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MECHANICAL ENGINEERING, TESTING & CONSULTING

Consulting Report MT-13-1134

Induced flow test and rain penetration test of fourth prototype static ventilator.

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June 5, 2013

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Incorporated in South Australia,
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1 Summary

This report describes measurements of induced flow and measurements of rain penetration (or leakage) through the fourth version of the client's prototype roof-top static-ventilator cap. The induced flow rate is expressed as the velocity ratio or "flow coefficient"

$$R = \frac{\text{[flow speed through the ventilator shaft]}}{\text{[wind speed]}}.$$

Induced flow speed U_i is averaged over cross-section area A so that flow rate is $Q = U_i A$. Induced flow speed is measured at 10 wind speeds from 3.2 m/s to 15 m/s.

The rain penetration P is expressed as the proportion of incident rainfall which leaks (or penetrates) through the ventilator cap:

$$P = \frac{\text{[leakage volume through ventilator cap]}}{\text{[rain volume falling through an open stub (vent shaft)]}}. \quad (1)$$

Rain penetration is measured at four wind speeds: 0 m/s, 3.3 m/s, 6.3 m/s and 9.3 m/s.

The principal results are that

1. the induced-flow velocity ratio R through the fourth static prototype ventilator changes from R= 0.346 at the lowest wind speed (3.2 m/s) to R=0.362 at the highest wind speed (15,0 m/s);

2. the induced velocity ratio through the prototype ventilator is higher than through the best performing Hurricane H400 ventilator by an average of 0.048 over the above range of wind speeds;

3. average uncertainty (95% confidence interval) in the measurements of induced-flow velocity ratio R is approximately ±1.6%;

4. the rain penetration through the prototype is approximately P=0.002 (0.2%) at all four wind speeds of the test;

5. at wind speeds higher than about 6 m/s, rain penetration through the prototype ventilator is smaller than through the Hurricane H400 ventilator; at wind speeds of zero and 3.3 m/s, leakage through the Hurricane ventilator (0.02% to0.03%) is too small to measure reliably.

6. the uncertainty (95% confidence interval) in the measurements of rain penetration P is approximately ±0.0006 (±0.06% at all four wind speeds of the test.

2 Compliance with AS/NZS 4740

2.1 Induced-flow test

The measurements of induced flow comply with Appendix E of the Australian/New Zealand Standard 4740, "natural ventilators —classification and performance".

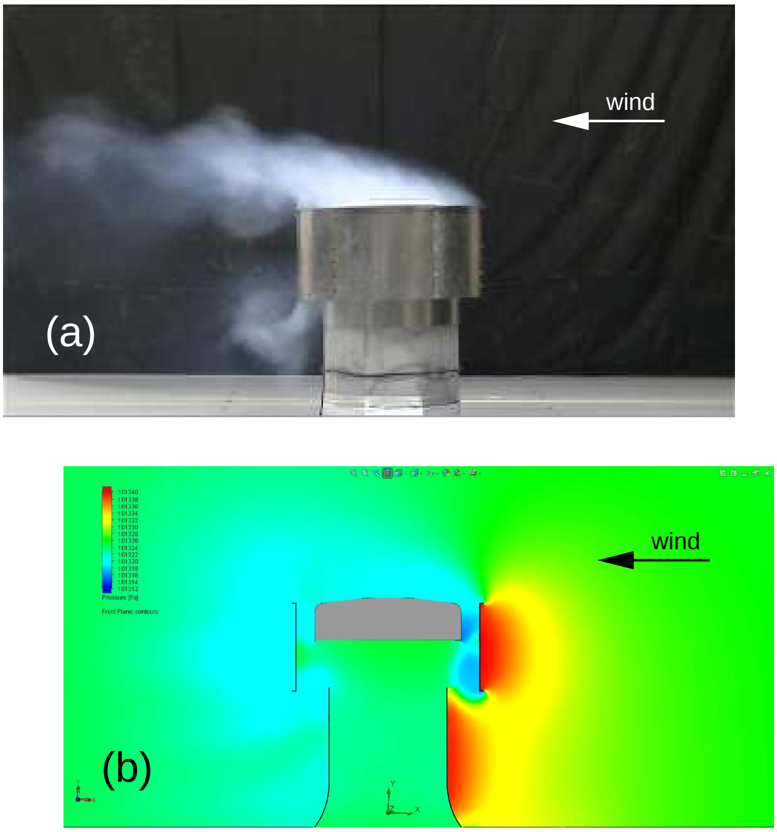


Figure 1: Comparison of (a) flow visualisation (using fog) of the induced flow through a prototype ventilator and (b) the pressure field in numerical simulation of induced flow through the fourth prototype ventilator. (Images are provided by the client. Wind is from right to left.)

