Description of the measurement set-up for wind and driving rain at the TUE

Fabien J.R. van Mook

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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

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Chapter 1

Introduction

This report describes the configuration of the measurements of wind and rain and driving rain at the Eindhoven University of Technology. The measurements are part of the PhD project on measurement and simulation of driving rain on building envelopes.

The objectives of the measurements are:

- development and testing of driving-rain gauges. They are not commercially available and there does not exist any standard for their design. Therefore two or three types of driving-rain gauges will be designed, tested and compared in practice.
- acquisition of weather data with data of driving rain (in real circumstances, in full scale). Weather series of measured driving rain are very rare. Detailed weather series with driving rain are not available. They are useful for the study on heat and moisture transport in building envelopes and, of course, for the theory on driving rain.

  The idea is to collect all important parameters (wind, rain, driving rain, temperature, air humidity, irradiance etc.) of the local climate around a building.
- information on wind and driving rain for comparison with c.f.d. simulations of the same situation (see [van Mook et al. 1997] for some preliminary c.f.d. simulations).

To meet these objectives one has to find a useful and practical situation. This is found in the Main Building of the TUE on which the driving rain is measured. The reasons for the choice of this building are:

- The building is orientated north-south and has a large west facade. The prevailing direction for wind and rain is between south and west. Therefore the west facade should be very suited for driving-rain measurements.
- There are no obstacles in south-west to westward direction. The fetch in this direction is rough (trees). The nearest building to the west side of the Main Building is the Auditorium.
- The Main Building and its westward surroundings have already been subject to a study on wind-induced pressures on building facades. This study of Chris Geurts (see e.g. [Geurts 1997]) gives information of the wind characteristics near the Main Building. For his study a mast with an ultrasonic anemometer on top has been erected on the Auditorium. The data of this instrument is also available to us.
- There is a meteorological station of the KMNI at Eindhoven Airport/Welschap (approx. 6 km westwards to the TUE-buildings). This is useful for comparison and interpretation.
- The Building Physics group is located at the two top floors of the Main Building. This and the general fact that the measurements are done at the university campus, facilitate the installation, accessibility and maintenance of the instruments. Moreover, the facade elements of the Main Building are easily removable, because the facade is a curtain wall, made out of glass windows in a frame of steel columns.

The reference location is thus the Auditorium (i.e. for the measurement of the reference rain intensity and reference wind speed); the obstacle of study is the Main Building (i.e. for the measurement of driving-rain intensity).

The PhD project started in February 1996. In spring 1997 preparations for the experiments were done. In July 1997 the first driving-rain gauge was installed and the period till November 1997 was used for testing and improving the instrumentation and data acquisition systems. Since October 1997, the complete set of quantities is measured, i.e. the reference wind velocity, the reference horizontal rain intensity and the wind velocity and driving-rain intensity at the facade of the Main Building. At the beginning of December 1997 a second driving-rain gauge with an improved design was installed, and the data-acquisition software was further improved. This report describes the situation from December 1997 till February 1998.

In the near future we will extend the measurement set-up by:

— installation of a driving-rain gauge at an other position on the west facade of the Main Building;

— installation of a disdrometer on the roof of the Auditorium, for the measurement of the rain drop spectrum at the reference location.

Supplemental information, discussion of the measurement results, future changes and extensions of the measurement set-up will be reported on in follow-up reports.

Chapter 2

Measurement positions

2.1 Geography and surroundings

The driving-rain measurements are carried out on the west facade of the Main Building, on the campus of the Eindhoven University of Technology (TUE). The campus is situated near to the center of the town. Eindhoven has approximately 200.000 inhabitants. The latitude and longitude coordinates are 51.45° N and 5.48° E. The height above sea level is approx. 16 m. Eindhoven is situated in the south of the Netherlands: 110 km from Amsterdam, 100 km from Rotterdam, 105 km from Brussels and 120 km from Cologne. The North-Sea coast is more than 110 km westwards and hills can only be found some 70 km south-east- and southwards.

The region around Eindhoven is characterised by a quite flat topography. The surrounding villages do not have high-rise buildings, also in Eindhoven the number of high-rise buildings is quite small.

See figure 2.1 for the direct surroundings of the TUE campus. The Auditorium and the Main Building are located to the west of the campus. The dimensions of the Main Building are: (height) 45 m, (width) 167 m and (depth) 20 m. The Auditorium is 14 m heigh and is located at 72 m from the west facade of the Main Building. The only high-rise buildings of 50 m height in the vicinity of the Main Building are 'TH' (at south-south-west from the the Main Building) and 'EH' (at north-east).

The Auditorium is surrounded by a park with many trees with a height of approx. 15 m. The park extends towards the John F. Kennedy avenue. West of this avenue there are mainly low-rise residence buildings. The Rabobank building is approx. 500 m south-eastwards from the Main Building, and has a height of 50 m. The PTT Telecom building and railway station in the south direction are maximally five stories high. In the north, high buildings are 1 km away.

Table below shows the directions of obstruction (in degrees clockwise from north) of the buildings mentioned above, seen from the center of the Main Building resp. Auditorium:

	angle seen from the Main Building	angle seen from the Auditorium
Main Building	—	59°–125°
EH	32°–53°	55°–70°
TH	195°–210°	150°–163°
Rabobank	235°–248°	225°–243°
PTT Telecom	207°–220°	190°–203°

On the roof of the Auditorium there is a mast of 30 m. It has been mounted well before the start of this project, and holds an ultrasonic anemometer on top. The anemometer is thus located 127 m from the facade of the Main Building, and at the same height as the roof of the Main Building. See figures 2.2 and 2.3. See [Geurts 1994] for more details about the mast.

Figures 2.8 to 2.10 show photos of the Auditorium, the Main Building and the surroundings. (In [Geurts 1994] there is a large number of photos showing the buildings and surroundings of the TUE campus.)

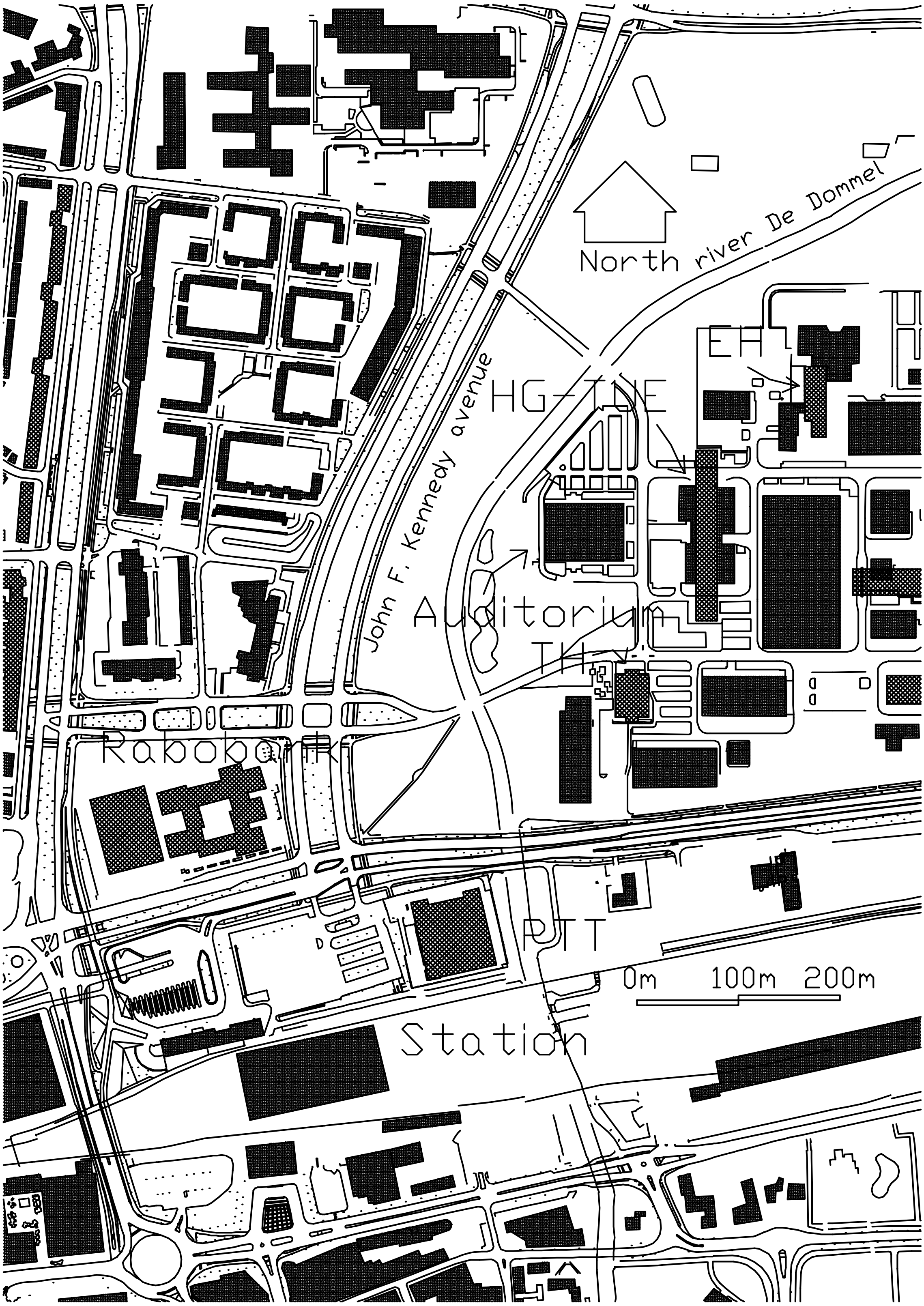


Figure 2.1: Part of the campus of the Eindhoven University of Technology and its surroundings. The Main Building is indicated with 'HG-TUE'. The buildings higher than five stories are indicated in gray.

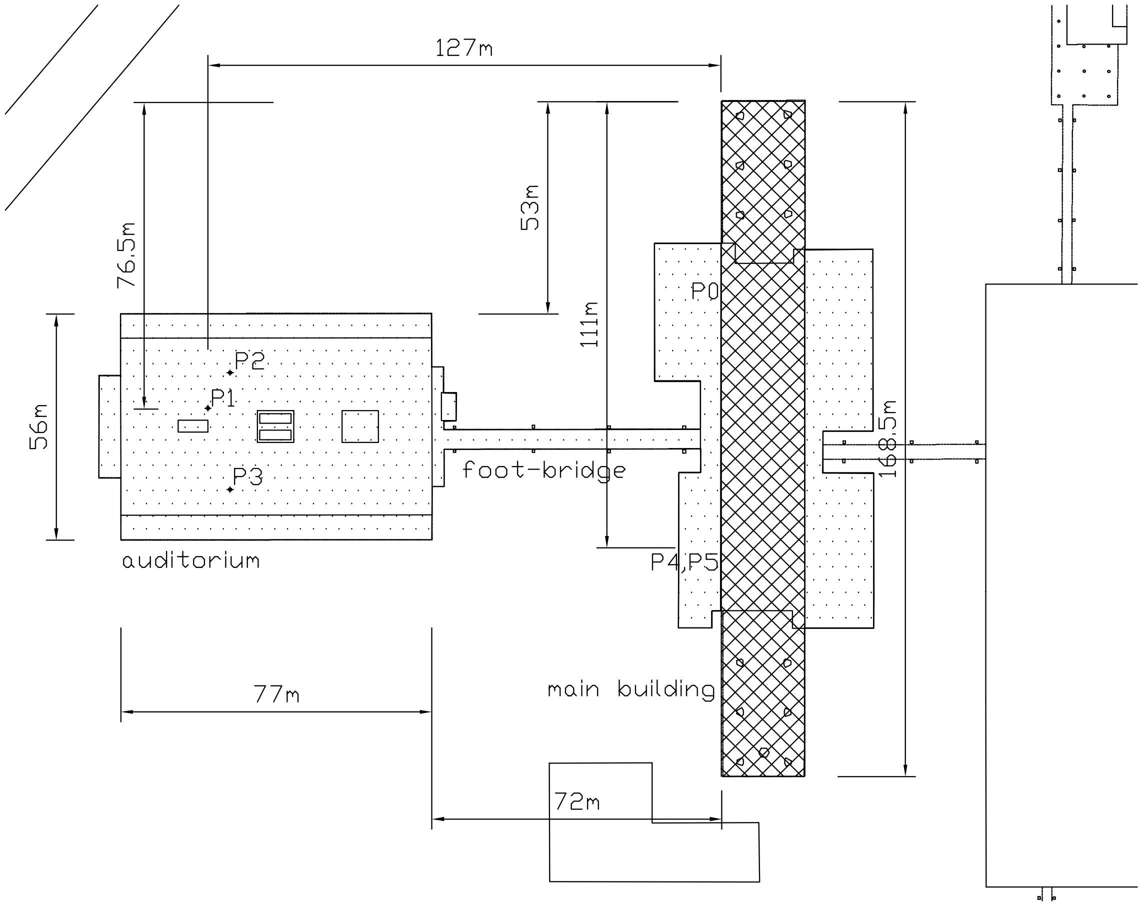


Figure 2.2: Measurement positions, plan.

