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A comparison of driving rain measurements with different gauges

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1 INTRODUCTION

Moisture in building envelopes is an important factor determining their durability, because moisture is involved in many types of deterioration, like corrosion, mould growth and salt crystallisation. An important source for it is driving rain, i.e. rain that is carried by wind and driven onto building envelopes. To design durable building envelopes, knowlegde of the exposure to driving rain is primordial. The amount of driving rain on a particular position on a building envelope depends on building geometry, wind velocity, rain intensity and raindrop spectrum.

Driving rain has been the subject of research for many years. Main surveys can be found in Lacy (1965), Frank (1973), Prior (1985) and in Flori (1988). Details of the used equipment for the measurement of driving rain are not often given; Frank (1973), Flori (1990) and Osmond (1995) are the exceptions known to us. We did not find any reference on a comparison of different types of driving rain gauges, and thus no reference dealing with the systematical error of a given driving rain gauge type.

Four different types of driving rain gauges have been developed at the Chalmers University of Technology (CTH), the Technical University of Denmark (TUD) and the Eindhoven University of Technology (TUE). The comparison test has been carried out on the west facade of the Main Building at the TUE since July 1998. The aim of this full-scale test is to investigate gauge responses as function of rain intensity, rain duration, wind velocity and gauge characteristics (such as the catchement area). In this paper we present results of the comparison test.

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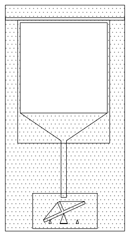
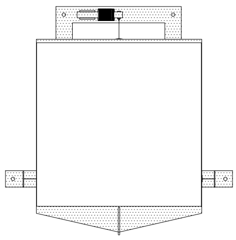
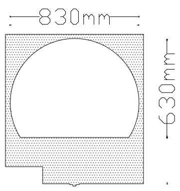
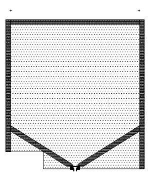
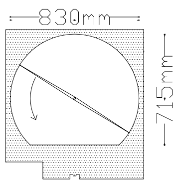
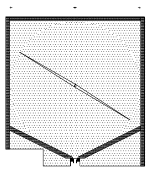
2 DRIVING RAIN GAUGES

As no standard on design and testing of driving rain gauges is available, driving rain gauges can differ significantly. A traditional driving rain gauge consists normally of:

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

The comparison test includes two traditional gauges. According to the abreviations of the collaborating universities, they are marked with 'CTH' and 'TUE-*I*' respectively. Gauge

Table 1: Details of the applied driving rain gauges.

type	principle min. intensity	material	catch area	geometry
CTH	traditional collector with tipping bucket (V_{tip} = 1 g) $\frac{1\text{tip}}{20\text{min}}$ = 0.09 mm/h	perspex	0.18×0.18 $= 0.032$ m^2	
TUD	collector weighted by a strain gauge ($\Delta m = \sim 3$ g) $\frac{3\text{g}}{20\text{min}}$ = 0.04 mm/h	stainless steel	0.46×0.46 $= 0.21$ m^2	
TUE-*I*	traditional collector with reservoir (3 l) and balance ($\Delta m = 0.1$ g) $\frac{0.1\text{g}}{20\text{min}}$ = 0.001 mm/h	teflon coating	0.44 m^2	  foreplate backplate
TUE-*II*	as TUE-*I* but with a rotating wiper $\frac{0.1\text{g}}{20\text{min}}$ = 0.001 mm/h	teflon coating	0.50 m^2	  foreplate backplate

CTH has a small catchment area (0.032 m^2), is made of perspex and the collected rain flux is measured by a tipping bucket with a tipping volume equal to 1 g of water. One tipping in 20 min represents a driving rain intensity of 0.09 mm/h. The gauge is described in Högberg (1998). Gauge TUE-*I* has a large collector (0.44 m^2); all its inner sides have been coated with teflon with the intention to improve dripping down of droplets; and the collected rain water is collected in a reservoir of which the mass is measured by a balance with an accuracy of 0.1 g. Pictures of the applied gauges and their main characteristics are presented in table 1.

