The Influence of Ventilated Rainscreens on the Interstitial Hygrothermal Environment of Straw Bale Walls

Kyle Holzhueter*[1] and Koji Itonaga[2]

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

Abstract

The greatest challenges facing straw bale building in Japan, and many other countries with high humidity and precipitation, are moisture and the susceptibility of straw to microbial decay. Researchers in Europe and North America have found the use of ventilated rainscreens to help control interstitial moisture in straw bale walls. The indoor, outdoor and interstitial hygrothermal environment of six straw bale structures in Japan have been monitored. The six buildings are organized into two groups. The first group includes buildings consisting of straw bales walls with an earthen or lime plastered exterior finish applied directly to the bale walls. The second group includes buildings consisting of straw bale walls utilizing ventilated rain screens. The purpose of the present study is: (one) evaluate the potential for mold growth in the six buildings, (two) clarify moisture dynamics, and (three) determine the effectiveness of ventilated rainscreens to control moisture in straw bale walls. As a result of the study, the potential for mold growth was found to vary by structure. Buildings utilizing rain screens were found to have lower interstitial relative humidity and a lower risk of mold growth.

Keywords: straw bale building; ventilated rainscreens; hygrothermal environment; mold growth; interstitial moisture

1. Introduction

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

Straw bale building has numerous ecological advantages. 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 are also highly insulative, reducing energy use and CO2 emissions due to heating and cooling (Bigland-Pritchard, 2005). 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 challenges facing straw bale buildings in Japan, and many other countries with high humidity and precipitation, are moisture and the susceptibility of straw to microbial decay.

However, controlling moisture to reduce microbial decay and improve building durability is an issue common to conventional construction and particularly buildings utilizing organic insulations such as straw, rice hulls, etc. (Lee *et al.*, 2013).

Straw bale walls are generally finished with earthen and/or lime plasters applied directly to the bale walls. In recent years, ventilated rainscreens have been employed to protect straw bale walls from moisture damage.

The term "rainscreen" refers to the use of a drainage plane/air gap between exterior siding and bale wall. Permeable plasters tend to be porous and absorb exterior moisture. In many cases, this moisture is then transferred to interstitial bales through capillary action. In order to prevent liquid water, i.e. rain, from direct contact with a plastered bale wall, rain-screens can be used. Previous research has found that rainscreens help control interstitial moisture in straw bale walls (Carfrae *et al.*, 2009; Lawrence *et al.*, 2009; Otto *et al.*, 2008; Thompson, 2006).

The indoor, outdoor and interstitial hygrothermal environment of six straw bale structures in Japan have been monitored. These six straw bale buildings are organized into two groups according to construction details (Fig.1., Table 1.). The first Group A includes

*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
(Received April 7, 2014 ; accepted November 12, 2014)

buildings consisting of straw bale walls with an earthen or lime plastered exterior finish applied directly to the bale walls. The second Group B includes buildings consisting of straw bale walls utilizing ventilated rain screens.

The purpose of the present study is to (one) evaluate the potential for mold growth in the six buildings, (two) clarify moisture dynamics, and (three) determine the effectiveness of ventilated rainscreens to control moisture in straw bale walls.

2. Materials and Methods

2.1 Monitoring the Hygrothermal Environment

T and D Corporation's Thermo Recorder sensors monitor the indoor, outdoor and interstitial hygrothermal conditions of the six straw bale structures (Fig.2.). These sensors measure temperature and relative humidity, and data is recorded at one hour intervals by data loggers.

In Group A buildings, a "stack" of nine interstitial sensors have been installed at various heights and

