Microclimate: Field Measurements, Driving Rain Analyses

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ABSTRACT

The objective of the paper is to show results from in situ measurements of local climate data and microclimate near a building. The measurements are made to validate a "microclimate description," in order to determine the influence of microclimate on the durability of building components. The "microclimate description" is a transformation of macroclimate data from a meteorological station or local station to obtain microclimate data for a particular site. The paper is focused on wind-driven rain. Driving rain is calculated by equations based on rainfall rate, wind speed, and empirical relationships between rainfall rate and drop size distribution. The calculated results are compared to measured driving rain results. The comparison between calculated and measured driving rain shows that they are not always in agreement. Low rainfall intensity, efficiency of collectors, and disruption of wind flow field close to building could be reasons for deviations between measured and calculated results.

INTRODUCTION

The durability of an external building component is determined by the rate of deterioration for its construction materials due to external loads, i.e., wind, rain, humidity, temperature, and solar radiation. Thus, it is necessary to determine the accurate external loads in order to estimate pressure, temperature, humidity condition, and radiation at the surface of a building component. Using these external loads, material properties and the building physic laws make it possible to achieve an accurate analysis of the physical behavior of building components. These external loads are also known as components of meteorological loads or climate effects.

Microclimate is the climate scale that deals with the climate close to a building component. It is not feasible to measure the external loads in microclimate scale for each individual building. Generally, microclimate data have been determined by transformation of macroclimate data or local climate data.

To generate new transformation models or for validation of existing models, measured microclimate data are needed. For that reason, in-situ micro- and local climate measurements were carried out at a university field station located at Fiskebäck, Göteborg, on the West Coast of Sweden. Wind speed, wind direction, air temperature, air humidity, global radiation, and horizontal precipitation are measured at the field station as a local reference station near the building. In addition to these measurements, local- and macroclimate data are obtained from three different meteorological stations near the field station.

Moisture in the building components can cause various types of deterioration, e.g., freezing of water in porous materials, salt decomposition, corrosion of concrete reinforcement, mold and rot, chemical conversion, biological attack, and corrosion of panel walls. Furthermore, the energy consumption of the building will increase, since drying of a building component demands energy.

Wind-driven rain is one of the parameters that increases the moisture content of the building component. Investigations concerning wind-driven rain deal with a number of parameters, for example, rain precipitation, raindrop size, wind speed, and type of collector.

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This study is focused on wind-driven rain. However, measurement results concerning local climate data will be presented. Finally, some of the measured local climate data are compared to obtained meteorological data in order to validate the measurements at the field station.

IN SITU MEASUREMENT

At the field station, a full-scale microclimate measurement setup has been established on top of the field station building. The measurements were carried out from January 1998 to December 1999. The building of the field station is situated 5 meters above sea level and it has a rectangular form with the following dimensions: length of 22.1 m, width of 7.2 m, and height of 4.3 m. The building has a flat roof and the orientation of the southeast short wall is 150°. The field station is located on the outskirts of Göteborg at a distance of about 10 km from the city center and only 50 meters from the seacoast. The surroundings are open terrain: the land offers no shelter to the building. There is no valley or group of buildings likely to produce funneling of wind. The ground slopes down with an average slope of less than 1 in 20.

Local Climate Measurements

Wind speed and wind direction are measured by using a meteorological tower. The tower, 10 m high, is located on the roof of the field station. Probes in a radiation and precipitation shield obtain the air temperature and humidity and they are placed about 2 m above ground and about 8 m from the west corner of the building. Global radiation is measured with a pyranometer sensor that has a diameter of 34 mm and a height of 38 mm. This equipment is placed on the roof of the field station in the meteorological tower, 2 m above the roof level. The total net radiation for horizontal surfaces is measured by a radiation energy balance system (REBS). Finally, the last instrument for local climate measurement is a rain gauge installed on the center part of the roof to collect and measure the horizontal precipitation.

Microclimate Measurement

The most interesting climatic parameters for describing the microclimate are air temperature, total net radiation (between a specific wall and its surrounding), and driving rain onto a vertical building surface.

The southeast short wall has been studied. This wall is equipped with a REBS radiometer for measuring the total radiation and two thermistor probes for checking the air temperature measurements.

Two different kinds of collectors are involved in these measurements, namely, eight tipping buckets and two apertures in the wall. Seven of these collectors, six tipping buckets and one aperture in the wall, measure the amount of driving rain on the southeast short wall and the remaining collectors are placed in the middle of the southwest wall.

