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Instituut vir Termodinamika en Meganika – Institute for Thermodynamics and Mechanics

Smoke and heat Ventilator Testing

by

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Introduction

Air ventilators are used to ventilate hot air between the ceiling and roof of a building to regulate its temperature. They are also (more importantly) smoke ventilators in the occurrence of a fire and a requirement for safety regulations of buildings. The type of air ventilator which was tested consists of various louvers connected to a spring-loaded mechanism which forces the louvers open in the incident of a fire. The spring-loaded mechanism is triggered with a diffusible link which breaks when its yield-temperature is exceeded.

The air ventilator was tested to BS 7346-1:1990 standards. Several tests were conducted which were coefficient of discharge; rain testing, wind-load testing, temperature rise and fatigue testing. The set up of these tests together with their results are explained in their various sections.

Coefficient of Discharge

The aim of this experiment was to determine the coefficient of discharge C_D for when the louvers open and the leakage coefficient C_D when the louvers are closed. The apparatus, an atmospheric draft tunnel, is being discussed together with the BS standards guide lines for the test set up. The ventilator was tested in closed and fire open configurations and the results are provided in forms of tables and figures.

Apparatus: Atmospheric open-loop draft tunnel with manometers and calibrated orifice plate

The wind tunnel (figure 1.1) consists of a radial fan (1) that draws air uniformly through the ventilator, where the wet- and dry bulb temperatures, as well as the turbulence level, are measured. The static pressure difference is measured across the ventilator at points located in the duct wall (2). After the ventilator, the air passes through an insulated connecting section (3) followed by a venturi (4). The purpose of the venturi arrangement tends to minimize the non-uniformity of the air-stream velocity. The air flow is determined by measuring the pressure drop across one or more elliptical nozzles mounted in plate (5) located between two perforated plates (6) which straighten the flow.

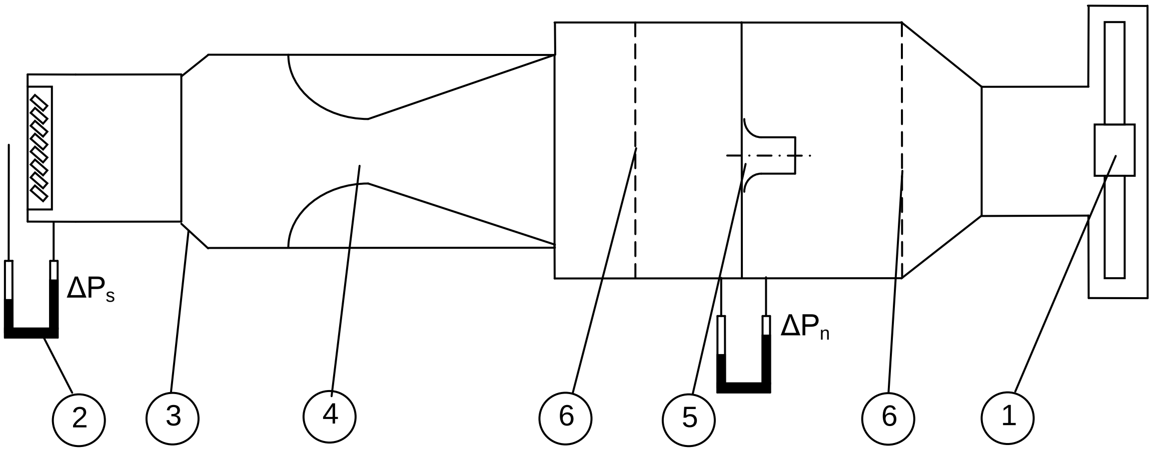

Figure 1.1 Atmospheric open loop draft tunnel

Figure 1.2 Ventilator connected to draft tunnel

Figure 1.3 describes the test set up for the ventilator before it is connected to the wind tunnel.

Test set up:

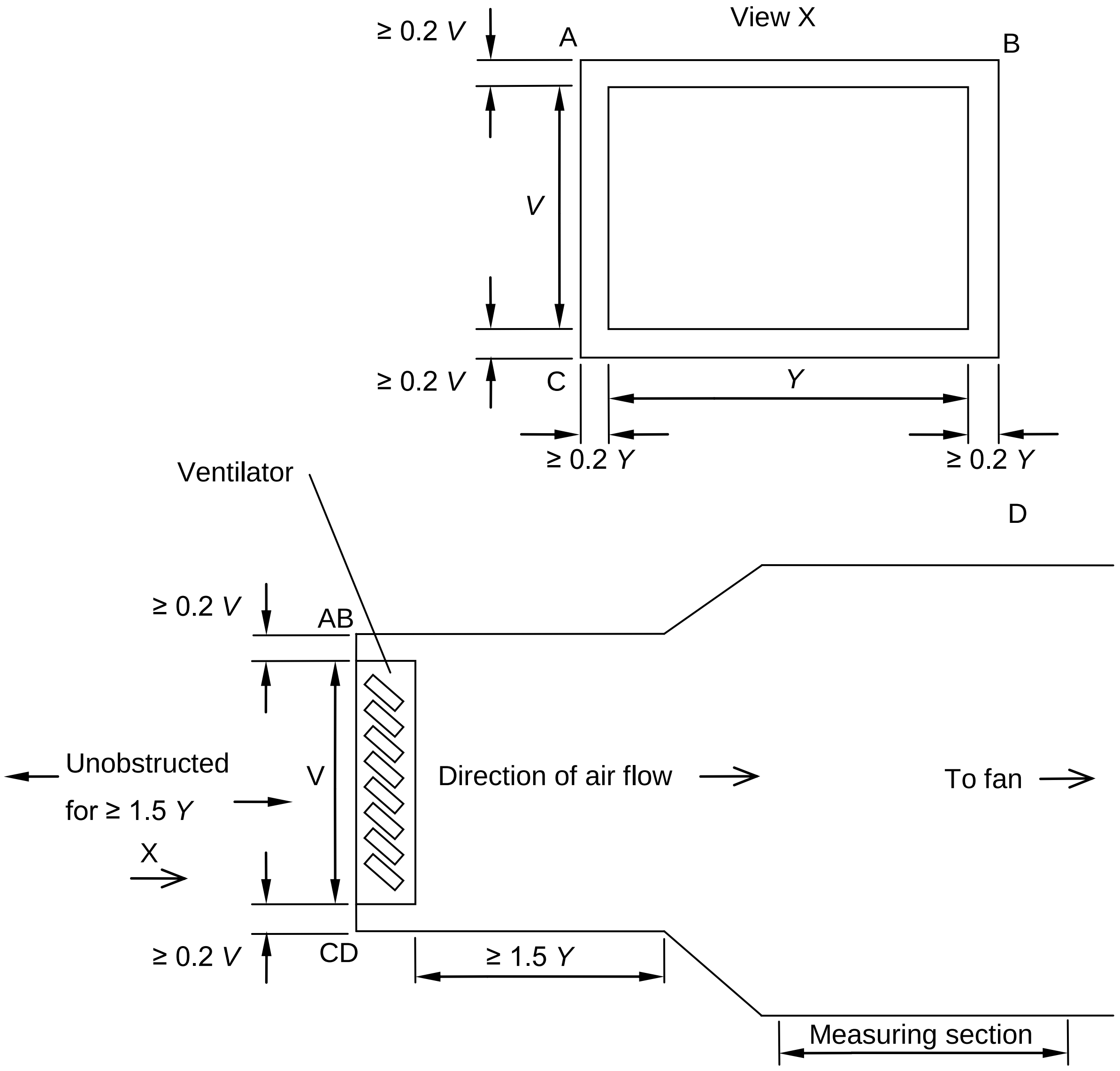

Figure 1.4 Test set up for ventilator to British standards

Calculations:

By graphical or calculation methods, determine the best straight line through the plotted points of Q_n^2 against differential pressure, and passing through zero where Q_n is the air flow through the ventilator in m^3/s. If all the points lie within ±5% differential pressure of the best line, then the values from any point on the line may be used in the calculation of C_D as the derived value of C_D will be independent of flow rate throughout the range tested.

If isolated points fall outside the ±5% band, then the tests shall be repeated at the relevant flow rates to check the validity of the data.

If groups of points fall outside the ±5% band indicating that the tests results do not follow a linear relationship between Q_n^2 and differential pressure, then calculate C_D for each of the test points and plot C_D against Q_n and determine the best line (curve) through the points. If the points fall within ±5% of C_D of the best line, then values from points on the line may be used in the interpolation of C_D. Derived data shall include at least the values of C_D at the minimum, median and maximum test flow rates.

Flow measurements shall be in accordance with BS 1042 (air flow measurement accuracy ±0.25%, pressure difference accuracy ±0.25%), using instruments that carry a current calibration certificate, traceable to a defined national standard.

Calculate the air density from the equation

$$\rho = \frac{346.8 \times P}{1000(273 + T)}$$

where

P is the barometric pressure in mbar

T is the ambient temperature in °C

Calculate the theoretical flow, Qt in m3/s, from the equation

$$Q_t = \frac{A\rho}{2\Delta P_s}$$

where

A is the ventilator throat area in m^2

ΔP_s is the static pressure difference at the test flow rate in Pa

ρ is the air density in kg/m^3

Calculate the coefficient of the ventilator from the aerodynamics tests using equation

$$C_D = \frac{Q_n}{Q_t}$$

where

Q_n is the actual flow determined by test

Results and Comments

The ventilator subjected to the tests is smaller than the actual size used in practice. Therefore it was suspected that the mechanisms which are responsible for the opening of the ventilator might have a negative effect on the discharge coefficient. The discharge coefficient test was then repeated without its opening mechanisms. The leakage coefficient test was conducted with the louvers closed and was calculated with the same method as the discharge coefficient which was explained in section 1.1. The results are shown in the following data tables and figures.