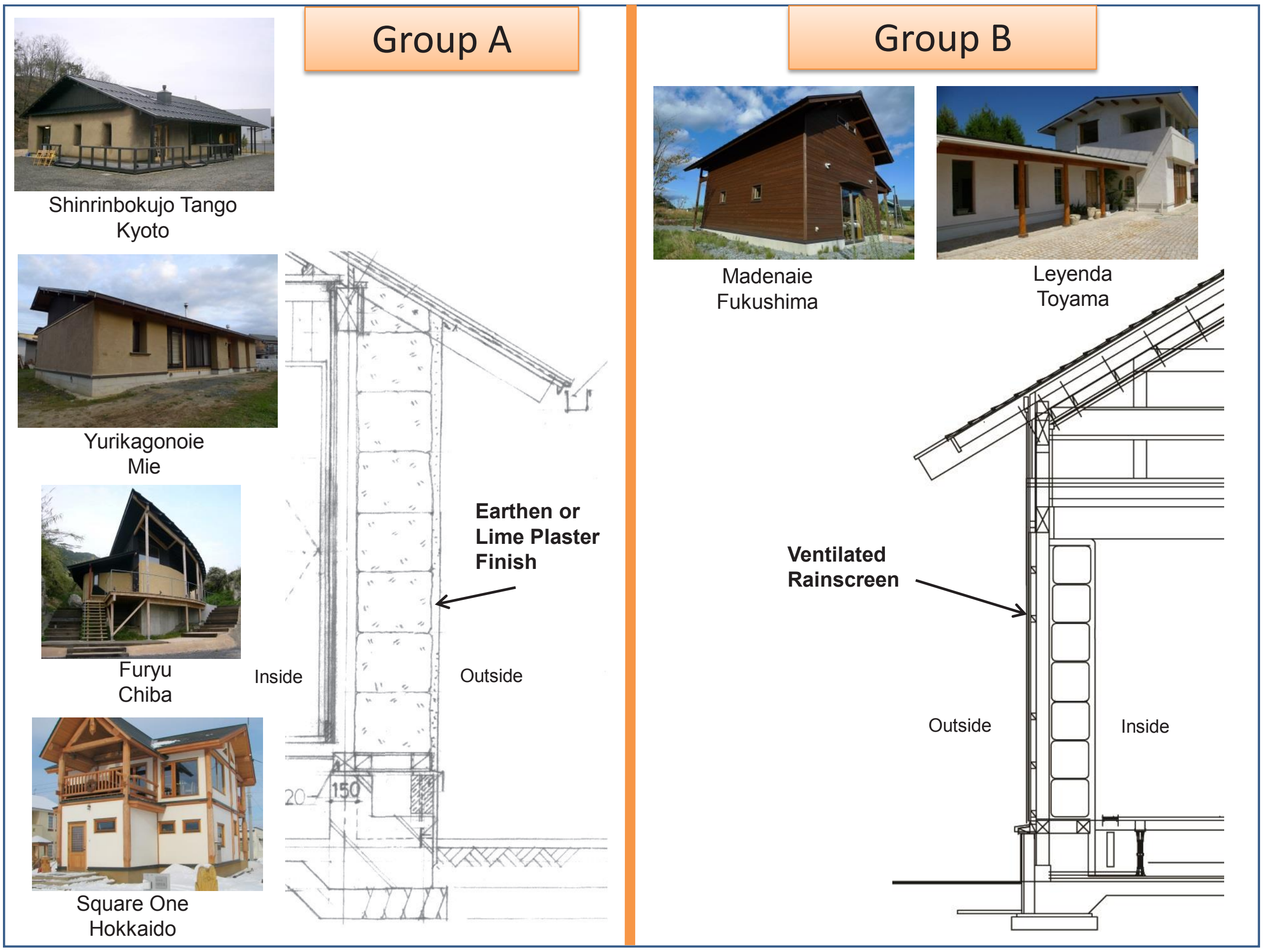

Fig.1. Six Straw Bale Buildings Divided into Two Groups

Table 1. Details of Each Building

Group	Building Name	Prefecture	City	Architect	Principle Builder of Straw Bale Walls	Construction		One Year Observation Period	
						Start	Finish	Start	Finish
A	Shinrinnobokujo Tango	Kyoto	Kyotango	Goichi Oiwa	Takao Kobayashi	Oct-07	Jun-08	Sep-08	Aug-09
	Furyu	Chiba	Minamiboso	Goichi Oiwa	Takao Kobayashi	Mar-08	Nov-08	Feb-09	Jan-10
	Yurikagonoie	Mie	Tsu	Masatoshi Sakamoto	Hideto Oshima	Feb-09	Jul-09	Jul-10	Jun-11
	Square One	Hokkaido	Asahikawa	Mikio and Masami Sakai	Stefan Bell	May-09	Jun-10	Nov-11	Oct-12
B	Madenaie	Fukushima	Itate	Yoshiyuki Toyoto	Kyle Holzhueter, Koji Itonaga	Nov-09	Mar-10	Dec-11	Nov-12
	Leyenda	Toyama	Toyama	Shoko Yoshimoto	Hiroaki Yoshimoto, Kyle Holzhueter	Aug-10	Sep-11	Apr-12	Mar-13

