The Influence of Passive Ventilation on the Interstitial Hygrothermal Environment of a Straw Bale Wall

Kyle Holzhueter* and Koji Itonaga

1 Research Associate, Graduate School of Bioresource Sciences, Nihon University, Japan
2 Professor, College of Bioresource Sciences, Nihon University, Japan

Abstract

The greatest challenges for straw bale construction in Japan are moisture and straw's susceptibility to microbial decay. In order to mitigate excessive moisture, some straw bale architects and builders in Japan have utilized passive ventilation. This paper examines the influence of passive ventilation on the interstitial hygrothermal environment of the straw bale walls of a building in Chiba Prefecture, Japan, known as Furyu. Furyu's walls consist of straw bales surrounding a conventional timber frame. Underneath the bale wall is a ventilation chamber vented to the outside. The bale wall is exposed to the ventilation chamber below and air passes freely between the outside and sub-wall ventilation chamber. Twenty-three temperature and relative humidity sensors monitor the hygrothermal environment of Furyu. The study found that the relative humidity of the ventilation cavity is strongly influenced by the outdoor environment. The lower bale wall is in turn strongly influenced by the ventilation cavity. The results suggest that passive ventilation is not an effective means to control interstitial moisture in straw bale walls. Rather, passive ventilation appears to be a source of interstitial moisture during warm summer months.

Keywords: straw bale building; passive ventilation; interstitial hygrothermal environment; moisture

1. Introduction

Straw bales are blocks of compressed straw. In straw bale construction, bales are stacked to create bearing or infill walls.

The first structure built of bales on record was a one-room school house built in 1896 near Bayard, Nebraska, USA, while the oldest straw bale home still in existence was built in 1903 outside Alliance, Nebraska (Myrman and Knox, 1993).

Straw bale building has numerous advantages. In Japan, straw is a byproduct of rice cultivation and is thus plentiful and locally available. Straw bales are low in embodied energy (Centre for Building Performance Research, 2010). Since straw consists of approximately 36% carbon, straw bale walls function as a carbon sink, sequestering carbon during the life of the building (Wihan, 2007). Straw bale walls provide sound insulation, seismic stability, and low fire risk (King, 2006). Straw bale walls are also highly insulative, reducing energy use and CO₂ emissions due to heating and cooling (Bigland-Pritchard, 2005). Compared to other building techniques, straw bale building is low-tech, requiring few specialized tools and skills. And lastly, upon deconstruction, straw bales can safely decompose without becoming landfill.

Straw bale building is relatively new to Japan. According to the Japan Straw Bale House Association (2009), the first straw bale home in Japan was completed in 2001 in Tochigi Prefecture.

The greatest concern for straw bale construction in Japan is moisture and straw's susceptibility to decay. In order to mitigate excessive moisture, some straw bale architects and builders in Japan have utilized passive ventilation. This paper examines the influence of passive ventilation on the interstitial hygrothermal environment of the straw bale walls of a building in Minamiboso City, Chiba Prefecture, Japan, known as Furyu (Fig.1.).

*Contact Author: Kyle Holzhueter, Research Associate, Graduate School of Bioresource Sciences, Nihon University, 1866 Kameino, Fujisawa, Kanagawa, 252-8510 Japan
Tel: +81-466-84-3364 Fax: +81-466-84-4464
E-mail: nihondaigaku.kairu@gmail.com
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The purpose of the present study is three-fold: (1) Evaluate the potential for mold growth in Furyu's straw bale walls, (2) clarify hygrothermal dynamics, and (3) examine the influence of passive ventilation on the interstitial hygrothermal environment.

2. Materials and Methods

2.1 Structure of Furyu
Furyu was designed by Goichi Oiwa of Slow Design Research Group and built by Ishii Construction Company. Takao Kobayashi, a professional plasterer, led construction of the straw bale walls. Furyu consists of straw bales surrounding a conventional timber frame. The exterior of the bale wall is finished with earthen plaster and the interior is finished with wood siding or earthen plaster on a lattice of split bamboo.

Believing that interstitial ventilation would reduce interstitial humidity, the design includes a ventilation chamber under the bale wall. Air passes freely between the outside and sub-wall ventilation chamber. The bale wall is exposed to the ventilation chamber below. In this case, passive ventilation denotes the absence of interstitial mechanical ventilation and also the absence of an air barrier between the bale wall and ventilation chamber. This allows air to move freely following a naturally occurring air pressure gradient.

Construction began in the spring of 2008 and was completed in the fall of the same year. The earthen plastered walls were completely dry by January 2009.