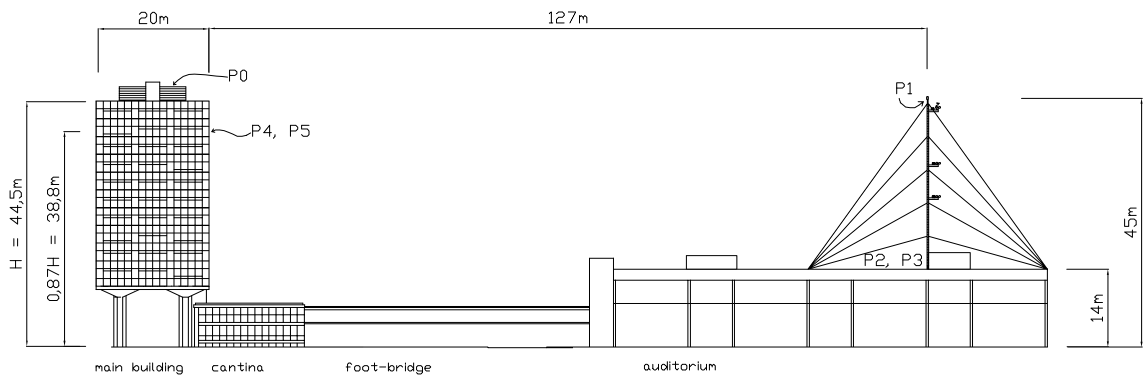


Figure 2.3: Measurement positions, view from north.

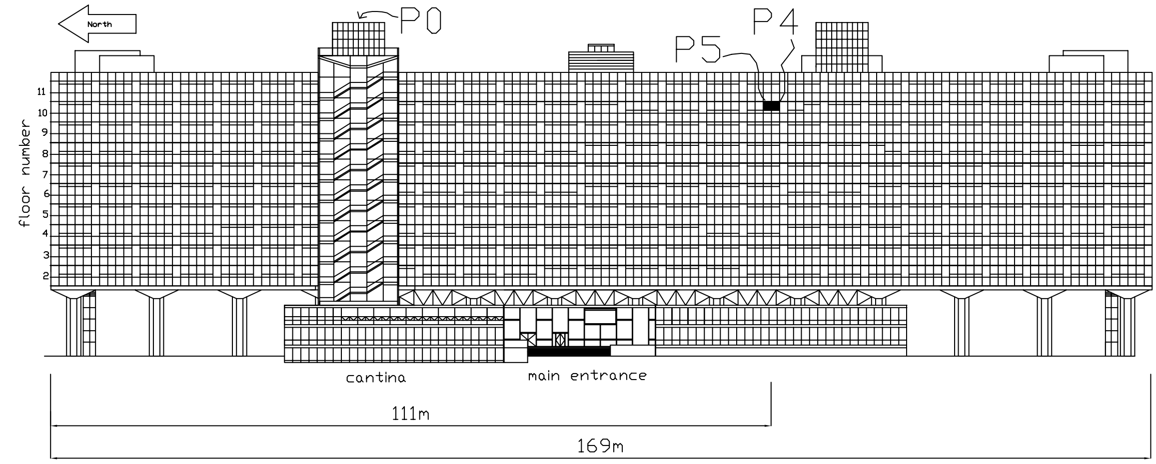


Figure 2.4: Measurement positions at the west facade of the Main Building of the TUE.

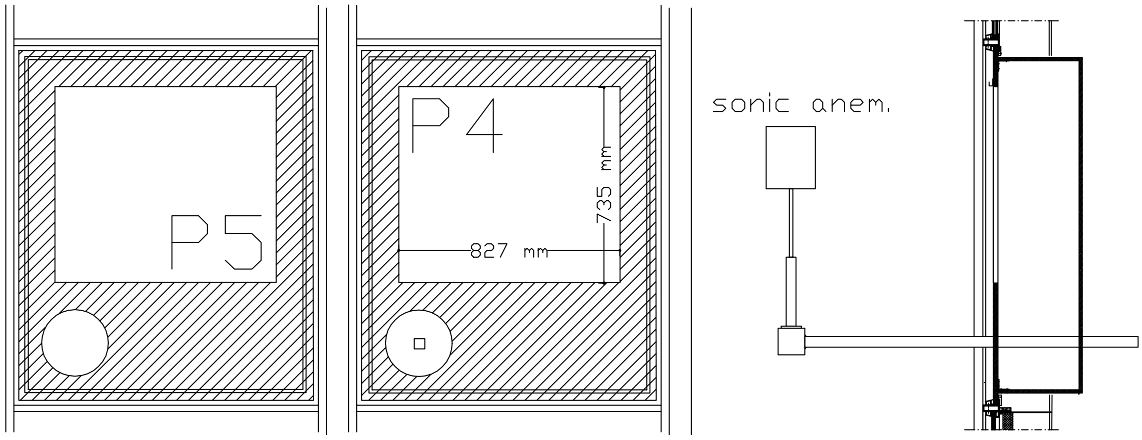


Figure 2.5: Details of the west facade of the Main Building. On the left the two measurement positions P4 and P5 are depicted. Behind the rectangular openings at these positions driving-rain collectors are installed. On the right: a cross section of position P4, at which also the wind velocity near the facade is measured. For installation the anemometer is put through the round opening; normally they are closed with a grid.

Figure 2.6: Driving-rain gauges in the west facade of the Main Building at position P5 (left) and P4 (right).

Figure 2.7: Rain indicator (left) and rain gauge (right) at position P3 (Auditorium). The Main Building is in the background.

Figure 2.8: View from the Main Building at position P5 in due west direction. At the foreground a part of the Auditorium is visible (the mast is just not visible, i.e. it is standing just to the right of the frame of the picture).

Figure 2.9: View from the Main Building near position P5, in south-west direction. In the center there is the Rabobank building.

Figure 2.10: View from the Main Building at position P5 towards south-west. Left: the ultrasonic anemometer. At the right side the Rabobank building is visible.

2.2 Measurement positions and instrumentation

Figures 2.2, 2.3 and 2.4 show the exact measurement positions which have been arranged for this study. They are numbered P0 to P5. The table below gives an overview of the quantities measured:

Table 2.1: Measurement positions and instrumentation.

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

Positions P1, P2 and P3 are at the reference location, i.e. above or on the roof of the Auditorium of the TUE. The reference wind velocity is measured on a mast on the Auditorium at 45 m height (position P1). The reference horizontal rain intensity is measured on two locations on the roof of the Auditorium. A position at the north side (P2) and one at the south side of the Auditorium roof have been elected to investigate the eventual spacial differences of horizontal rain intensities. At position P3 a rain indicator has also been installed (figure 2.7).

Positions P4 and P5 are at the west facade of the Main Building of the TUE. The height is 39 m from ground (87% of the building height) and the horizontal distance from the north facade is 111 m (66% related to the total width of the building). The two positions are adjacent and have been chosen to investigate two types of driving-rain gauges. The driving-rain gauges are placed behind specially arranged openings in the facade of the Main Building. These openings have been formed by removing the original glass windows and replacing them by a plywood board with an opening of 827 × 735 mm^2 (see figures 2.5 and 2.6 for details).

At position P4 an anemometer has also been mounted on an arm, fixed to the facade. The length of the arm is variable. This enables measurements of wind velocities at a distance of 0.25–1.5 m near the facade. Until now the anemometer has been located at a distance of 75 cm from the facade surface.

On the roof of the Main Building, at position P0, there is an already existing meteostation:

Table 2.2: Measurement position P0 and instrumentation.

position	quantity	instrument	(output) sample rate
P0	air temperature	Vaisala HMD 30U/Y humidity and temperature transmitter	1 / min
P0	dewpoint temperature	Kroneis 620	1 / min
P0	relative humidity	Vaisala HMD 30U/Y humidity and temperature transmitter	1 / min
P0	horizontal global irrandiance	pyranometer Kipp CM11	1 / min
P0	horizontal diffuse irrandiance	pyranometer Kipp CM11 with CM121 shade ring	1 / min

Data of P0 is logged by an independent data acquisition system, and is easily available via the local computer network. From September 1997 till now the system has unfornunately not been operational due to revision and maintenance.

Chapter 3

Measurement systems

3.1 Data acquisition

There are two independent data acquisition systems:
— *PhyDAS*, for the measurement of wind velocity above the roof of the Auditorium (position `P1`),
— *personal computer with eight RS232 ports*, for the acquisition of all the other data.

The PhyDAS and the ultrasonic anemometer at `P1` are maintained by an other group of the Faculty, the Structural Engineering group, and therefore the measurements of the wind velocity at `P1` are logged by a separate machine.

Most of the data acquisition is done by a personal computer (with a 486DX66 processor and Windows 95). It is equiped with a *Digi Intelligent Serial Communications Board*. This card enables the transmission of serial data by 8 ports according to the RS232 standard. (Normally a pc has only 2 to 4 RS232 ports.) This board is choosen, because the used devices and interfaces can all communicate via RS232.

The whole data acquisition system is depicted in figure 3.1 (compare with table 2.1).

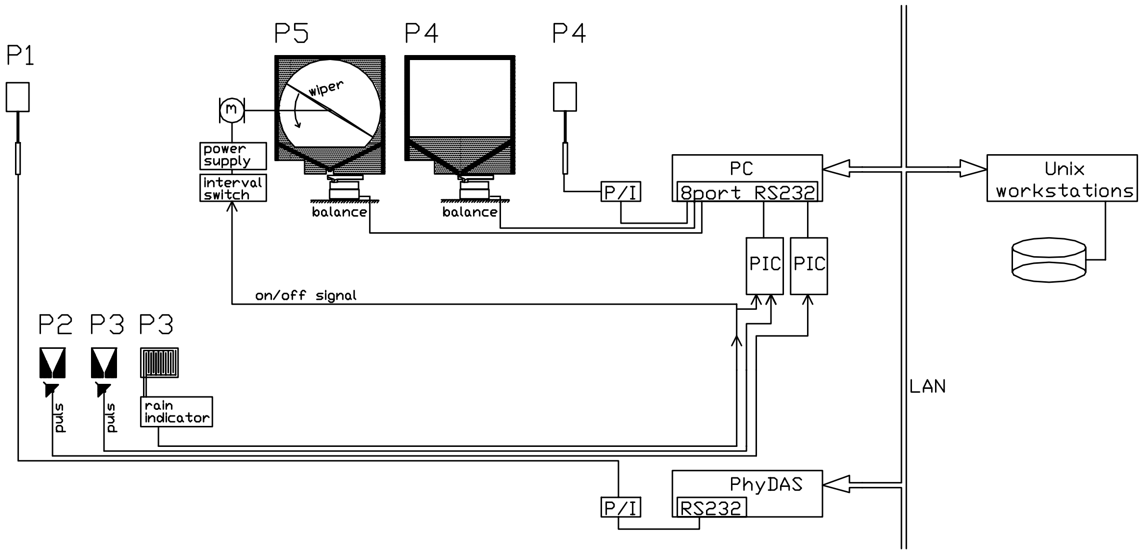


Figure 3.1: Data acquisition systems.

For managing the communications through the ports and for logging the measurements, a program has been written with help of the *Borland Delphi 3* programming environment and a libary for asynchronous communications (*Async Professional 2.00 for Delphi*, TurboPower Software Company). The program, named *Eight Port Logger* (EPL), runs in Windows 95 (figure 3.2).

Figure 3.2: Eight Port Logger: the main, setup, devices and a device-setup window. Linking a device to a port is done by dragging the icon of a device in the devices window onto the icon of a port in the setup window. Then clicking onto a device in the setup window will give the device-setup window, by which the sample rate, device identification code etc, is defined. The command for starting or stopping the logging of the device is also done in this window. Results are shown in the results window (not shown here) and stored on disk.

The program enables to connect any device (balance, anemometer, PIC-processor) to any port. After defining the sample rate, the user can start or stop the logging of a particular device on a particular port. When the start-button is pressed, an initialising string is sent to the concerned device via RS232. Every time when the sample time has elapsed, the computer sends a polling string, and waits for response of the device (this is called 'polling'). From the received data the measured value is deduced, and finaly stored (logged) in a data file. An example of a data file is given below:

```
...
1997-12-11 16:23:21 B4P4 ON
1997-12-11 16:23:22 A2P4 1 +002.79 -001.85 +000.45
1997-12-11 16:23:23 B3P5 15       308.1 0.4923
1997-12-11 16:23:23 A2P4 1 +001.99 -001.86 +000.89
1997-12-11 16:23:24 A2P4 1 +002.05 -001.72 +000.88
1997-12-11 16:23:25 A2P4 1 +001.93 -001.42 +001.40
1997-12-11 16:23:26 A2P4 1 +001.34 -001.31 +001.56
```

```
...
1997-12-11 16:23:31 R1P2 30   000 1.8999   230
...
1997-12-11 16:23:37 B4P4 15      273.8 0.5270
...
```

Every line starts with date, time, and a code for the device and its position. The following string of characters indicate, whether the device is put on or off (indicated by `ON` resp. `OFF`), whether an error in communication occurred (`ERROR`), or it containes the measured values. In the latter case the measured values are preceeded by the value of the sample rate in seconds.