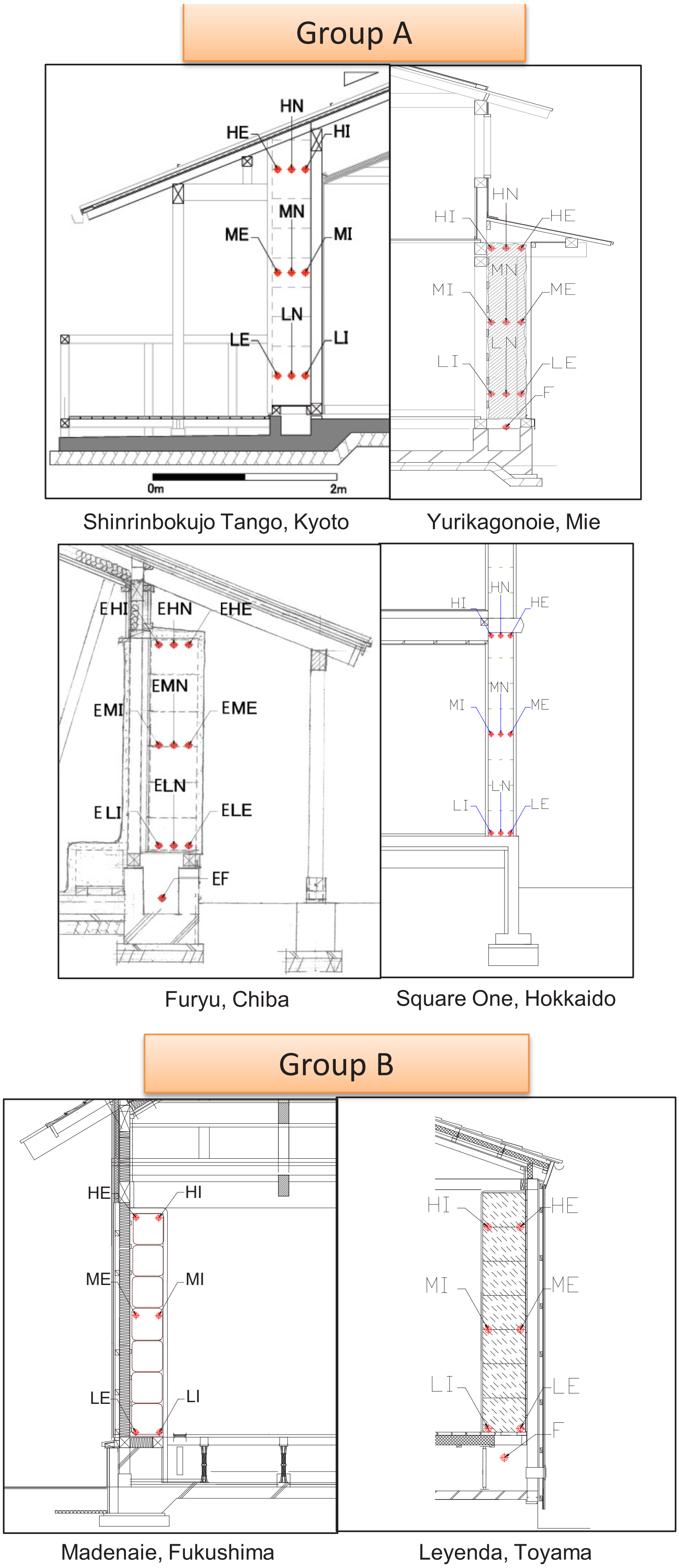

Fig.2. Wall Section and Sensor Locations for Each Building

depths perpendicular to the plane of the wall in each building (Fig.3.). Each interstitial sensor is given a name consisting of multiple letters. The first letter designates the height: "L" stands for low, "M" for middle, and "H" for high. The second letter describes the sensors depth: "I" stands for interior, "N" for interstitial and "E" for exterior.