Discharge coefficient

Table 1.1 Test data for fire open configuration with mechanisms

No.	Barometric Pressure	Abient Air Temperature	Air Density	Static Pressure Difference	Ventilator Throat Area
	N/m2	°C	kg/m^3	Pa	m^2
1	101860	16.2	1.21677	13.74575	0.22755
2	101860	16.2	1.21587	28.39460	0.22755
3	101860	16.2	1.21489	43.94619	0.22755
4	101860	16.2	1.21368	63.17367	0.22755
5	101860	16.2	1.21231	85.79117	0.22755
6	101860	16.2	1.21071	111.65255	0.22755
7	101860	16.2	1.20892	138.18840	0.22755
8	101860	16.2	1.20516	195.64125	0.22755
9	101860	16.2	1.20237	237.37302	0.22755
10	101860	16.2	1.19936	284.08466	0.22755

Table 1.2 Test results for fire open configuration with mechanisms

No.	Volume Flow (Q_n)	Volume Flow (Q_n^2)	Correlation Values (Q_n^2)	Percentage Difference	Theoretical Flow, (Q_t)	Coefficient of Discharge
	m^3/s			%	m^3/s	C_d
1	0.57034	0.32529	0.31459	-3.40	1.08161	0.527
2	0.81191	0.65920	0.65544	-0.57	1.55513	0.522
3	1.01374	1.02767	1.01729	-1.02	1.93546	0.524
4	1.20812	1.45955	1.46466	0.35	2.32171	0.520
5	1.40853	1.98396	1.99092	0.35	2.70712	0.520
6	1.60378	2.57211	2.59266	0.79	3.09033	0.519
7	1.79697	3.22909	3.21009	-0.59	3.44055	0.522
8	2.12010	4.49482	4.54688	1.15	4.10014	0.517
9	2.35004	5.52268	5.51789	-0.09	4.52156	0.520
10	2.57590	6.63528	6.60476	-0.46	4.95269	0.520

Table 1.3 Test data for fire open configuration without mechanisms

No.	Barometric Pressure	Abient Air Temperature	Air Density	Static Pressure Difference	Ventilator Throat Area
	N/m2	°C	kg/m^3	Pa	m^2
1	101650	13	1.22848	8.30000	0.22755
2	101650	13	1.22757	32.05783	0.22755
3	101650	13	1.22658	79.23082	0.22755
4	101650	13	1.22536	126.80570	0.22755
5	101650	13	1.22396	194.48768	0.22755
6	101650	13	1.22235	233.07906	0.22755
7	101650	13	1.22935	0.00000	0.22755
8	101650	13	1.22935	0.00000	0.22755
9	101650	13	1.22935	0.00000	0.22755
10	101650	13	1.22935	0.00000	0.22755

Table 1.4 Test data for fire open configuration without mechanisms

No.	Volume Flow (Q_n)	Volume Flow (Q_n^2)	Correlation Values (Q_n^2)	Percentage Difference	Theoretical Flow, (Q_t)	Coefficient of Discharge
	m^3/s			%	m^3/s	C_d
1	0.63967	0.40918	0.43177	5.23	0.83646	0.765
2	1.20651	1.45566	1.43505	-1.44	1.64451	0.734
3	1.88344	3.54733	3.42715	-3.51	2.58638	0.728
4	2.33904	5.47111	5.43623	-0.64	3.27363	0.715
5	2.87237	8.25053	8.29442	0.53	4.05652	0.708
6	3.14586	9.89643	9.92412	0.28	4.44370	0.708

