Hygrothermal simulation on effective dehumidification methods in a museum storage room

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Abstract. The hygrothermal environment must be controlled in facilities like museums and galleries to suitably conserve the stored cultural artifacts. The present study proposes a humidity control technique for a museum storage room in Kyoto, Japan. This method requires limited energy and no large-scale equipment or major building renovation. The relative humidity of the room measured during the preliminary field survey exceeded the range for the conservation of metal artifacts (under 45%RH) throughout the year, and dehumidification was experimentally performed. The possible range of humidity control and the energy are quantitatively evaluated in the present study by simulating various ways of operating a dehumidifier in combination with the improvement of the room’s property of being airtight. The results of the study indicated that simple building modifications and operational improvements could improve the storage environment. For instance, measures to ameliorate airtightness and sensing control along with the addition of small-scale equipment such as a home-use compressor-type dehumidifier can yield long-term low humidity suitable for the conservation of metal cultural artifacts. Such measures are also considered advantageous in terms of energy and labor consumption.

1. Introduction
The hygrothermal environment of facilities like museums and galleries must be controlled to suitably conserve cultural artifacts. Studies considering the energy and cost required for control have been conducted on some methods of mechanical temperature and humidity control in such facilities [1,2]. However, only a few studies have quantitatively examined temperature and humidity control methods with low energy consumption by using detailed hygrothermal simulation models considering the heat and moisture capacity and airtightness of building. In addition, the temperature and humidity control methods using air conditioning system for a storage room with a buffer spaces between inner and outer walls, widely used in Japan, have not been established.

The authors of this paper previously conducted dehumidification experiments using a home-use compressor-type dehumidifier in a museum storage room with buffer spaces for metal cultural artifacts. The relative humidity (RH) of this storage room was over 70%RH in the summer and was too high for metal conservation throughout the year [3]. A low humidity environment of less than 45%RH is recommended for the storage of metallic artifacts by ICCROM [4]. The abovementioned experiment revealed the RH in the room could be maintained at a low figure through the use of a dehumidifier; however, in terms of practicality, the method posed a problem because it required labor for the manual drainage of the water tank in a room without a drain. The inflow of humid outdoor air in summer was...
assumed to be the source of the humidity; thus, the airtightness of the window and the balance of the building ventilation was improved using simple methods. Consequently, the rate of increase of the dehumidified water volume subsided.

Some numerical simulations are conducted in the present study to propose a humidity control method that can be realized in the storage room with buffer spaces through limited energy expense and without the need for large-scale equipment or major building renovations. The possible range of humidity control and the energy requirements are quantitatively evaluated by simulating varied ways of operating a small-capacity dehumidifier in combination with the enhancement of the airtightness of the designated room. The material treated in this research is metal, and low humidity over the long-term is considered a priority rather than suppressing short-term temperature and humidity fluctuations.

2. Methods

2.1. Hygrothermal simulation model of the storage room considering the operation of a dehumidifier

A hygrothermal simulation model (Figure 1) was developed uniquely by the authors for a storage room and was validated by comparing the calculated temperature and humidity with the measured outcomes [5]. Based on the measurement results, the temperature and humidity of the surrounding spaces (blue circles) were updated every 1 s, and the heat and moisture balance of the room and the buffer spaces (red circles) were calculated. The model treated the exchange of heat and moisture between the building components and the room air and the heat and moisture transport associated with the airflow. The model assumed a one-dimensional heat and moisture transfer in the direction of component thickness. The quantity of the airflow was calculated through the ventilation network model. The sensible and latent heat processing and the heat generation by the equipment were added to the heat and moisture balance of the room (Figure 2) to simulate the operation of the dehumidifier on the model. The model assumed a small-capacity compressor-type dehumidifier (Table 1).

![Figure 1. Hygrothermal simulation model of the storage room.](image1)

![Figure 2. Dehumidification in the simulation.](image2)

| Table 1. Specifications of Dehumidifier. |
|------------------------------------------|
| Power source | 100 W, 60Hz |
| Blowing/intaking air volume | 0.04 [m³/s] |
| Dehumidification capacity | 10.0 [L/day] at 27°C and 60%RH (equivalent with 763.8[W]) |
| Rated power consumption | 215 [W] for operation |
dehumidified water were calculated, and each was considered an indicator of the energy required for the operation of the equipment and the labor required for manual drainage.

3. Results and discussion

The annual maximum RH of the room was over 50% RH (Figure 3) even when the dehumidifier was operated year-round. The annual RH of the room could be controlled to comply with the recommended range for the conservation of metal artifacts (less than 45% RH) through not only year-round operation but also the adoption of measures for the suppression of the inflow of outdoor air. The amount of dehumidified water per year also reduced from 455 kg to 115 kg (Figure 4). The procedures adopted for the suppression of the inflow of outdoor air lowered the dehumidification load. Other simulations which did not adopt airtight measures provide inadequate humidity control for the storage of metal artifacts.

When the dehumidifier was turned off and was subsequently stabilized by the moisture buffering effect of the building components. As a result, the RH in the room was suppressed to levels approximately below 45% RH. The RH in the room was controlled at 40%-45% RH when the humidity sensor was operational and when procedures to suppress the inflow of outdoor air were applied. The operational time of the dehumidifier was reduced to 91.9 days per year using this method. It was concluded that humidity control apt to the conservation of metal artifacts could be achieved with reduced operation time and energy consumption through the utilization of techniques to suppress the inflow of outdoor and to apply sensing-based operation control.

4. Conclusion

This study proposed a humidity control method for a museum storage room with buffer spaces for metal cultural artifacts. The temperature and humidity in the storage room were simulated through varied operational methods applied to a dehumidifier combined with measures to improve the airtightness of the room. The procedures to suppress the inflow of outdoor air reduced the dehumidification load, which contributed to the regulation of humidity, reducing the need for labor for humidity control. The fluctuations in the room’s RH when the intermittent operation method was applied became moderate because of the moisture buffering effects of the building components. Further, the energy required for the operation of the dehumidifier could be reduced via operational controls associated with humidity sensing. The installation of small-scale equipment such as a home-use compressor-type dehumidifier combined with simple building modifications, operational improvements such as steps taken to suppress the inflow of outdoor air, and the institution of sensing controls can easily enhance storage environments. Hence, long-term low humidity suitable for the conservation of metal cultural artifacts can easily be achieved in a manner that is also advantageous in terms of energy and labor consumption.

References
[1] Kompatscher K et al. 2019 Build Environ 147 50-66
[2] Ferdyn-Grygierek J et al. 2019 Build Environ 149 90-99
[3] Ishikawa K et al. 2020 Proc. REHABEND 2020 (Granada) 2477-85
[4] Guichen G 1988 Climate in museums (ICCROM)
[5] Ishikawa K et al. 2021 Energies 14(11) 3309