In Group B buildings, a "stack" of six interstitial sensors have been installed at various heights and depths perpendicular to the plane of the wall. The nomenclature of the sensors follows Group A. Due to funding limitations, interstitial sensors were not installed. Previous research by Holzhueter and Itonaga (2010, 2014) and the results of the present study suggest that a thorough investigation of the interstitial hygrothermal environment is possible with the sensor arrangement of Group B.

Collecting data over several years from multiple buildings has resulted in the loss of some data. However, despite the absence of some data, an accurate and thorough investigation is attainable.

No data is available from Furyu's indoor sensor between 17:00 September, 15, 2009 and 23:00 January 31, 2010.

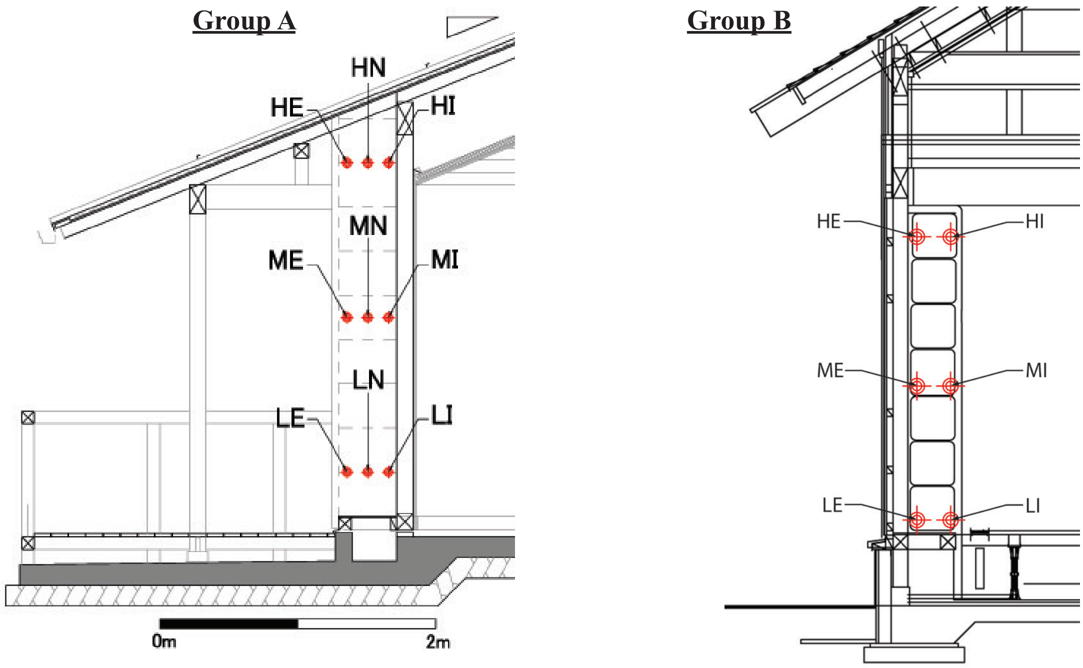

Fig.3. Stack of Nine Interstitial Sensors in Group A Buildings and Stack of Six Interstitial Sensors in Group B Buildings