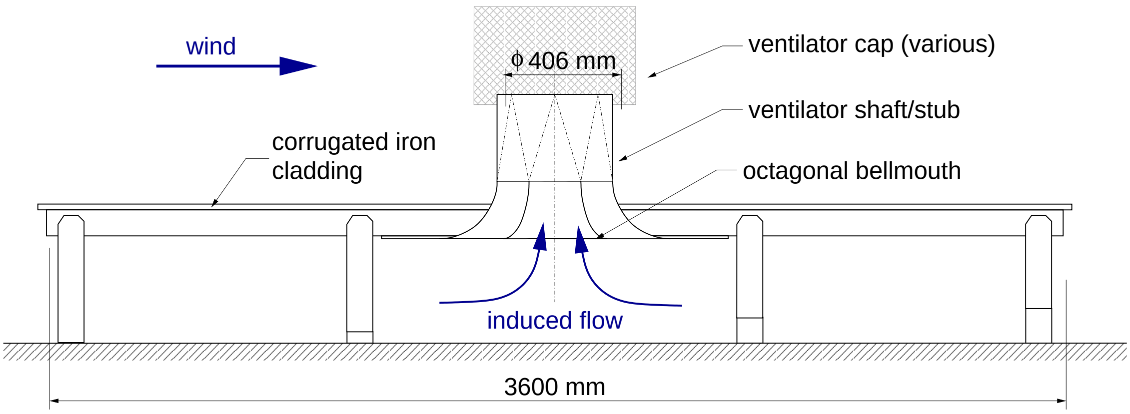


Figure 2: Induced flow test: cross-section diagram of platform and ventilator.

2.2 Rain-penetration test

AS/NZS 4740 appendix C specifies some details of the apparatus and procedure for a rain-penetration test. Constraints imposed by the available apparatus require some departures from these specifications.

For example, the physical size of the apparatus implied by clause C3 of the standard is much greater than the space actually available for the tests and is much greater than the cross-section area (2.75×2.0 m^2) of the wind-tunnel flow. Also, the maximum wind speed is limited to about 9.3 m/s by the need to avoid damaging the wind tunnel with wind-blown water.

The following aspects of the test comply with AS/NZS 4740:

1. the intensity of simulated rain exceeds the 291 mm/hour given by the apparatus described in clause C3(b) of AS/NZS 4740;
2. as agreed by the client, the pitch of the “roof” is effectively zero;
3. the roof is sealed to prevent leakage through the roof;
4. the method of measuring the volume of water penetrating the ventilator is compliant with clause C4 of AS/NZS 4740.

3 Background

This report, which follows MT-12-1123C and MT-12-1123A, is the fourth report on the testing of prototype roof-top ventilators. The MT-12-1123C and MT-12-1123A report the performance of the Hurricane H400 ventilator.

Figure 1 shows a positive correlation between flow visualisation of the induced flow through a prototype ventilator and regions of low pressure (blue) in a numerical simulation (CFD) of the induced flow.

4 Induced flow test: description of apparatus

The main apparatus used for these tests consists of a 3.6×3.6 m^2 platform pierced by a central ventilator shaft (or stub) which opens into a bellmouth on the underside of the platform. Figure 2 is a diagram showing a cross-section elevation of the platform. The diagram also shows wind and induced flow as blue arrows. The platform is horizontal.

As shown in Figures 3 and 4, the platform is placed in the open-jet flow from the 4:1 (area ratio) contraction of the Adelaide Wind Tunnel. The leading edge of the platform is at the same height as the bottom edge of the contraction exit, and the gap of approximately 200 mm is covered by a sheet-metal fairing.

