INVESTIGATION OF ACTUAL HUMIDITY CONDITIONS IN HOUSES AND EVALUATION OF INDOOR ENVIRONMENT BY FUNGAL INDEX

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ABSTRACT

The characteristics of climate in Japan are hot and humid in summer, with cold and dry winter. For this reason, mold growing in rooms is common during summer period. On the other hand, in winter, due to space heating, indoor environment is over-dry as a result of low humidity. This situation is particularly distinctive in the well-insulated and air-tightened houses.

The aim of this study was to understand the current indoor humidity environmental conditions by the means of long-term measurement data for obtaining the fundamental information to evaluate the measures to mitigate the dry or humid indoor environment. In addition, the conditions of fungal contamination influenced by indoor environment were predicted.

A detailed long-term field measurement program on energy consumption and indoor thermal environment was carried out in 2003, for 80 dwellings (including detached houses and apartments) in six regions of Japan. The data obtained from the field measurement were analyzed and the results based on indoor humidity distribution were reported in this paper.

KEYWORDS

Indoor humidity environment, Indoor temperature, Indoor humidity, Fungal contamination, Fungal index

INTRODUCTION

The characteristics of climate in Japan are hot and humid in summer, with cold and dry winter. For this reason, mold growing in rooms is common during summer period. On the other hand, in winter, due to space heating, indoor environment is over-dry as a result of low humidity. This situation is particularly distinctive in the well-insulated and air-tightened houses.

The objective of this study was thus to understand the current indoor humidity environmental conditions by the means of long-term measurement data for obtaining the fundamental information to evaluate the measures to mitigate the dry or humid indoor environment. In addition, the conditions of fungal contamination influenced by indoor environment were predicted.

In order to obtain the fundamental information of residential energy saving strategies, a detailed long-term field measurement program on energy consumption and indoor thermal environment had

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been carried out in 2003 for 80 dwellings, including detached houses and apartments, over six regions of Japan, i.e. Hokkaido, Tohoku, Hokuriku, Kanto, Kansai, Kyushu (including Okinawa) [Note 1]. Further to this investigation, detailed study on residential attribution and energy consumption has been carried out by the current authors and parts of the results have been reported previously by Murakami et al. (2005, 2006a, 2006b). In this current paper, based on the data from the said study, humidity environment in the living rooms of 72 houses (some are air-conditioning rooms), including 51 detached houses and 21 apartments, in six regions of Japan were analyzed.

MEASUREMENT

Outline of the houses

72 households distributed in six regions (from north to south: Hokkaido, Tohoku, Hokuriku, Kanto, Kansai, Kyushu) of Japan were investigated. In each region, 6~9 detached houses and 3~4 apartments were included, cf. Table 1. Most of the houses are newly constructed with well insulated and airtightened. Some of these houses were using moisture control equipments such as humidifier, dehumidifier, portable heater which generates vapor, air-conditioner, etc.

Items of measurement

Temperature and relative humidity were measured in each house’s living room by using small sensors and data loggers with an interval of 15 minutes (10 minutes in Hokkaido).

Table 1 Descriptions of investigated houses

<table>
<thead>
<tr>
<th>No</th>
<th>House Location</th>
<th>Completions</th>
<th>Floor area (m2)</th>
<th>Equiv. Leakage area (cm²/m²)</th>
<th>Heat loss coefficient (W/m²/K)</th>
<th>Heat loss (W)</th>
<th>Number of occupants</th>
<th>Construction</th>
<th>Heat loss (W)</th>
<th>Number of occupants</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Hokkaido</td>
<td>1989</td>
<td>120.0</td>
<td>0.70</td>
<td>20.1</td>
<td>85.3</td>
<td>2</td>
<td>Wood 2</td>
<td>185.9</td>
<td>0.35</td>
</tr>
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<td>Wood 2</td>
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</table>

RESULTS

Temperature and humidity of living room in winter season

Figure 1 shows the measurement results with statistical values (average, standard deviation, maximum and minimum) of the living rooms in 72 houses for winter season (Jan. and Feb.) in the order of relative humidity from high to low.

