# Effect of ventilation on mould growth in a Japanese bathroom

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## ABSTRACT
This paper investigates the effect of ventilation on mould growth in a typical Japanese bathroom by use of the fungal index which indicates the growth rate of a mould, *Alternaria alternata* S-78. The bathroom was set in an artificial climate where the temperature and relative humidity (RH) were kept constant. The temperature, RH and fungal index in the bathroom were measured under several ventilation methods after taking a bath. The results showed that it is extremely effective to ventilate mechanically in order to decrease the mould growth rate and also useful to ventilate with circulation of heated air and exhaust (drying and exhaust) in order to dry the bathroom near the floor. Experimental data indicated that ventilation with drying and exhaust after taking a bath has a great influence on the control of mould growth and has twice the control effect as with only exhaust.

## INDEX TERMS
Fungi; Microbial growth, Humidity, Mechanical ventilation, Test room

## INTRODUCTION
Mould contamination is considered to be an IAQ problem. Mould causes problems to human health and damages buildings. As mould propagates actively in an atmosphere of high relative humidity, it is very effective to control the humidity to avoid mould growth. In Japan, the humidity is high not only in the rainy season but also in summer. Japanese investigations in apartment houses, that had ventilation fans, described that the mould growth rate in bathrooms was high and that mould growth in winter was found in the bathrooms because of large amounts of vapour generation. It is therefore important to pay attention to the humidity.

When designing a ventilation system for controlling mould growth in bathrooms, the relation between mould growth and behaviour of vapour must be understood. However, few detailed studies have been done. Although ventilation is one of the easier and more effective methods to control the humidity in bathrooms for suppression of mould growth, previous proposals for proper ventilation were inadequate.

To examine the effect of ventilation on mould growth, in this study mould growth, temperature and humidity in a ventilated Japanese style bathroom were simulated and analyzed experimentally by using fungal detectors that were put on the surfaces of the bathroom.

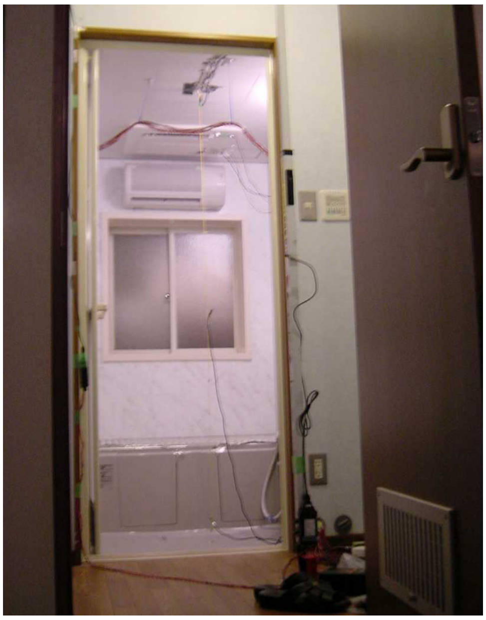


**Photo 1** Test bathroom.

## METHODS
### Test Bathroom and Process of Taking a Bath
Photo 1 shows the inside of the test bathroom, which is a typical Japanese one. The size of the bathroom is 1150 mm × 1600 mm × 2000 mm and the width of the tub is 780 mm. The walls of the bathroom have a structure consist of plastic board with no moisture absorption, air layer and heat insulator. The test bathroom was set in an artificial climate where the temperature and RH were kept constant (temperature, 20°C; RH, 50%). Simulating

typical Japanese bathing, two behaviours corresponding to high humidity were reproduced: opening the cover under which heated water of 40°C is filled and showering the surface of the water in the tub from a height of 600 mm above at an angle of 45° for 6 min, and spraying the ceiling for 1 min with water of 40°C and 12 l/min. The total period of taking a bath is 20 min and in this experiment the number of persons who took a bath is three.

### Ventilation Mode and Details

Two type of ventilation unit which had two modes (exhaust, drying and exhaust by heat coil) were set on the wall above the window and on the ceiling. The heated air is produced from the return air to the unit and blown at the flow volume of 336 $m^3$/h at 45° to the floor. The exhaust air flow rate is 90 $m^3$/h. The air flows into the bathroom through the slit below the entrance door.

