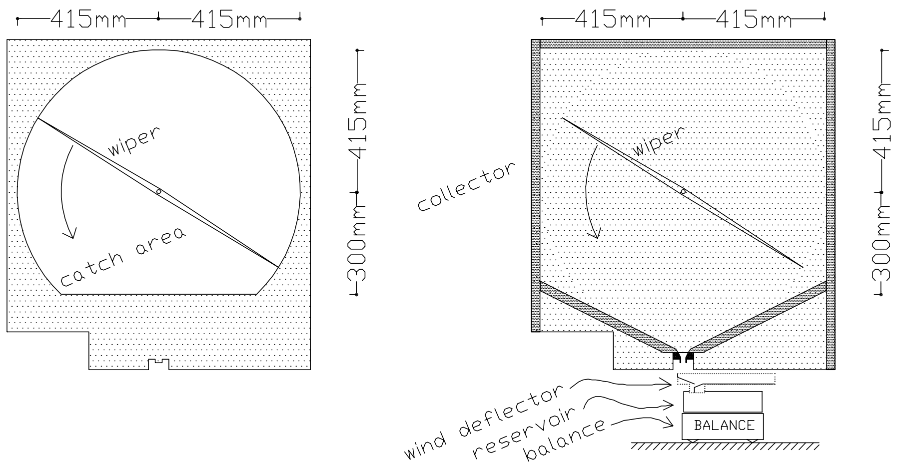

Figure 2: Driving-rain gauge, with driving-rain collector II, wind deflector, reservoir (3 litres) and balance. Left: foreplate with the round catchment area (0.492 m^2). Right: backplate and the inside.

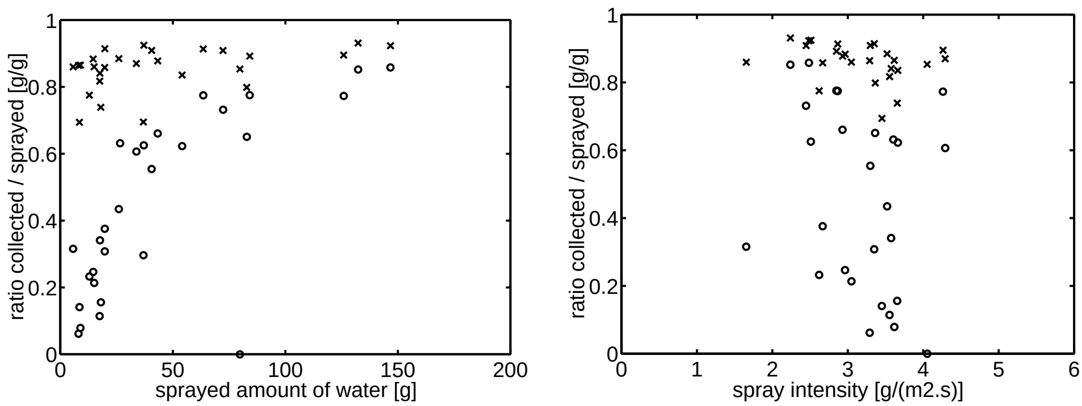

Figure 3: Laboratory spray test on driving-rain collector *II* before exposition to the outdoor climate. The collection efficiency is given without wiping (∘) and with wiping (×). A spray intensity of 1 g m^{-2} s^{-1} equals to 3.6 mm/h.

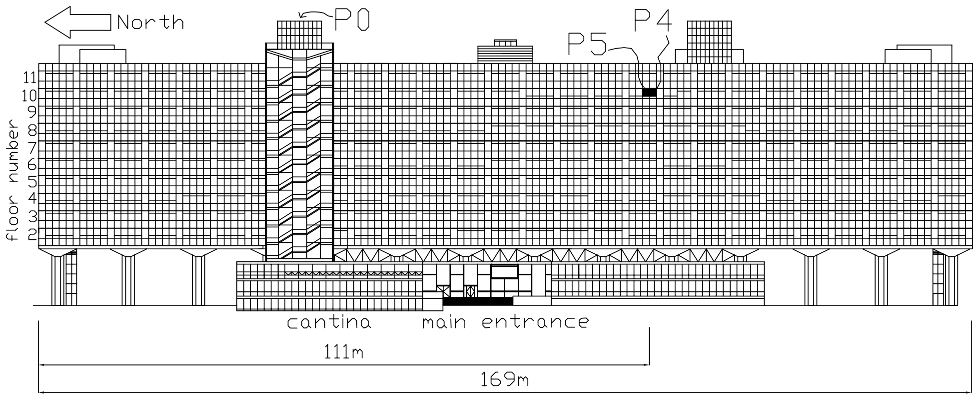

Figure 4: Measurement positions at the west facade of the Main Building of the TUE.