The other two driving rain gauges are designed as improvements of the traditional driving rain gauges. The main concern has been the reduction of the measurement error due to raindrops which remain stuck on the collector surface and subsequently are not measured in the flux gauge. Two solutions have been developed: (a) weighting the whole collector, i.e. inclusively the drops on the collector, and (b) improving the coagulation and dripping-down of drops on the collector surface. These solutions have been applied in gauge TUD and gauge TUE-*II* respectively.

The collector of gauge TUD is suspended freely from a strain gauge (though horizontal movements are prohibited). The collector consists of a stainless steel tray with a net mounted on the tray to reduce raindrop bouncing. A reservoir is integrated in the collector and is self-siphoning with a capacity of approximately 300 ml. Details are described in Kragh (1998). Obviously, the reading of the strain gauge is sensitive to wind fluctuations. This is partially overcome by averaging the reading during each 10-min period. The driving rain sum over a 10-min period is calculated by the difference of the mass of the collector in two subsequent 10-min periods. Only positive differences exceeding a threshold value of 1.3 g and during periods of rain according to a rain indicator, are taken into account.

Gauge TUE-*II* is similar to gauge TUE-*I*, but has been equiped with a wiper. The wiper is basically a standard windscreen wiper for cars, and is automatically switched on by a rain indicator. The speed is approx. 1 rotation per 3 seconds; after every 5 seconds the wiper rests during 5 s to reduce wear and tear. In van Mook (1998) the driving rain gauge is described more thoroughly.

3 SITE AND MEASUREMENT SET-UP

The full-scale experiments have been carried out at the Main Building on the campus of the TUE. The dimensions of the Main Building are: (height) 44.5 m, (width) 167 m and (depth) 20

m. Figures 1 and 2 show the west facade of the Main Building, on which the four driving rain gauges have been installed. See the previous section for a technical description.

The site is suited because the prevailing direction for wind and rain is westerly. West from the Main Building there are no large obstacles. The fetch in this section is rough (roughness length of 1 ± 0.4 m, with a displacement height of 10 m (Geurts 1997)), and consists mainly of trees over a distance of 400 m. The nearest high-rise building is building T (45 m high) in south-south-west direction (figure 1). The wind characteristics of the site have been presented in Geurts (1997).