### Fungal Detectors

The film on which two kinds of spores (*Alternaria alternate* S-78, *Eurotium herbariorum* J-183) and a nutriment were adhered was covered by another gas-permeable transparent film and fixed in a slide to prevent the scattering of spores into the environment during growing. This specimen is designated as the fungal detector. The fungal index, which is determined from the growth response of the sensor in a given environment for 7 days, represents the capacity of the environment to allow the growth of fungus as a biosensor. The response represents the growth of the sensor in the standard climate (temperature, 25°C; RH, 93.6%). At 7 days, the hypha length in the tested environment corresponded to the hypha length at *X* hours in the standard curve, and the fungal index is defined as *X*.

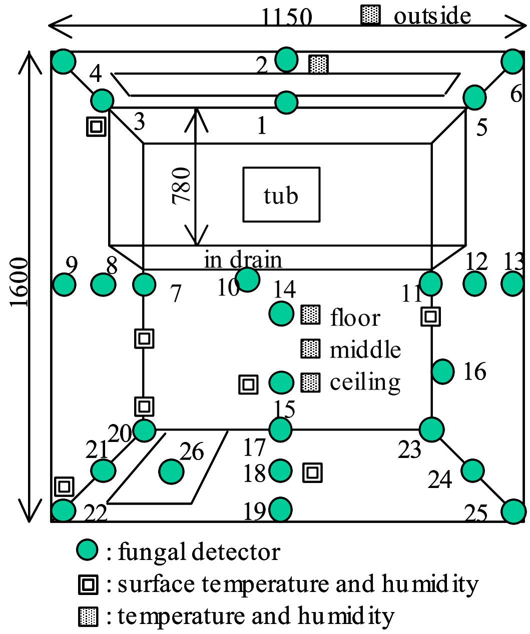



**Figure 1** Schematic of the test bathroom and sensor positions.

### Measurement of Fungal Index and Indoor Environment (Temperature and RH)

Figure 1 shows the plane of the test bathroom. To obtain measurements, 26 fungal detectors were used in a bathroom for one experiment. The temperature and humidity sensors were connected to a logger and the data was recorded automatically on a PC.

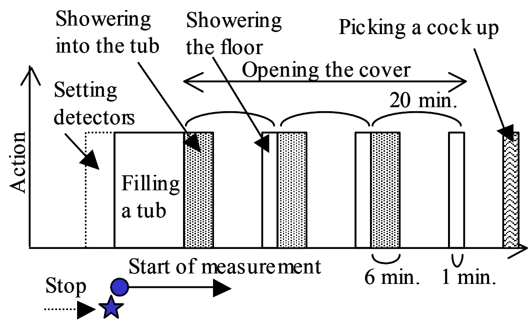



**Figure 2** Experiment procedure.

### Experimental Procedure and Measured Cases

Figure 2 shows the experimental procedure. Just before starting the experiment, all the fungal detectors were put in position on the surfaces. The cover was opened throughout taking a bath for an hour. Table 1 shows the measured cases. The entrance door and window of the bathroom were closed in Cases 1–7.

## RESULTS AND DISCUSSION

### Distribution of Mould Growth in Bathroom

Table 2 shows the distributions of fungal index (S-78) in Cases 1, 2 and 4. In Case 1, the average value near the floor was almost the same as that near the ceiling and because the growth rate was large, there was a large difference between the maximum and minimum. In Case 2, the average value near the floor was 1.7 times that near the ceiling. On the other hand, in Case 4 the average value near the floor was almost the same as that near the ceiling, and was a small value. The

**Table 1** Measured cases.

| Case | Ventilation type | Ventilation mode | Operation time [hours] | Duration of measurement |
|---|---|---|---|---|
| Case 1 | - | NOT | - | 2 |
| Case 2 | Wall | Exhaust | 2 | 4 |
| Case 3 | ↑ | ↑ | 8 | 4 |
| Case 4 | ↑ | Drying & exhaust | 2 | 4 |
| Case 5 | Ceiling | Drying & exhaust | 2 | 2 |
| Case 6 | ↑ | ↑ | 2 | 4 |
| Case 7 | - | Window is opened | 2 | 2 |
| Case 8 | - | NOT | - | 8 hours (only showering) |

difference between the maximum and minimum was least among the three cases and it was possible to say that all the indexes were the same. Figure 3 shows the experimental error of fungal index for two measurements in Case 6. As the number of measuring position showed little difference in fungal index at the same position, it was considered that the experimental error was small. The fungal index for J-183 was not found except for Cases 1 and 7 because humidity was very high. Therefore, the results by use of S-78 were used as fungal index in this study.