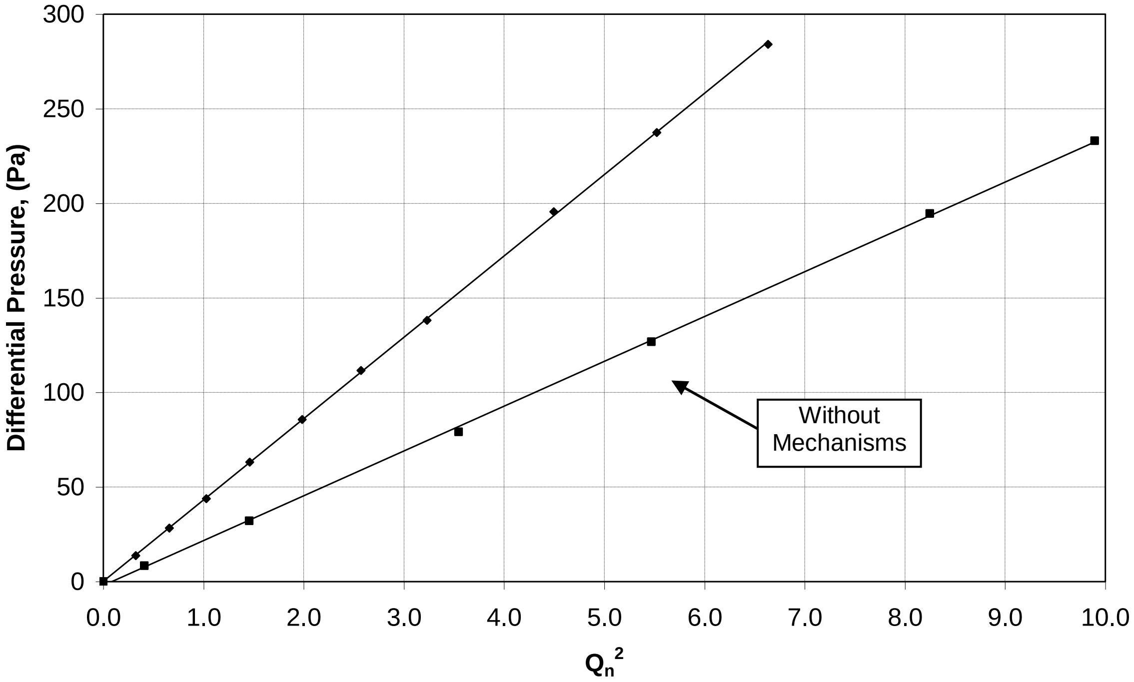

Figure 2.4 Graph of differential pressure versus Q_n^2 for fire open configuration with and without mechanisms

Leakage coefficient

Table 1.5 Test data for leakage coefficient when louvers are closed

No.	Barometric Pressure	Abient Air Temperature	Air Density	Static Pressure Difference	Ventilator Throat Area
	N/m2	°C	kg/m^3	Pa	m^2
1	101860	16.2	1.21458	67.21796	0.22755
2	101860	16.2	1.21382	125.04840	0.22755
3	101860	16.2	1.21284	198.54599	0.22755
4	101860	16.2	1.21168	285.36035	0.22755
5	101860	16.2	1.21032	387.71022	0.22755
6	101860	16.2	1.20878	501.78798	0.22755
7	101860	16.2	1.20703	631.63481	0.22755
8	101860	16.2	1.20512	773.38864	0.22755

Table 2.6 Test data for leakage coefficient when louvers are closed

No.	Volume Flow (Q_n)	Volume Flow (Q_n^2)	Correlation Values (Q_n^2)	Percentage Difference	Theoretical Flow, (Q_t)	Coefficient of Discharge
	m^3/s			%	m^3/s	C_d
1	0.22778	0.05189	0.05138	-0.99	2.3939849	0.095
2	0.30539	0.09327	0.09488	1.70	3.2662840	0.093
3	0.38371	0.14724	0.15017	1.95	4.1173743	0.093
4	0.46064	0.21219	0.21547	1.52	4.9384881	0.093
5	0.53904	0.29056	0.29246	0.65	5.7596514	0.094
6	0.61293	0.37569	0.37827	0.68	6.5566063	0.093
7	0.68767	0.47289	0.47594	0.64	7.3614831	0.093
8	0.76394	0.58361	0.58257	-0.18	8.1522255	0.094

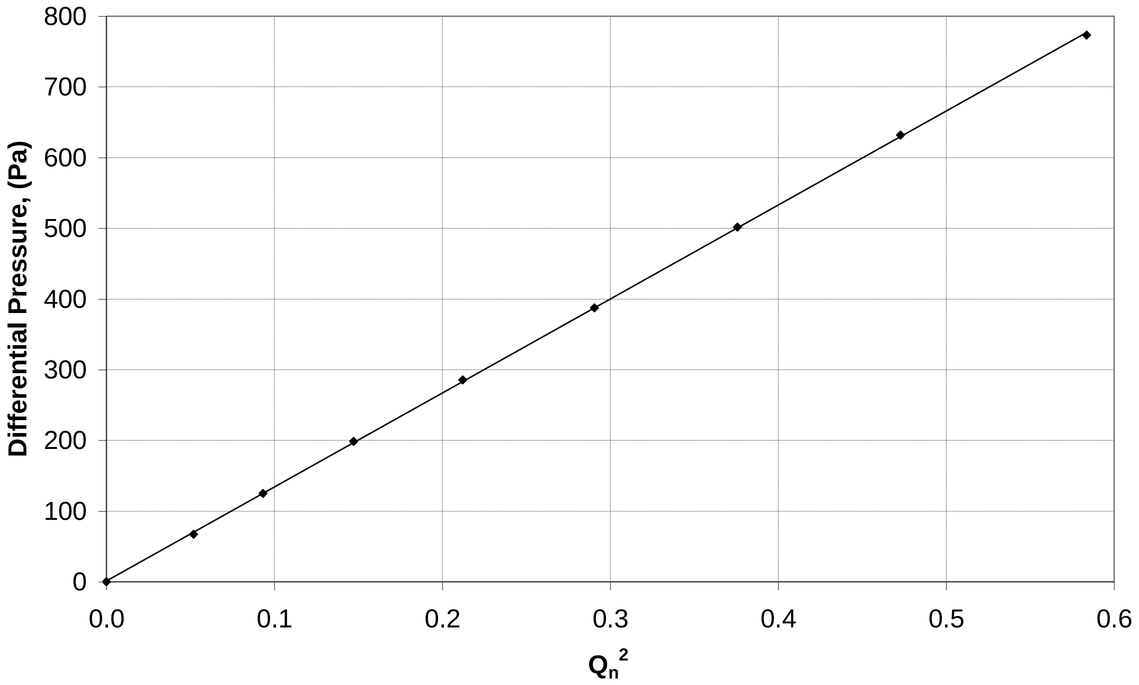

Figure 2.5 Graph of differential pressure versus Q_n^2 for closed louvers

The ventilator is not to size according to BS 7346-1: 1990. The dimensions of the smallest ventilator are specified as 1.2m by 1.2m. The size of the tested ventilator is 0.615m by 0.37m . It can be seen from figures 2.4 and 2.5 that the test results are very linear as required by the BS. The accuracy is denoted by the percentage differences in tables 2.2, 2.4 and 2.6 and is within 5% as also required by the BS.