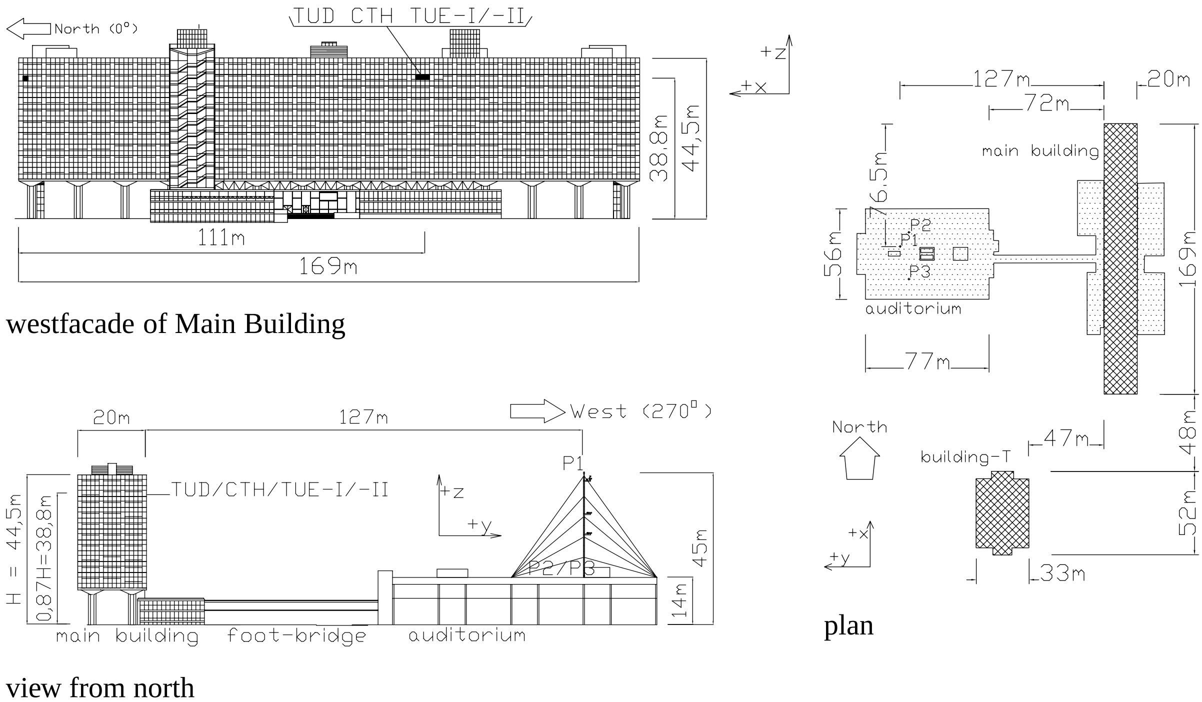


Figure 1: Test site, measurement positions and definition of *x*-*y*-*z* axis system.

Figure 2: The four driving rain gauges on the west fasade. From left to right: TUD, CTH, TUE-*I* and TUE-*II*. An ultrasonic anemometer has been mounted below TUE-*II*.

The reference wind velocity is measured at 45 m height (from ground level) on a mast, located 127 m westwards from the Main Building (figure 1, position P1). The mast is standing on the Auditorium, which is 14 m high, 77 m long and 56 m wide, and which is located at 72 m from the Main Building. The reference horizontal rain intensity is measured by two tipping-bucket rain gauges on the roof of the Auditorium at positions P2 and P3. The rain indicator is installed at position P3.

4 RESULTS

After a period of 5 months, the total (cumulative) driving rain sum measured by the gauges CTH, TUD and TUE-*II* deviate only 3 mm (15% of total sum). The total driving rain sum of TUE-*I* is approximately half of the value of the other gauges. Figure 3 shows this for the period from 1-10-1998 to 28-2-1999. The data have not been selected. A remark should be made for 28 October 1998. On this day, there was extreme rain, so that the reservoirs of the driving rain gauges TUE-*I* and TUE-*II* had to be emptied several times, unfortunately also once during rain.

On much smaller time-bases, gauge responses can deviate significantly. In the following we will show 20-min values measured in the forementioned period of 5 months. A correlation of 20-min driving rain intensities of gauge TUE-*II* with the other gauges is depicted in figure 4. The correlation between the TUE-*II* values (with wiper) and the TUE-*I* values (without wiper) is aproximately 2:1. The correlation between TUE-*II* and CTH is aproximately 1:1, although it shows much scatter. The TUD gauge gives slightly higher 20-min values than TUE-*II* (1:1.3).

Figure 5 shows gauge responses of 20-min values of driving rain ratios (R_f/R_h, i.e. the driving rain intensity R_f normalised by the reference horizontal rain intensity R_h) as function

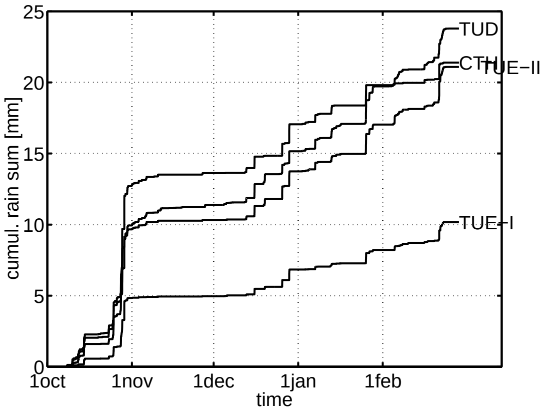


Figure 3: Cumulative driving rain sum from 1-10-1998 to 28-2-1999.