**Table 2** Distributions of fungal index

| | Average near the floor | Average near the ceiling | Maximum | Minimum |
|---|---|---|---|---|
| Case 1 | 210.3 | 224.1 | 260 | 170 |
| Case 2 | 26.7 | 15.3 | 65 | 12 |
| Case 4 | 13.2 | 12.9 | 14 | 12 |

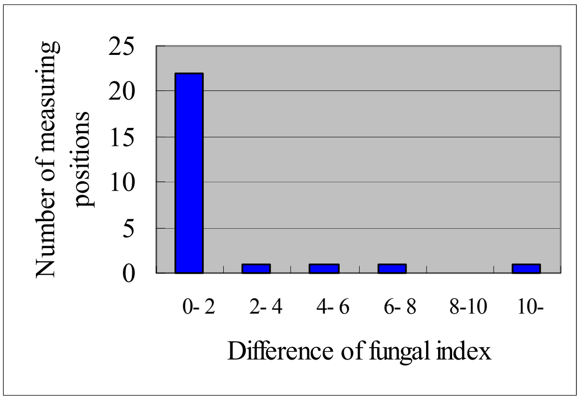


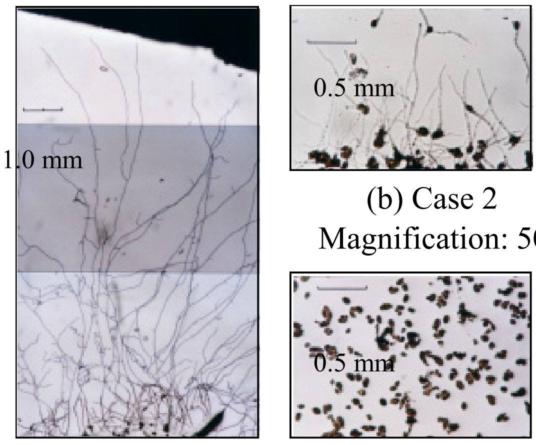

**Figure 3** Experimental error of fungal index for two measurements in Case 6

## Effect of Ventilation on Mould Growth

Photo 2 shows the photos at the same position (No. 17) after finishing the measurement. The magnification in Case 1 is 20 and in Case 2 and Case 4 is 50. The average fungal indexes were respectively 223, 19 and 13. The value of the index in Case 2 was about 10% that of Cases 1 and 4 was about 70%. Thus, in the case of exhaust ventilation, the fungal index becomes extremely small, about one-tenth, and furthermore in the case of drying and exhaust, the index becomes small and the ventilation is effective for mould control.

Figure 4 compares the average fungal index between Case 2 and Case 4. Adding the circulation with heated air, all the indexes near the floor in particular became small and the average fungal index near the floor was half the value of that in Case 2.

Figure 5 shows the effect of ventilation operation time and opening the window on mould growth in Cases 2, 3 and 7. As the decrease in Cases 2 and 3 was very little, ventilation operation time exceeding 2 h




(a) Case 1
Magnification: 20

(b) Case 2
Magnification: 50

(a) Case 4
Magnification: 50

**Photo 2** Comparison of mould growth.

has little effect on controlling the mould growth and is not effective. On the other hand, as the average value of fungal index became large in Case 7, ventilation by opening the window has little effect on controlling mould growth and mechanical ventilation is necessary. This is the reason why ventilation with the window open has a small driving force only upon finishing taking a bath, as the ventilation rate is small compared with mechanical ventilation. Furthermore, as in this experiment the entrance door was always closed, the ventilation rate was low.

In Case 6, the average fungal index was 14.1 and in Case 5, no growth was found. This indicates that mould growth did not occur for 2 days due to drying and good exhaust of humidity.