Collectors with a tipping bucket contain a collection plate, 0.176×0.184 m^2. The collection plate is designed to register the amount of medium rain. The tipping bucket contains a volume of 2×1 cm^3. On the tipping bucket a hall-effect switch, completed with a resistance, is placed. The data logger counts every pulse from the switch, i.e., every time the bucket tips. Each pulse is equal to 1 gram or about 0.031 L/m^2.

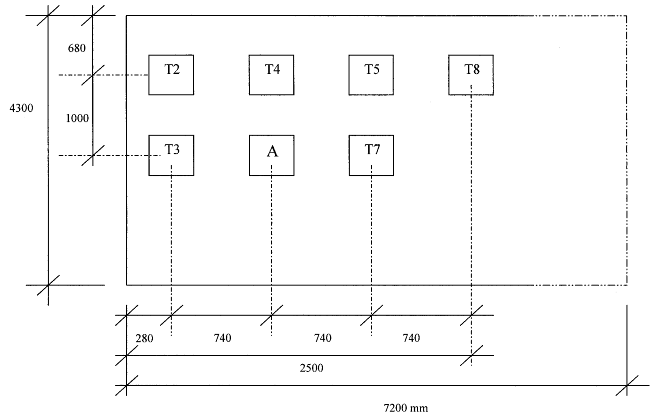

Figure 1 *Positions of the tipping buckets T2-T5 and T7-T8 and aperture (A) on the short wall are shown.*

The positions of the driving rain collectors were chosen with the help of computational fluid dynamic (CFD) modeling of wind-induced surface pressure, performed by the Swedish Meteorological and Hydrological Institute (SMHI). Figure 1 shows the position of the tipping buckets on the southeast short wall. For more details about setup, calibration, location, and devices see Högberg (1998).

MICROCLIMATE DESCRIPTION: DRIVING RAIN

Driving rain is not systematically measured at meteorological stations. Thus, measured parameters in meteorological stations, such as wind direction, wind speed, and rain precipitation, are used for calculations of the precipitated amount of driving rain.

Here, a calculation procedure according to BSI (1992) is chosen. According to this report, the rate of water deposition on vertical walls can be calculated by Equation 1. This equation expresses an empirical relationship between the rain drop size, drop size distribution, and terminal velocity.

$$r_v = \frac{2}{9} \cdot v \cdot r_h^{8/9} \tag{1}$$

where, r_v (L/m^{2}h) is the rate of driving rain on a vertical surface, r_h (mm/h) is the rainfall rate on a horizontal surface, and v (m/s) is the wind speed against the wall.

The air field spell index can be calculated by Equation 2 for any location and any wall orientation for as many years as possible of hourly values of wind speed, wind direction, and rainfall by summing for each spell of driving rain.

$$D'_s = \sum r_v \cdot \cos(D - \Theta) \tag{2}$$

where D is the hourly mean wind direction from the north in

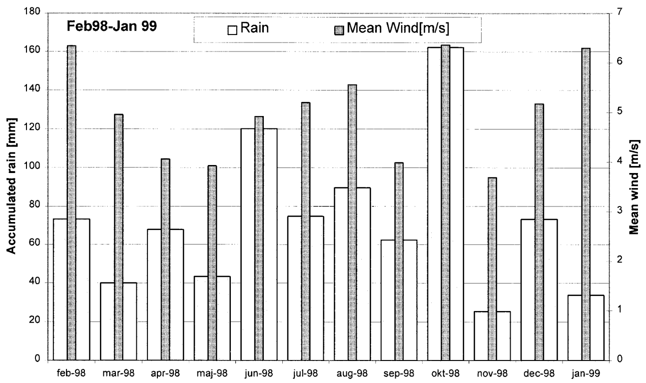

Figure 2 *Monthly cumulative rainfall on a horizontal surface and monthly mean wind speed are shown for the period February 1998 to January 1999.*

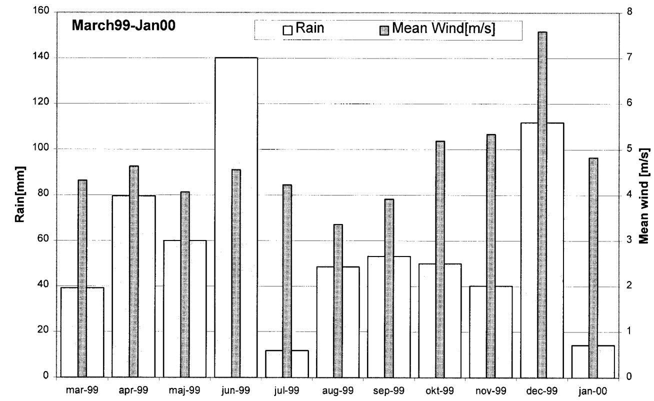

Figure 3 *Monthly cumulative rainfall on a horizontal surface and monthly mean wind speed are shown for the period March 1999 to January 2000.*

(°) and Θ is the angle between the north and a line normal to the wall (°). When cos(D-Θ) is negative it is put to zero, i.e., driving rain only hits the wall when the wind is blowing against it.