The average coefficient of discharge for the fire open position is 0.521 with the mechanisms and 0.726 without the mechanisms. It can now be concluded that the discharge coefficient of the actual size ventilator used in the industry lies between these two values of 0.521 and 0.726. The average coefficient of leakage is 0.094 for when the louvers are closed.

Rain Testing

The weatherproof characteristics of natural/smoke ventilators in the closed position were tested at a variety of angles by driving rain at them. A draught tunnel was used instead of a wind machine as specified in the BS to create a wind speed of 13m/s across the ventilator. A water nozzle was used to create a rainfall of 75mm/h and the details of the ventilator under tests were recorded. The rainfall was measured with a rain meter connected to the test rig (figures 3.2 and 3.5). The test positions of the ventilator will now be explained together with the results.

Results and Comments

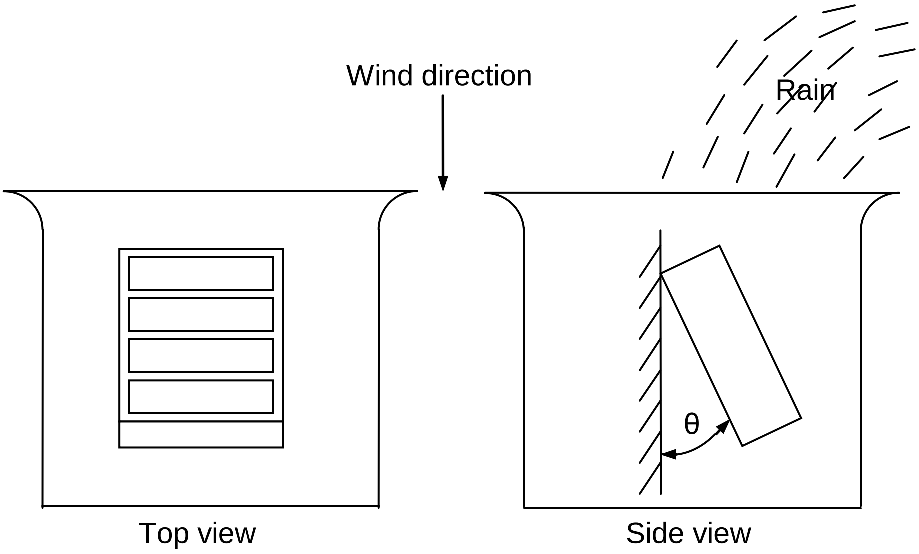

Figure 3.1 Rain test configuration 1

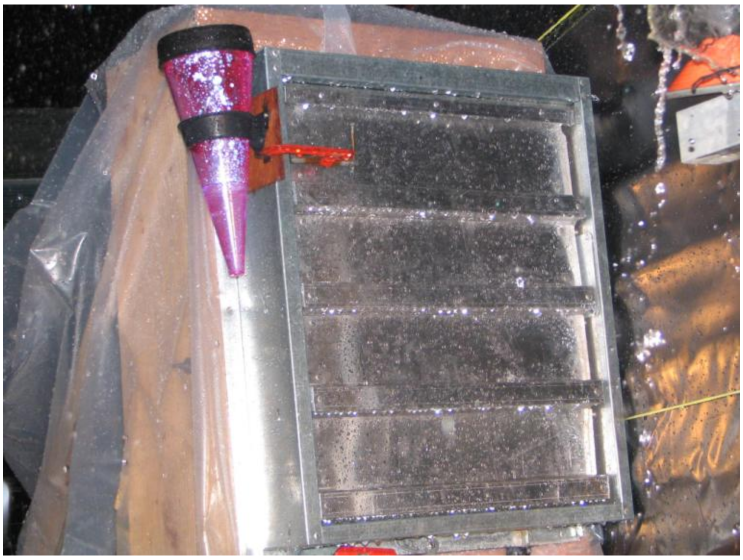

Figure 3.2 Picture of ventilator in rain test (configuration 1)

The ventilator was tested at different angles in configuration 1 where the values of θ were 0, 15, 30, 45, 90 degrees. There were no leakages.