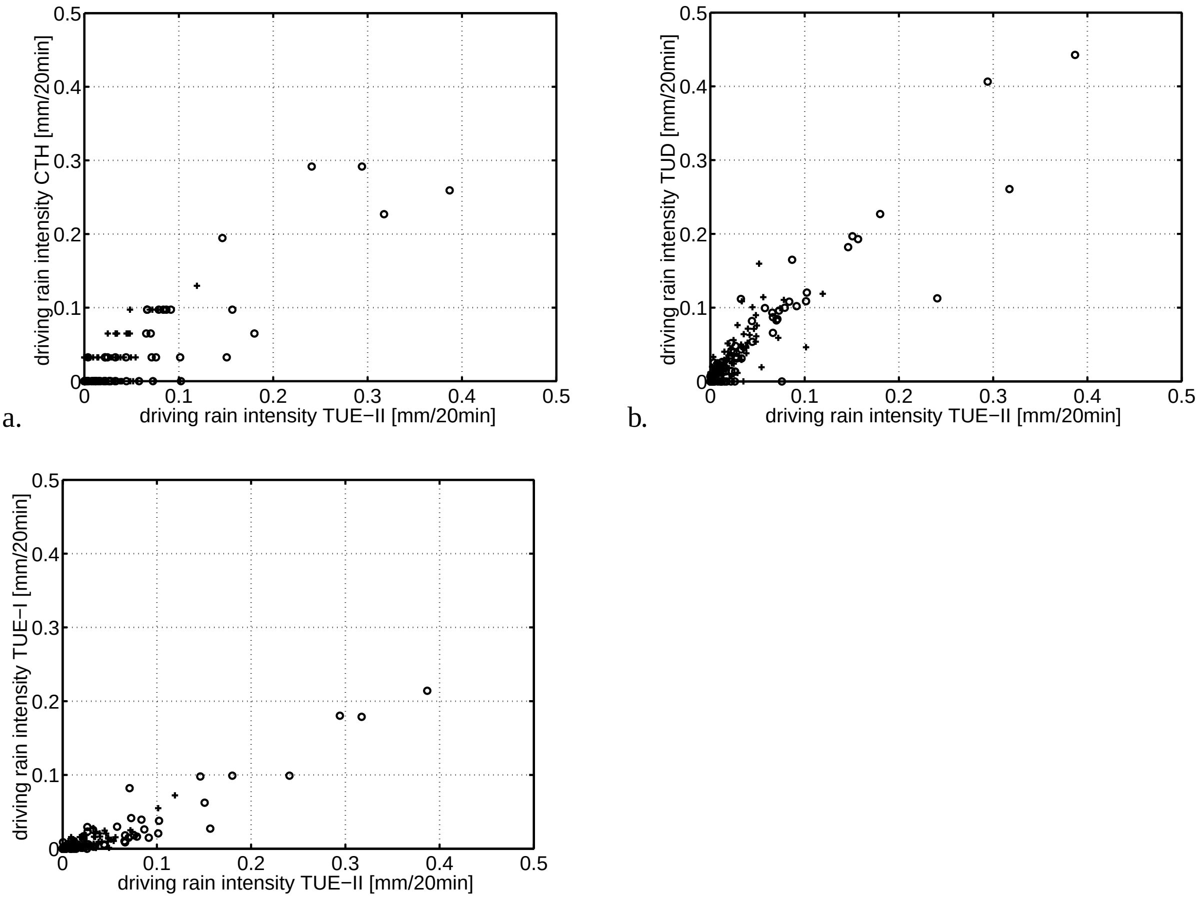


Figure 4: Correlation of 20-min driving rain intensities of gauge CTH, TUD and TUE-*I* with gauge TUE-*II*. Reference wind velocity normal to the facade: + = 4–5 m s^{-1}, $\circ$ = 6–7 m s^{-1}.

of the reference horizontal rain intensity R_h and the reference wind velocity component normal to the facade (U_y). Although the measurements show much scatter (most probably due to the chaotic nature of wind and rain), the graphs show that for a chosen wind velocity interval, driving rain ratios measured by TUD, TUE-*I* and TUE-*II* do not depend on the horizontal rain intensity. The results of gauge CTH show that often this gauge does not measure driving rain whereas gauges TUD and TUE-*II* do. This is explained by the measurement principle of the CTH gauge: the tipping bucket has to be filled completely before it can tip and give a reading. One tipping of gauge CTH in 20 minutes represents a driving rain intensity of approximately 0.09 mm/h; this is indicated by the dashed line in figure 5a. Measured values below this line are not possible. The other gauges do not have such a high threshold.

5 CONCLUSIONS

Our experiences with the driving rain gauges can be summarised by:

- The 5-month driving rain sum of three out of four types of driving rain gauges (CTH, TUD and TUE-*II*), deviate within 15%. Gauge TUE-*I*, which is a version of TUE-*II* without wiper, measures half of the 5-month driving rain sum.

  On much smaller time bases, such as 20-min intervals, gauge responses can deviate significantly. This applies especially for 20-min values of the used tipping-bucket driving rain gauge (CTH): it tips only during a 20 min period at driving rain intensities of more than 0.09 mm/h. Therefore we suggest that for short-time intervals one should apply a continuous measuring principle instead of the tipping-bucket principle, both for driving rain and normal rain measurements.