The airfield indices that are calculated by Equation 2 are the amount that would be collected by a free-standing driving rain gauge in flat open country. To convert the airfield indices into the wall indices needs terrain roughness factor R, the topography factor T, the obstruction factor O, and the wall factor W.

$$D_{ws} = D'_s \cdot R \cdot T \cdot O \cdot W \quad (3)$$

According to BSI (1992), these factors for the field station are $R = 1.15$, $T = O = 1$, $W = 0.5$ for the upper part (vertical variation) and $W = 0.2$ for the lower part. Wall factors concern vertical variation and flat roof. Here it should be mentioned that no horizontal variation is given in BSI (1992) and Sanders (1996).

According to this calculation procedure, the local climate data that are required for simulating driving rain on a building component are rainfall on a horizontal surface, wind speed, and wind direction.

MEASUREMENT RESULTS AND ANALYSIS

Measurements were carried out from January 1998 to December 1999. The external loads are registered minute-wise for this period of time. The measured climate data, which are necessary for calculation of driving rain, will be presented.

The strategy of the analysis is to identify the rainiest months during the measuring period. Driving rain will be calculated for these months and results of the calculations will be compared to the measured driving rain collected by driving rain collectors.

Results

The local climate data for simulation of driving rain are rainfall on a horizontal surface, wind speed, and wind direction. In Figures 2 and 3, rainfall and wind speed for the measuring period are presented.

The annual main wind speed is about 5 m/s and the maximum monthly mean wind speed from February 1998 through January 1999 is 6 m/s. The maximum accumulated rain and maximum mean wind speed occur during October 1998.

The results presented in Figures 2 and 3 indicate that June 1998, October 1998, June 1999, and December 1999 are the most rainy months during these years. During December 1999, air temperature is often close to or below zero. These temperature conditions make it difficult to determine if the collected amount is just rain or is a mixture of rain and snow. Therefore, December 1999 cannot be counted as a rainy month. June 1998, June 1999, and October 1998 are chosen for further analyses concerning calculation of driving rain. In order to compare the calculated values and measured values, the measured results for these months will be presented.

Measured Results: June and October 1998 and June 1999

Measured results concerning rainfall on a horizontal surface, wind speed, and wind direction during June and October 1998 and June 1999 are presented in Figures 4 through 6 and Tables 1 and 2. Measured results for wind-driven rain will be presented in the next chapter.

The measured results of wind direction indicate that the south-southwest and south-southeast are dominating wind directions during these three months. The orientation of the southeast wall is 150°. Thus, wind directions greater than 60° and less than 240° can contribute to driving rain.