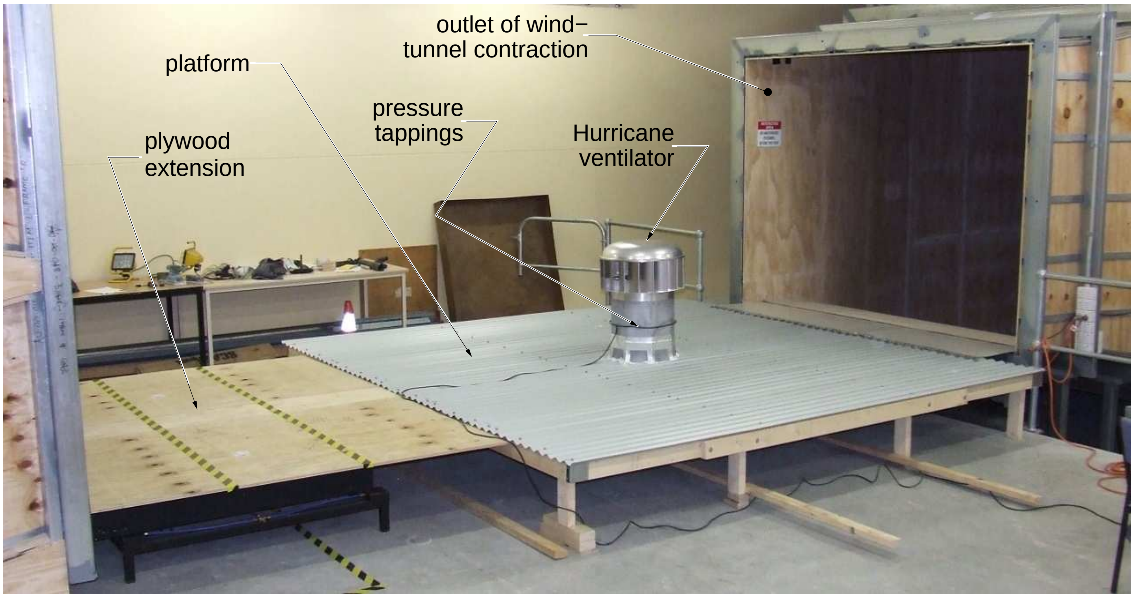


Figure 3: Induced flow test: photograph of platform, bellmouth and Hurricane ventilator.

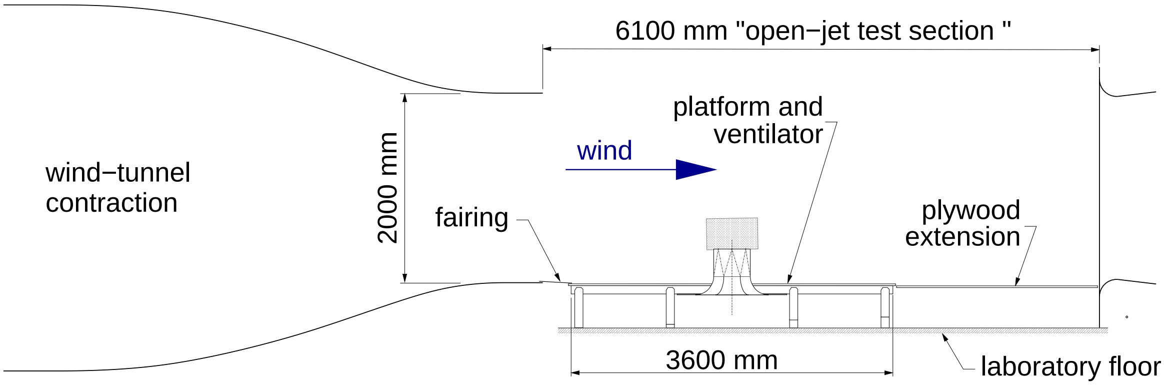
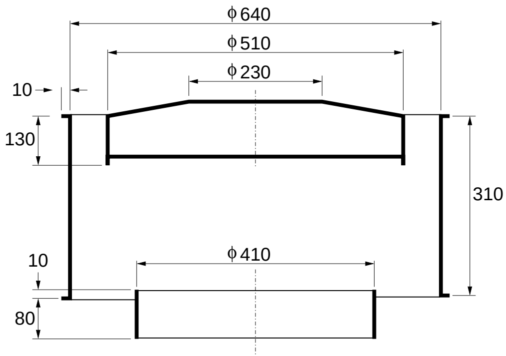


Figure 4: Induced flow test: platform and ventilator in the open-jet wind-tunnel flow.