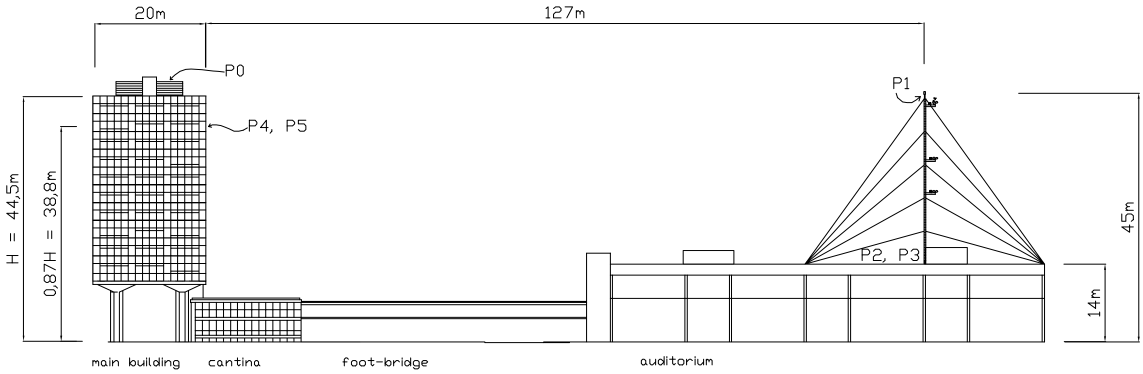

Figure 5: Measurement positions, view from north.

Figure 6: Driving-rain gauges in the west facade of the Main Building at position `P5` (left, d.r. gauge *II* with wiper) and `P4` (right, d.r. gauge *I* without wiper).

Table 1: Measurement positions and instrumentation. The reference quantities are marked with an asterisk; they are measured at the Auditorium. See also: figures 5 and 4

position	quantity	instrument	(output) sample rate
P1	wind velocity (3d)*	Solent Research Ultrasonic Anemometer	1 / min
P2	horizontal rain intensity*	Young tipping bucket rain gauge 52202	2 / min
P3	horizontal rain intensity*	Young tipping bucket rain gauge 52202	2 / min
P3	duration of horizontal rain*	rain indicator	2 / min
P4	wind velocity (3d) at 75 cm from facade surface	Solent Windmaster 1086M Ultrasonic Anemometer	1 / s
P4	driving-rain intensity	driving-rain collector I without wiper + balance Mettler PB 3001	4 / min
P5	driving-rain intensity	driving-rain collector II with wiper + balance Mettler PB 3001	4 / min