Table 2. Monitoring Results Summary of Six Buildings

Group	Building	One Year Observation Period	Interstitial Hours Surpassing 80% Relative Humidity and 10℃ Guideline					Total Indoor Hours Surpassing Guideline	Total Outdoor Hours Surpassing Guideline	Difference between Total Outdoor and Greatest Total Interstitial Hours	Interstitial Maximum Monthly Mean Relative Humidity			Outdoor Maximum Monthly Mean Relative Humidity	
			Total		Max Consecutive										
			Location	Total Hours	Location	Hours	Date				(%)	Date	Location	(%)	Date
A	Shinrinnobokujo Tango	2008/09-2009/08	LI HE MI HN HI ME LN	1705 303 169 50 34 33 15	LI	1369	2009/7/5-8/31	275	2849	1144	86	Aug-09	LI	87	Nov-08
A	Furyu	2009/02-2010/01	LN LE LI HN HE ME MN MI HI	2849 2730 2682 1512 1387 1227 1165 1093 961	LN	1865	2009/6/2-8/19	661	3700	851	92	Jul-09	LN, LE	92	Jul-09
A	Yurikagonoie	2010/07-2011/06	LI LE	105 6	LI	75	2010/07/18-21	8	1711	1606	76	Aug-10	LI	73	Aug-10
A	Square One	2011/11-2012/10	ME HE	4177 1158	ME	3183	2012/05/28-10/08	0	1990	-2187	95	Feb-12	HE	93	Jan-12
B	Madeinaie	2011/12-2012/11	na	0	na	0	na	0	2875	2875	76	Aug-12	LE	89	Sep-12
B	Leyenda	2012/04-2013/03	LE	4	LE	4	13/3/7	29	2485	2481	75	Jan-13	LE	84	Dec-12