(a) installed on test apparatus



(b) measured dimensions

Figure 5: Photograph of the installed prototype ventilator and diagram with measured dimensions.

5 Induced-flow test: description of method

Wind speed, U_∞, is obtained by measuring the static pressure difference ΔP_c from outlet to inlet of the contraction:

$$U_\infty = \sqrt{\frac{2\Delta P_c/\rho}{1 - A^2}}, \quad (2)$$

where ρ is air density and $A = 0.25$ is the area ratio of the wind-tunnel contraction. A "Fluke 922 airflow meter" is used for reading the pressure ΔP_c.

Induced flow speed, U_i, through the ventilator is obtained by measuring gauge static pressure ΔP_i in the ventilator shaft and by applying the Bernoulli theorem:

$$U_i = \sqrt{\frac{-2\Delta P_i}{\rho}} \quad (3)$$

The pressure transducer is a 1-Torr Baratron 398HD-00001 pressure sensor and each reading from the Baratron is an average of the output voltage over a period of 20 seconds.

At the start of the wind-tunnel contraction there are 4 pressure tappings, each near a corner of the duct. The 4 tappings are connected by a ring of tube to give an average pressure at inlet plane of the contraction. A similar arrangement is used for measuring static pressure at the exit of the contraction and the static pressure in the ventilator shaft.

Figure 5 shows the dimensions of the prototype ventilator.

6 Induced-flow test: results

Figures 6 and 7 show the results of the tests for wind speeds (U_∞) between 3 m/s and 15 m/s. Wind speed is expressed as a Reynolds number defined as

$$Re = \frac{U_\infty D}{\nu}, \quad (4)$$

where D is the diameter of the open stub and ν is kinematic viscosity. Each data point on the graphs is obtained by averaging 5 readings of the Fluke 922, and 5 readings from the Baratron pressure sensor, and includes corrections for offset and thermal drift.

Figure 6 shows that all the measurements of velocity ratio lie within the range 0.34 to 0.37. In Figure 7 the vertical scale is expanded so that individual measurements can be compared more easily.

The graphs include measurements obtained from MT-12-1123C of the induced-flow velocity ratio for two Hurricane H400 ventilators. The Hurricane ventilators have different performance because the manufactured dimensions are different.

7 Rain penetration test: description of apparatus

Figure 8 is a diagram showing a cross-section elevation of the platform. The rain penetration test requires the addition of a 1.7-degree slope, gutters and storm-water drainage. The diagram also shows wind and simulated rainfall from an array of drippers. Figure 10 shows the frame supporting the dripper array.