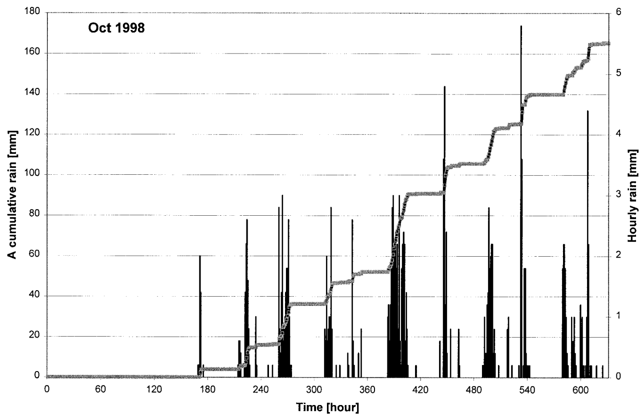

Figure 4 *Cumulative rainfall on a horizontal surface during October 1998.*

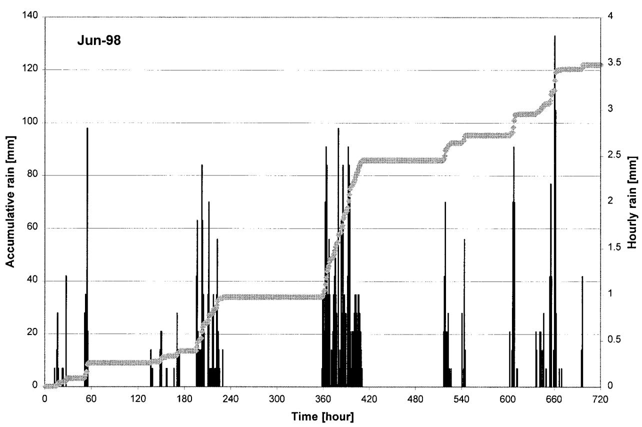

Figure 5 *Cumulative rainfall on a horizontal surface during June 1998.*

COMPARISON AND CONCLUSIONS

Comparison

The results measured by collectors with tipping buckets are compared to calculated ones. Driving rain indices are calculated by Equations 1 through 3. In these calculations, the following terrain values are used: terrain roughness factor R is 1.15, topography factor T and obstruction factor O are equal to unity. Finally, wall factor is 0.5 for the upper parts and 0.4 for the center parts.

By using these factors, Equation 3 can be rewritten for the upper part and the lower part of the wall as:

$$D_{ws} = 0.575 \cdot D'_s \tag{4}$$

$$D_{ws} = 0.460 \cdot D'_s \tag{5}$$

The results of comparisons are presented in Figures 7 through 9. The measurement results of driving rain verify the well-known influence of the vertical position, i.e., the upper part of the wall is exposed to more driving rain than the lower

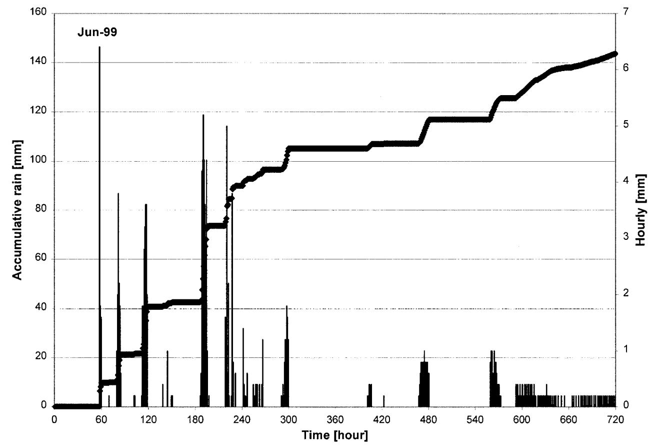

Figure 6 *Cumulative rainfall on a horizontal surface during June 1999.*

TABLE 1
Different Wind Direction Portions During the Month

	Fraction of month [%]		
Wind direction [°]	**June 98**	**Oct. 98**	**June 99**
>0-45	5.8	4.7	3.0
>45-90	6.9	25.5	6.4
>90-135	8.0	5.5	11.0
>135-180	8.0	7.0	12.7
>180-225	18.9	17.0	22.6
>225-270	28.7	24.0	21.6
>270-315	16.2	12.4	17.0
>315-360	7.4	3.6	5.4

TABLE 2
Different Wind Speeds

	Fraction of month [%]		
Wind speed [m/s]	**June 98**	**Oct. 98**	**June 99**
0-2	16.2	5.6	11.1
>2-3	14.3	11.0	14.6
>3-4	15.5	14.3	18.2
>4-5	12.4	11.2	18.9
>5-6	8.9	9.8	13.9
>6-7	7.4	9.1	9.7
>7-8	6.8	8.7	5.9
>8-9	6.6	7.1	3.7
>9-10	5.8	5.5	2.2
>10-11	3.9	4.4	1.1
>11-12	1.9	4.3	0.4
>12-	0.3	8.0	0.3