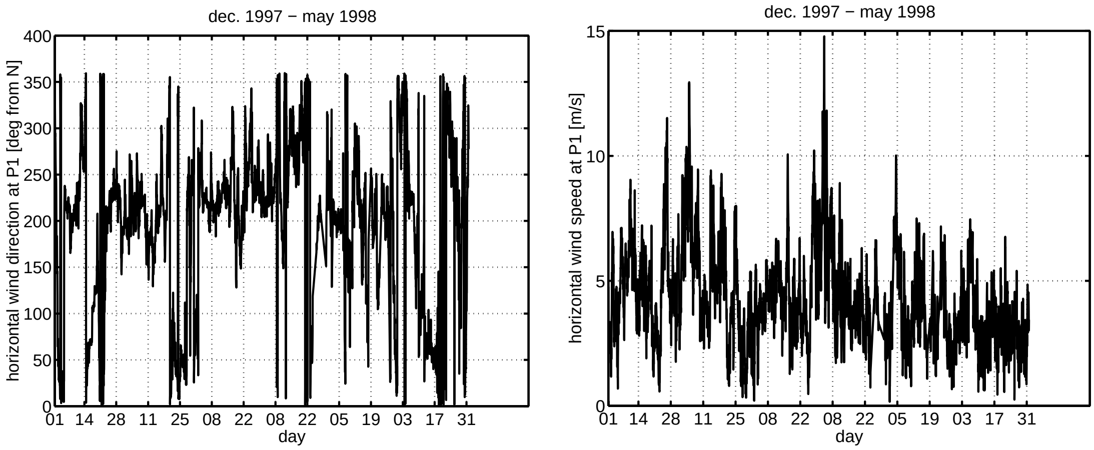

Figure 7: Horizontal wind direction [left] and horizontal wind speed [right] at position `P1` (Auditorium) as function of time. Average period $cp = 1$ hour.

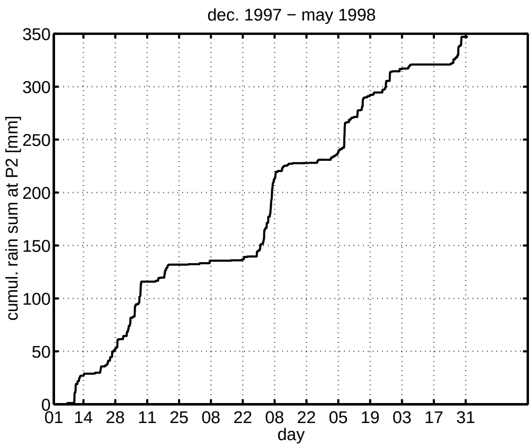

Figure 8: Horizontal rain sum S_h at position `P2` (Auditorium), as function of time.

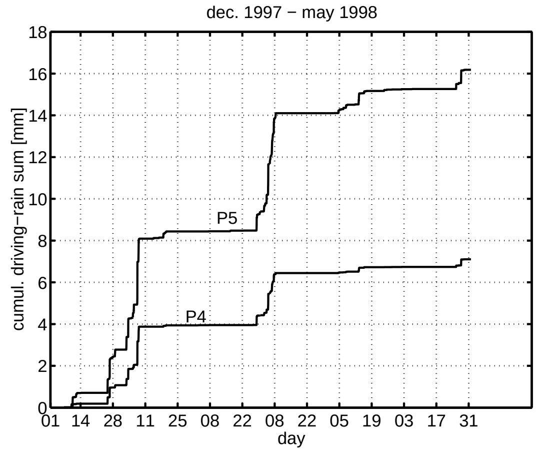

Figure 9: Cumulative driving-rain sum at position `P4` (facade of Main Building, d.-r. gauge *I* without wiper), and at position `P5` (facade of Main Building, d.-r. gauge *II* with wiper) as function of time.

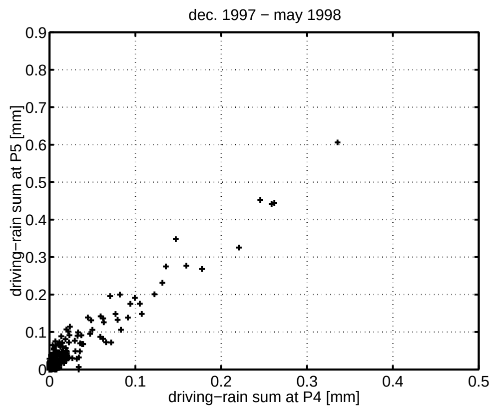

Figure 10: Comparison of the driving-rain gauge results: driving-rain sum at position `P4` (d.r. gauge *I*) resp. `P5` (d.r. gauge *II*). Summation period $cp = 10$ min.