The code for the device and its position consists of a two-character device identification (e.g. `A1` for anemometer 1, `B1` for balance 1) followed by a two-character position identification (`P1`, `P2`, `P3`, etc.). The applied sample rates are shown in table 2.1.

The time of the clocks of the PhyDAS and the pc is the local winter time. This means that the logged time equals to UTC + 1 hour, and that the extra hour for daylight saving during summer is not applied. The computer clocks are manually adjusted to the time according to atomic clocks (of e.g. the National Institute of Standards and Technology of the USA via Internet). The adjustment is done with a precision of 1 to 2 seconds.

All data of the PhyDAS and of the pc are collected and stored on the hard disks of Unix workstations. Backups are stored on tape. Data processing and analysis are done on the Unix workstations, with help of basic Unix commands and Matlab.

3.2 Instruments

On page 21 to 27, a data sheet of every instrument is given. See figure 3.1 for their place in the total data acquisition system. Every data sheet contains information on type, measured quantities, measurement principle and finally information on the log format in the data files.

In addition to the data sheets one will find information on choice and design considerations of the instruments in the following subsections.

3.2.1 Anemometers

As said before, the ultrasonic anemometer on the mast on the Auditorium (position `P1`) is maintained by an other group of the Faculty. It is an anemometer which is specially suited for measurements of wind speed spectra. The sample rate is 168 per second; the output sample rate is 21 per s. Because of this it has been used for the PhD research of Chris Geurts on wind-induced pressure fluctuations on buildings [Geurts 1997].

For the measurements for the study on driving rain, the details of wind fluctuations are not of interest. So a simpler type of ultrasonic anemometer has been chosen (with a sample rate of 9 per second). Major advantages of the used anemometers are: no moving parts (and thus no maintenance), accurate, no calibration, and easy communication via RS232.

3.2.2 Tipping-bucket rain gauges

The major requirements for the rain gauges for the measurement of the horizontal rain intensity on the roof of the Auditorium (positions `P2` and `P3`) are: high resolution (approx. 0.1 mm), catchment area of 200 cm^2 or more, aerodynamic outer shape (for reduced wind-induced error), and electronic logging.

The used Young tipping-bucket rain gauges satisfy most of the requirements (the aerodynamic qualities and thus the wind-induced error have not been checked). Moreover these rain gauges are not too costly, and are used by meterological organisations (and satisfy international standards). The two major disadvantages of tipping-bucket rain gauges are: measurement errors due to not completely filled buckets (at rains with low intensities) and the need for calibration.

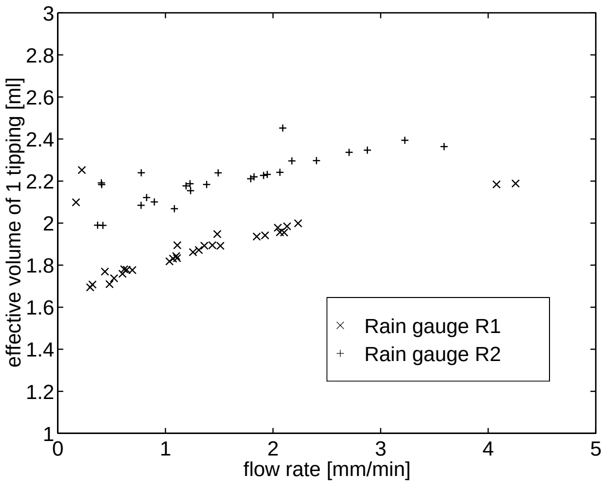


Figure 3.3: Effective volume of a bucket (V_{tip}) of rain gauge R1 and R2 as function of flow rate expressed in mm/min. Calibration of July 1997.

Calibration In July of 1997 the two Young tipping-bucket rain gauges were calibrated for the first time. For calibration, a rain gauge is put on the ground and the rain gauge is then leveled so that the inner board on with the tipping buckets are fixed, is horizontal. A vessel with water is put above the rain gauge. Via an ajustable tap in the bottom of the vessel water pours slowly and with a constant flow rate into the funnel of the rain gauge. The calibration procedure is as follows: (1) measument of the flow rate by a beker, balance and stopwatch, (2) counting the tippings during a certain period of time. This procedure is repeated with different flow rates and periods of time. From the obtained data one can calculate the effective volume of a bucket (V_{tip}). The effective volume can be adjusted by the calibration screws of the rain gauge.

In figure 3.3 the results of the calibration of July are shown. The effective volume per tip V_{tip} of rain gauges R1 and R2 is 1.90 ml resp. 2.21 ml. The reason of the difference in V_{tip} of the further identical rain gauges is that the calibration screws of R1 have been adjusted.

PIC-interface The tipping-bucket rain gauge can not communicate directly via RS232. Therefore a PIC-processor is used as an interface: the processor counts the tippings of the buckets and communicates via RS232 to the logging computer. We used *Pascalite* (Control Plus, Breda, NL), a ready-to-use processor board and programming environment for PIC-processor PIC16C71. The PIC-processor has got one counter input port and therefore every of the two rain gauges has its own PIC-interface. (The *Pascalite* architecture has several other input/output ports (with 8-bit A/D converters), which can be used for e.g. measurement of temperature.)

3.2.3 Driving-rain gauges

Driving-rain gauges are not made industrially, nor does there exist any standard. To find the requirements for a driving-rain gauge we did a literature research and a simple estimation according to Brittish Standard 8104 [BSI 1992] with help of hourly meteorological data of De Bilt (KNMI). The conclusions were written down in [van Mook 1996].

The most important requirements for the design of a driving-rain gauge have been formulated as follows [van Mook 1996]:

— estimated driving-rain intensity range: 0.05 ... $\geq$ 2.0 mm/h,
— sampling rate: 1 per min,
— practical realisable catchment area due to the window size of the Main Building: approx. 0.5 m^2,
— estimated maximal collected driving-rain sum during 3 consecutive days: 5 mm.

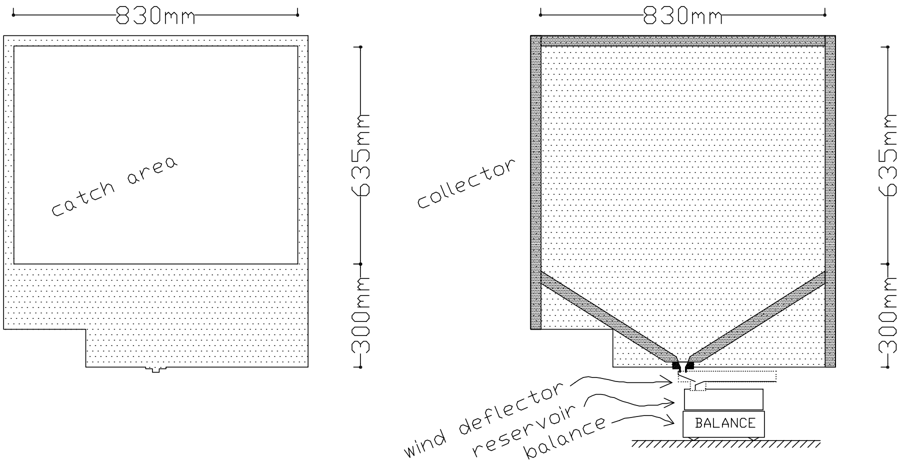


Figure 3.4: Driving-rain gauge, with driving-rain collector I, wind deflector and balance. Left: foreplate with the rectangular catchment area. Right: backplate and the inside.

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. 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.

The resolution of 0.5 ml can hardly be detected by commercially available tipping-bucket rain gauges ($\geq$ 2 ml). Therefore we chose to use balances for the measurement of the collected driving-rain water (range 0–3000 g; readability 0.1 g).

Two other important considerations for the design of the driving-rain gauges are:

— decreasing the number of drops remaining on the surface of the collector by use of a hydrophobic coating. When it rains, one can clearly see on the windows of the Main Building that some of the drops hitting the window glass remain on its surface. So, to prevent that drops remain and thus are not detected, we try to use a very hydrophobic coating, such as teflon. (Later on, we will see that this is not totally effective.)

— decreasing the influence of the wind. This means preventing that the wind blows into the reservoir and preventing that the wind influences the desired flow of the drops into the reservoir (e.g. due to wind sucking). This may be solved by pressure equalisation and a so-called wind deflector.

A driving-rain gauge thus consists of the following parts: (a) a collector, consisting of a collector plate and funnel, (b) a wind deflector, (c) a reservoir and (d) a balance. See figure 3.4.

Driving-rain collector I The firstly built driving-rain collector (`D1`) is a shallow tray with a rectangular catchment area of 0.527 m^2 and a depth of 18 mm. See figure 3.4 and the photo on page 25. All the inner sides are coated with special teflon foil which is glued onto the plywood structure of the collector.

The principle is as follows: Raindrops fall through the catchment area onto the backplate of the collector. The drops which drip downwards are collected by a large funnel, which ends in a small funnel with a spout. The little funnel is made out of a block of teflon and the opening of the spout measures 10 mm in diameter.

In our lab the driving-rain collector was tested for its collection efficiency. By a house-hold plant sprayer drops were sprayed onto the collector and the collected amount of water and the sprayed amount of water were measured by a balance. A stopwatch was used to measure time. Also the effect of wiping (done manually with a plastic ruler) was taken into account. The results are shown in figure 3.5. The results show that the collection efficiency of `D1` without wiping strongly depends on the total amount of water sprayed onto the collector, but it does not depend strongly on the spray intensity. For low spray intensities and for short wetting periods drops thus remain on the surface of the collector, and so are not detected by the balance.

Measurement errors could thus be quite large. Though, it is hard to give an realistic figure, just also because the drop spectrum of the used spray is different from rain spectra. An important conclusion of the collection test is, though, that wiping has a favorable effect: wiping decreases significantly the dependence of the collection efficiency to total sprayed amount and the spray intensity. After wiping the collection efficiency is approx. 90 percent.

In November 1997 the driving-rain collector I was dismounted from the facade and washed with water, and subsequently the same test with the same house-hold plant sprayer was done. The results of the test do not differ much from the test of July; three months of exposition did not really deteriorate the coating.

Driving-rain collector II The spray tests showed that the efficiency of rain collection by wiping is higher, although a teflon coating was used. This gave us the idea to build a second driving-rain collector with a wiper. This collector (D2) is depicted in figure 3.6 and on the photo on page 25.

It is again a sort of wooden tray (depth 30 mm). All the inner sides have been coated with teflon. In the foreplate there is a round catchment opening of 0.492 m^2.

The wiper is made of two standard windscreen wipers of 40 cm length, and is driven by an electric motor, used in cars for windscreen wipers. Through such an electric motor flows 4–6 ampères. Moreover normally the motor rotates too fast, so the drops are driven to the edges of the collector. To get the motor run slower without loosing its force, the motor is supplied with a pulsed direct current with a frequency of approx. 80 Hz. The duty cycle of the pulsed current is adjusted so that the wiper turns with a speed of approx. 1 rotation per 3 secondes.

The motor of the wiper is switched on by rain indicator R3 (at position P3, on the roof of the Auditorium). See subsection 3.2.4.

To spare the motor and wipers during long rains, an interval switch has been installed between power supply and rain indicator. When it rains, the rain indicator puts the interval switch on, which then switches the wiper motor periodically 5 s on and 5 s off.

Figure 3.7 shows the results of the collection efficiency test with the house-hold plant sprayer. The collection efficiency (with wiping) does not depend much from spray intensity and total sprayed amount, and is approx. 87 percent for the sprayed drop spectrum.

Wind deflector and pressure equalisation A so-called wind deflector is placed under the spout of the little funnel of a collector. It assures that the wind can not blow into the reservoir and that the collected rain water does enter the reservoir. Figure 3.8 shows the actual designs of the defectors. The wind deflector of driving-rain gauge I (D1 at postion P4) has been checked on a windy day in October 1997: even at wind gusts of 8 m/s (measured at 75 cm from the facade surface) the balance did not show deviations greater than its inaccuracy (0.1 g).

The other way to reduce the influence of the wind on the driving-rain measurements is pressure equalisation. The driving-rain collectors are placed behind the openings in the facade of the Main Building at position P4 and P5 (figure 2.5). The wind deflector and balance are positioned behind the facade in a large box which is closed from the indoor climate. Pressure equalisation in the box with the outdoor climate is realised by a round grid in the facade. In practice, no measurement differences have been found with the situation without pressure equalisation, i.e. when the grid was totally closed and the box opened to the indoor climate. The effect of pressure equalisation thus seems to be small.

