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Development of a Ventilation System against Volcanic Ash Fall in Kagoshima

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ABSTRACT

Kagoshima has an active volcano, Sakurajima, at the southern edge of Japan, which belches out smoke and ash almost every day. The volcanic ash falls over Kagoshima, a city of more than 530 000 people, situated only 10 km from Sakurajima. Therefore, indoor air pollution due to the volcanic ash is a serious local problem. In these circumstances, a natural ventilation system with an ash-resistant device was developed, and its performance was tested. It has been proved from exposure tests that the amount of ash entering a room is reduced to about 1/4 of that from ventilation systems in general use.

1. INTRODUCTION

Kagoshima Prefecture is located at the southern edge of Japan. Nearby there is a volcano, Mount Sakurajima (Figs. 1 and 2), which is famous as one of the most active volcanoes in Japan. Several times, great eruptions have occurred. In 1914, a large-scale eruption with vast amounts of lava connected Sakurajima to the land of the Osumi Peninsula.

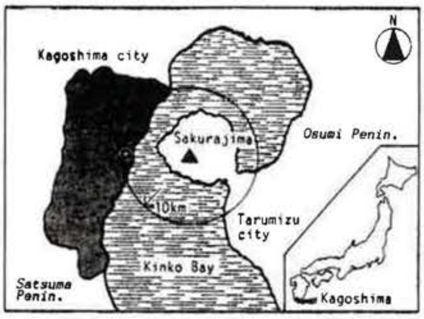

Fig. 2. Location of Sakurajima.

When volcanic smoke is belched out, areas on the leeward side of the volcano are showered with volcanic dust, called falling ash (Fig. 3). Falling ash has greatly affected people, houses, transportation, agriculture, etc. Various effects of volcanic ash on housing are serious as local problems.

In the present situation where Sakurajima is erupting repeatedly every year, it is necessary to understand the real effects of ash on

Fig. 1. Mount Sakurajima with an active crater 1040 m high (the north view from an aircraft).

Fig. 3. The downtown of Kagoshima showered with a volcanic dust.

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housing, and also to adopt the appropriate ash-resistant devices. In the last decade, the amounts of falling ash have been increasing. Although many studies on the volcanic fields of Sakurajima or physical and chemical aspects are carried out, housing damage and ash effects are not fully grasped [1 - 3]. Few extensive studies are found concerning devices of buildings and houses for reducing the ash effects.

For these circumstances, a natural ventilation system as an ash-resistant device was developed, and the efficiency for ash-reducing performance was examined by exposure tests.

2. ASH EFFECTS ON DWELLINGS

2.1. Volcanic activities of Sakurajima

Sakurajima rises in the center of Kinko Bay and forms a small land-tied island with an area of about 80 km^2 and a circumference of about 52 km (Fig. 2). One of the three peaks, 1040 m high, still continues to erupt.

Large-scale eruptions are recorded in the following periods: Tenpyo Eruption A.D. 764; Bunmei Eruptions 1471 - 1478, An-ei Eruptions 1779 - 1782, Taisho Eruptions 1914 - 1915, and Showa Eruption 1946 [4 - 6]. In the Taisho Eruption, lava from the east-side crater, amounting to an equivalent of some 340 million 10-ton truck-loads, buried the channel to Osumi Peninsula [4].

The type of volcanic activity observed presently is the summit eruption, which releases volcanic rocks, volcanic ash and gas. It started at the end of October, 1955, and has continued until now. Since 1955 there have been more than 5400 explosive eruptions. When the annual number of remarkable eruptions amounted to more than 400, the peak stage of eruptive activity occurred three times, in 1960, 1983 and 1985 (Fig. 4). More than 200 eruptions have happened almost every year since 1974 except for a few years.

2.2. Amount of ash falling

Figure 5 shows the annual amounts of falling ash observed at Kagoshima Meteorological Observatory. In 1985, a record year, a total of 15 980 g/m^2 of ash fell in 454 eruptions. A monthly maximum of 5902 g/m^2 ash fell in August and a maximum spell of 17 days of ash falling was also recorded. Total volcanic ashes of 29 410 000 t wt. were calculated to have belched from the active crater in 1985. On June 16, 1988, a daily maximum ash fall of 2671 g/m^2 attacked Kagoshima city as shown in Fig. 6.

