Field Monitoring of Embedded Wood Members in Insulated Masonry Walls in a Cold Climate

Kohta Ueno[1], Joseph W. Lstiburek, Ph.D., P.Eng.[2]

ABSTRACT

One durability risk when applying interior insulation to mass masonry walls is the hygrothermal behavior of wood beams embedded in the wall. With the retrofit of interior insulation, the embedded beam ends will spend longer periods at colder temperatures than their pre-retrofit condition. Therefore, these wood members will have lower drying potential (due to reduced heat flow), and experience higher relative humidity and moisture contents.

This work involves the field monitoring of embedded wood joist ends in a solid brick building which is being retrofitted with interior insulation. Eleven joists are being monitored, with a variety of orientations and exposures; they are being monitored for wood moisture content, and temperature and relative humidity in the joist pocket. Results have been collected over two years and are continuing; one limitation is that construction is still ongoing, and some of the building's interior is still unheated and unoccupied.

At many orientations (especially north), joist moisture contents are high (20-30% or higher), which is higher than the range considered conducive to long-term durability; RH levels often remained at 100%. On other, solar-heated orientations (south), the moisture content is in the safe, 10-13% range. However, installation of sensors and the removal of a joist end sample indicate that these wood members (dense, old-growth framing) can survive these moisture contents without damage. Seasonal MC cycles indicate that interior heating results in joist end drying (even with interior insulation), consistent with the change in moisture vapor gradient direction. The moisture contents at bottom part of the joist (near the beam "seat") are consistently higher than the corresponding upper position.

INTRODUCTION

There are durability risks and concerns when applying interior insulation to mass masonry walls. Some of them have been well researched, including interstitial condensation and brick freeze-thaw damage. However, another durability risk is the hygrothermal behavior of moisture-sensitive wood beams embedded in the load-bearing masonry. With the retrofit of interior insulation, the embedded beam ends will have reduced drying potential due to reduced heat or energy flow (as described by Lstiburek 2008). The wood will also be subjected to higher relative humidity (RH) conditions in the beam pocket, and therefore remain at higher moisture contents (MC): both factors increase durability risks.

This work involves the field monitoring of embedded wood joist ends in a solid brick building which is being retrofitted with interior insulation. Eleven joists are being monitored, with a variety of orientations and exposures; they are being monitored for wood moisture content, and temperature and relative humidity in the joist pocket.

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PREVIOUS WORK

Several practitioners have examined the problem of moisture risks at embedded members, using both in-situ monitoring and simulations.

Dumont et al. (2005) monitored moisture content of wood structural members embedded in masonry in two residences retrofitted with insulation in Wolseley, SK (DOE Zone 7, “dry” climate) and Kincardine, ON (DOE Zone 6A, “moist” climate). The Wolseley house was insulated with mineral wool, with a polyethylene vapor barrier; the Kincardine house was insulated with spray polyurethane foam, encasing the wood members at the beam pocket.

Data showed that the wood members of the Wolseley house remained at safe moisture content levels (10-15%) throughout the monitoring period. The lack of rain moisture load (dry climate) is likely the dominant factor. In contrast, the Kincardine house showed consistently elevated moisture contents (20%$^+$) at several locations. Potential moisture sources included capillary uptake from the wet foundation and rainwater absorption through the face of the masonry (due to surface detailing); reduced drying to the interior due to spray polyurethane foam was another potential factor.

Scheffler (2009) used simulations to examine the problem of moisture accumulation at wooden beam ends embedded in brick masonry under steady state conditions (23°F/-5°C/80% RH exterior; 68°F/20°C/50% RH interior; 90 days). These simulations indicated the moisture risks associated with insufficient control of airflow or moisture vapor flow (diffusion) from interior sources. This was followed by one-dimensional and two-dimensional simulations using transient weather data (Bremen; mild, maritime climate with high rain and humidity), showing higher RH levels and condensation risks due to the addition of insulation.

Scheffler described the historic methods to increase embedded beam longevity, including charring the beam end to increase moisture resistance, and the addition of exterior-to-interior ventilation at the beam pocket. He discussed current methods to ameliorate these moisture issues due to insulation retrofits, including replacing the wood floor/ceiling assemblies with moisture-insensitive materials (e.g., concrete), and possibly the addition of heat and/or ventilation at the wood beam end.