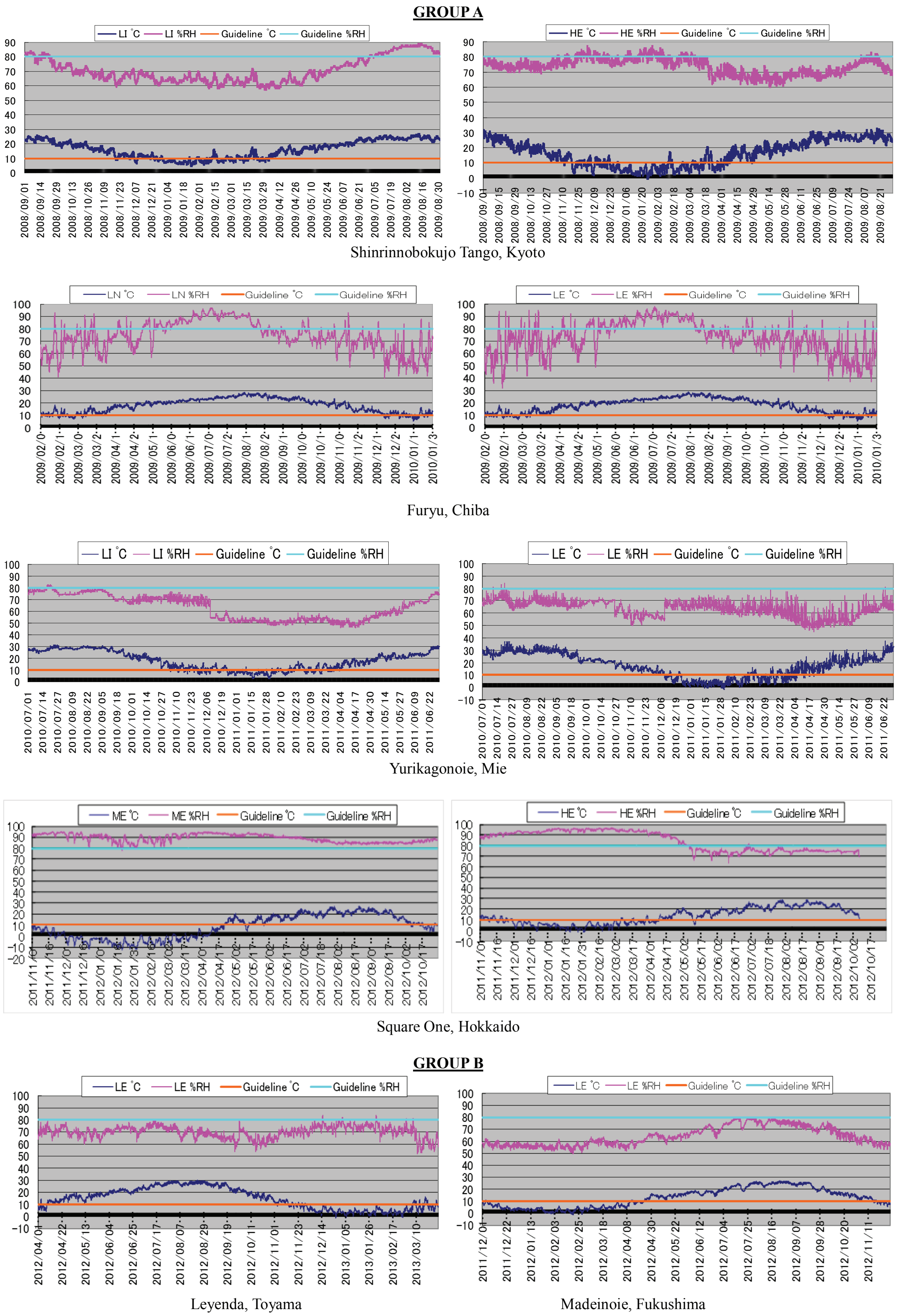

Fig.4. Evaluation of Mold Growth Given an 80% Relative Humidity and 10ºC Temperature Guideline

No data is available from Square One's HI, HN and HE sensors between 11:00, October 8, 2012 and 23:00, October 31, 2012. Data is also not available from Square One's Outdoor sensor between 0:00, November 1, 2011 and 17:00, November 9, 2011.

No data is available from Leyenda's Outdoor sensor between 19:00 November 13, 2012 and 0:00 December 6, 2012.

No data is available from Madeinaie's MI sensor between 15:00 February 27, 2012 and 23:00 November, 30, 2012.

2.2 Predicting Mold Growth

First, in order to evaluate the potential for mold growth in straw bale walls, the interstitial hygrothermal environment is evaluated given a relative humidity and temperature guideline. 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.

The straw bale walls of the six buildings are evaluated given this guideline.

2.3 Clarifying Moisture Dynamics

The sensor locations which surpass the guideline are further investigated to clarify moisture dynamics.