Ash-falling areas change owing to the wind direction over Sakurajima. North-west winds prevail in winter, and in summer the east to south winds are highly frequent (Fig. 7). The distributions of ash-fall amounts are shown in

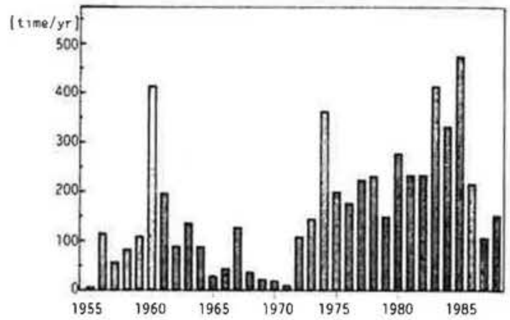


Fig. 4. Number of eruptions per annum of Sakurajima, 1955 - 1988.

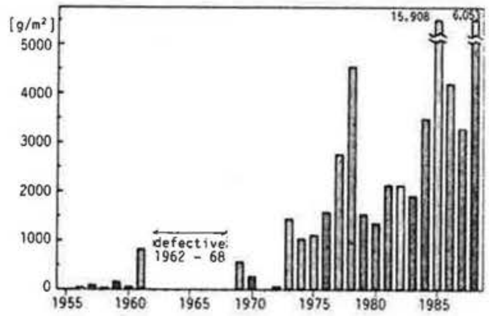


Fig. 5. Annual amounts of ash fall over Kagoshima city, observed at Kagoshima Meteorological Observatory.

Fig. 6. Volcanic ash of 2671 g/m^2 in weight — the daily record — fell over Kagoshima city on June 16, 1988.

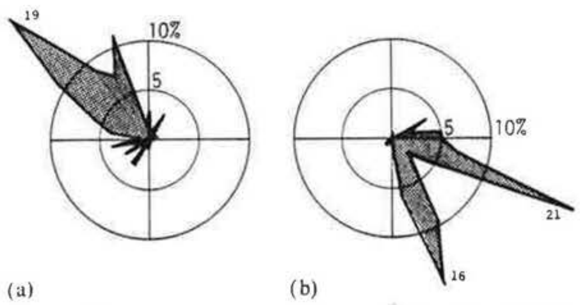


Fig. 7. Wind roses over Kagoshima city in 1985 (in standard isobaric surface of 850 mb). (a) January; (b) August.

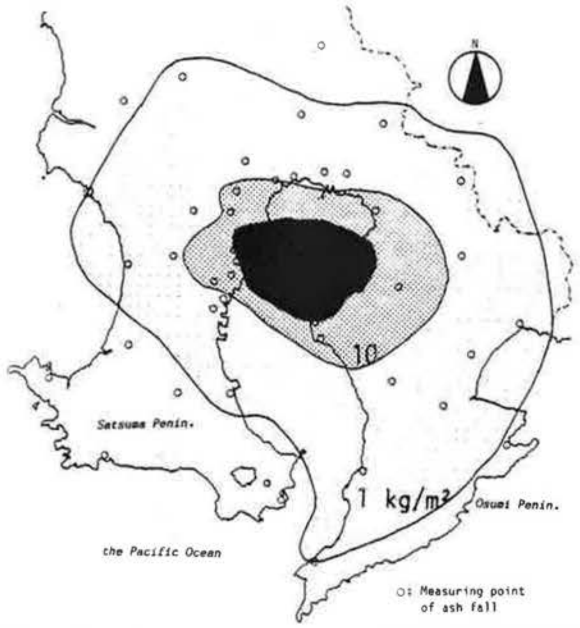


Fig. 8. Distributions of cumulative ash weights which fell over Kagoshima Prefecture from May 1979, to April 1988.

Fig. 8 in cumulative weight from May 1979 to April 1988.

2.3. *Ash effects on houses*

At the foot of Sakurajima island, there live more than 8500 people. Furthermore, the inhabitants of the land gravitate towards Kagoshima city, which has a population of 530 000.

Volcanic rocks as well as ash fall from the summit to the foot of Sakurajima island. Windows and roofs are sometimes broken. In 1986 a large extrusive rock, 2.5 m in diameter, hit an hotel at the bottom of Sakurajima. It destroyed the ceiling of the entrance hall of the hotel and fell through to the basement floor. (It is said that the floor slab was badly constructed.)