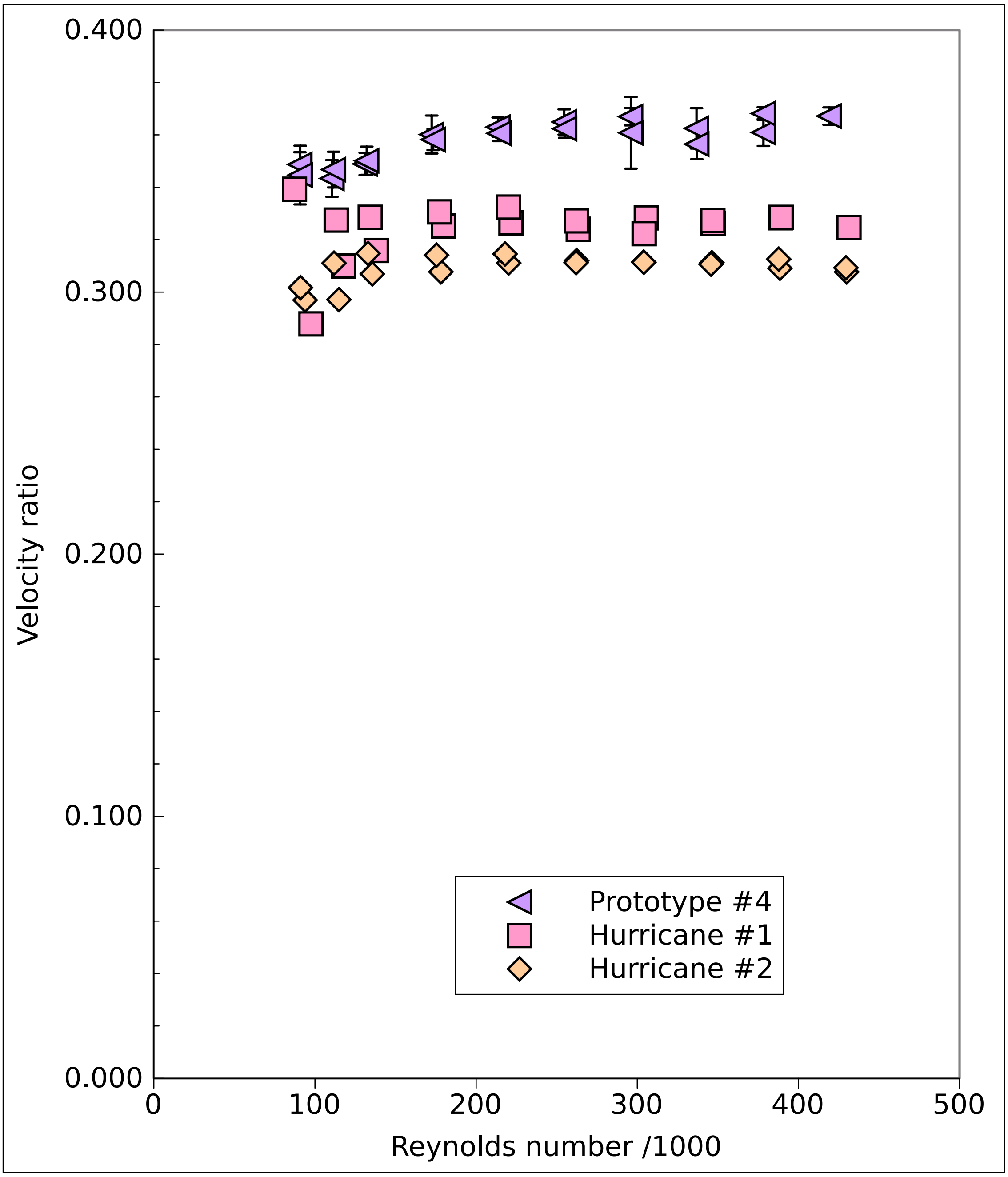


Figure 6: Induced flow test: velocity ratios, R, as a function of Reynolds number for the fourth third prototype static ventilator cap. Measurements of Hurricane H400 ventilators are also shown on the graph