3.2.4 Rain indicator

The rain indicator is a device which only indicates whether there is precipitation or not. Here, it is installed on the roof of the Auditorium (position P3), and therefore it detects horizontal rain. It serves two purposes: (1) it switches the wiper of driving-rain gauge II on when it rains, (2) by it one can

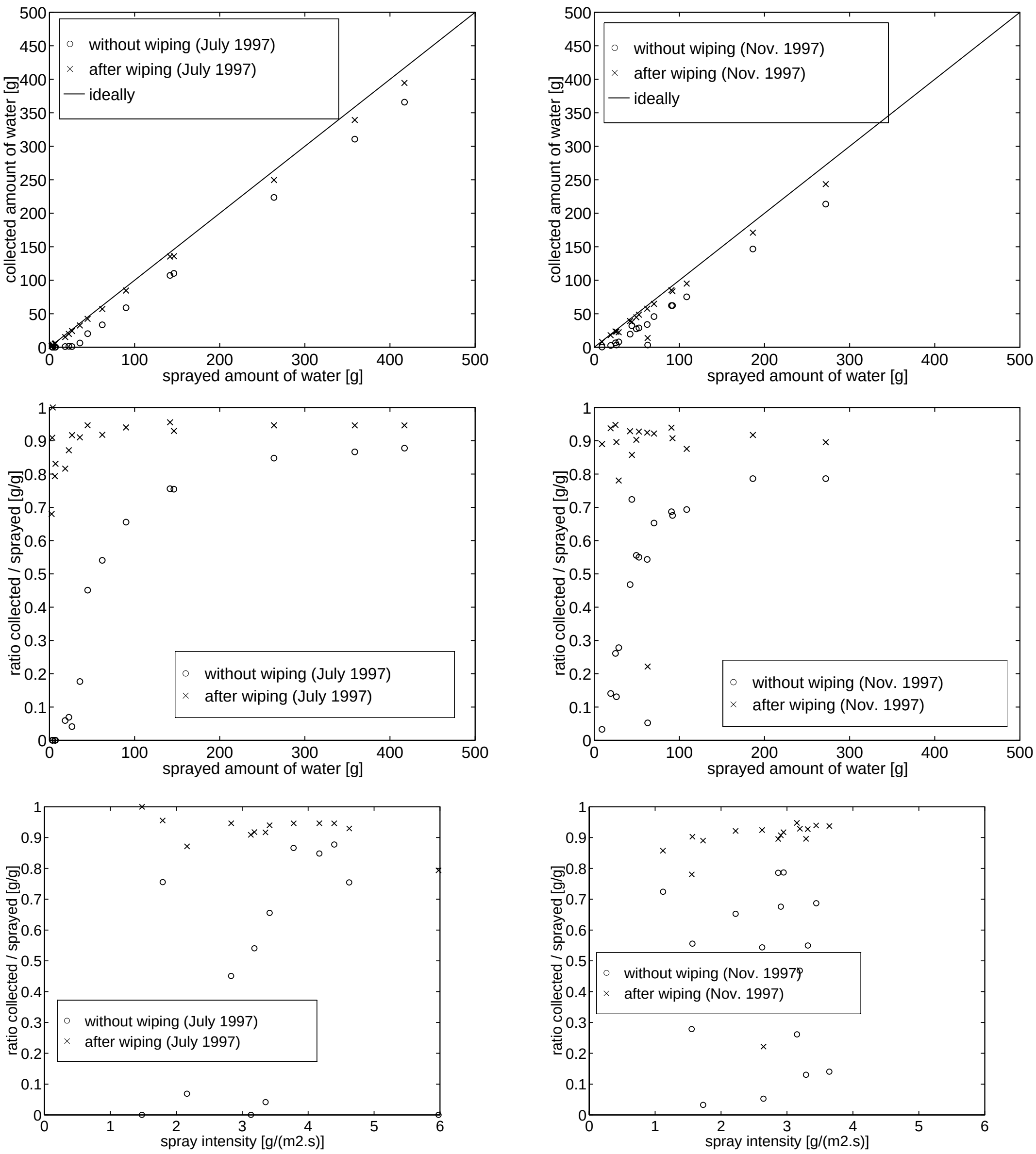


Figure 3.5: Results of the spray tests on driving-rain collector I of July 1997 (left, before any exposition of the collector to the outdoor climate) and of November 1997 (right, after a period of exposition of 3 months and after cleaning with water). A spray intensity of 1 g m^{-2} s^{-1} equals to 3.6 mm/h.

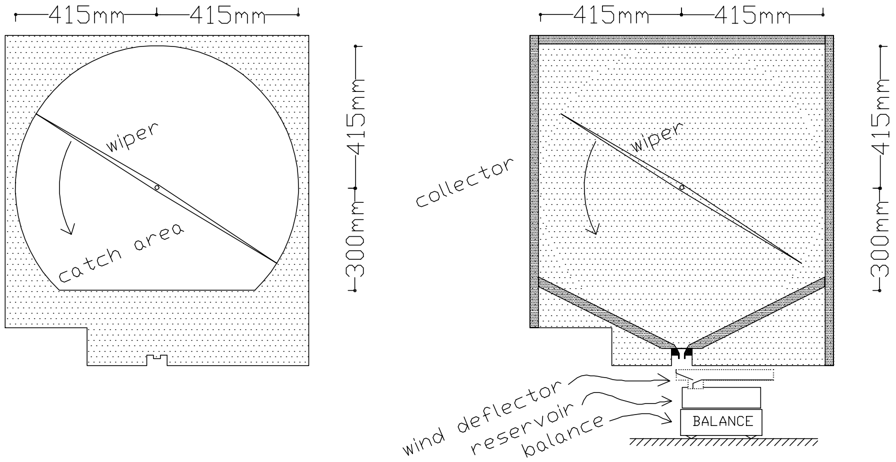


Figure 3.6: Driving-rain gauge, with driving-rain collector II, wind deflector and balance. Left: foreplate with the round catchment area. Right: backplate and the inside.

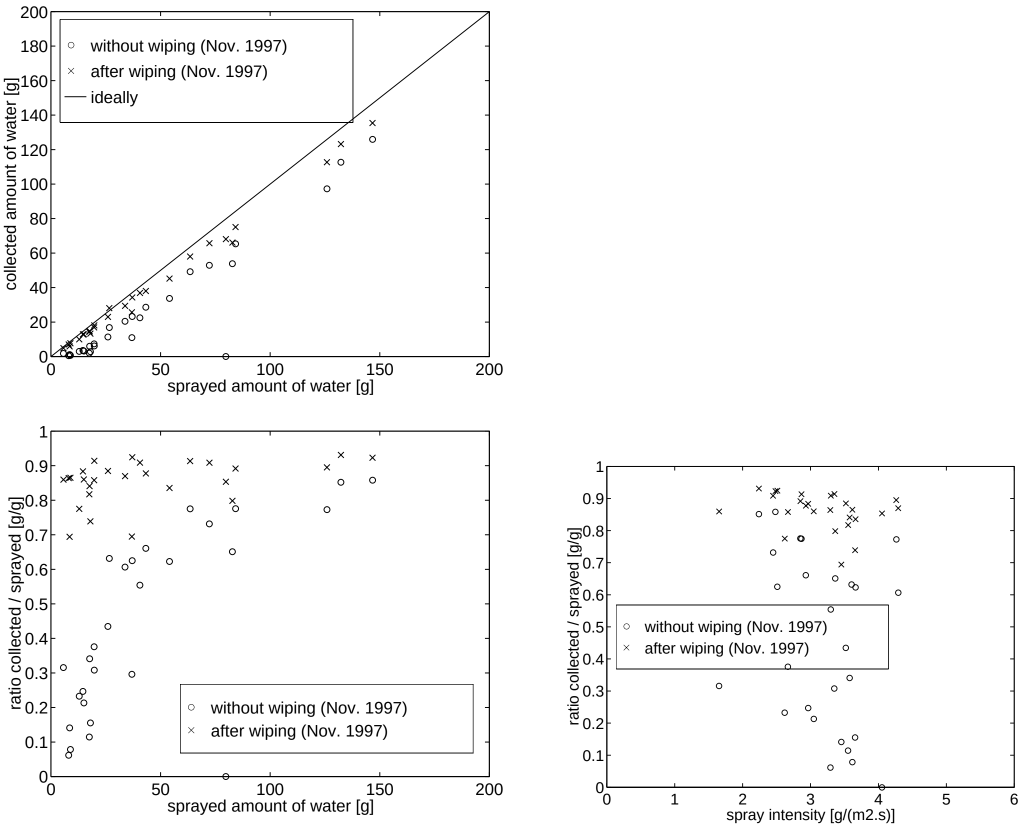


Figure 3.7: Spray test on driving-rain collector II of November 1997. The collector has not been exposed to the outdoor climate yet.

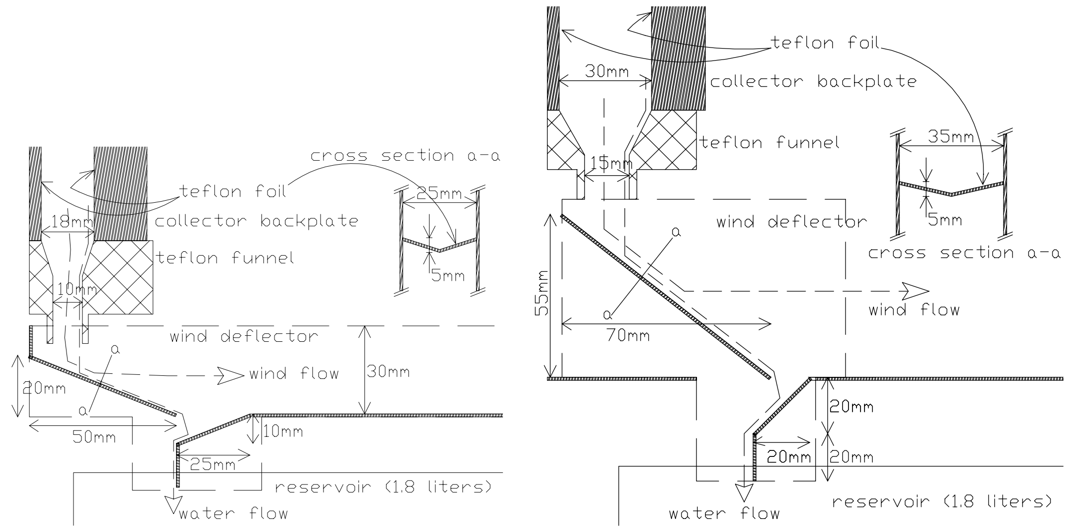


Figure 3.8: Detail of the wind deflector for driving-rain collector I (left) and driving-rain collector II (right).

measure the duration of rains. The measurement of the rain duration by a rain indicator is more direct and more accurate than by a tipping-bucket rain gauge, which gives only a signal after a time when the bucket is full.

The rain indicator consists of two arrays of 3 rain sensors. Every rain sensor consists of a sensor board exposed to the rain, and proper electronics. Pictures of the rain indicator and of a rain sensor are printed on page 27.

On the upper surface of a sensor board, gilded tracks are printed. A drop fallen on these tracks causes a change of electrical resistance and this is detected by the electronics. Then, resistors mounted on the underside heat the sensor board, so that drops evaporate quicker. All the rain sensors are parallel connected; the output signal of the rain indicator is logged via PIC-interface 2.

The reason that six rain sensors are used to compose the rain indicator is that, especially by laying the sensor boards at some distance from each other, the gross catchment area is increased.

The accuracy of the rain indicator has not been determined. The indicated time of rain could well be an overestimate, because it does not discriminate rain from dew or other forms of precipitation, and because drops can remain on the rain sensor's surface, after the end of a rain.