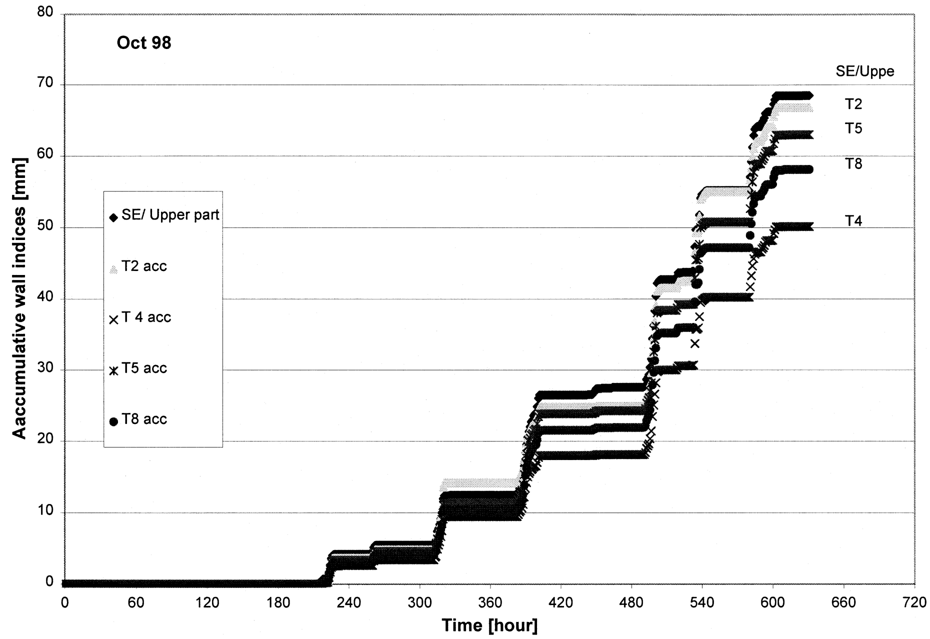

Figure 7 *Comparison of calculated wall indices according to Sanders (1996) and measured values by collectors for the upper part of southeast short wall.*

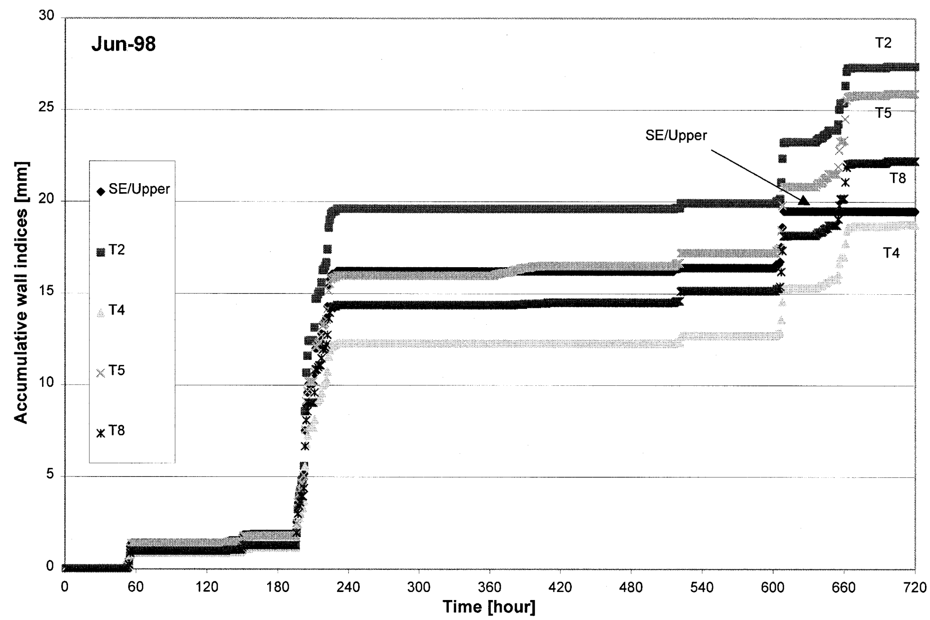

Figure 8 *Comparison of calculated wall indices according to Sanders (1996) and measured values by collectors for the upper part of the southeast short wall.*

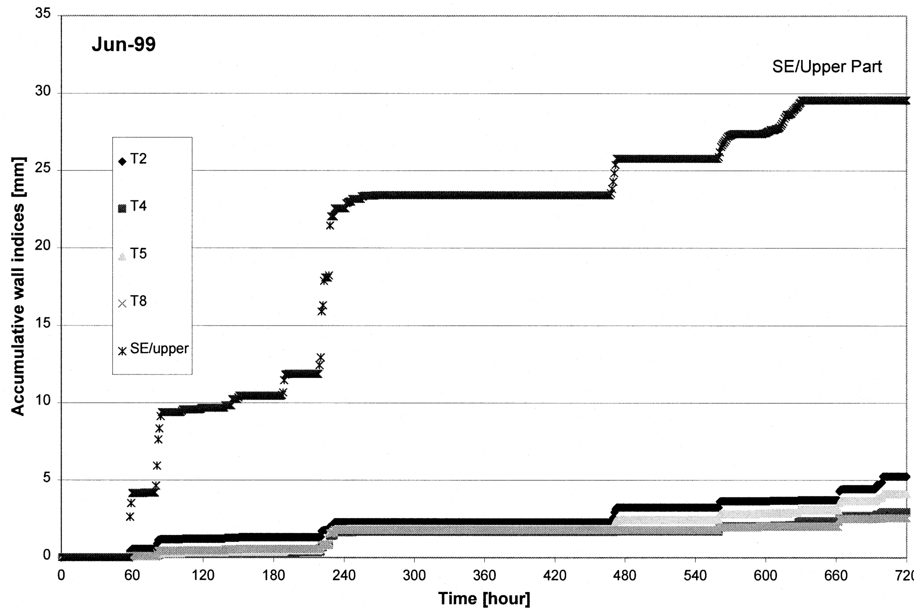

Figure 9 *Comparison of calculated wall indices according to Sanders (1996) and measured values by collectors for the upper part of the southeast short wall.*