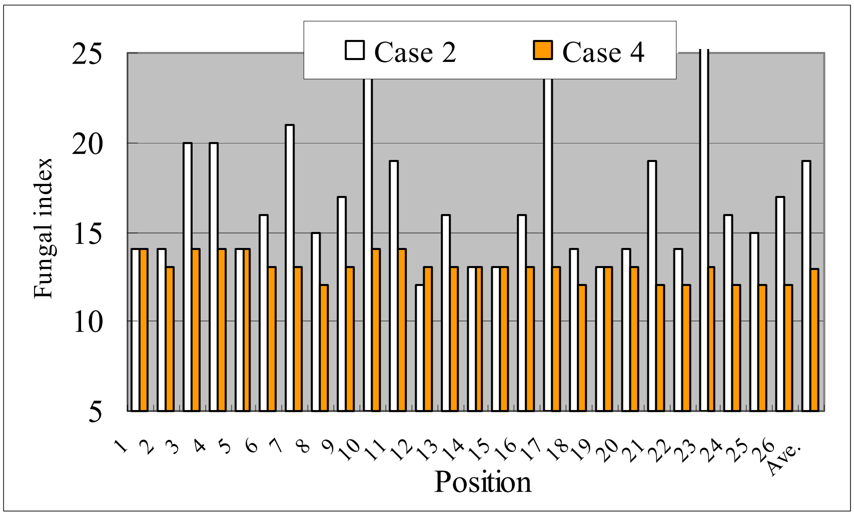



**Figure 4** Effect of ventilation with drying on controlling mold growth.

**Relationship between Mould Growth and Indoor Environment**

Figure 6 shows the temperature and relative humidity at the same position (No. 17) in a day in Cases 1, 2 and 4. In Case 1, as there was no ventilation, the relative humidity remained high at almost RH 100% throughout this day and condensation remained on the floor and the inside walls. In Case 2, the humidity was exhausted little by little with RH 100% and after 1 h of ventilation the absolute humidity became small with temperature constant. On the other hand, in Case 4 after taking a bath, the temperature rose due to the heated circulation air and the RH gradually reduced. There was a large difference of accumulation time during high relative humidity.

Figure 7 shows the relationship between accumulation of time over RH 70% and fungal index in Cases 2 and 4 at the same position (No. 11, near the floor below the table). It is found that there is a correlation between the fungal index and the accumulated time over RH 70%. Therefore, it is important to exhaust the humidity for controlling the mould growth.

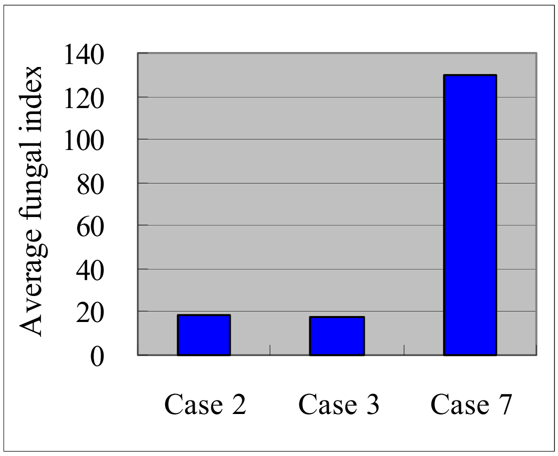



**Figure 5** Effect of ventilation operation time and opening the window on mold growth.

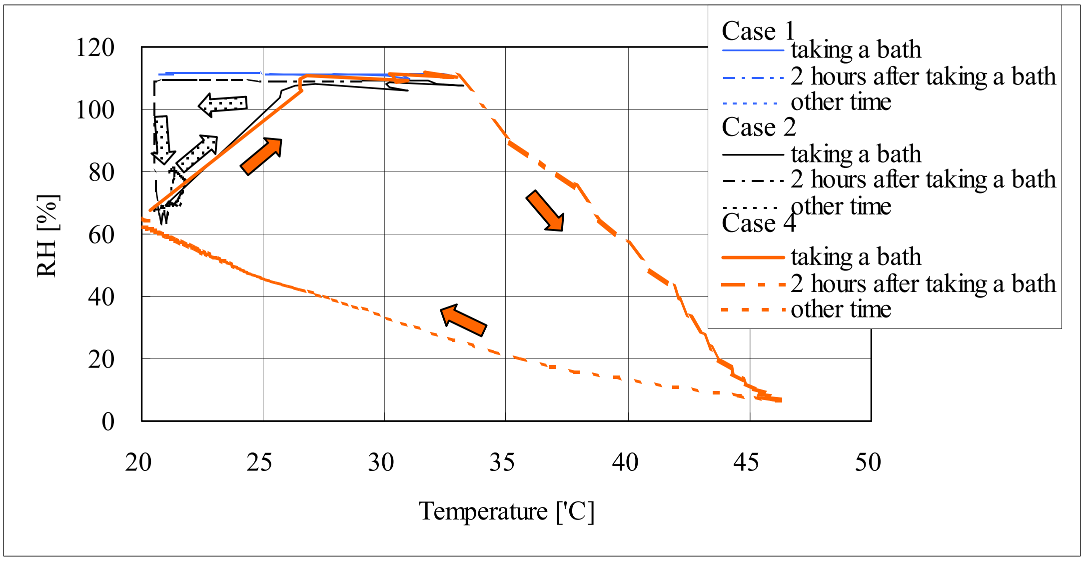



Figure 6. Comparison of temperature and RH during the day with different ventilation methods