Data sheets of the instruments

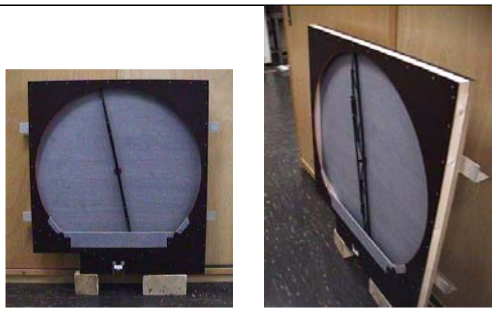
device	ultrasonic anemometer
manufacturer	Gill Instruments
type	Solent Research Ultrasonic Anemometer
measures	u, v, w velocity, wind direction
principle	transit times of ultrasonic pulses are measured. The built-in processor calculates velocities and averages for serial output.
range	0-60 m/s
wind speed accuracy	± 1.5% (< 30 m/s, 10 s average) ± 3% (> 30 m/s, 10 s average)
direction accuracy	± 2° (< 30 m/s, 10 s average) ± 3° (> 30 m/s, 10 s average)
wind speed offset	0.02 m/s
sampling rate per vector	168 /s
serial output rate	21 /s
communications	RS485 (long distance, from sensor to power/interface) RS232 (from power/interface to PhyDAS)
data acquisition	the anemometer is polled by the PhyDAS and sends 21 outputs of 3d wind velocity values. Minute-averaged velocities are calculated and stored in data files.
device id. for logging	`A1`
log format	`<date> <time> A1P1 <Δt> <U1> <U2> <U3>` with: `<Δt>` the sample rate in s, `<U1>, <U2>, <U3>` velocity in cm/s according to the axis system of the anemometer.

device	ultrasonic anemometer
manufacturer	Gill Instruments
type	WindMaster Anemometer 1086M
measures	*u*, *v*, *w* velocity, wind direction
principle	transit times of ultrasonic pulses are measured. The built-in processor calculates velocities and averages for serial output.
range	0-60 m/s
wind speed accuracy	± 1.5% (< 20 m/s, rms error for *u* and *v*)
	± 1.5-3% (> 20 m/s, < 35 m/s, rms error for *u* and *v*)
	± 3% (> 35 m/s, rms error for *u* and *v*)
	± 3% (rms error for *w*)
direction accuracy	± 2° (< 25 m/s)
	± 4° (> 25 m/s)
wind speed offset	0.01 m/s
sampling rate per vector	39 /s (1 output/s)
	9 /s (4 outputs/s)
serial output rate	1 or 4 /s
communications	RS485 (long distance, from sensor to power/interface)
	RS232 (from power/interface to computer)
settings	`M3` *u*, *v*, *w* polled
	`U1` units in m/s
	`G1` measurement average off
	`I1` analogue inputs off
	`NA` polling address `A`
	`B3` 9600 bits/s
	`F1` 8 bits, no parity
	`O1` comma seperated variable
data acquisistion	polling by pc
polling character	`A`
initialising character	? (polling mode on)
response format	S_{tx}A,+uuu.uu,+vvv.vv,+www.ww,M,SS,E_{tx}cc$C_r$$L_f$
device id. for logging	A2
log format	<date> <time> A2P4 <Δt> <U1> <U2> <U3>
	with: <Δt> the sample rate in s,
	<U1>, <U2>, <U3> velocity in m/s according to the axis system of the anemometer.

device	rain gauge
manufacturer	Young
type	Tipping Bucket Rain Gauge 52202 with heater
series numbers	#413, #414
measures	horizontal rain intensity
principle	rain collected by a funnel remains in a bucket, untill it is full. The tipping of the bucket is detected by the closing of a reed switch.
catchment area	200 cm^2
typical resolution	2 ml (0.1 mm) per tip
accuracy	2% (< 25 mm/h)
calibration result	for #413, 1.90 ± 0.14 ml per tip (July 1997)
	for #414, 2.21 ± 0.11 ml per tip (July 1997)
interface for data acqu.	PIC-interface
device id. for logging	`R1` for #413, `R2` for #414

device	PIC-interface
manufacturer	electronics workshop of TUE
type	PIC-1 (of May 1997, with one counter input port) PIC-2 (of November 1997, with one counter input port and 4 analogue input ports)
purpose	counting of tips and communication with pc
principle	the signal due to the brief closing of the reed switch of the tipping bucket is conditioned by a NAND-Schmitt-trigger. The conditioned pulse is counted by a PIC-processor, which gives the count value by polling via RS232. 
manuf. PIC-processor board	Control Plus, Breda, Netherlands
type PIC-processor board	Pascalite (board and software for the PIC16C71)
clock rate	4 MHz
PIC-processor ports	1 counter port 4 analogue input ports (with 8-bit A/D converters) 4 digital (1-bit) input/output ports
communications	RS232
comm. settings	9600 baud, 8 databits, 1 stopbit, no parity
data acquisition	polling by pc
polling character	P
initialising character	I (sets counter to nill)
response format	S_{tx}ddddd,CCCCC,uuuuu,uuuuu,uuuuu,uuuuuE_{tx}cc$C_r L_f$ with: S_{tx} ascii-character 2, ddddd number of tips since last polling (5 char.), CCCCC actual value of counter on PIC-processor (5 char.). uuuuu voltage on an analogue port (5 char., if not applied: 5 blanks), E_{tx} ascii-character 3, cc (2 characters, no purpose), C_r ascii-character 13, L_f ascii-character 10.
log format of PIC-1	<date> <time> <code> <Δt> <ΔC> <V> <C>
log format of PIC-2	<date> <time> <codes> <Δt> <ΔC> <V> <C> <U> <U> with: <code(s)> measuring device id.('s) and its (their) position(s) <Δt> the sample rate in s, <ΔC> number of tips during Δt, <V> volume per tip in ml, <C> actual value of counter on PIC-processor, <U> voltage of the analogue port in cV.

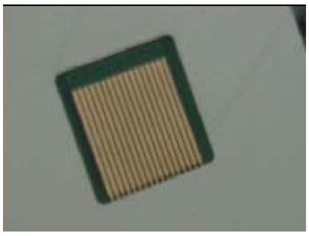
device	driving-rain collector
manufacturer	TUE
type	no. I (of June 1997)
purpose	collection of driving rain. Drops hitting onto the vertical backplate drip downwards and are collected by a funnel. The collected water is discharged by a spout with a diametre of 10 mm.
coating	teflon foil (0.25 mm thick)
catchment area	$830 \times 635\ mm^2 = 0.5270\ m^2$
device id. for logging	`D1`



device	driving-rain collector
manufacturer	TUE
type	no. II (of October 1997)
purpose	collection of driving rain, like driving-rain collector I, but it is equiped with a rotating wiper, which should collect also the smaller drops which would otherwise remain on the surface. The motor of the wiper is switched on by a rain indicator. To spare the motor an interval switch is placed between the motor and rain indicator. It switches the motor 5 s on and 5 s off when the rain indicator detects rain.
coating	teflon foil (0.25 mm thick)
catchment area	$0.4923\ m^2$
spout diametre	15 mm
wiper speed	approx. 10 rotations per minute
wiper	standard 40-cm windscreen wipers for cars
motor type	standard car windscreen wiper motor (exact manufacturer and type are unknown)
motor power supply	12 V direct current, pulsed at approx. 80 Hz, duty cycle of 30%
interval switch	built with integrated circuit 4060. Rate: 5 s on, 5 s off.
device id. for logging	`D2`

device	balance
manufacturer	Sartorius
type	BP 4100
series number	#70704073
measures	mass
range	0-4100 g
readability	0.1 g
reproducibility	< 0.1 g
linearity	< 0.1 g
response time	1 s
sensitivity drift	$\geq 5.10^{-6}$ /K
communications	RS232
comm. settings	9600 baud, 7 databits, odd parity, software handshake
non-factory settings	5.1.7 9600 baud
	5.4.1 Software handshake
	6.1.1 Polling mode
	7.2.2 Long data output string
data acquisition	polling by pc
polling character	E_{scp}P
response format	N␣␣␣␣␣+␣␣vvvvvvv␣g␣C_rL_f
device id. for logging	B1
log format	<date> <time> B1.. <Δt> <M> <A>
	with: <Δt> the sample rate in s,
	<M> actual mass reading in grams,
	<A> catch area of the driving-rain collector in m^2.

device	balance
manufacturer	Mettler-Toledo
type	PB 3001
series numbers	#1116372940, #1116450214, #2116086975
measures	mass
range	0-3100 g
readability	0.1 g
reproducibility	0.05 g
linearity	0.1 g
communications	RS232
comm. settings	9600 baud, 8 databits, no parity, software handshake
data acquisition	polling by pc
polling character	SIC_rL_f
response format	S␣S␣vvvvvvvvvv␣gC_rL_f (stable weight value)
	S␣D␣vvvvvvvvvv␣gC_rL_f (nonstable weight value)
device id. for logging	B2 for #1116372940, B3 for #1116450214, B4 for #2116086975
log format	<date> <time> B... <Δt> <M> <A>
	with: <Δt> the sample rate in s,
	<M> actual mass reading in grams,
	<A> catch area of the driving-rain collector in m^2.

device	rain indicator
manufacturer	electronics workshop of TUE
type	no. Ia and Ib (set of two identical boxes)
purpose	sensing of rain, hail or snow. Switch for wiper of driving-rain gauge II.
principle	the rain indicator consists of 2×3 rain sensors, parallel connected. Every rain sensor consists of a sensor board exposed to the rain, and proper electronics. The change of electrical resistance of the sensor board is detected by integrated circuit LM1830, and a relais is activated for switching on the wiper motor. The switching is also logged by PIC-2.
gross catchment area	$2 \times 160 \times 240$ mm^2
	 sensor board of a rain sensor
rain sensor manufacturer	Conrad Electronic
rain sensor type	Conrad's 1997 catalogue no. 11 52 40-44
rain sensor catchment area	4×4 cm^2
interface for data acqu.	PIC-2
device id. for logging	`R3`

Chapter 4

Data processing

4.1 Procedure

As figure 3.1 indicates, the raw data is stored on the hard disks of the Unix workstations of Building Physics group. Backups on tape are regularily made.

The first step for analysis of the data is described in this chapter 4, and is simply called « data processing ». The input is the raw data; the output is a time series for every instrument. The second step is using these time series for plotting and statistics; this is described in chapter 5.

The Unix workstations are used for the data processing. It is done within the Matlab environment, but sometimes Unix commands are used. The processing consists of the following steps:

1. the contents of the raw data files are sorted by device (done in Unix), then the data is read and enters the Matlab environment;
2. with the raw data per device the desired quantities are calculated, i.e. sums, means and/or standard deviations,
3. the results are stored in a time series, which forms a matrix. Each row contains the desired quantities, measured at a certain time interval. A time interval is always a « clock period », i.e. a period according to the clock and calendar;
4. the time series are stored on disk and can be used for plotting graphs and further analysis (see chapter 5).

4.2 Sorting, averaging and standard deviation

Sorting, averaging and standard deviation are three basic operations used for the processing and analysis of the measured data logged by the data acquisition systems.

Let us consider an « infinite » sequence X of samples taken at regularly intervals of time δt:

$$\ldots, x_{t_0+0}, x_{t_0+1\delta t}, x_{t_0+2\delta t}, \ldots. \tag{4.1}$$

By « sorting » is meant the selection of data on a certain condition. The resulting sequence of samples is thus a subset of the original sequence. An example to show the used symbols:

$$X|_{t_1<t<t_2} \tag{4.2}$$

The average of a finite sequence of samples $x_1, x_2, x_3, \ldots, x_N$ is commonly defined as:

$$\langle x \rangle = \frac{1}{N}\sum_{i=1}^{N} x_i. \tag{4.3}$$

The average of a quantity x during a clock period (cp) is written as $\langle x \rangle_{cp}$.
Averaging can also be done repeatedly, as e.g. for the calculation of hourly wind speed averages from 10-minute averages: $\langle\langle u \rangle_{c10}\rangle_{ch}$.
Standard deviation of a finite sequence of samples is defined as:

$$\sigma(x) = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \langle x \rangle)^2} \tag{4.4}$$

Standard deviation of a quantity x during a clock period (cp) is written as $\sigma(x)_{cp}$.

4.3 Wind data

One does not have to calibrate ultrasonic anemometers, unlike e.g. hot-wire anemometers. The output of the ultrasonic anemometers is directly given in a standard unit of velocity, for every component (U_1, U_2, U_3).

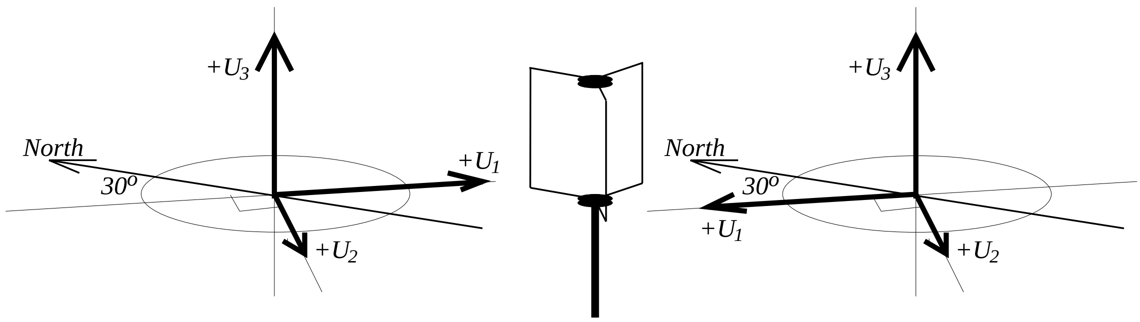


Figure 4.1: Anemometer axis systems of the Solent Research (left) and the Solent Windmaster (right).