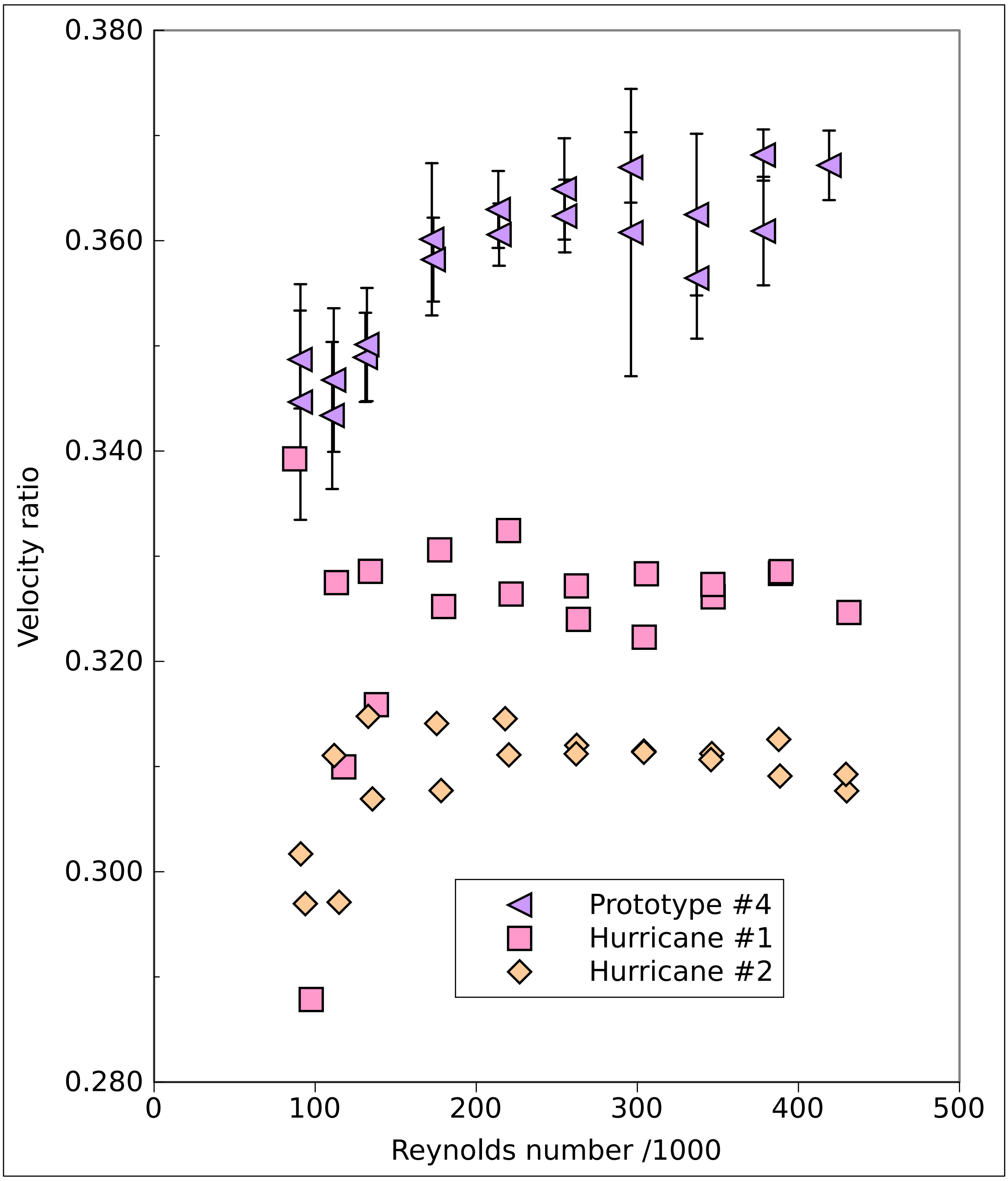


Figure 7: Induced flow test: velocity ratios, R, as a function of Reynolds number for the fourth third prototype static ventilator cap — with expanded vertical scale. Measurements of Hurricane H400 ventilators are also shown on the graph. Error bars are calculated from scatter in the manometer readings.