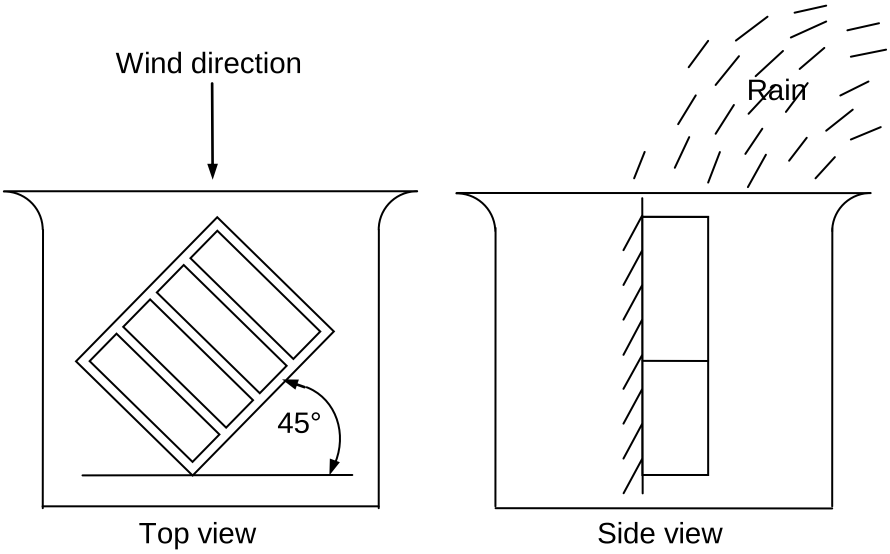

Figure 3.3 Rain test configuration 2 (flat)

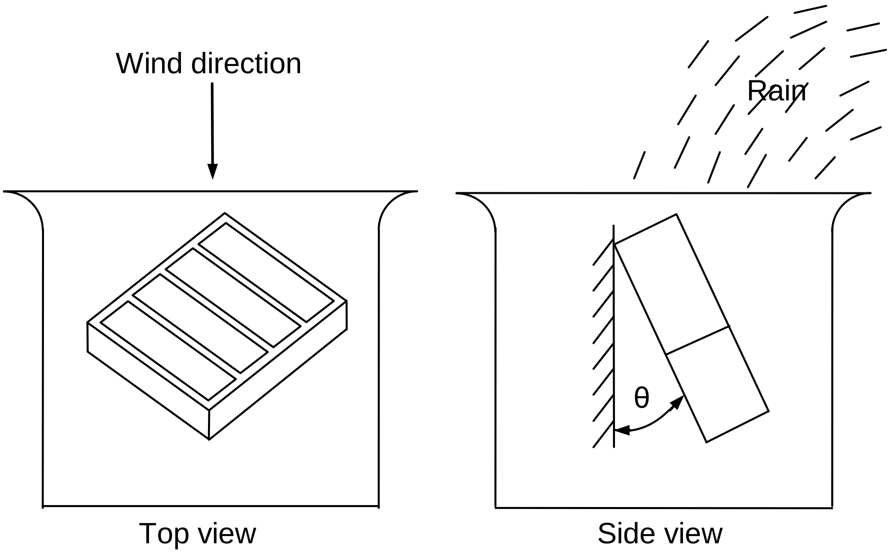

Figure 3.4 Rain test configuration 2 at an angle

Figure 3.5 Picture of ventilator in rain test (configuration 2)

The ventilator was tested at different angles in configuration 1 where the values of θ were 0, 45, 90 degrees. There were no leakages.

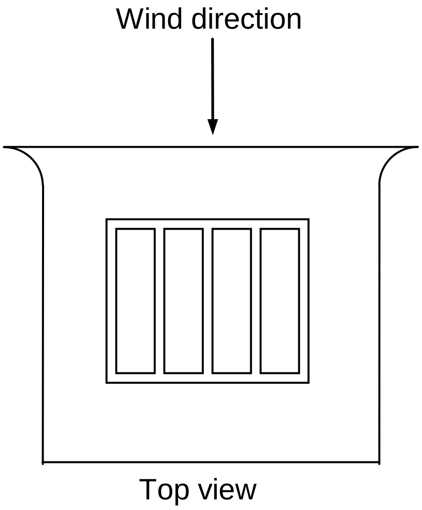

Figure 3.6 Rain test configuration 3 (flat)

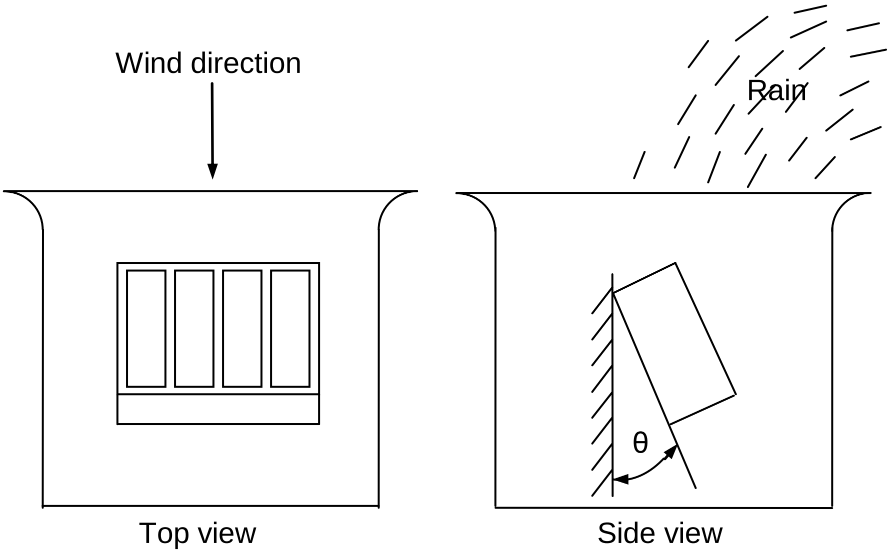

Figure 3.7 Rain test configuration 3 at an angle

This was only tested in a horizontal position and there were no leaks. It can now be concluded that the ventilator succeeded the rain tests to British standards (BS 7346-1:1990).

