Environmental Study of Storage Houses for Floats (Dashi) in Japan

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ABSTRACT: In Asian countries, traditional fireproof storage houses with earthen walls have been widely used for keeping food since the 6th century [1]. Because of the high capacity of earthen walls to absorb moisture, humidity inside a storage house is kept relatively constant throughout the year. Up until now, such storage houses have been used for keeping important cultural properties, since it is quite important to avoid large variations of humidity around important objects. This paper reports on the changes of temperature and humidity as well as measurement of ventilation rate in different types of storage houses in Kawagoe city. We also performed a numerical simulation of humidity changes due to outside humidity change. We compared the simulated humidity changes and measured ones. From these results, we found the effectiveness of earthen walls in buffering humidity. Since the storage houses provide preferable humidity condition without using electric energy, they can be used as storage facilities for important cultural properties.

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INTRODUCTION

Kawagoe city in Japan is known as the town of kura, traditional fireproof storage houses with earthen walls. Humidity is relatively constant in these traditional storage houses because of the high capacity of earthen walls to absorb humidity. Extravagant floats used for a festival in Kawagoe are stored in such storage houses.

Since severe humidity change in a storage house damages the stored cultural properties, it is important to keep the humidity relatively constant throughout the year. We carried out measurements of temperature and humidity at 6 storage houses from October 2001 to October 2002, using data loggers. The measured results showed that humidity was relatively constant in the storage houses with earthen walls while it changed greatly in storage houses with iron shutters. Storage houses with iron shutters have water tanks for supplying humidity. A numerical simulation was performed to check the effectiveness of these water tanks. Simulation results showed that the water tanks were quite effective when air exchange rate was low (around once a day) but were not effective when air exchange rate was high (around once an hour). Also, since humidity inside a wooden case is relatively constant even when the environmental humidity change is large, important objects in all the storage houses are kept inside wooden cases which act to buffer humidity.

2. OVERVIEW OF STORAGE HOUSES

2.1 Characteristics of storage houses

We measured temperature and humidity changes in 6 storage houses in Kawagoe city located 40 km north of Tokyo. The characteristics of these storage houses are as follows:

Storage A (Kaku-cho) There are 6 sections in Storage A, one section for one float. Walls are made of reinforced concrete. There are iron shutters on the south face of the storage. The inside space of each section is 3.9m wide, 8.2m high and 6.1m deep.

Storage B (Shita-cho) Walls are made of reinforced concrete. There is an iron shutter in one direction. The inside space is 4.0m wide, 5.5m high and 7.5m deep.

Storage C (Naka-cho) Walls are made of reinforced concrete. There is an autoclaved lightweight concrete entrance. The floor is made of compacted soil. The inside space is 4.0m wide, 8.2m high and 4.5m deep.

Storage D (Matsue-cho) Walls are made of compacted soil with lime plaster on the surface. The floor is also made of compacted soil. The inside space is 5.6m wide, 4.6m high and 9.2m deep.

Storage E (Saiwai-cho) Walls are made of compacted soil with lime plaster on the surface. There is a glass door entrance in the south direction. The floor is also made of compacted soil. The inside space is 5m wide, 4.6m high and 10.5m deep.

Storage F (Kita-cho) Walls are made of compacted soil with lime plaster on the surface. Half of the floor is made of compacted soil. The other half is made of natural earth.
The inside space is 4.5m wide, 5.6m high and 7.2m deep. Photos of storage houses (Storage A, Storage D and Storage F) are shown in Photos 1 to 3.

3. MEASUREMENTS

3.1 Temperature and humidity

The temperature and humidity inside the storage houses and outside were measured at 30-minute intervals by using data loggers (Hobo 08-032, Onset Co. Ltd.) Fig.1 shows the temperature and relative humidity changes in the outside air near Storage A from October 2001 to October 2002. Fig.2 shows the temperature and humidity changes in June 2002. For three days from June 9 to 11, humidity was around 20 to 30%, and after that period it increased to around 90%.

Figure 1: Relative humidity and temperature changes of the air outside Storage A from October 2001 to October 2002

Figure 2: Relative humidity and temperature changes of the air outside Storage A in June 2002.

Figure 3: Relative humidity and temperature changes of the air inside Storage A in June 2002.
3.2 Ventilation rate

In order to clarify the difference in the observed change in humidity due to the outside humidity change, ventilation rates of Storage A and Storage F were measured by using SF6 tracer gas.