In Kagoshima city, about 10 km from the summit, no volcanic rocks fall, but damage due to ash falling is found in various places. People walk with umbrellas to keep the ash out of their faces and hair (Fig. 9). An eaves trough filled with the ash causes overflowing gutters (Fig. 10), walls are soiled (Fig. 11), and the ash also gets beneath the roof tiles (Fig. 12) and causes corrosion in materials.

The chemical composition of volcanic ash is about 60% of SiO_2, 15% of Al_2O_3, 7% of Fe_2O_3, etc. [7], with volcanic gas on the surface. The ash is acid, pH 3.5 - 7 [8, 9]. Due to

Fig. 9. A man walking with an umbrella to keep the ash out of his face and hair.

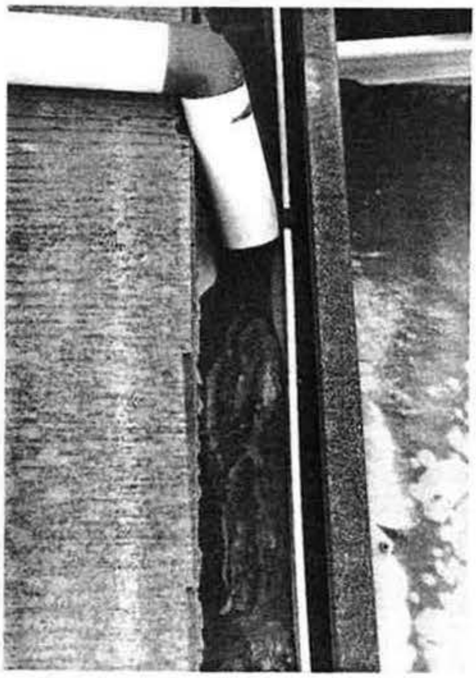


Fig. 10. An eaves trough filled with volcanic ash.

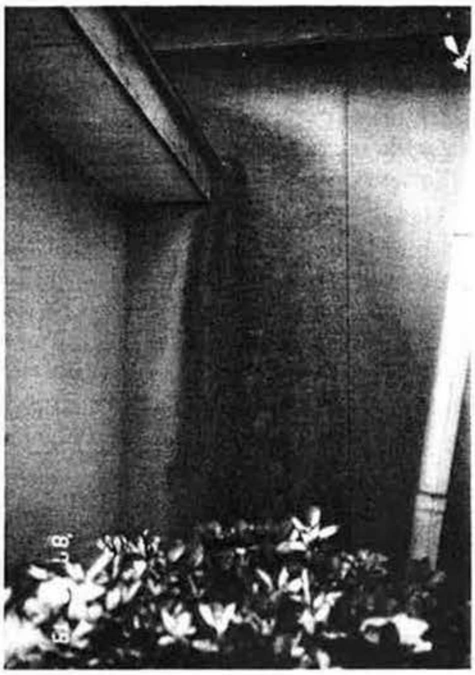


Fig. 11. A wall soiled with ash and rain.

Fig. 12. Ash of 13 172 g/m^2 in weight lying beneath roofing tiles (observed in Tarumizu city, 6.7 km from Sakurajima; house age = 24 years; roof pitch = 40/100; Japanese style of tile).

the ions of SO_4^{2-} and Cl^- in the soluble matter of volcanic gas, metals easily become rusty.

2.4. Prevention method

Because ash amounts have been increasing only in the past decade, preventive methods of ash for housing are not well developed. However, some preventive methods are found.

An open-air swimming pool in a school has a folding top (Fig. 13). Some eaves troughs were removed as in snow-falling regions, and the ash is gathered by ditches around the house. Scavenging cars sweep the ash off the roads (Fig. 14), but in private areas the ashes must be removed briskly by the occupants. Recently, municipal dwelling houses with ash-resistant devices were built and some projects are being planned.