Averages and standard deviations of wind velocity components are calculated according to formulae 4.3 and 4.4. The result of the data processing is a time series with $\langle U_1 \rangle_{cp}$, $\langle U_2 \rangle_{cp}$, $\langle U_3 \rangle_{cp}$, $\sigma(U_1)_{cp}$, $\sigma(U_2)_{cp}$ and $\sigma(U_3)_{cp}$.

4.4 Horizontal rain data

Horizontal rain is measured by tipping-bucket rain gauges. The tipping of the buckets (the volume of a bucket is approx. 2 ml) is counted and logged. So, the horizontal rain sum during a time interval Δt is calculated from the number of tippings (n):

$$S_{h,\Delta t} = \frac{nV_{tip}}{A_{catch}}, \tag{4.5}$$

with V_{tip} = the effective volume of a bucket, found by calibration, and A_{catch} = the catchment area of the rain gauge.
The result of the data processing is a time series with $S_{h,cp}$.

4.5 Driving-rain data

Driving rain is measured by a balance, of which simply the weight values are logged. The driving-rain sum during a time interval Δt is calculated regarding only the positive differences between begin and end values of the logged mass:

$$\Delta m = m_{t+\Delta t} - m_t, \tag{4.6}$$

$$\begin{aligned} S_{dr,\Delta t} &= \frac{\Delta m}{A_{catch}} &&, \text{if } \Delta m \geq m_{min}, \\ &= 0 &&, \text{if } \Delta m < m_{min}, \end{aligned} \tag{4.7}$$

with m_{min} = a threshold value for the minimal detectable mass difference during a clock period, and A_{catch} = the catchment area of the driving-rain gauge.

By the threshold value m_{min} one takes variations of the measured mass value due to temperature changes into account. It depends on the readability of the balance and its sensitivity to temperature changes ($m_{min} = 0.105$ g for the Mettler-Toledo PB 3001).

The result of the data processing is a time series with $S_{dr,cp}$.

4.6 Data of the rain indicator

The duration of horizontal rain is measured by the rain indicator. The rain duration of a clock period equals:

$$T_{wet,cp} = n\delta t, \tag{4.8}$$

with n = the number of sample time intervals δt when the rain indicator senses rain.

The result of the data processing is a time series with rain durations $T_{wet,cp}$. This quantity is also called « rain/wet time » in this report, because the rain indicator actually gives a signal when it senses any moisture on its sensor boards, whether it is rain or not.

Chapter 5

Data analysis — some examples

5.1 Procedure

The second step for analysis of the measured data is described in this chapter 5. The input is a time series of every instrument, obtained by processing the data according to the procedures in chapter 4.

The time series are further analysed with help of further calculation, statistics and plots. This is done within the Matlab environment on the Unix workstations of the group. Eventual sorting, averaging and standard deviation is done upon the data of the time series (see section 4.2 for the formulae). Also other calculations can be carried out, these are described in this chapter. The Matlab environment is chosen because of its easiness in maniputation of large matrices, in programming and in plotting graphs.

5.2 Measurements of 1-12-1997 to 11-1-1998

In this section we will show some of the possible representations of the measurements of wind, rain and driving rain. The results presented here are of the period 1-12-1997 to 11-1-1998. It was a period of much rain and strong winds. So it was ideal to test the whole measurement set-up and to compare the two different driving-rain gauges: driving-rain gauge I without wiper and driving-rain gauge II with wiper.

5.2.1 Reference wind velocity

The reference wind in the present study is measured 130 m westwards to Main Building, on a mast on the Auditorium at 45 m height (position `P1`). It is seen as the wind undisturbed by the Main Building and other obstacles.

The time series contain the averages and standard deviations (per clock period) of the wind velocity components according to the anemometer axis system (see figure 4.1). For further analysis the axis system is converted into the desired axis system. There are two conventions:

1. the global axis system, which is directed to the north pole of the Earth (see figure 5.1):
   - the positive velocity components U and V are due north resp. west. The positive W is directed upwards;
   - the wind direction Φ is defined as the angle, from which the wind comes, clockwise from north, in a horizontal plane;

   Subsequently one can define:
   - the horizontal wind speed:

$$U_{uv} = \sqrt{U^2 + V^2}; \tag{5.1}$$

— the absolute wind speed:

$$U_{abs} = \sqrt{U^2 + V^2 + W^2}; \quad (5.2)$$

— the elevation angle ε, as the angle between the wind vector and the horizontal.

2. the axis system relative to the mean wind direction:
   - — the longitudinal wind speed u is parallel to the mean horizontal wind direction (thus: $u = U_{uv}$);
   - — the lateral wind speed v is perpendicular to the mean horizontal wind direction (thus: $\langle v \rangle = 0$);
   - — the vertical wind speed w is directed upwards (thus: $w = W$).

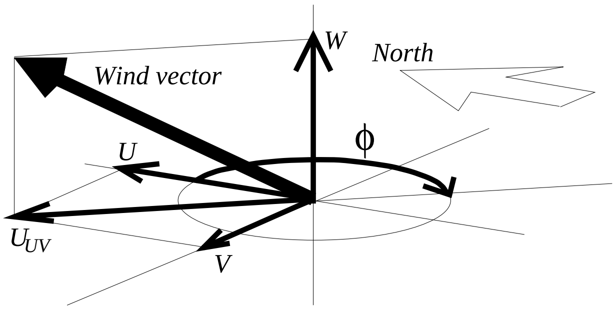


Figure 5.1: Global wind axis system: the definition of wind velcocity components U, V, W, horizontal wind speed U_{uv} and horizontal wind direction Φ.

The quantities $\langle\Phi\rangle_{cp}$, $\langle\varepsilon\rangle_{cp}$, $\langle U_{uv}\rangle_{cp}$, $\langle u\rangle_{cp}$ etc. are calculated from the averaged velocity components according to the anemometer axis system, stored in the time series files, e.g.:

$$(\langle U\rangle_{cp}, \langle V\rangle_{cp}, \langle W\rangle_{cp}, \langle\Phi\rangle_{cp}, \langle U_{uv}\rangle_{cp}) = f(\langle U_1\rangle_{cp}, \langle U_2\rangle_{cp}, \langle U_3\rangle_{cp}). \quad (5.3)$$

Some of the possible graphs are plotted in figures 5.2 to 5.4. Over the whole period the mean horizontal wind speed at position P1 is 5.1 m s^{-1} ($\pm$ 2.1 m s^{-1}). The KNMI bulletin [KNMI 1997] states a mean of 5.1 m s^{-1} for December 1997 at meteostation Eindhoven/Welschap.

Figure 5.3 shows that the elevation angle at the reference position is between -15° and 10°, which is normal for undisturbed wind flow. It also shows a downward directed wind vector at a horizontal wind direction of 60°–170°; this very problably the influence of the Main Building and building 'TH', which are located south- and east-wards from position P1.

5.2.2 Wind velocity at the facade

The data of the wind velocity at 75 cm from the facade of the Main Building (position P4) is processed in the same way as described in subsection 5.2.1. The interpretation of the data is especially useful for comparison with c.f.d. simulations of the same situation.

Here we only show the relation between the wind direction and elevation of the reference location and those at the facade. Figures 5.5 and 5.6 show that (1) the horizontal wind direction at 75 cm from the facade is either from north or from south, (2) the elevation angle is very variable and is in a complex way related to the reference horizontal wind direction.

The manufacturer states that the indicated accuracy (1.5% rms) applies only for elevation angles of less than $\pm 10°$, because of the configuration of the transducers (see figure 2.10). Because at position P4 this range is often exceeded, the anemometer should be oriented in an other direction.

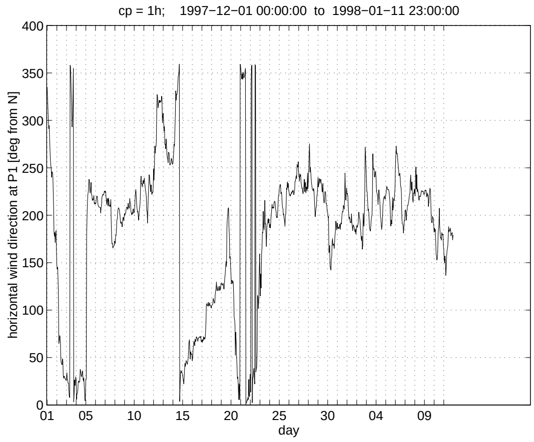


Figure 5.2: Horizontal wind direction $\langle \Phi \rangle_{cp}$ at position P1 (Auditorium) as function of time. Clock period $cp = 1$ hour.

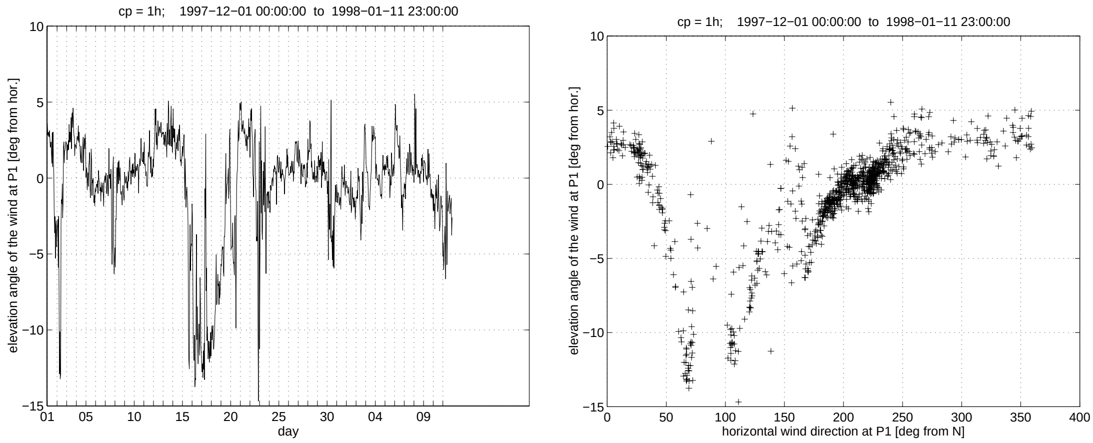


Figure 5.3: Elevation angle of the wind ($\langle \varepsilon \rangle_{cp}$) at position P1 (Auditorium) as function of time [left] and horizontal wind direction [right] at the same position. Clock period $cp = 1$ hour.

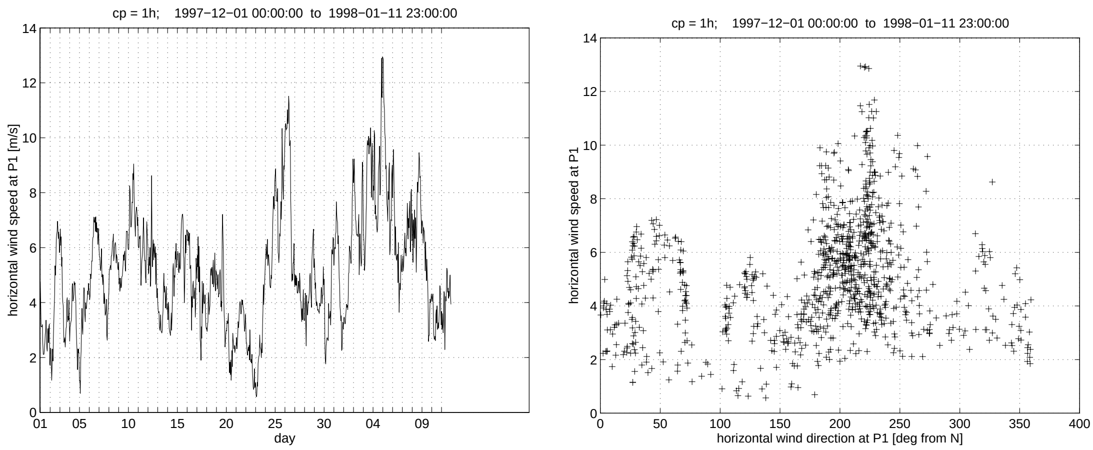


Figure 5.4: Horizontal wind speed $\langle U_{uv} \rangle_{cp}$ at position P1 (Auditorium) as function of time [left] and horizontal wind direction [right] at the same position. Clock period $cp = 1$ hour.

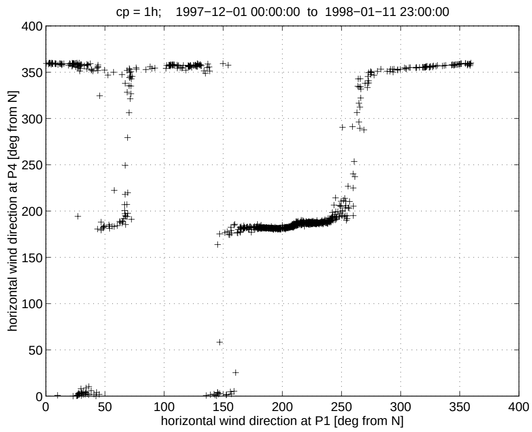


Figure 5.5: Horizontal wind direction $\langle\Phi\rangle_{cp}$ at position P4 (facade of Main Building) as function of the horizontal wind direction at position P1 (Auditorium). Clock period $cp = 1$ hour.