2.2 Monitoring the Hygrothermal Environment
Holzhueter and Itonaga (2010) monitored the hygrothermal environment and potential for mold growth within the straw bale wall of a building in Kyotango, Kyoto Prefecture, Japan. Replicating their placement of sensors, 23 temperature and relative humidity sensors monitor the hygrothermal environment of Furyu: One indoor sensor, two outdoor sensors, 18 interstitial sensors, and two sensors monitor the ventilation cavity under the bale walls (Fig.2.). Developing from previous research by Holzhueter and Itonaga (2010), two additional sensors were installed in the ventilation chamber under Furyu's straw bale walls. Interstitial sensors have been installed in two locations, the west wall and east wall. In each location, a "stack" of 10 sensors has been installed at various
heights and depths perpendicular to the plane of the wall (Fig.3.). Each interstitial sensor is given a name consisting of multiple letters. The first letter designates the location: "W" stands for west and "E" stands for east. The second letter designates the height: "L" stands for low, "M" for middle, and "H" for high. The third letter describes the sensors depth: "I" stands for interior, "N" for interstitial and "E" for exterior. "F" stands for "foundation" and designates the ventilation cavity sensor under each stack of interstitial sensors. The ventilation cavity sensors are located 100mm from the bottom of the ventilation cavity, directly under the West and East interstitial sensors. WME became dysfunctional and no data is available from this location.

These sensors measure temperature and relative humidity, and data is recorded at one-hour intervals by TR-72U data loggers. According to the manufacturer, the temperature range of the sensor is 0ºC-50ºC, and the relative humidity range is 10 to 95%. The sensors are accurate to ±0.3ºC between -20 and 80ºC, and ±5% relative humidity at 25ºC and 50% relative humidity.

2.3 Predicting Mold Growth

Developing from previous research by Holzhueter and Itonaga (2010) and a review of the literature, Holzhueter (2011) found that hygrothermal conditions of 80% relative humidity and 10ºC are understood to be a safe guideline for straw bale walls. Above 80% relative humidity and 10ºC, mold growth is predicted. At and below 80% relative humidity and 10ºC, some biological activity may be present, but is not believed to impact the life of the building.

Furyu’s straw bale walls are evaluated given this guideline.

2.4 Clarifying Hygrothermal Dynamics and the Influence of Passive Ventilation on Interstitial Relative Humidity

Simultaneously depicting the temperature and relative humidity readings of multiple interstitial sensors recorded at one-hour intervals over an entire year on the same graph results in incomprehensible figures. In order to visually depict the hygrothermal environment over an entire year in an easily understandable manner, monthly averages are graphed. Moreover, temperature and relative humidity are graphed separately. Trends in temperature and relative humidity will be identified.

Through an evaluation of the potential for mold growth and a clarification of hygrothermal dynamics, the influence of passive ventilation on interstitial relative humidity can be examined.

3. Results and Discussion

Table 1. lists the total number of hours each interstitial sensor surpassed the guideline between February 1, 2009 and January 31, 2010. All interstitial sensors surpassed the guideline. The maximum number of consecutive hours the interstitial hygrothermal environment surpassed the guideline is 1,862 hours and was recorded by Sensor ELN between June 2 and August 19, 2009 (Fig.4.). The total number of hours ELN surpassed the guideline was 2849. Mold growth is predicted.

Table 1. The Total Number of Hours Each Interstitial Sensor Surpassed 80% Relative Humidity and 10ºC

| West Wall Interstitial Sensor | Number of Hours Guideline Surpassed | East Wall Interstitial Sensor | Number of Hours Guideline Surpassed |
|-----------------------------|-----------------------------------|------------------------------|-----------------------------------|
| WLI                         | 1646                              | ELI                          | 2682                              |
| WLN                         | 1908                              | ELN                          | 2849                              |
| WLE                         | 2088                              | ELE                          | 2730                              |
| WMI                         | 857                               | EMI                          | 1093                              |
| WMN                         | 824                               | EMN                          | 1165                              |
| WME                         | NA                                | EME                          | 1227                              |
| WHI                         | 1316                              | EHI                          | 961                               |
| WHN                         | 1094                              | EHN                          | 1512                              |
| WHE                         | 2353                              | EHE                          | 1387                              |

Fig.4. ELN Interstitial Temperature and Relative Humidity from February 2009 to January 2010
Figs. 5. and 6. depict the monthly mean temperature and relative humidity of the west and east sensors from February 2009 to January 2010. Of all 23 sensors, the indoor sensor recorded the lowest relative humidity and amongst the highest temperatures. However, indoor temperature and relative humidity data is missing from September 2009 to January 2010.