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

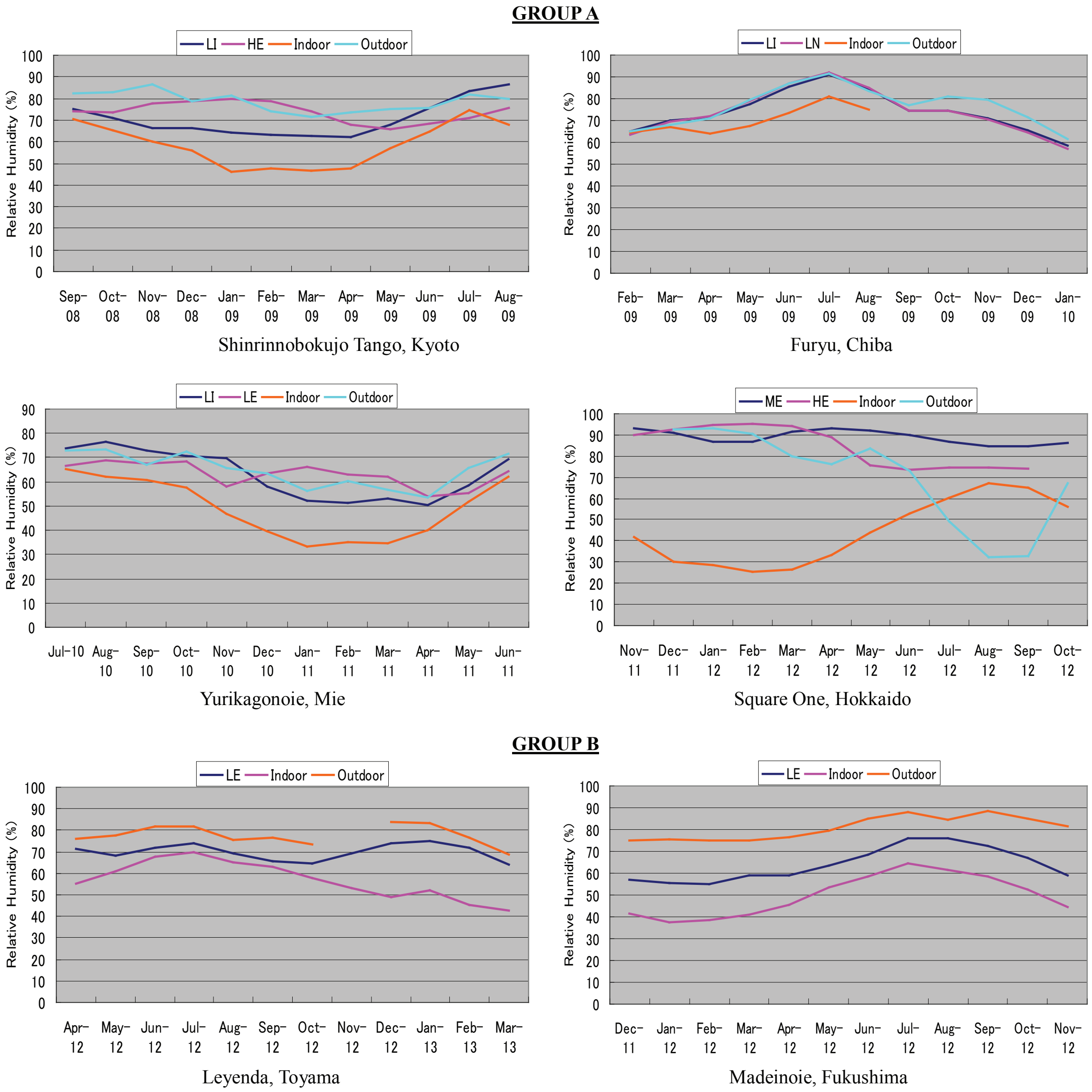

Fig.5. Mean Monthly Relative Humidity of Indoor, Outdoor and Interstitial Sensors with the Highest Monthly Mean Relative Humidity

2.4 Determining the Effectiveness of Ventilated Rainscreens to Reduce Interstitial Moisture

Through an evaluation of the potential for mold growth and a clarification of moisture dynamics, the influence of rainscreens on interstitial moisture can be examined.

Furthermore, it must be remembered that the six buildings monitored are located in unique locations and climates. In order to compare buildings in different locations and climates, the interstitial hygrothermal environment is evaluated given its specific climate. The sensor which surpasses the guideline by the greatest number of hours is compared to the ambient environment. For example, the number of hours the interstitial sensor surpasses the guideline is subtracted from the number of hours the outdoor sensor surpasses the guideline. A building with a positive value has performed well given its specific climate. That is, although the ambient environment has surpassed the guideline for a given number of hours, the interstitial sensors only surpassed the guideline for a fraction of those hours. A building with a negative value has not performed well given its environment. That is, although the ambient environment only surpassed the guideline for a specific number of hours, the interstitial sensor surpassed the guideline for more hours.

3. Results and Discussion

Table 2. summarizes the results of the monitoring. Of the six buildings monitored, the interstitial hygrothermal environment of five buildings surpassed the 80% relative humidity and 10°C guideline. The number of consecutive hours the guideline was exceeded varies by building. The number of consecutive hours the interstitial environment of Group B buildings surpassed the guideline was only four hours. Both of these buildings utilize rainscreens. On the other hand, the interstitial environment of three of the four Group A buildings surpass the guideline for over 1000 hours. These buildings have exterior plaster finishes directly applied to bale walls.

The temperature and relative humidity of the two sensors from each building that surpassed the guideline the greatest number of hours are graphed in Fig.4.

From Group B, only one sensor from Leyenda surpassed the guideline and no sensors surpassed the guideline from Madeinaie. Although it never surpassed the guideline, Madeinaie's interstitial sensor with the greatest monthly mean relative humidity, LE, was chosen to depict Madeinaie's interstitial hygrothermal environment.

The monthly mean relative humidity of indoor, outdoor and interstitial sensors with the highest monthly mean relative humidity are graphed in Fig.5. At some point during the observation period, all of the Group A buildings' interstitial monthly mean relative humidity surpass the outdoor monthly mean relative humidity. However, during the observation period, none of the Group B buildings' interstitial monthly mean relative humidity surpass the outdoor monthly mean relative humidity.

All of Furyu's sensors surpassed the guideline by hundreds of hours. However, Furyu also had the most severe climate.

When comparing the difference between interstitial and outdoor hours surpassing the guideline, Square One performed the worst. However, despite having the sensor with the highest number of hours surpass the guideline, only two of Square One's nine interstitial sensors surpassed the guideline. This suggests a localized problem near the exterior finish.