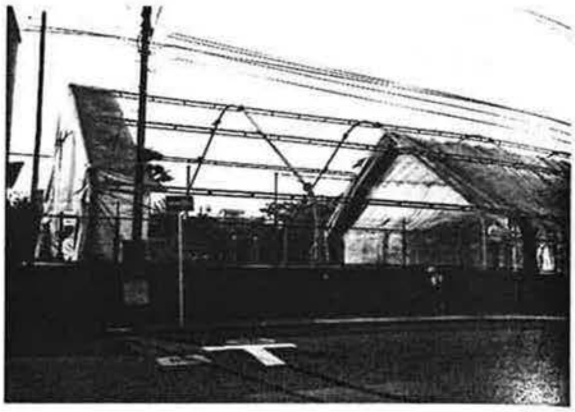


Fig. 13. A swimming pool with a folding top.

Fig. 14. A mini-scavenging car sweeping the ash off the road.

3. DEVELOPMENT OF AN ASH-RESISTANT VENTILATION SYSTEM

3.1. Fundamentals

A natural ventilation system against falling ash has been developed. Its components and the principle of ash removal are shown in Fig. 15. It consists of a body with several ventilation tunnel holes and an air filter, a screen (mesh), etc. A ventilating tunnel hole, 50 mm in diameter and 450 mm in length, is designed straight in order not to cause resistance to the air current.

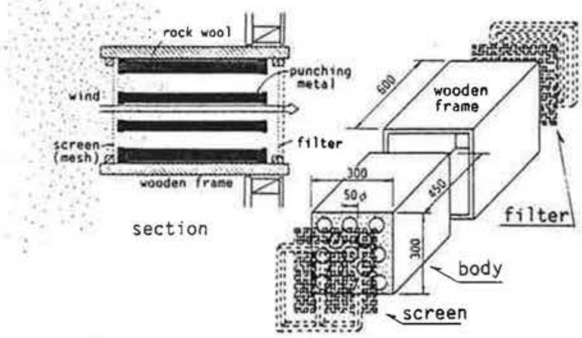


Fig. 15. Ash-resistant ventilation system.

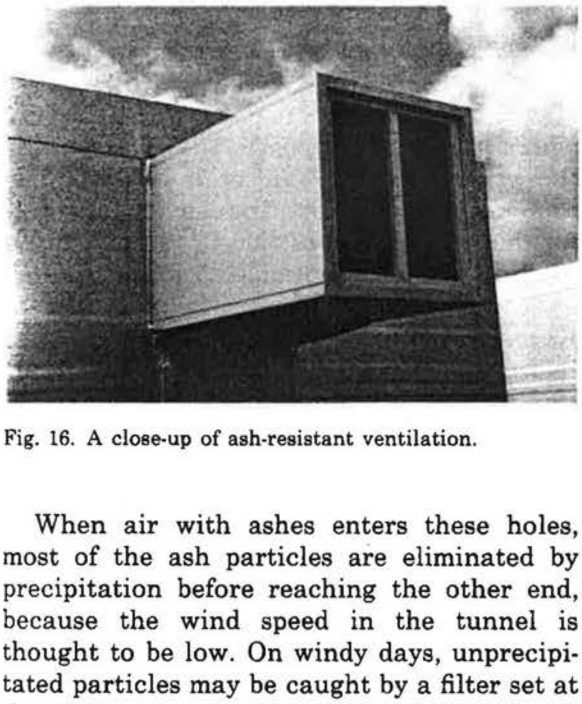


Fig. 16. A close-up of ash-resistant ventilation.

When air with ashes enters these holes, most of the ash particles are eliminated by precipitation before reaching the other end, because the wind speed in the tunnel is thought to be low. On windy days, unprecipitated particles may be caught by a filter set at the inner side. In this study, units with 13 holes were used (Fig. 16).

3.2. Ventilation tests

3.2.1. Outline of ventilation tests

Measurements of ventilation amounts of this ventilation system have two meanings: one means the actual performance of ventilation amount for this system and the other is to act as a "control" ventilation unit for the following ash exposure tests. To accomplish these aims, two house models, each a 1.5 m cube, were used (Fig. 17). One model (model A) was installed with two ash-resistant ventilation units on the facing walls, and the other (model B) had two simple holes, the sizes of which were adjustable.