Wind Load Testing

The ventilator was connected to a fan unit with a short wind tunnel section. The pressure on the ventilator was measured with a pressure transducer. The load on the ventilator was 2.4 kN/m^2 for suction and pressure.

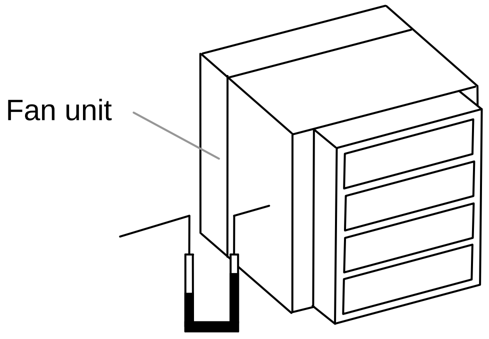

Figure 4.1 Ventilator on wind pressure test rig

Results and Comments

The ventilator did not fail during this test. The ventilator was not to size and smaller than the actual ventilators used in the industry. It is not possible to comment on what the outcome of this test would have been if the ventilator area was larger. A larger area will influence the outcome of the test negatively.

Temperature Rise

This test simulated the rise in temperature above a developing fire. The aim of this test was to determine at what temperature the diffusible link fails which causes the ventilator to open. Two sets of conditions were simulated:

a) a slowly developing fire producing a slow rate of rise in temperature;
b) a rapidly developing fire producing a rapid rate of rise in temperature.

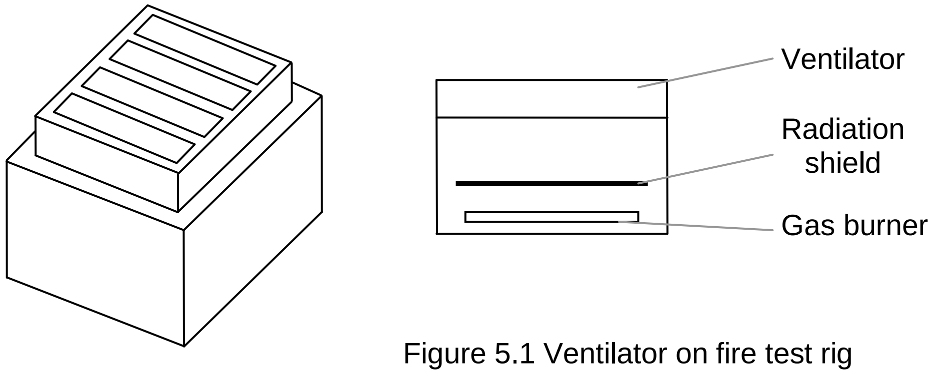

Figure 5.1 Ventilator on fire test rig

Results and Comments

The results for the slow and fast temperature rise are shown in figures 5.1 and 5.2. The temperatures at the point where the louvers opened is depicted on these figures. It can be seen that the louvers opened when the temperature of the diffusible link was 73°C for the slow temperature rise test and 89.1°C for the fast temperature rise test. It was expected that the temperature of the diffusible link at its yield point would be higher during the fast temperature rise test. The reason for this is that the temperature measured of diffusible link was its surface temperature and not its average temperature. The convective heat transfer from the hot air to the diffusible link and the melting of the diffusible link is time dependant. The surface temperature of the diffusible link increased while its melting process occurred relatively slowly compared to the temperature rise.