The ventilation rate was measured in the following procedure.
1) The tracer gas (SF6) was put into the storage house until the concentration reached around 1 ppm.
2) Ventilation fan was operated to get uniform distribution of tracer gas.
3) The concentration of tracer gas was measured periodically by FTIR and the obtained data were recorded on the computer.
4) At the end of the measurement, distribution of the tracer gas was observed to check the uniformity of its distribution.
5) The ventilation rate was measured from the change of concentration of the tracer gas.

The ventilation rate was calculated with the following equation:

$$Q = 2.303 \left( \frac{V}{t \log_{10} \left[ \frac{Cs - C_0}{C - C_0} \right]} \right) \quad (1)$$

where

- $C_0$: concentration of tracer gas in the outside air
- $Cs$: initial concentration of tracer gas in the storage house
- $C$: concentration of tracer gas at elapsed time $t$ in the storage house
- $Q$: ventilation rate
- $V$: volume of air space in the storage house.

From these measurements the ventilation rate of Storage A, first floor of Storage F and second floor of Storage F were found to be 20.5, 7.2 and 3.9 (times/day), respectively.

4. SIMULATION OF HUMIDITY CHANGE IN STORAGE HOUSE

4.1 Simulation model

The schematic diagram of one section of Storage A is shown in Fig. 6. The walls are made of reinforced concrete. There is an iron shutter in the south face. The inside space is 3.9m wide, 8.2m high and 3.9m deep at the base and 6.1m deep at the height of 2.5m.
The schematic diagram of Storage F is shown in Fig. 7. The walls are made of compacted soil with lime plaster on the surface. The floor is also made of compacted soil. The inside space is 4.5m wide, 5.6m high and 7.3m deep.

Figure 7: Schematic diagram of Storage F (unit: mm)

4.2 Simulation method

As the first step, the inside humidity change was calculated with the obtained ventilation rate shown in Section 3. In this simulation, the humidity buffering effect of a wall was not taken into account. For the CFD calculation, STREAM (Version 5, CRADLE Co. Ltd.) was used. The following parameters were used for the simulation:

- **Concrete wall**: 200mm thick reinforced concrete  
  - density: 2310 kg/m³  
  - heat capacity: 879 J/kgK  
  - thermal conductivity: 1.5 J/msK

- **Shutter**: 1.6mm thick iron shutter  
  - density: 7900 kg/m³  
  - heat capacity: 1924 J/kgK  
  - thermal conductivity: 33 J/msK

- **Earthen wall**: 350mm thick compacted soil  
  - density: 1710 kg/m³  
  - heat capacity: 879 J/kgK  
  - thermal conductivity: 0.6 J/msK

- **Roof tile**: 100mm thick clay tile  
  - density: 2000 kg/m³  
  - heat capacity: 753 J/kgK  
  - thermal conductivity: 1.0 J/msK

- **Compacted soil floor**  
  - density: 1180 kg/m³  
  - heat capacity: 880 J/kgK  
  - thermal conductivity: 0.65 J/msK

The calculation was performed at 600-second intervals for 30 days (2,592,000 seconds). The calculated relative humidity change for Storage A is shown in Fig. 8 and the calculated relative humidity change for Storage F is shown in Fig. 9.

The calculated humidity change for Storage A and Storage F showed large humidity change due to a rapid change in the outside humidity. The measured humidity changes in Storage A (Fig. 3) also changed greatly. This shows that the humidity buffering effect of concrete is relatively small. The measured relative humidity change for Storage F with thick earthen walls was relatively constant in this period. This difference between the measured value and calculated value is due to the fact that in this simulation humidity buffering effect of a wall was not taken into account. However, as a next step, we plan to consider the humidity buffering effect in this CFD simulation.

Figure 8: Calculated relative humidity change in Storage A in June 2002

Figure 9: Calculated relative humidity change in Storage F in June 2002

CONCLUSION

We measured the temperature and humidity changes as well as ventilation rate in different types of storage houses in Kawagoe city. We also performed a numerical simulation of humidity change due to the outside humidity change. We compared the simulated humidity changes and measured ones. From these results, we found the effectiveness of earthen walls as a humidity buffer. Since the storage houses provide preferable humidity condition without using electric energy, they can be used as suitable places for storing important cultural properties.

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REFERENCES