TABLE 3
Comparison Results Between Fiskebäck and Säve Meteorological Sation

	Accumulated rain [mm]	Mean wind speed [m/s]				Wind direction			
Peak	-	1	2	3	4	1	2	3	4
Säve	160	5	4	2	7	S	SSE	SW	SSE
Fiskebäck	140	5.5	5	2.3	8.6	S	SSE	SW	SSE

parts. However, the calculated driving rain indices generally overestimate the amount of driving rain on the walls. A reason could be the absence of a reduction factor, which concerns the horizontal position of the collectors. For instance, in Figure 7, the calculated values for the southeast upper parts are close to measured values at collector (T2), which is located close to the edge of the wall; the other collectors are overestimated. However, collector (T4), which is closer to collector (T2) than collectors (T5) and (T8), shows a lower collected amount than collectors (T5) and (T8). This pattern is repeated during the measurement period. There are two possible explanations for this pattern. This pattern can be caused by physical phenomena or collector (T4) is defective.

The comparison results also show a large deviation between calculated values and measured values during June 1999. The collector's response is very weak although wind direction is against the wall and it is rainy weather. The results measured by collectors located on the southeast short wall are almost five to six times lower than the calculated ones (see Figure 9).

To find out the reason for this deviation, a more detailed analysis of the rain spell is needed. The measurement results indicate driving rain peaks during four different time periods: for instance, at about 60 hours (first peak), between 60 and 120 hours (second peak), between 180 and 200 hours (third peak), and finally between 215 and 231 hours (fourth peak). The collectors do not respond or respond weakly during these time periods. These peaks can also be identified in Figure 6. The measured results, minute-wise, of wind speed, wind direction, and rain intensity for these time periods are presented in Figures 10 through 13.

The calculated results are proportional to rain on a horizontal surface, wind speed, and wind direction. A possibility is that these measured parameters are not correct. In order to validate the measured climate data at Fiskebäck, they are compared to measured climate data at Säve meteorological station, which is close to the Fiskebäck field station. The result of this comparison is presented in Table 3.

The comparison results presented in Table 3 show that there are minor differences between measured climate data from these two stations. Furthermore, these minor differences cannot be the reason why deviations appeared during June 1999.

The orientation of the southeast short wall is 150°, and the results presented in Figures 10, 11, and 13 for peaks 1, 2, and 4 show that the wind direction is perpendicular to the surface of the wall. The wind direction in Figure 12, peak 3, is almost parallel, 240°, to the wall surface.

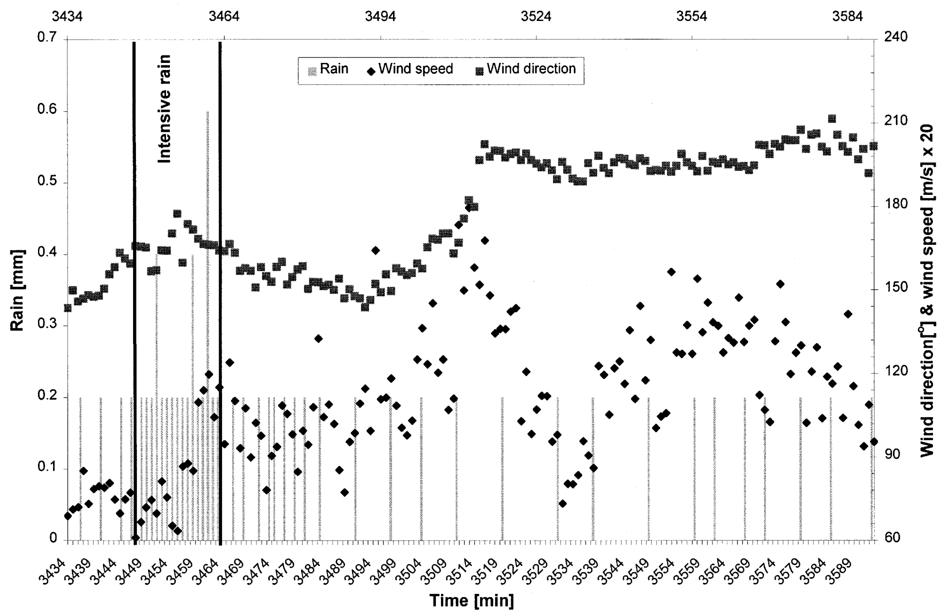

Figure 10 *Peak 1: Wind direction, wind speed, and rain intensity on the horizontal surface between 57 and 60 hours (3434 and 3589 minutes) are presented. The more intensive rain period is marked. The vertical axis is the same for wind direction and wind speed. In order to make the wind speed values readable, they have been scaled to 20 times higher.*