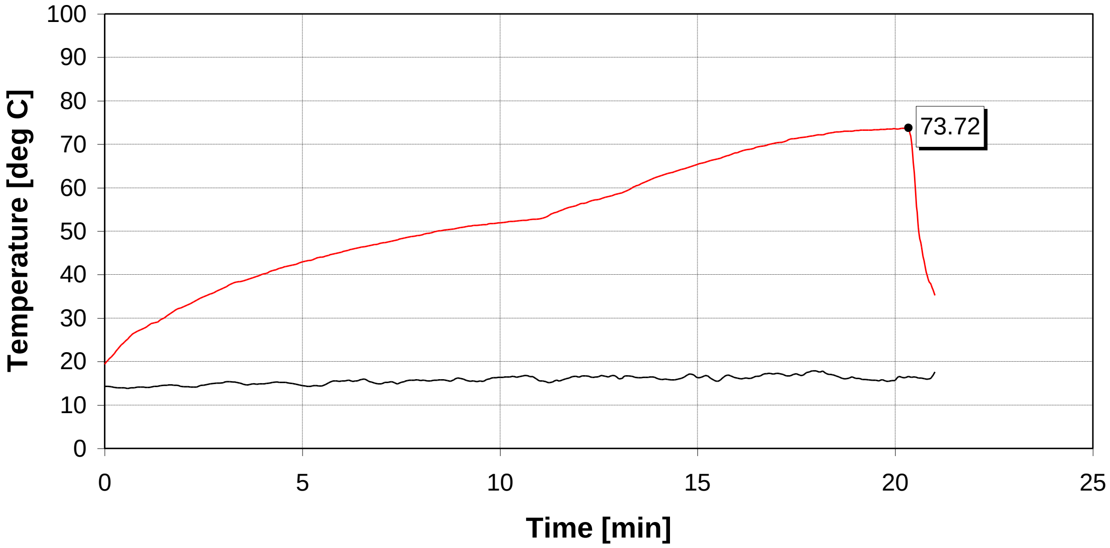

Figure 5.2 Graph of temperature versus time of the diffusible link and outside environment for the slow temperature rise test

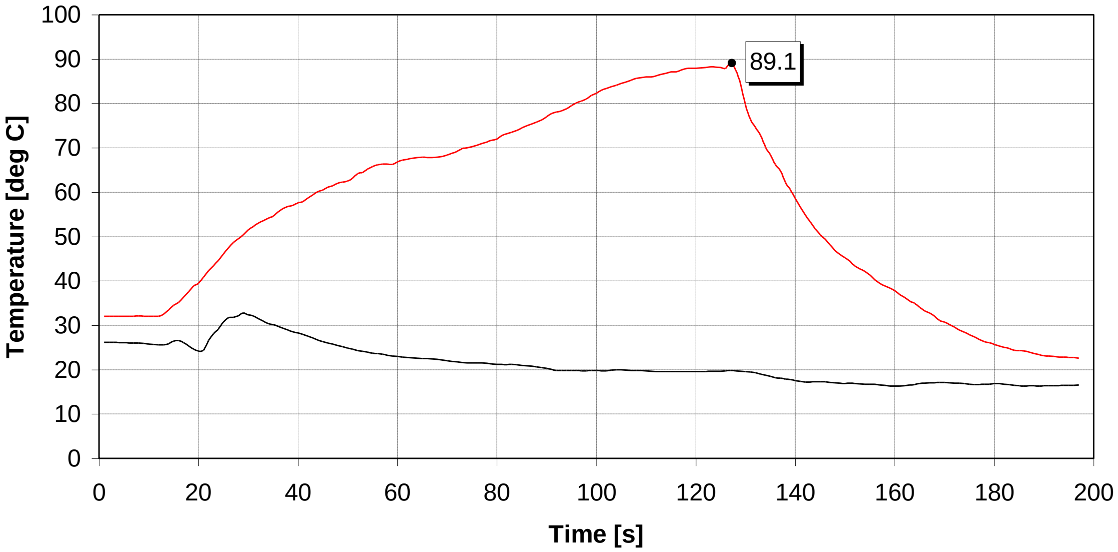

Figure 5.3 Graph of temperature versus time of the diffusible link and outside environment for the fast temperature rise test

Fatigue Testing

The ventilator was opened and closed 30000 times without any breakages. A pneumatic actuator was used to open and close the ventilator and a counter was used to count the cycles.

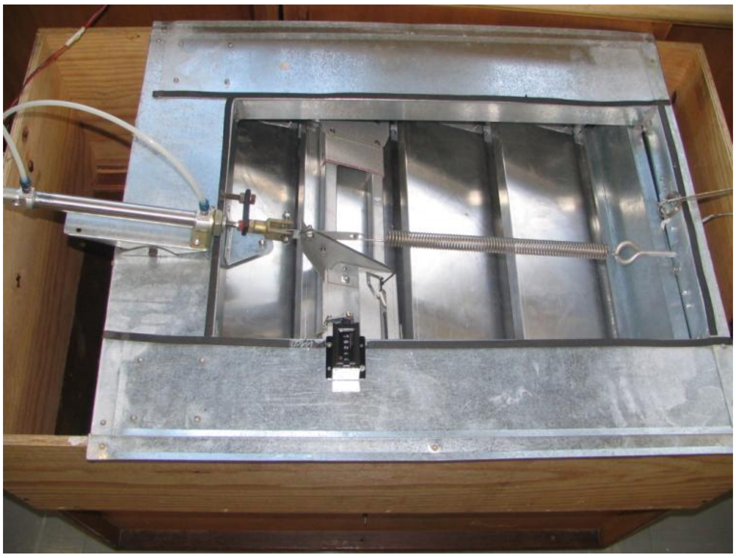

Figure 6.1 Photo of the test set up for the fatigue testing of the ventilator

Conclusion

The air ventilator was successfully tested to BS 7346-1:1990 standards. The test setups and results were explained. The only discrepancy of these tests was that the ventilator is not to size according to the BS standards.