Morelli et al. (2010) collaborated with Scheffler; they proposed the solution of leaving a gap in the insulation of 12” (300mm) above and below the floor, resulting in a 30” (770 mm) gap. Heat transfer simulations showed that the heat flow was reduced by 60% going from the uninsulated to fully-insulated cases, while the “gap” case was only a 45% reduction. This work was followed by two-dimensional DELPHIN hygrothermal simulations of the embedded beam (in a Bremen climate). Relative humidity levels in a corner of the beam pocket (and equilibrium wood moisture content) were simulated. The existing, uninsulated wall showed a drying trend; the fully insulated wall showed seasonal increases in RH; and the “gapped” wall showed performance between the two previous cases (but with increasing moisture levels). However, these results assumed a relatively high wind-driven rain loading factor. Switching to a lower loading factor resulted in a general drying trend for the “gapped” assembly.

Morelli and Svendsen (2012) continued the previous work of Morelli (2010), presenting further simulations with continuous interior insulation, and insulation installed with a gap at the floor beams. Another result of this research was a methodology for assessing retrofit measures on brick masonry walls based on a failure mode and effect analysis.

Morelli and Svendsen also performed an extensive literature review from the 1980s to current day. Several in-situ field studies were examined; the typical findings were that driving rain did not result in moisture problems at beam ends. Some researchers found that cracks in the façade could result in problems, but crack-free façades had acceptable performance. Another researcher examined the effect of interior air leakage at beam ends: at high air leakage rates, temperatures in the beam pocket were increased, reducing condensation risks. At low air leakage rates, air-transported moisture was negligible. However, at intermediate flows, condensation did occur. That researcher recommended the addition of localized exterior wall insulation at beam ends, or insulating the beam end cavity. Other researchers examined techniques such as adding heat to the beam ends to avoid moisture problems. The results kept wood moisture contents low, but this is an expensive (and therefore unlikely) retrofit.

Ueno (2012) examined this problem by first using three dimensional heat flow simulations to determine embedded beam and joist end temperatures with and without interior insulation. Various mitigation techniques, such as heat flow plates or omitting insulation, were also simulated. These results were then used to inform one-dimensional hygrothermal simulations of embedded beam ends. These hygrothermal simulations gave inconclusive results; the author recommended first switching to a two-dimensional hygrothermal simulations. However, greater and more defensible insight could be gained by in-situ measurements of beam pocket temperatures, relative humidity, and wood moisture content (in both insulated and uninsulated configurations, and various orientations and rainfall exposure levels). This recommendation was the impetus behind this research project.

EXPERIMENTAL SETUP AND ASSEMBLIES

The field monitoring work was done at an existing brick mass masonry building in Lawrence, MA (DOE Zone 5A), which is being renovated into ten condominium units (Figure 1).

Figure 1: Mass masonry retrofit building from west /front (left) and northeast (right)

The masonry walls at this project include both multi-wythe solid brick walls, and exterior brick with a hollow clay block infill/backup wall. Finishes interior to the masonry were demolished. Although these assemblies appear to be monolithic from the interior and exterior, there are a variety of interconnected spaces, such as the incompletely filled collar joints between brick wythes, and/or the hollow cores of the clay blocks.

The building is being retrofitted with interior insulation, which consists of three 2” (50 mm) layers of extruded polystyrene (XPS) insulation adhered to the existing masonry with polyurethane adhesive; the seams are staggered and taped to improve air barrier performance. Wood 2x4 framing is installed inboard of the XPS insulation for mechanical services and finishes; the cavity is left uninsulated (Figure 2, left).

The embedded floor structure consists of dimension lumber (roughly 2"/50mm thickness) joists at 16"/400 mm on center (as opposed to large, widely-spaced timbers). The joist bays are insulated with scraps of rigid XPS foam insulation, attached with polyurethane adhesive; the perimeter of each block is then air sealed with a spray foam kit (Figure 2 right).