Of the 23 sensors, the highest relative humidities of both the west and east walls were recorded in the ventilation cavity in July. Of all 23 sensors, in July 2009, the west and east ventilation cavity sensors recorded the lowest mean monthly temperatures. The relative humidities of the ventilation chambers follow outdoor relative humidity. Amongst the interstitial sensors in July, the low sensors of the east and west walls had the highest monthly mean relative humidities (Fig. 7.). The lower interstitial relative humidities closely follow the ventilation cavity and outdoor relative humidities. The results suggest that ventilation cavity moisture enters the bale wall. Because there is no air or moisture barrier separating the bale wall and

Fig.5. Monthly Mean Temperature and Relative Humidity of Indoor and West Outdoor, Interstitial, and Ventilation Cavity Sensors from February 2009 to January 2010
ventilation cavity, it appears that the hygrothermal environment of the ventilation cavity strongly influences the lower bale wall.

The monthly mean relative humidities of the middle and high sensors are lower than the lower sensors for both the east and west walls. In July, interstitial temperatures tend to increase from low to high sensors. Interstitial moisture sources are presumably atmospheric and ground moisture. The results of Furyu's hygrothermal monitoring suggest that a gross air leak via the ventilation chamber allows water vapor into the bale walls, especially in summer when water vapor is likely to move from outside to inside. In summer, warm humid outside air entering the ventilation cavity cools and the relative humidity of the ventilation cavity increases. The relative humidity of the ventilation cavity is strongly influenced by the outdoor environment. The lower bale wall is in turn strongly influenced by the ventilation cavity. The results suggest that passive ventilation is not an effective means to control interstitial moisture in straw bale walls. Rather, passive ventilation appears to be

Fig.6. Monthly Mean Temperature and Relative Humidity of Indoor and East Outdoor, Interstitial, and Ventilation Cavity Sensors from February 2009 to January 2010
a source of interstitial moisture during warm summer months.

In addition, there is no waterproof layer between the bale wall and concrete foundation, which is in contact with the earth. Thus, there is nothing to prevent evaporating ground moisture from entering the bale wall from below.

The use of ventilation cavities under bale walls seems to be a problematic building practice particular to Japan and evolves from traditional temperate climate Japanese architecture.

Load bearing walls more often utilize a perimeter footing (including basement, crawlspace, and slab on grade) than a pier and beam foundation. Load bearing walls and perimeter foundations are traditionally more common in North America and Europe than in Japan. Colder temperatures in North America and Europe also increase the risk of frost heave under foundations. In North America and Europe, ground moisture is traditionally dealt with through drainage tiles sloped to daylight. In conventional North American and European architecture, drainage pipes are used to carry ground moisture away from buildings.

Traditional Japanese homes are built on pier foundations with little risk of frost heave due to moderate winter temperatures. Traditionally in Japan, ground moisture is not drained away from buildings, but is dealt with through ventilation. Homes are built off the ground with an open floor plan to increase ventilation under floors and through the house. Following the traditional Japanese practice of dealing with ground moisture through ventilation, straw bale architects and builders in Japan believed that increasing ventilation would decrease interstitial moisture. Instead, the results suggest that interstitial moisture increases with ventilation, particularly in summer. Furthermore, not only does this practice increase interstitial moisture, but it could also have two potentially negative consequences:

1. Ventilation could increase thermal convection, which would reduce thermal insulation and could lead to condensation on cold, nonhygroscopic surfaces.
2. Ventilation could provide a source of oxygen in the event of a fire.

Hot and humid areas of North America have encountered a similar problem in conventional buildings. For many decades, building codes and conventional wisdom prescribed ventilation with outside air to control moisture in crawl spaces. However, in humid regions in summer, ventilation with outside air only makes moisture problems worse. Research into sealed crawlspace designs in the humid southeast US indicate that sealed crawlspace stays drier and maintain lower humidity levels than crawlspace with traditional wall vents (Dastur and Davis, 2005, Davis et al., 2005a, 2005b, Davis and Dastur, 2004). Alex Wilson (2003) of Environmental Building News concludes that "while experts used to recommend ventilating unheated basements during the summer months, most now discourage that practice in humid climates because the ventilation introduces more moisture than it removes". This is essentially the same phenomenon happening in ventilation chambers under straw bale walls in Japan.

4. Conclusion

The relative humidity of the ventilation cavity is strongly influenced by the outdoor environment. The lower bale wall is in turn strongly influenced by the ventilation cavity. The results suggest that passive ventilation is not an effective means to control interstitial moisture in straw bale walls. Rather, passive ventilation appears to be a source of interstitial moisture during warm summer months.

Informing straw bale architects and builders of the results of this study is an important step towards improving the performance of straw bale buildings in Japan.

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