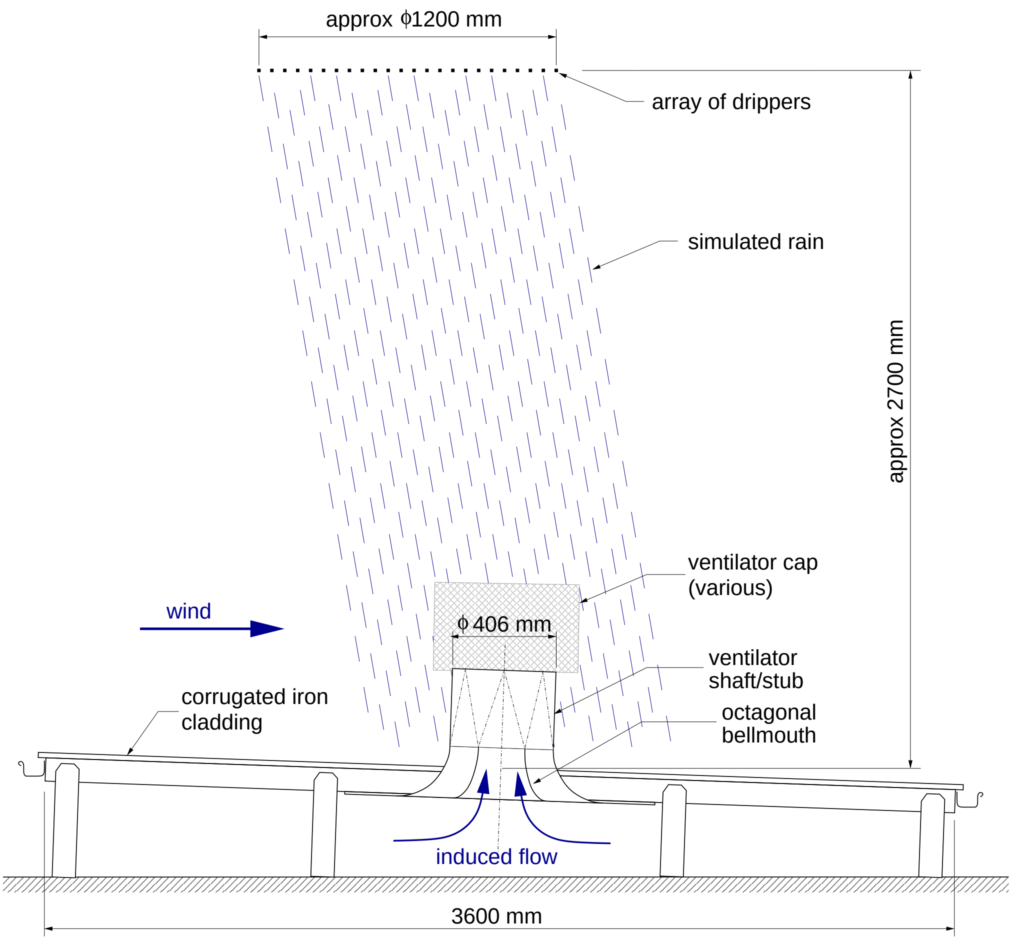


Figure 8: Rain penetration test: cross-section diagram of platform and ventilator, also showing height and diameter of the array of drippers.

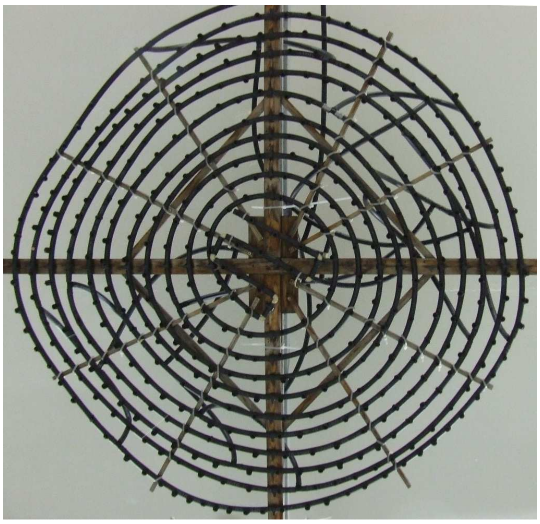


Figure 9: Dripper array.

Figure 10: Rain penetration test: photograph of platform, installed prototype ventilator elevated dripper array.

There are approximately 430 drippers in the array (Figure 9) located above the ventilator. The drippers are located so that the middle of the drip pattern falls on the ventilator cap. The position of the drippers is adjusted to account for the change in rain angle when the wind speed is changed. The flow rate of water is measured and monitored with a flow meter graduated in litres/minute.

8 Rain penetration test: description of method

Wind speed, U_∞, is obtained in the same way as for the induced-flow test. Each test of rain penetration requires separate measurements of the leakage volume through the installed ventilator cap and through the open stub. For both the ventilator cap and the open stub, leakage volumes are measured at four wind speeds: 0 m/s, 3.3 m/s, 6.3 m/s and 9.3 m/s. Wind speeds of 6.3 m/s and 9.3 m/s produce significant volumes of convected spray. Wind speeds higher than 9.3 m/s produce an unacceptable risk of water damage to the wind tunnel.

Water leaking through the ventilator or falling through the open stub is collected in a drip tray which is placed underneath the bellmouth. The flow rate of water to the dripper array is set at 15 litres/minute. Measurements of water volume though the open stub show that this corresponds to a rainfall intensity of between 410 mm/hour and 450 mm/hour. Measurements of rain penetration are, however, expected to be independent of rainfall intensity.