Figure 2: Framing installed inboard of insulation (right); insulation and air seal at joists (right)

BUILDING MONITORING LOCATIONS

In order to capture a variety of conditions, joists were monitored in multiple locations throughout the building. The variables included cardinal orientations (solar heating/drying, and wind-driven rain exposure), masonry wall type (solid brick masonry vs. hollow clay tile backup), localized wetting exposure, and insulation strategy. There are eleven monitored joist locations in total; eight are at the basement ceiling framing level (shown on the building plan in Figure 4), and three are at the first floor ceiling (Figure 5).

Basement ceiling joists are monitored on all four orientations, using the nomenclature (BSMT-[orientation][number]). All are embedded in solid brick masonry.

BSMT-N1/N2/N3 are joists with identical exposure, but using different retrofit strategies. BSMT-N1 is insulated as per the remainder of this project (board and spray foam); BSMT-N2 is insulated with air-permeable insulation (R-26 fiberglass), which insulates but allows airflow; BSMT-N3 is left uninsulated (see Figure 3).

Figure 3: Comparison of insulation strategies for joist ends BSMT-N-1/2/3, pre-drywall

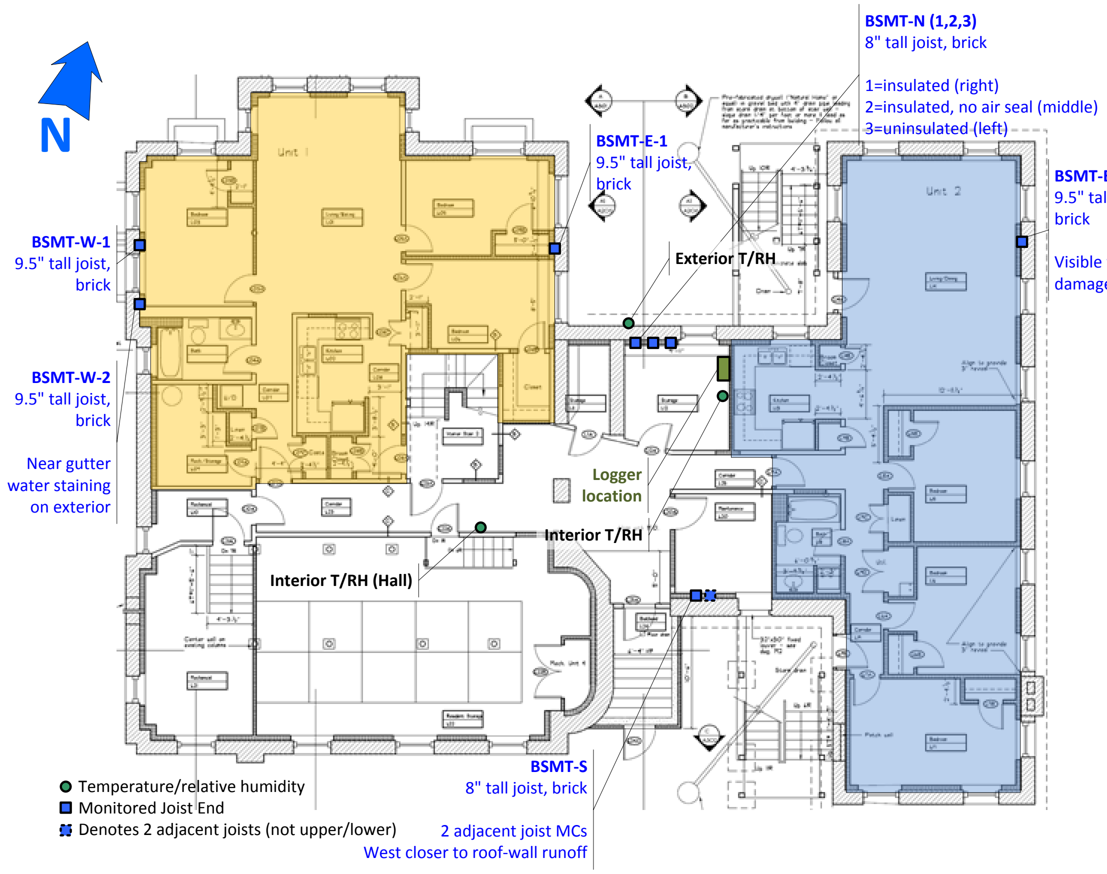

Figure 4: Location of monitored joist ends at basement level (basement ceiling)

BSMT-E2 is of interest because it shows evidence of previous water penetration (staining of the beam end). The east orientation at the rear of the building also has the highest exposure for driving rain. During construction, it was unclear if bulk water issues were solved or still active.