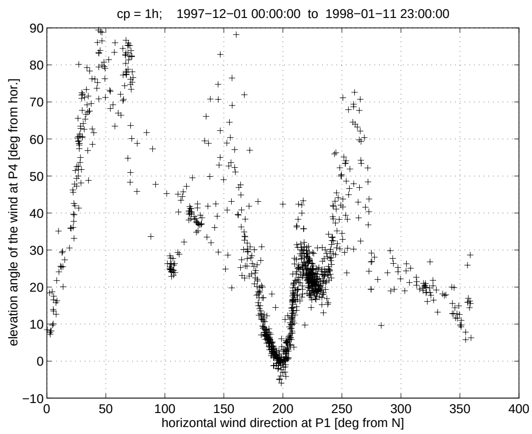


Figure 5.6: Elevation angle of the wind ($\langle\varepsilon\rangle_{cp}$) at position P4 (facade of Main Building) as function of reference horizontal wind direction at position P1 (Auditorium). Clock period cp = 1 hour.

5.2.3 Horizontal rain

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 top graph of figure 5.7 shows the cumulative rain sum S_h at position P3, obtained from the time series of horizontal rain sums per clock periods. According to KNMI [KNMI 1997] the rain sum for December 1997 was 53 mm. Above the Auditorium we measured approx. 62 mm at P2 and 57 mm at P3.

The bottom graphs of figure 5.7 show that (horizontal) rain (above the Auditorium) is mainly coming with winds from south to west. The middle graphs show that rain is coming at a large scatter of horizontal wind velocities.

Comparing the units of the axis of the left and right middle plots (i.e. for clock periods of 1 h resp. 10 min), one sees that the range of the rain sum per clock period does not differ with a factor 6 (= 1 h / 10 min). This can be explained by investigating the frequency distribution of durations of rain/wet periods. Figure 5.8 shows that rain periods do often not take more than 20 minutes.

Figure 5.9 is obtained from the time series data of the rain indicator (figure 5.8). The duration of a rain/wet period is defined as a sum of successive rain/wet times per clock period which all or almost all have a nonzero value. A 'pause' of maximally ζ clock periods between two clock periods with nonzero rain/wet times is allowed. For figure 5.9 ζ equals to 3 clock periods.

5.2.4 Driving rain

As for the horizontal rain, a direct plot of the time series data gives us important information. See figures 5.10 and 5.11.

The most important conclusions and remarks from these graphs are:

- The driving-rain gauge with wiper (at position P5) catches two times more driving rain than the driving-rain gauge without wiper (at P4).
- The middle and bottom graphs of figures 5.10 and 5.11 show that (1) driving-rain sums per clock period are very low (mostly below 0.1 mm), (2) driving rain occurs at range of reference wind speeds between 4 and 10 m s^{-1} and not lower than 2 m s^{-1}, (3) driving rain only occurs at reference horizontal wind directions between 180° (south) and 280° (west) and (4), as for the horizontal rain sum graphs, different summation periods yield different values of driving-rain sums which are not simply related to the factor between the summation periods.
- A reservoir of a driving-rain gauge can contain maximally 1.8 kg of water. This is almost 4 mm of driving rain. The reservoir of driving-rain gauge at position P5 was completely full when the gauge was checked on the 5th of January 1998 (just after the holidays) and the 8th of January (after a very rainy day). This means that the reservoir at P5 should be greater for the very heavy rains and for longer periods of no possible maintenance.

5.2.5 Catch ratio of driving rain (Lacy's equation)

Lacy's equation [Lacy 1965] is often used for calculations on driving rain. The driving-rain intensity in the free wind is a function of horizontal rain intensity R_h and horizontal wind speed U_h:

$$R_v = \alpha U_h R_h^b, \qquad (5.4)$$

with $\alpha = 0.22$, and $b = 0.88$.

This equation is often simplified by assuming $b = 1$. The driving-rain intensity on building envelopes is thought to be related to the free driving-rain intensity by a catch ratio κ:

$$R_{dr} = \kappa R_v. \qquad (5.5)$$

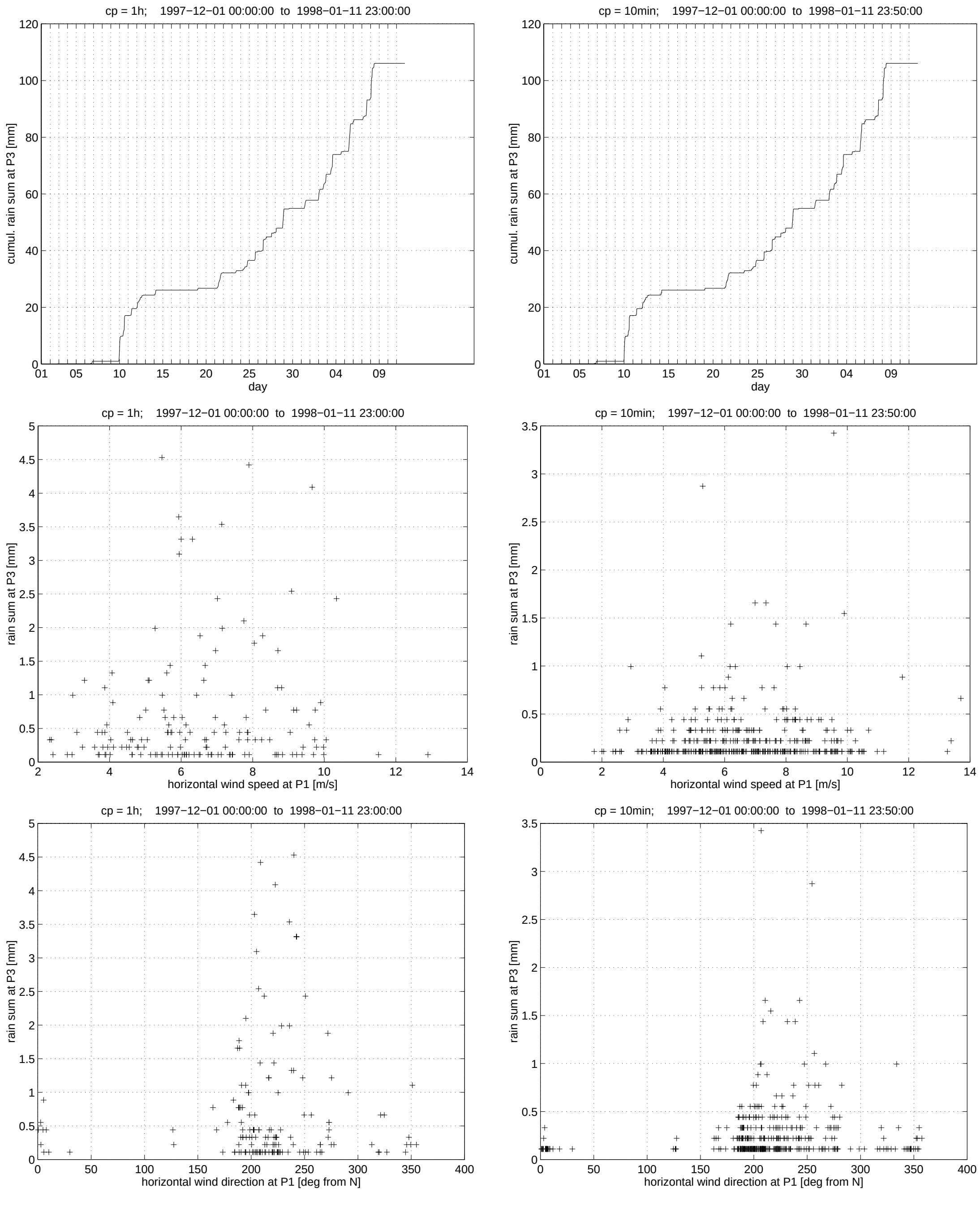


Figure 5.7: Horizontal rain sum $S_{h,cp}$ at position P3 (Auditorium), as function of time [top], horizontal wind speed [middle] and horizontal wind direction [bottom] at P1 (Auditorium). Clock periods of $cp = 1$ hour [left] and $cp = 10$ min [right].

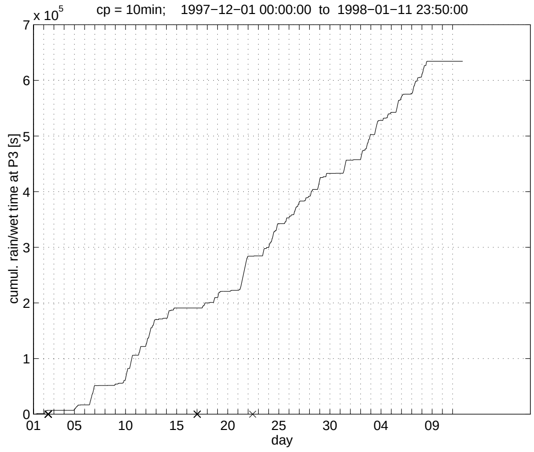


Figure 5.8: Cumulative rain/wet time at position P3 (Auditorium), as function of time. Clock period $cp = 10$ min.

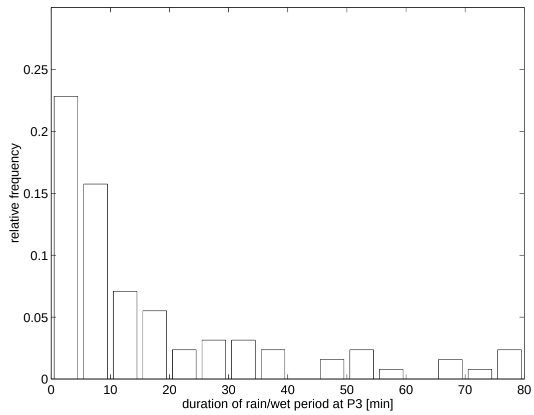


Figure 5.9: Relative frequency distribution of the durations of rain/wet periods at position P3 (Auditorium). Clock period $cp = 10$ min.

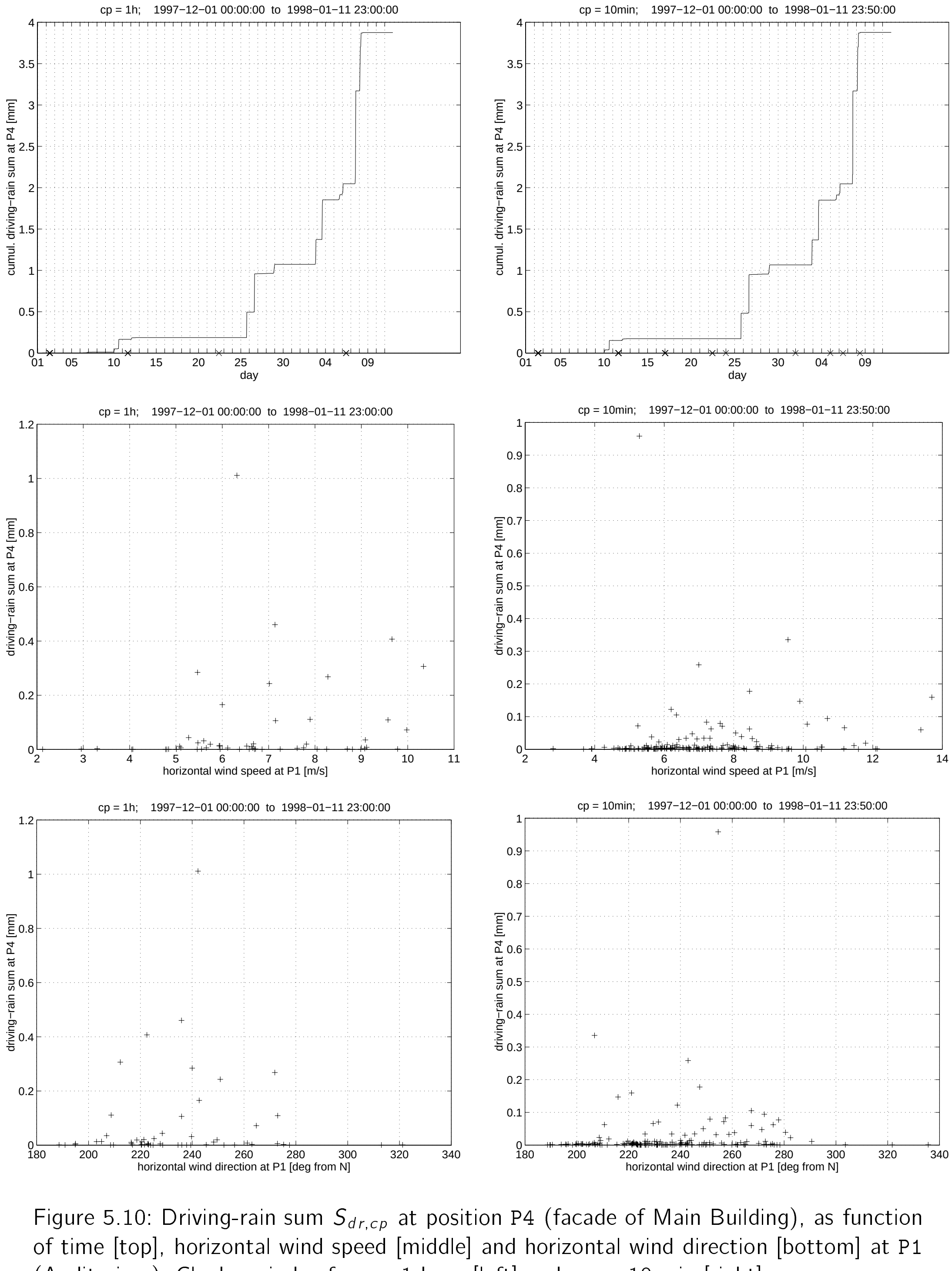


Figure 5.10: Driving-rain sum $S_{dr,cp}$ at position P4 (facade of Main Building), as function of time [top], horizontal wind speed [middle] and horizontal wind direction [bottom] at P1 (Auditorium). Clock periods of $cp = 1$ hour [left] and $cp = 10$ min [right].