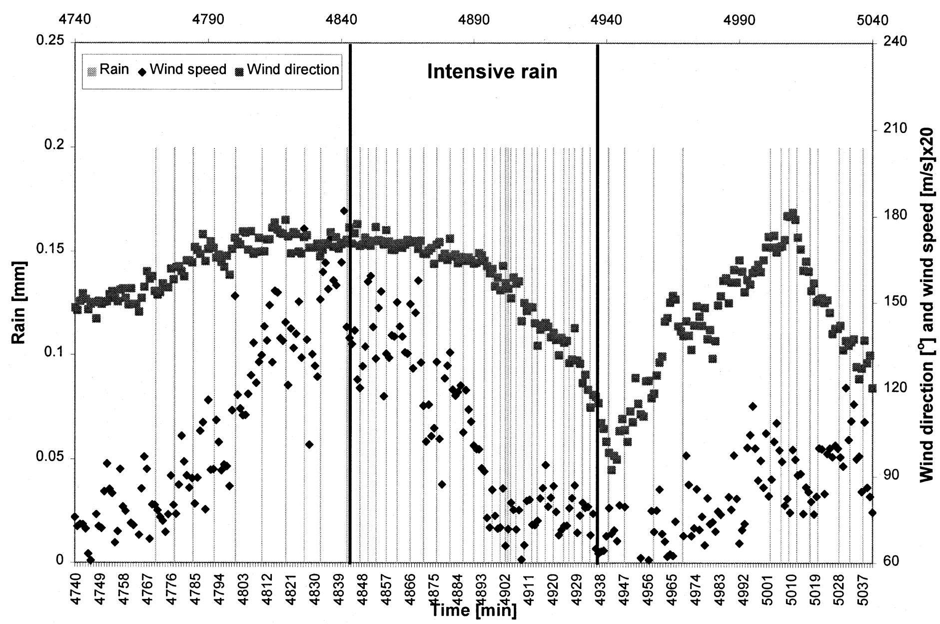

Figure 11 *Peak 2: Wind direction, wind speed, and rain intensity on the horizontal surface between 79 and 82 hours (4740 and 5040 minutes) are presented. The more intensive rain period is marked. The vertical axis is the same for wind direction and wind speed. In order to make the wind speed values readable, they have been scaled to 20 times higher.*

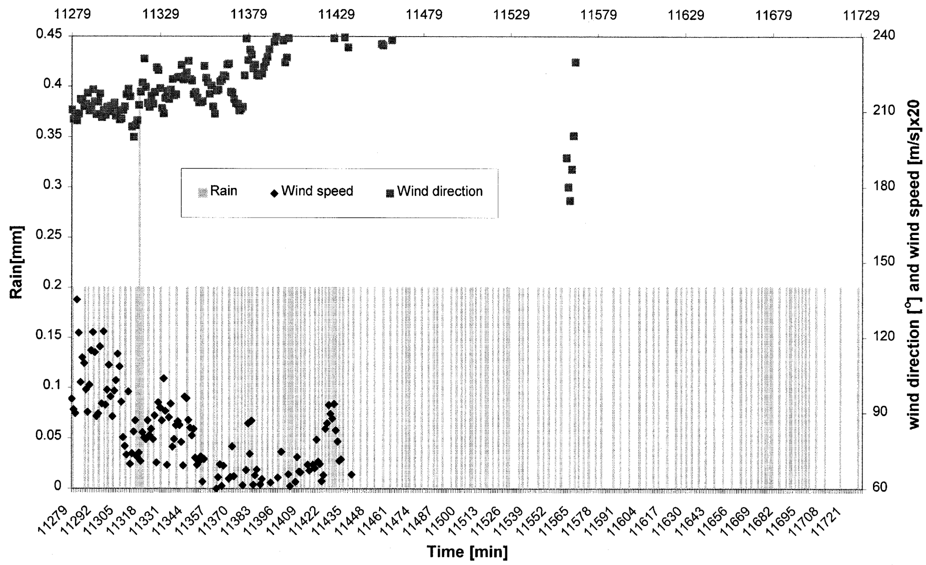

Figure 12 *Peak 3: Wind direction, wind speed, and rain intensity on the horizontal surface between 188 and 196 hours (11279 and 11729 minutes) are presented. The vertical axis is the same for wind direction and wind speed. In order to make the wind speed values readable, they have been scaled to 20 times higher.*