BSMT-W1 and BSMT-W2 are of interest because during the site inspection, rainwater was being deposited on the wall near BSMT-W2. BSMT-W1 was set up to capture the mostly-dry field of the wall as a comparison.

BSMT-S1 is of interest because hygrothermal simulations (Ueno 2012) indicated that south-facing embedded wood members could be vulnerable to moisture accumulation due to summertime inward vapor drives.

On the first floor, joists were only monitored in hollow clay block walls, due to access issues. Monitoring was installed in north, south, and east-facing joists (Figure 5). The east-facing joist has noticeably softer wood that is a different color; this difference in wood species may have an effect on moisture content measurements via electrical resistance.

The interior renovation was “staged,” on a unit-by-unit basis, so joist ends were insulated and air sealed over time. Construction heating was used intermittently during construction; the strongest signal of heated conditions was at the front (west) wing, which contains BSMT-W1, BSMT-W2, and BSMT-E1. The remaining joists typically ran close to ambient temperatures and dewpoints.

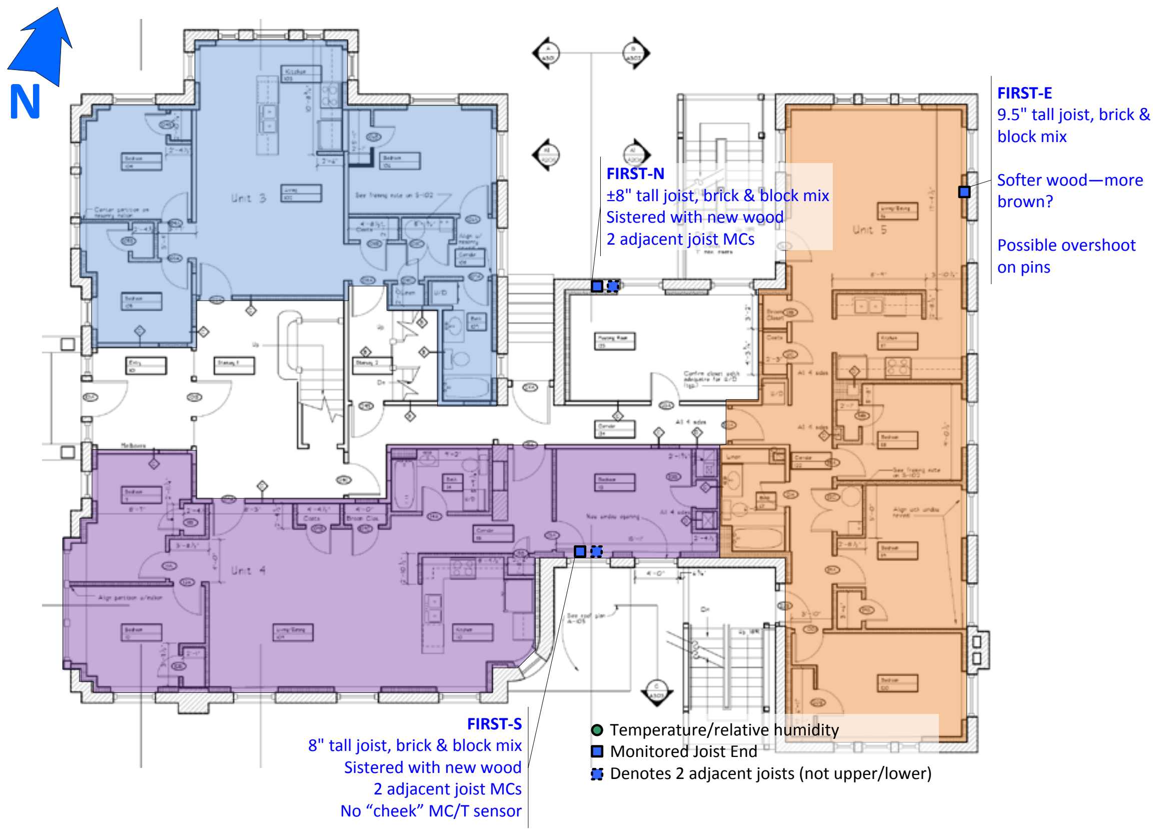

Figure 5: Location of monitored joist ends at first floor (first floor ceiling)

JOIST SENSORS PACKAGE

Three types of sensors are used to monitor conditions at the joist end:

- Temperature sensors (10k NTC thermistors (accuracy ±0.2°C)
- Relative humidity (RH) sensors (thermoset polymer capacitive based sensors with onboard signal conditioning (accuracy ±3% between 10 & 90% RH)
- Wood Moisture Content (MC) (in-situ electrical based resistance measurements between corrosion resistant insulated pins)