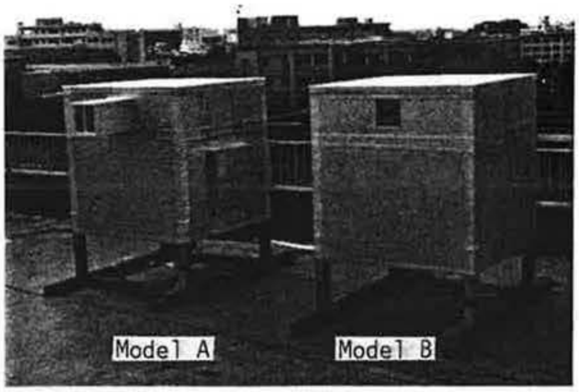


Fig. 17. Cubic room models used in the experiments. The left model (A) is set with the ash-resistant ventilation units and right one (B) with simple holes. These two are equal in ventilation capacity.

The measurements of ventilation amounts were carried out on the rooftop of Kagoshima University, by means of a CO_2 tracer-gas technique. The CO_2 concentrations for the ash-resistant units were measured at three points in a vertical or five in a horizontal plane. An example of the results is shown in Fig. 18(a). The values do not vary around each point, and the center point takes almost an average value of all points. Next, to standardize the condition for ash exposure tests, the ventilation amounts for the two models were measured simultaneously at the central points (Fig. 18(b)). If a difference in these two values arose, the sizes of the simple holes were changed, and tests were repeated until they became almost the same.

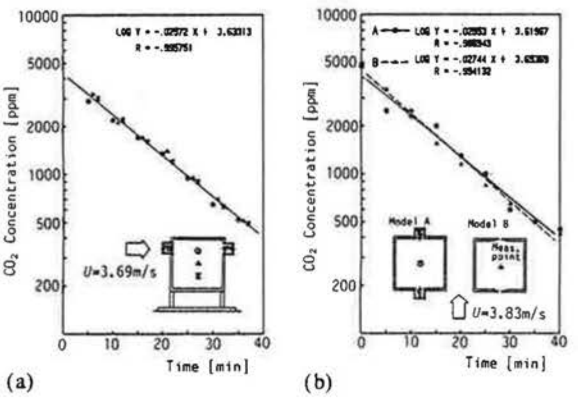


Fig. 18. An example of ventilation tests, by means of a CO_2 tracer-gas technique. (a) Measurements of model A at points in a vertical plane. (b) Simultaneous measurements of models A and B.

Two options existed for the operation of the ash-resistant ventilation: one is the case with a filter, and the other without the filter.

3.2.2. Test results of ventilation

Ventilation amounts are calculated by the decay of carbon dioxide concentrations:

$$Q = 2.303 \times (V/t) \times \log(C_i - C_o)/(C_t - C_o)$$

where Q = ventilation amount (m^3/h), V = volume of model (m^3), t = elapsed time (h), C_i = initial concentration of CO_2, C_t = concentration at time t, and C_o = concentration of outside air.

The results of ventilation amounts are shown in Tables 1 and 2. They are also illustrated in Fig. 19 as a function of outside wind speed. The values of this ventilation system are expressed regressively as follows:

$$Q = 22.1 \times U \quad \text{without a filter,}$$

$$= 2.67 \times U \quad \text{with a filter.}$$

TABLE 1

Amount of ventilation in the case without a filter

Exp. no.	Ventilation amount		Ratio Q_B/Q_A	Wind speed (m/s)
	Model A Q_A (m^3/h)	Model B Q_B (m^3/h)		
1	11.90	12.80	1.08	3.83
2	13.84	13.00	0.94	4.38
7	7.70	8.62	1.12	3.10
8	7.24	7.14	0.99	3.02
9	7.70	8.16	1.06	2.71
10	5.13	5.81	1.13	2.29

Average of $Q_B/Q_A = 1.05$

TABLE 2

Amount of ventilation in the case with a filter

Exp. no.	Ventilation amount		Ratio Q_B/Q_A	Wind speed (m/s)
	Model A Q_A (m^3/h)	Model B Q_B (m^3/h)		
201	44.62	40.57	0.91	1.98
202	40.71	44.72	1.10	1.92
203	65.99	60.71	0.92	2.78
205	37.20	40.81	1.10	2.23
206	58.08	65.99	1.14	2.22
207	54.10	58.47	1.08	2.41