- **Indoor temperature** In Hokkaido region, the temperatures of living rooms were stable and the temperature variation among the investigated houses was small. The maximum mean temperature was approximately 22°C. On the other hand, the temperatures in the other five regions were unstable and
the temperature variation among those houses was large. It can be seen that the maximum mean temperature values varied from northern region to southern region. The maximum mean temperature in Kansai region was 16°C and it was the smallest value among the other regions.

- **Relative humidity** In Hokkaido, Tohoku and Hokuriku regions, nearly 40 percent of the investigated houses were in dry indoor condition with average relative humidity below 40%. The lowest relative humidity was 31% found in Tohoku region (House Tohoku D01). On the other hand, average relative humidity over 60% was found in Houses Kanto A02 and Kansai D04, D07 and A04. In Hokkaido, indoor relative humidity was generally stable, but it was unstable in Kansai and Kyushu.

- **Absolute humidity** Indoor absolute humidity ranged from 4g/kg' to 10g/kg'. The overall mean value in Hokkaido was the highest with 7.05g/kg' while the lowest value was found in Kansai with 5.96g/kg'. In the houses of Hokkaido, both absolute humidity and temperature were high, and hence caused a low relative humidity situation. In contrast to northern region, the absolute humidity and temperature of the houses in Kansai were low, which leads to high relative humidity.

- **Absolute humidity difference between indoor and outdoor** Absolute humidity difference between indoor and outdoor in Hokkaido and Tohoku regions was larger than those in other regions. Outdoor temperature and relative humidity data were sourced from the Japan Meteorological Agency. It can be inferred that the houses of Hokkaido and Tohoku are well airtight. In some houses i.e. Hokkaido A03, Hokuriku A01 and Kanto A02, were either using portable heater or humidifier, hence the differences were obviously bigger.

![Figure 1. Results of temperature and humidity in each house in winter](image)

- **Changes of temperature and humidity in living room** Low relative humidity houses (Tohoku D01, Kanto D07) and high relative humidity houses (Kanto A02, Kansai D04) were taken as examples for discussion. The changes of temperature and humidity of these 4 houses in a week in winter are showed in Figure 2. In Tohoku D01, relative humidity was found mostly below 30% in this one week period, because temperature remained high at 24°C due to heating equipment. In Kanto D07, the temperature varied largely under the operating of heating equipment, as a result relative humidity altered from 30% to 45%. The indoor environment of this house was in dry condition as the absolute humidity was generally low. On the other hand, low temperature in Kansai D04 and high absolute humidity in Kanto A02 were the causes of high relative humidity.

**Temperature and humidity of living room in summer season**

Figure 3 shows the measurement results with statistical values (average, standard deviation, maximum and minimum) of the living rooms in 72 houses during summer (Jul. and Aug.).

- **Indoor temperature** In Hokkaido and Tohoku regions, indoor temperatures were around 25°C.
In Kanto, Kansai and Kyushu regions, indoor temperatures were generally high, between 27~28°C, and there was one house (Kansai D02) with average temperatures over 30°C.

- **Relative humidity** In Hokkaido, the mean relative humidity value of the houses was about 60%, while in other regions the mean values ranged from 65% to 68%. It was also found that a quarter of the houses in these regions (except Hokkaido) were over 70%.

- **Absolute humidity** Indoor absolute humidity changed from 10g/kg to 16g/kg. In Hokkaido, indoor absolute humidity was generally low while it was relatively high in Kyushu.

- **Absolute humidity difference between indoor and outdoor** In Hokkaido, Tohoku and Kanto, the indoor absolute humidity was generally higher than the outdoor. On the other hand, in Kansai and Kyushu, the indoor absolute humidity was lower than the outdoor as a whole. That was due to the use of cooling equipment. There were 6 houses out of the 72 investigated houses using dehumidification equipment. However, the reduction of indoor absolute humidity in these 6 houses was not observed.