The specifics of these sensors are covered in detail by Straube et al. (2002). The sensor package installed at each joist is shown schematically in Figure 6. Note that the ends of the joists are "fire cut," or cut at an angle so that a fire which burns through a joist will not collapse the masonry wall by "levering" the structure upward and outward.

The moisture content at the embedded end of the joist is monitored by two pairs of extended electrical resistance pins, which are driven from the interior side through pilot holes. Moisture contents are typically measured at low and high portions of each joist end. This is meant to capture whether or not moisture contents are higher where the joist is seated into (and in direct contact with) the mortar and masonry walls. The pins are driven to measure moisture content at the outermost 1"/25 mm of the beam.

In some cases, instead of a low/high pair, two "lower" moisture content sensors were installed in adjacent beams. These cases are noted in the description of sensor locations in Figure 4 and

Figure 5; it was done at BMST-S, FIRST-N, and FIRST-S.

The side face or "cheek" of the joist is also measured for moisture content and temperature. This was done primarily as a reference check: it provides a third reference point for moisture content measurement anomalies, which might be due to wood species differences. In addition, it provides some spatial resolution: it can indicate the extent of moisture migration, when the deeply embedded end of a joist shows high moisture contents. This "cheek" location is typically concealed within the interior insulation after spray foam is applied.