Average of $Q_B/Q_A = 1.04$

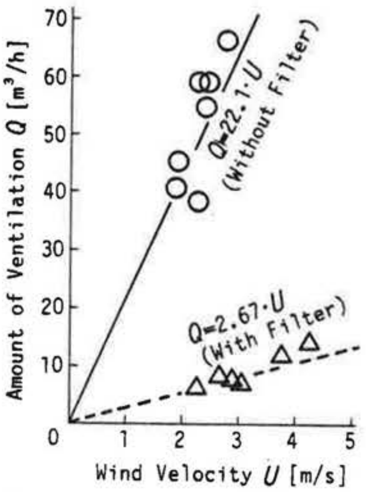


Fig. 19. Ventilation amount as a function of wind speed.

where U = wind speed (m/s). The result in the condition with a filter is about 1/8 of that without a filter. The air change rate for this cubic model of side 1.5 m (3.375 m^3) is 20.0 ach without filter, and 2.5 ach with filter, at 3.2 m/s annual average wind speed in Kagoshima.

To satisfy the conditions for the ash exposure tests, the ventilation amounts with these two models must be equal in quantity. These two are approximately equal with errors between 4 - 5% as shown in Tables 1 and 2. The hole size of 152 mm × 152 mm corresponds to the non-filtered condition and 56 mm × 56 mm to the filtered condition.

3.3. *Efficiency of ash resistance*

3.3.1. Outlines of exposure tests

Exposure tests were executed to examine the ash-resistant effect. The room model with ash-resistant ventilation units and one with simple holes were exposed to the natural ash falling on the roof of Kagoshima University which is situated about 10 km from the summit of the volcano.

The units with 13 tunnel holes were used. The ventilation units were "without filter" (ventilation body only), and "with filter". Test terms were 71 days (without filter) and 50 days (with filter). Data of falling ash amounts and outside wind speeds are shown in Fig. 20 and Fig. 21 respectively. Cumulative ash weights in the test terms were 666 g/m^2 and 1207 g/m^2, and averaged wind speeds were 2.34 m/s and 2.80 m/s, respectively.

3.3.2. Test results of exposure

The models were exposed for durations of 71 or 50 days. Examples of the floors on which the volcanic ash lies are shown in Fig. 22, in the case without the filter. The gathered ash was measured after dried. Volcanic ash which lay on the model floor, 1.5 m × 1.5 m, was 13.8 g in the case of the ash-resistant ventilation unit without the filter and 52.0 g in the unit with the simple holes, which is converted to 6.1 g/m^2 and 23.1 g/m^2, respectively, as shown in Table 3. Thus, the effect of ash resistance is to reduce the problem to about 1/4 for this ventilation system. In the exposure with the filter, values are expressed in particle number, gathered by 5 glass dishes on the floor (Table 3). Those totals are 132 with ash-resistant units and 457 with simple holes. Also

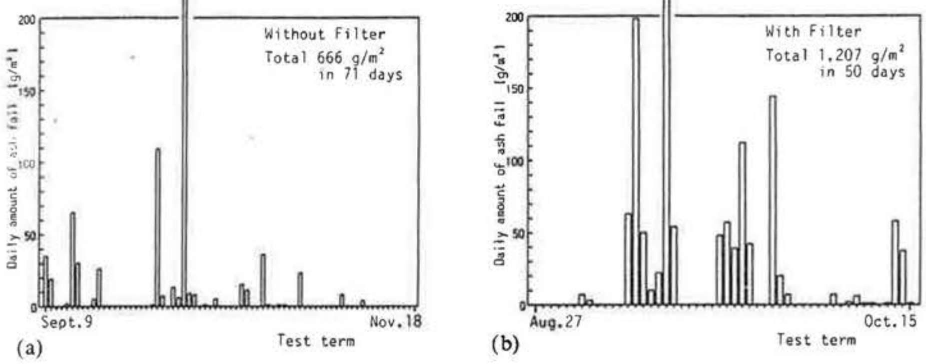


Fig. 20. Daily amounts of ash falling in the exposure period. (a) Without filter. (b) With filter.