Each test runs for a total of 24 minutes. In tests where leakage exceeds approximately one

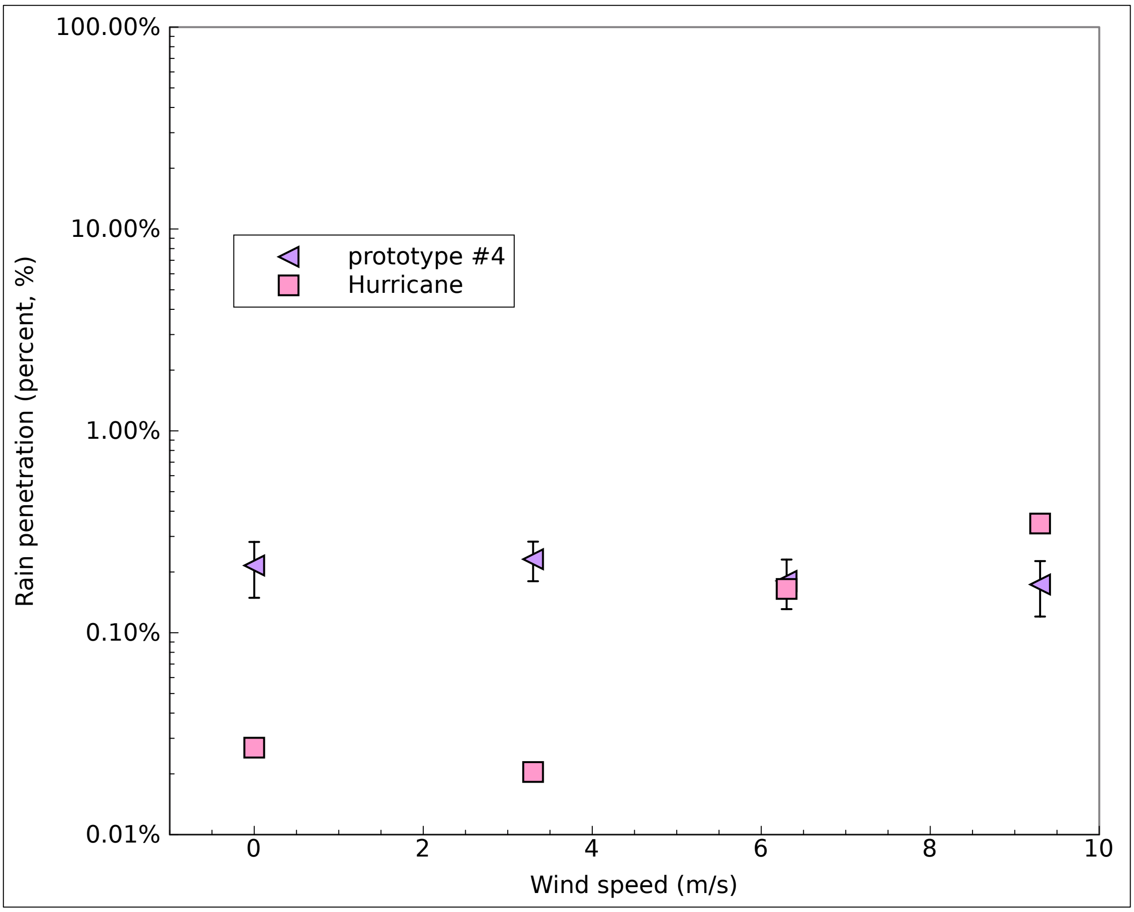


Figure 11: Rain penetration of the fourth prototype as a function of wind speed. Measurements of a Hurricane H400 ventilator are also shown on the graph.

Table 1: Rain penetration of the fourth prototype and the Hurricane ventilator as a function of wind speed.

	Fourth prototype		Hurricane
wind speed (m/s)	Penetration (%)	confidence limits (%)	Penetration (%)
0	0.22	±0.05	0.03
3.3	0.23	±0.05	0.02
6.3	0.18	±0.05	0.16
9.3	0.17	±0.05	0.35

litre per hour, the leakage volume is measured at intervals of 6 minutes, giving 4 readings per test. This makes it possible to assess the reliability (confidence limits) of the measurements. When leakage is less than one litre per hour, best accuracy is obtained by running the test continuously for 24 minutes, with just one reading of the leakage volume.

9 Rain penetration test: results

Figure 11 and Table 1 show the rain penetration P as a function of wind speed for the fourth prototype ventilator. The error bars are 95% confidence limits. The penetration (or leakage) and confidence limits are expressed as a percentage of rain falling through the open stub.

The graph and the table include measurements obtained from MT-12-1123A of the rain penetration of a Hurricane H400 ventilator.