- **Changes in temperature and humidity in living room** Two houses with low relative humidity (Kansai A01 and D02) and two with high relative humidity (Hokuriku D06, Kyushu D05) were taken as examples for discussion. The changes of temperature and humidity in a week in summer are shown in Figure 4. In each house, temperature exceeded 30°C during daytime. In Kansai A01 and D02 where relative humidity was low, the absolute humidity dropped dramatically. The reason may be due to long time operation of cooling system. In Hokuriku D06 and Kyushu D05, because the absolute humidity was high and temperature was low, the relative humidity was found as high as 80%.
Correlation between the level of thermal insulation (air-tightness) and humidity

Figure 5 shows the correlation between average relative humidity and heat loss coefficient in winter and summer seasons. Figure 6 shows the correlation between average relative humidity and equivalent leakage area in winter and summer seasons. Many occupants from the houses with high insulation and air-tightness complained that the indoor air of the houses was too dry in winter. Indeed, some of the houses in which heat loss coefficient were below 2W/m²K or equivalent leakage area was below 1cm²/m², the relative humidity dropped below 40%.

Figure 7 shows the correlation between indoor and outdoor absolute humidity differences and heat loss coefficient in winter and summer seasons, while Figure 8 shows the correlation between indoor and outdoor absolute humidity differences and equivalent leakage area. In the case of winter mode (cf. Figure 7), the less the heat loss coefficient was, the larger the difference of absolute humidity between indoor and outdoor was. In the houses where equivalent leakage areas were small, the difference of absolute humidity increased largely. The reason could be inferred that ventilation rate was small in air-tightened houses.

Prediction of indoor fungal contamination

Fungal index is a biological climate-parameter, which expresses the fungal response unit (ru/week, which was proposed as a measure of the fungal growth response) during the exposure period (week) at a certain temperature and relative humidity (Abe 2006). Fungal index represents the environmental capacity to allow fungal growth. Using fungal index, the possibility of fungal contamination can be evaluated (Abe 1993). In this work, the temperature and relative humidity in the living room of the 72 investigated houses were distilled by an interval of one hour, in order to calculate the fungal indices. As an example, Figure 9 shows the variation of fungal indices in year 2003 of House Kansai D04. It can be seen that the fungal indices are high. The period with high fungal indices was from June to September. There is high possibility of the occurrence of fungal contamination when the fungal index was above 3ru/week (Abe 2001). Figure 10 shows the cumulative time of 72 houses when fungal indices exceeded 3ru/week. In Hokkaido, the cumulative time was short in a range of 0 to 328 hours. On the other hand, in Kansai and Kyushu, the cumulative time of most houses was long with over 1000 hours.
In Tohoku region, a questionnaire survey on fungal contamination was carried out for Houses Tohoku A01, A03, D01, D03, D06 and D08. The results showed that fungal was found in the living rooms of Tohoku A01, A03 and D06. In Houses of Tohoku D01 and D03, fungal was also found in many other places besides living room. However, fungal was not found in the living room of Tohoku D08 because many plants were laid there.

CONCLUSIONS
The conclusions of this study can be drawn as follows:
1. In winter season, about 40% of the investigated houses in Hokkaido, Tohoku and Hokuriku regions were under dry condition, with average relative humidity below 40%. Fluctuations of indoor temperature and humidity were found small in Hokkaido, while in Kansai and Kyushu, the fluctuations were large.
2. In summer season, the average relative humidity was above 70% in a quarter of the total houses, except those in Hokkaido.
3. Highly insulated and air-tightened houses tend to have high absolute humidity but in dry condition during winter season.
4. Most of the houses in Kansai and Kyushu regions, as well as some houses in Tohoku, Hokuriku and Kanto regions, are considered having fungal contamination.

NOTE
[Note 1]: The present study was carried out as part of the long-term field measurement program entitled “Investigation on Energy Consumption of Residences all over Japan”. The program was organized by the committee of Architecture Institute of Japan, and directed by Prof. Shuzo Murakami (Keio University). The database of long-term field measurement program is available in; http://tkkankyo.eng.niigata-u.ac.jp/HP/HP/database/index.htm

REFERENCES