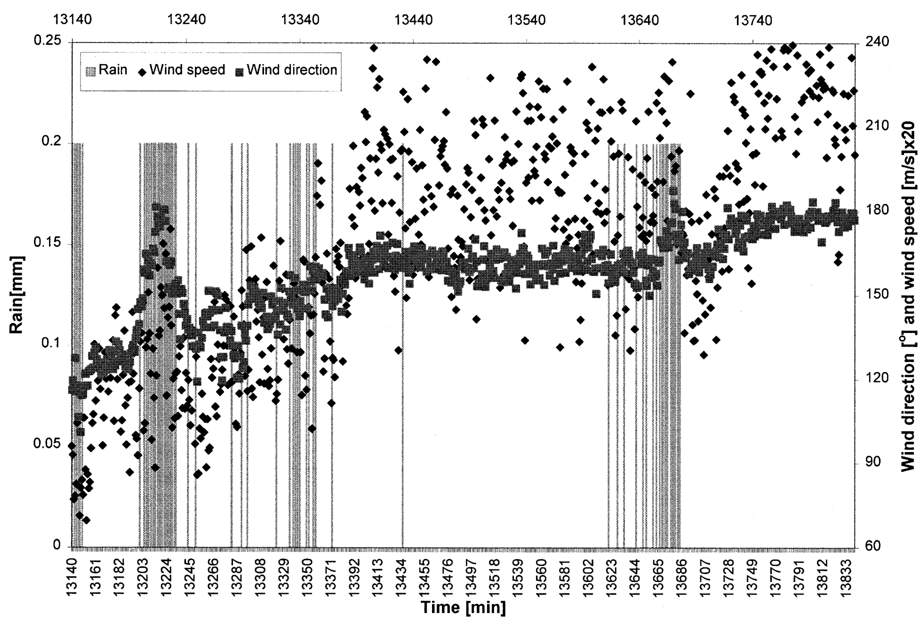

Figure 13 *Peak 4: Wind direction, wind speed, and rain intensity on the horizontal surface between 19 and 231 hours (13140 and 13833 minutes) are presented. The vertical axis is the same for wind direction and wind speed. In order to make the wind speed values readable, they have been scaled to 20 times higher.*

During the time period 188 to196 hours, peak 3, the wind direction is almost parallel to the wall surface (240°) and wind speed is as low as 2.3 m/s. The raindrop diameter in combination with the wind speed can increase or reduce the contact angle between the surface of the collector and raindrops. For example, if wind speed is 2 m/s and raindrop diameter is larger than 6 mm, the contact angle is about 15°. A sharp angle in combination with interruption of the airflow close to a building or field station can affect the amount of collected driving rain.

During the time period of peaks 1, 2, and 4, the wind direction is perpendicular to the wall surface and collectors should normally respond to this direction more easily than the other directions with moderate wind speed. The mean wind speed of peak 4 is 8.6 m/s and the mean wind speed of peaks 1 and 2 is about 5 m/s. According to these circumstances, i.e., perpendicular wind direction and wind speed greater than 5 m/s, raindrops are reflected out from the surface of the collectors. Thus, the amount of the driving rain that will be registered by collectors is less than the existing one.

Finally, the result of the aperture in the wall is compared to the results of the collectors with tipping buckets. The comparison results show that the amount of driving rain collected by the aperture is at least twice as much as the amount collected by collectors with tipping buckets.

Without further analysis concerning the weather situation, different collector's sensitivity, and the influence of the building, it is difficult to fully determine the reason for the deviations between measured and calculated.

CONCLUSION

The comparison between the measured climate data from Fickebäck station and from Säve meteorological station indicates that the measured local climate data at Fiskebäck are accurate.

The horizontal position of the collectors on the wall is important for determination of the amount of precipitated driving rain. Collectors close to corners and edges are normally exposed to higher amounts of driving rain. Therefore, a horizontal reduction factor is needed, as well as the common vertical one, in order to determine the accurate driving rain distribution over a wall surface.

The comparisons between measured and calculated values indicate that Equations 1 through 3 could be a good approximation for transformation of rain (precipitation on a horizontal surface) to driving rain indices. In order to establish the reason for the deviations seen under June 1999, further investigation is required. These investigations can focus on subjects such as collectors' efficiency at various wind speeds and raindrops spectra, what kind of collectors are more suitable for different weather situations, and, finally, the influence of the building on the air flow field.

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