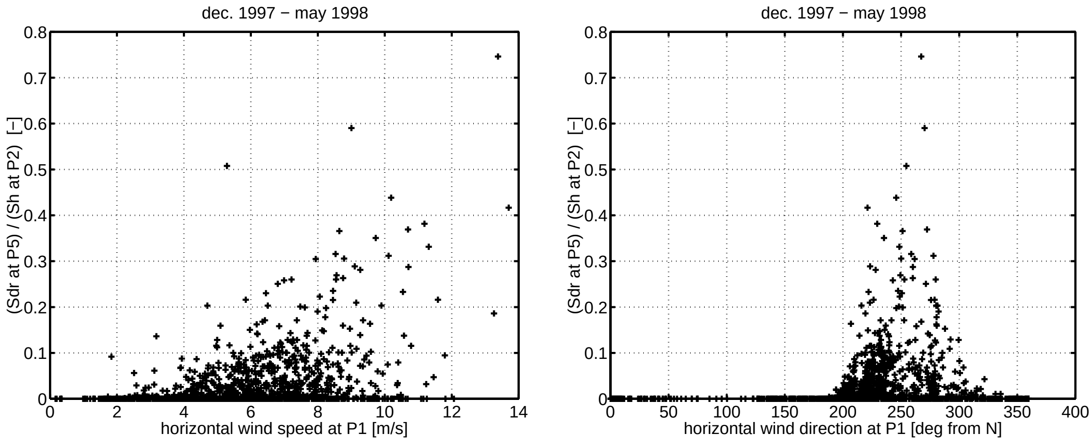

Figure 11: Ratio of driving-rain sum S_{dr} at position `P5` (facade of Main Building, d.r. gauge *II*) over reference horizontal rain sum S_h at position `P2` (Auditorium), as function of horizontal wind speed [left] and reference horizontal wind direction [right] at `P1` (Auditorium). Summation period cp = 10 min.

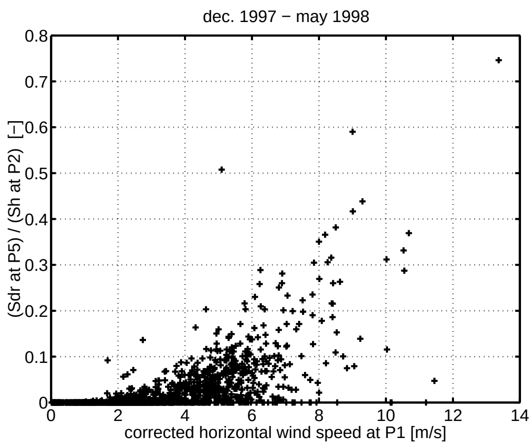

Figure 12: Ratio of driving-rain sum $S_{dr,\mathtt{P5}}/S_{h,\mathtt{P2}}$ (d.r. gauge *II*) as function of reference wind velocity component normal to the facade. Summation period cp = 10 min.

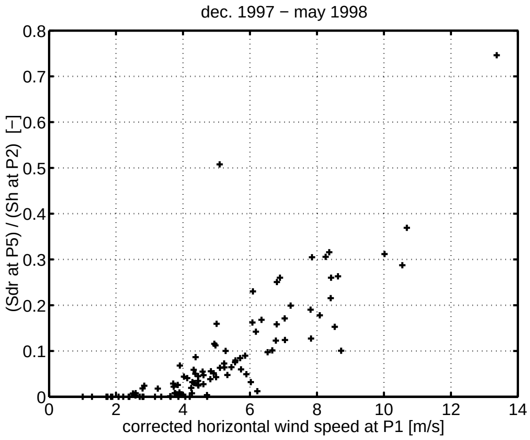

Figure 13: Ratio of $S_{dr,\mathtt{P5}}/S_{h,\mathtt{P2}}$ (d.r. gauge *II*) as function of reference wind velocity component normal to the facade, selected for reference wind directions of 250°–290°, and for horizontal rain sums $S_h > 0.1$ mm. Summation period cp = 10 min.

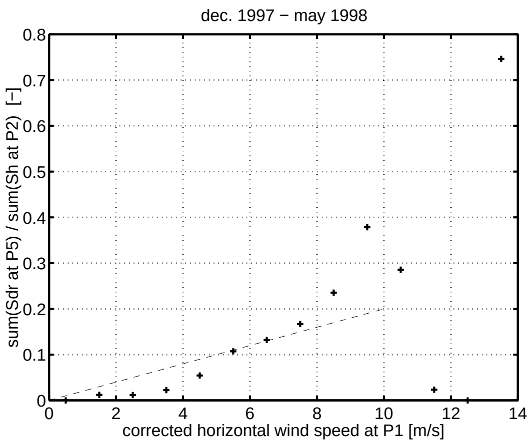

Figure 14: Total driving-rain ratio $\Sigma S_{dr,\mathtt{P5}}/\Sigma S_{h,\mathtt{P2}}$ (d.r. gauge *II*) per corrected wind speed interval. The dashed line is the relationship according to (3) with $\kappa = 0.1$.