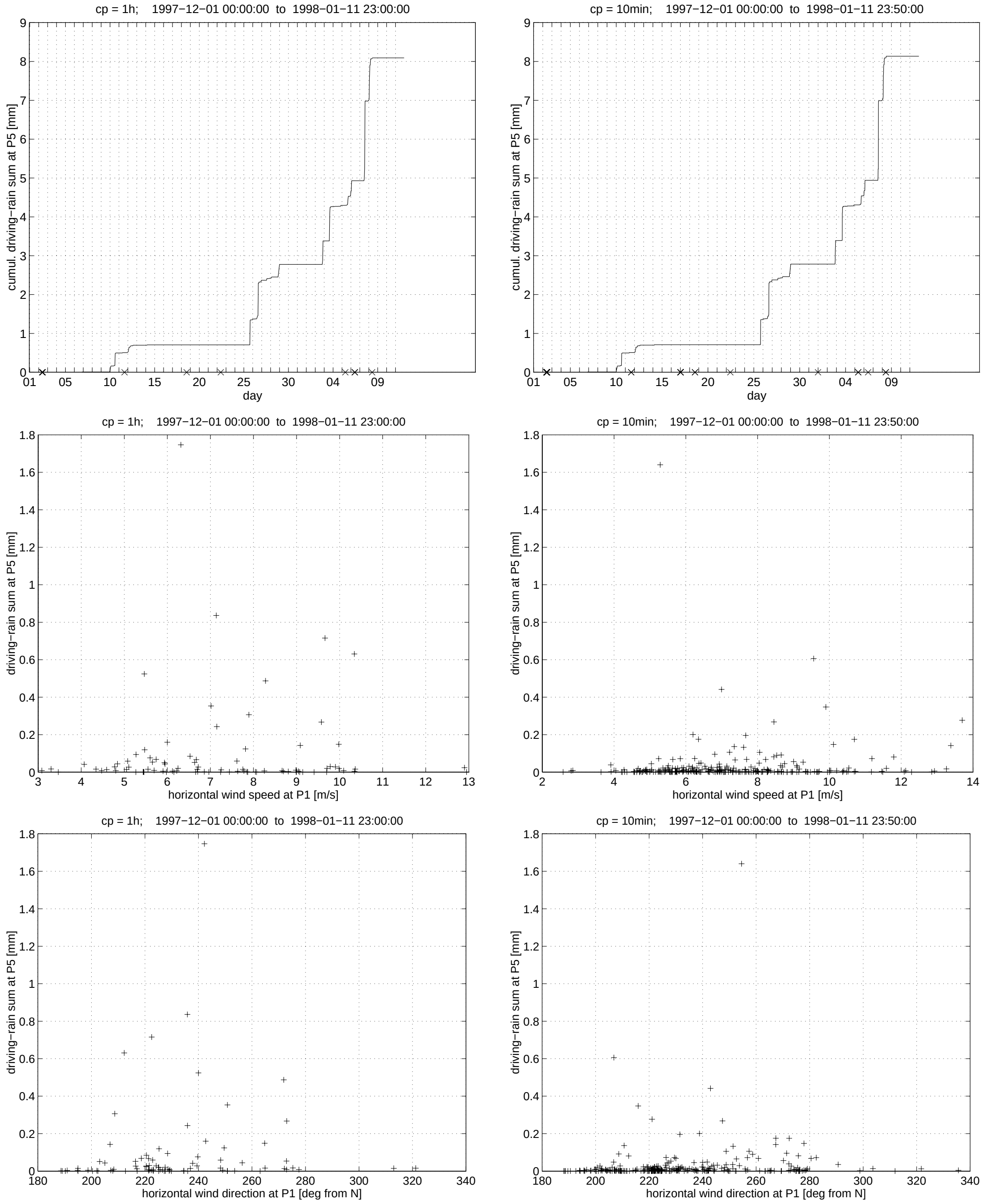


Figure 5.11: Driving-rain sum $S_{dr,cp}$ at position P5 (facade of Main Building), as function of time [top], horizontal wind speed [middle] and horizontal wind direction [bottom] at P1 (Auditorium). Clock periods of $cp = 1$ hour [left] and $cp = 10$ min [right].

The catch ratio κ ranges from 0.1 to 2. One would like that it depends mainly on the building geometry, although it is clear that it also depends on rain-drop spectrum and wind velocity.

If one considers an interval of time, one can substitute rain intensities by rain sums:

$$S_{v,cp} = \alpha \langle U_h \rangle_{cp} S_{h,cp}^{b}, \quad S_{dr,cp} = \kappa S_{v,cp}. \tag{5.6}$$

And we make a refinement to equation 5.6 by only considering the wind velocity component normal to the facade:

$$\langle U_h \rangle_{cp} = \langle U_{uv} \rangle_{cp} \ pos(\cos(\langle \Phi \rangle_{cp} - \theta)), \tag{5.7}$$

with θ = the normal to the facade in degrees, clockwise from north (here $\theta = 270°$), and the function pos for which applies: $pos(x) = x$ if $x \geq 0$ and $pos(x) = 0$ if $x < 0$

From the measurement data (the time series) one can obtain the product of α and κ:

$$\kappa\alpha_{cp} = \frac{S_{dr,cp}}{\langle U_{uv} \rangle_{cp} \ pos(\cos(\langle \Phi \rangle_{cp} - \theta)) \ S_{h,cp}}. \tag{5.8}$$

This is plotted in figure 5.12. The data in this figure is calculated from the time series data of the driving-rain gauge with wiper at position P5.

The constant value of $\kappa\alpha_{cp}$ which we would like to see in the top graphs of figure 5.12, is not really evident due to the large scatter. There seems still to be a dependency to wind speed and, probably also to other parameters like drop spectrum and wind turbulence.

5.2.6 Conclusions

From the findings presented in the previous subsections one can conclude:

1. A driving-rain gauge with wiper catches substantially more driving-rain than a driving-rain gauges without wiper.
2. Different summation periods give different results in the horizontal rain sum and driving-rain sum. These differences are not simply related to the factor between the summation periods, but they are explained by the fact that many rain periods do not last more than 20 minutes (figure 5.9).
3. The equation 5.8, according to Lacy, does not satisfactorily describe the measured data.
4. The wind near to the facade (at position P4, at a distance of 75 cm from the facade surface), is almost always flowing parallel to facade: from north or south, and almost always upwards. It does not correlate well with the driving-rain data, for which the wind data at position P1 (Auditorium) is more meaningful.
5. Seen the results of the rainy period of December 1997 and beginning of January 1998, the reservoir of a driving-rain gauge should be able to contain at least 3 kg.

The first and last conclusions affect directly further improvements of the design of the driving-rain gauges. From the measurement data one can reveal much more aspects of wind and driving rain; this will be the subject for following reports.

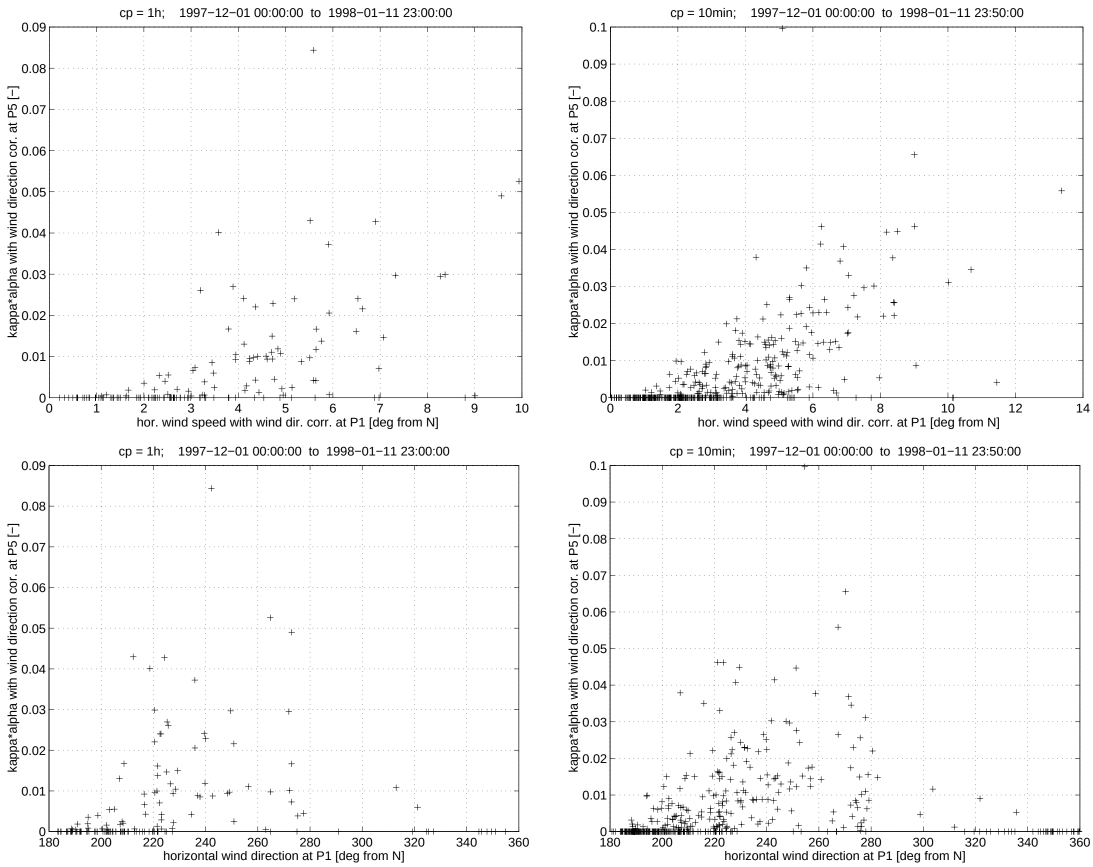


Figure 5.12: Catch ratio $\kappa\alpha_{cp}$ corrected for wind direction according to equation 5.8 at position P5 (facade of Main Building) calculated with horizontal rain sum $S_{h,cp}$ at position P2 (Auditorium), as function of the corrected horizontal wind speed $U_{uv,cp} \times \cos(\phi - \theta)$ [top] and horizontal wind direction [bottom] at P1 (Auditorium). The normal to the facade is $\theta = 270°$. Clock periods of $cp = 1$ hour [left] and $cp = 10$ min [right].

Symbols

Latin symbols:

A_{catch}	[m^2]	catchment area
m	[kg]	mass
n	[-]	number
R	[mm/h]	rain intensity
S	[mm]	sum of rain
t	[s]	time
T_{wet}	[s]	rain/wet time
u, v, w	[m s^{-1}]	longitudinal, lateral and vertical wind velocity
U_1, U_2, U_3	[m s^{-1}]	wind velocity vectors according to the anemometer axis system
U, V, W	[m s^{-1}]	wind velocity vectors (U is due north, V west, W upwards)
U_{abs}	[m s^{-1}]	absolute wind speed
U_{uv}	[m s^{-1}]	horizontal wind speed
V_{tip}	[ml]	effective volume of a rain gauge bucket
x, y, z	[m]	position, z is upwards

Greek symbols:

α	[-]	catch ratio for the free driving rain
ε	[°]	elevation angle of the wind to the horizontal
κ	[-]	catch ratio
Φ	[°]	horizontal wind direction, angle from which the wind blows, clock wise from north (e.g. 270° is wind from west)

Subscripts:

cp	clock period
$c10$	clock period of 10 minutes
ch	clock hour
dr	driving rain
h	horizontal
`P1, P2, P3, ...`	measurement positions, see figure 2.2
v	vertical

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