- The effect of size and shape of the catchment area can not clearly be concluded from the experiment. A comparison of the CTH gauge (0.032 m^2) and the TUE-*I* gauge (0.5 m^2) does not give a straightforward conclusion, because of the difference in measuring principle for the collected rain flux, as pointed out in the previous item. However, the results of gauges TUE-*I* and TUE-*II* suggest that for large catchment areas (e.g. 0.5 m^2)

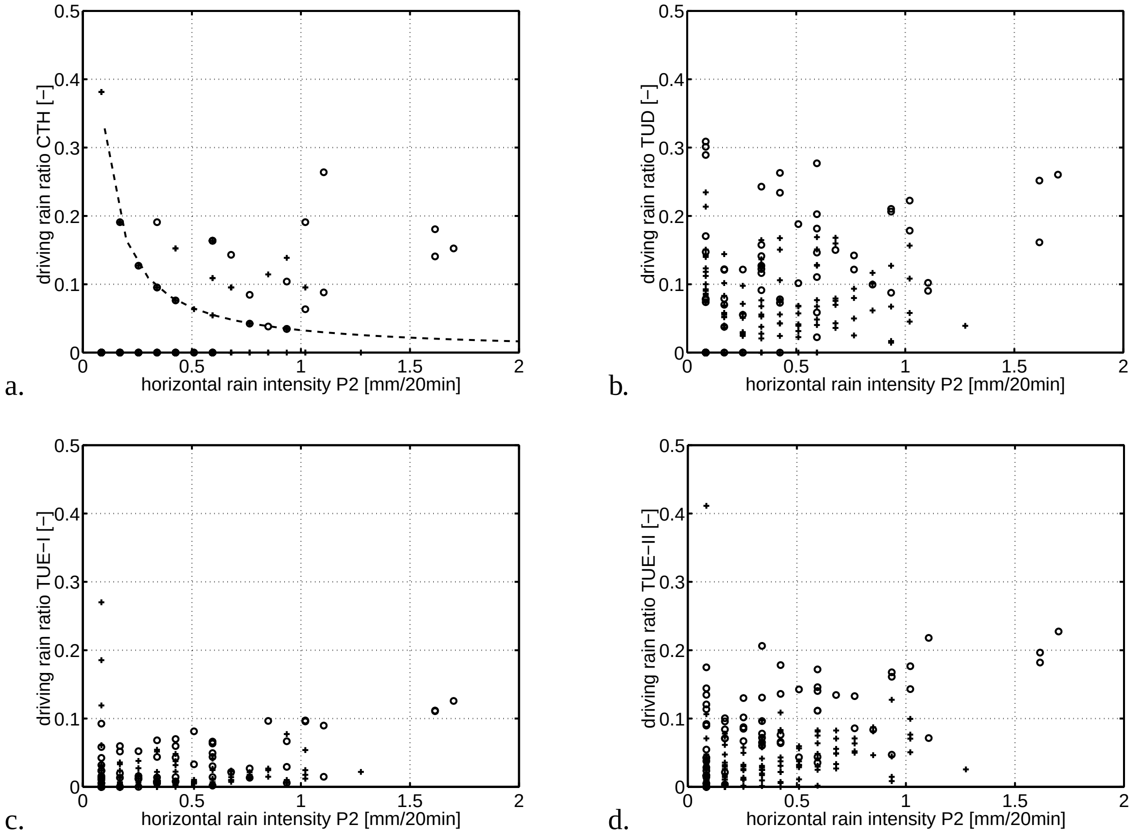


Figure 5: 20-min driving rain ratios R_f/R_h as function of horizontal rain intensity R_h and reference wind velocity component normal to the facade (+ = 4–5 m s^{-1}, ∘ = 6–7 m s^{-1}).

a wiper is necesary.

- Teflon coating for a smooth, hydrophobic collector surface is not a totally sufficient measure. This has also been concluded from laboratory tests at the CTH. Teflon also becomes dirty. A wiper can serve to keep the surface clean, and to improve coagulation and dripping-down of collected raindrops.

Further research should imply a closer investigation on the influence of the size and shape of driving rain collectors and on the possible influence of raindrop spectra.

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