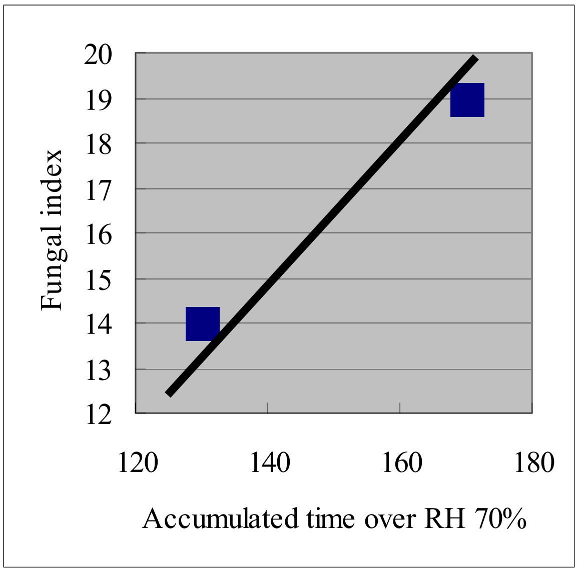



**Figure 7** Relationship between accumulated time over RH 70% and fungal index.

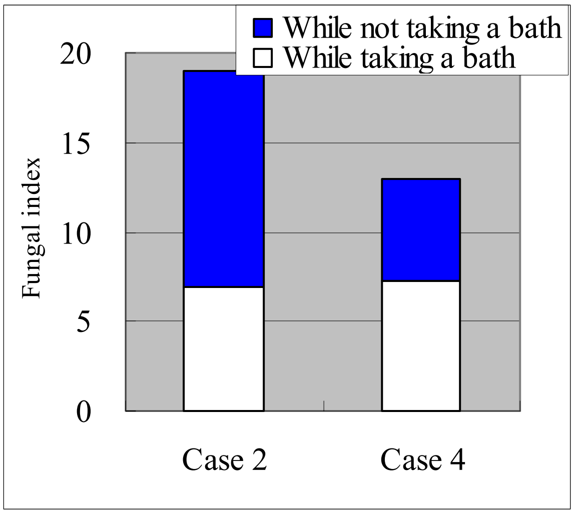



**Figure 8** Effect of drying and exhaust after taking a bath on controlling mould growth.

**Effect of Indoor Environment after Taking a Bath on Controlling Mould Growth**

Though a large amount of vapour was generated, mould grows while taking a bath. By estimating the fungal index while taking a bath (Case 8), the ratio of fungal index while taking a bath to that at other times can be found.

Figure 8 shows the effect of drying and exhaust after taking a bath on controlling mould growth. It was found that the average fungal index while taking a bath was about 7.0 and the ventilation by using both drying and exhaust reduces the fungal index to about 1 s and is effective for controlling the mould growth during times except for while taking a bath.

## CONCLUSIONS

To examine the effect of ventilation on mould growth and vapour distribution in a ventilated bathroom in which the Japanese bathing style was simulated were analysed experimentally by using of fungal detectors that were put on the surfaces of the bathroom. The results were as follows:

(1) In the case of exhaust, the fungal index near the floor was 1.7 times higher than that near the ceiling. By using both drying and exhaust at the same time, the distribution of mould growth in the bathroom became small.
(2) In the case of exhaust, the fungal index became extremely small, about one-tenth to that without ventilation. Furthermore, in the case of drying and exhaust the fungal index became small, 30% lower.
(3) The experimental data for the case of exhaust and drying and exhaust revealed a correlation between the accumulated time over RH 70% and the fungal index.
(4) Estimation of the growth while taking a typical Japanese bath indicates that ventilation by using of both exhaust and drying reduces the fungal index to about 1 s and is effective for controlling the mould growth.

Further examination is necessary for investigating various conditions such as ventilation rate, operation time, outdoor environment and so on. Proposals for energy-efficient ventilation are also desirable.

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