Many of Shinrinnobokujo Tango's sensors surpassed the guideline. Shinrinnobokujo Tango also had a severe climate, but the climate was similar to Group B's Madeinaie's climate in terms of monthly mean relative humidity and hours surpassing the temperature and relative humidity guideline.

Despite being located in rather severe climates where the ambient environment surpassed the guideline for well over 2000 hours, the number of hours the interstitial environment of Group B buildings surpassed the guideline was only 4 hours.

The research results suggest that rainscreens are an effective means to reduce moisture and prevent mold growth in straw bale walls.

4. Conclusion

The hygrothermal conditions of six straw bale structures in Japan were monitored. The purpose of the present study was to (one) evaluate the potential for mold growth in the six buildings, (two) clarify moisture dynamics, and (three) determine the effectiveness of ventilated rainscreens to control moisture in straw bale walls. (1) The potential for mold growth was found to vary by structure. Buildings utilizing rainscreens were found to have a lower risk of mold growth. (2) Buildings utilizing rainscreens were found to have less interstitial moisture. Presumably, the use of rainscreens deflected rain from the plastered straw bale walls, which in turn reduced interstitial moisture. And (3) the research results suggest that rainscreens are an effective means to reduce moisture and prevent mold growth in straw bale walls.

References

1) Bigland-Pritchard, M. (2005) An assessment of the viability of strawbale wall construction in buildings in maritime temperate climates. PhD Thesis, University of Sheffield.
2) Carfrae, J., Wilde, P. D., Littlewood, J., Goodhew, S., Walker, P. (2009) Long term evaluation of the performance of a straw bale house built in a temperate maritime climate. In: 11th International Conference on Non-conventional Materials and Technologies, NOCMAT 2009, 6-9 September 2009, Bath.
3) Centre for Building Performance Research, Victoria University of Wellington (2010) Table of embodied energy coefficients. Available Online: http://www.victoria.ac.nz/cbpr/documents/pdfs/ee-coefficients.pd

4) Holzhueter, K. (2011) The hygrothermal environment of straw bale walls in Japan and building practices to control interstitial moisture. PhD Thesis, Nihon University.
5) Holzhueter K. and Itonaga K. (2010) The hygrothermal environment and potential for mold growth within a straw bale wall. Journal of Asian Architecture and Building Engineering, Vol. 9, No. 2, pp.495-499.
6) Holzhueter, K., Itonaga, K. (2014) The influence of passive ventilation on the interstitial hygrothermal environment of a straw bale wall, Journal of Asian Architecture and Building Engineering, Vol. 13, No. 1, pp.223-229.
7) Japan Straw Bale House Association (2009) First straw bale house in Japan. Available Online: http://www.japanstraw.com/index/main/03hatuno/03hatuno.html
8) Lawrence, M., Heath, A., Walker, P. (2009) The impact of external finishes on the weather resistance of straw bale walls. In: 11th International Conference on Non-conventional Materials and Technologies, NOCMAT 2009, 6-9 September 2009, Bath. Available Online: http://opus.bath.ac.uk
9) Lee, K., Yeom, D., Kim, E. (2013) Experimental research on the correlation of temperature, humidity, and CO_2 level of a rice hull insulated indoor environment, Journal of Asian Architecture and Building Engineering, Vol. 12, No. 2, pp.221-228.
10) Otto, F., Klatecki, M. (2008) B1 Voruntersuchungen durch das Zentrum für Umweltbewusstes Bauen in Kassel. In: Grundlagen zur bauaufsichtlichen Anerkennung der Strohballenbauweise-Weiterentwicklung der lasttragenden Konstruktionsart und Optimierung der bauphysikalischen Performance. Deutsche Bundesstiftung Umwelt, pp.114-293.
11) Thompson, K. (2006) External research program: straw bale construction in Atlantic Canada. Ottawa, Canada: Canada Mortgage and Housing Corporation.
12) Wihan, J. (2007) Humidity in straw bale walls and its effect on the decomposition of straw. Master's Thesis. University of East London School of Computing and Technology.