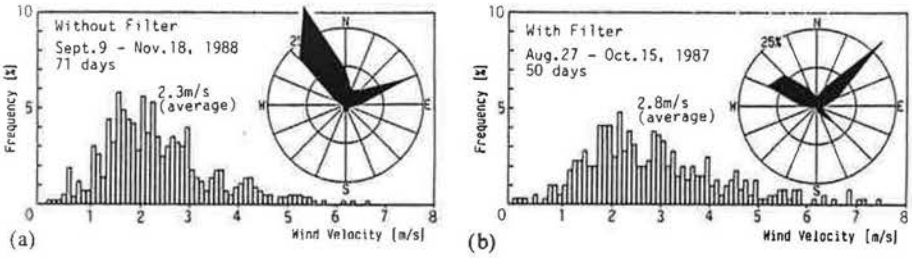
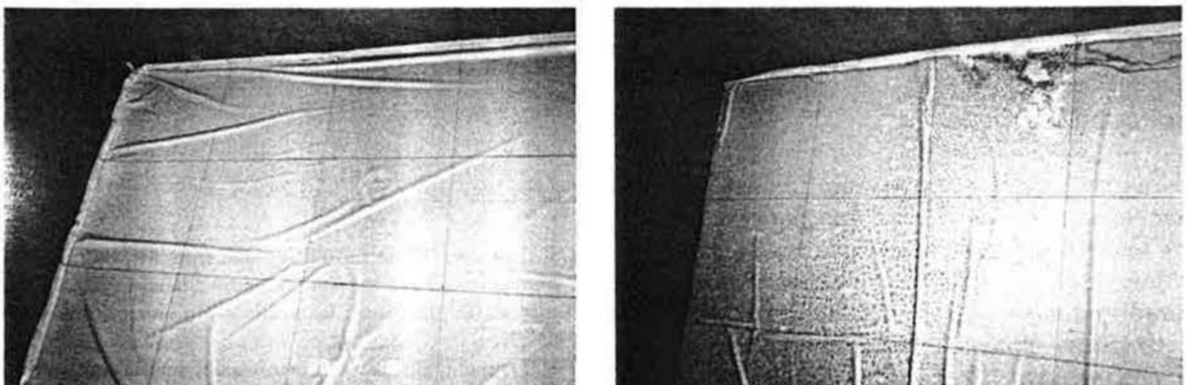


Fig. 21. Frequency histograms of wind speed in the exposure term (a) Without filter. (b) With filter.

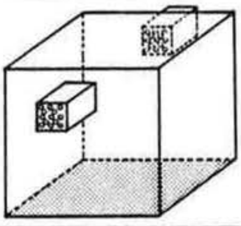
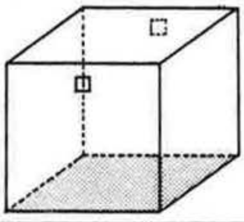
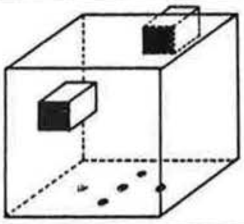
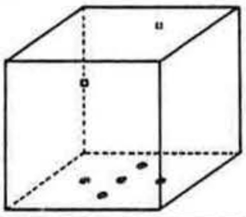


(a) (b)

Fig. 22. The volcanic ash lying in the room model (one grid: 300 mm by 300 mm) (a) Model A (without filter). (b) Model B.

TABLE 3

Results of ash exposure tests

Conditions	Model A *Ash resistant ventilation*	Model B *Simple hole*
Without Filter *Size of a simple hole: 152mmx152mm* *Number of air change rate at 1m/s: 6.1/h* *Test term: 71 days Sept.9-Nov.18, 1988* *Cumulative ash amount: 666 g/m²*		
Ash weight entered inside	6.1 g/m^2	23.1 g/m^2
With Filter *Size of a simple hole: 56mmx56mm* *Number of air change rate at 1m/s: 0.8/h* *Test term: 50 days Aug.27-Oct.15, 1987* *Cumulative ash amount: 1,207 g/m²*		
Number of ash particles	132	457

in the case with the filter, the ash-resistant effect is to reduce the problem to about 1/3 - 1/4 of its previous magnitude.

From the results mentioned above, this ash-resistant ventilation system is proved to be effective for ash resistance.

4. CONCLUSIONS

A natural ventilation system for ash resistance was developed, and its performances were tested experimentally. As a result of ventilation tests, the ventilation amount for this filtered system is $2.67 \times U$ (U is outside wind speed). From exposure tests, the quantity of ash getting into the room is about 1/4 compared to the simple hole condition of the same ventilation amount. This developed ventilation system proved to be effective for ash resistance.

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