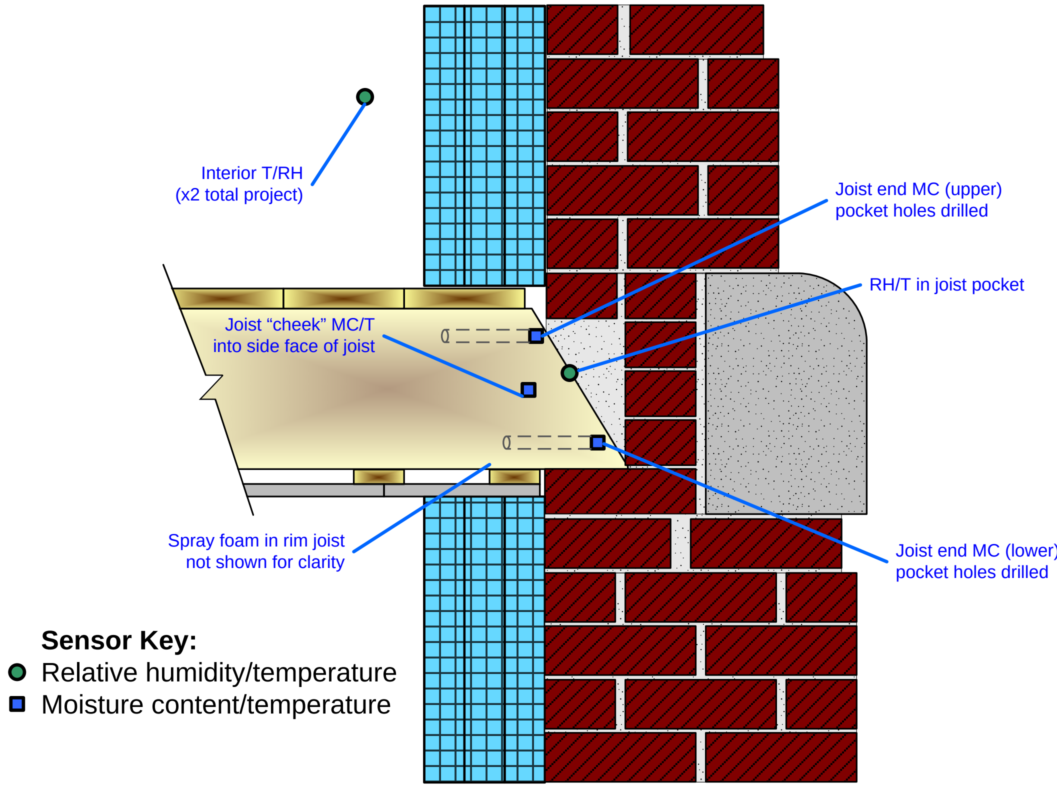

Figure 6: Schematic of typical joist end sensor monitoring package

Figure 7: 6" extended moisture content pins (left) and installed moisture content pins (right)

The joist ends moisture pins are 6"/150 mm long sharpened stainless steel pins attached to wire leads, as shown in Figure 7 (left). Pilot holes were drilled at an shallow angle in the beam, using a pocket hole jig; a 1/8"/3 mm diameter hole was then drilled for clearance for the pin, but the joist end was left undisturbed, so that the pin would be driven directly into wood fibers. Figure 7 (right) shows the upper and lower joist end moisture content measurements and the "cheek" moisture content/temperature measurement.

The pocket holes for the joist end moisture contents were sealed from interior air and water vapor with a vapor-impermeable synthetic rubber caulk. The joist pockets were air sealed from the interior with polyurethane foam.

A temperature and relative humidity sensor is installed within the "pocket" where the joist is embedded in the masonry wall. Installation of this sensor was not necessarily consistent, as many of these joists were grouted in place with mortar, with a limited (or no) air gap. Other joists had a distinct air gap. A lack of an air gap increases the vulnerability of an embedded wood member, as the wood is in direct capillary contact with the moisture-absorbent masonry on the sides (as well as the bottom).

ADDITIONAL SENSORS & DATA COLLECTION LOGISTICS

Interior temperature and relative humidity conditions are measured at two basement locations, as shown in Figure 4; the basement level was chosen because the majority of the sensors are located on this floor. The front of the building (west) was heated with temporary construction heat, while the rear portion is operating near ambient conditions. The two interior sensors measure these two disparate conditions.

An exterior temperature and relative humidity sensor (Campbell Scientific HMP60 Temperature and Relative Humidity probe) provides outdoor conditions synchronized to the joist end measurements; additional outdoor weather conditions (including precipitation, and wind speed and direction) are provided by local weather station data (Lawrence Municipal Airport/KLWM).

Data are being collected by a Campbell Scientific CR1000 measurement and control system, installed in a basement storage room. Data are being measured at five minute intervals, and average values are recorded hourly. No battery backup for the data logger is provided; however, the unit has non-volatile memory, and will resume data collection after a power failure

RESULTS (OVERVIEW AND BOUNDARY CONDITIONS)

Roughly two years (25 months) of data have been collected and analyzed to date (December 2012 through January 2015); however, there are some limitations to the data collected thus far:

- The building is still under construction; it is an ongoing renovation that is nearing completion in winter 2014-2015. As a result, much of the building was at cold interior temperatures through the winters, as opposed to typical (heated) interior conditions.
- Most joists received interior insulation (their final completed state) partway through monitoring. However, this is useful as a before/after comparison.

Interior and exterior temperatures are shown in Figure 8; they include both site-collected temperature (T ambient) and airport weather station data (T KWLM airport). Intermittent construction heating was used during the winters; the front portion (T Hallway) typically had interior temperatures in the 50-75°F (10-24°C) range, but with great variability. The rear of the building (T Logger) had conditions close to ambient, with some heating in winter 2013-2014. The start of heated periods is noted in Figure 8.

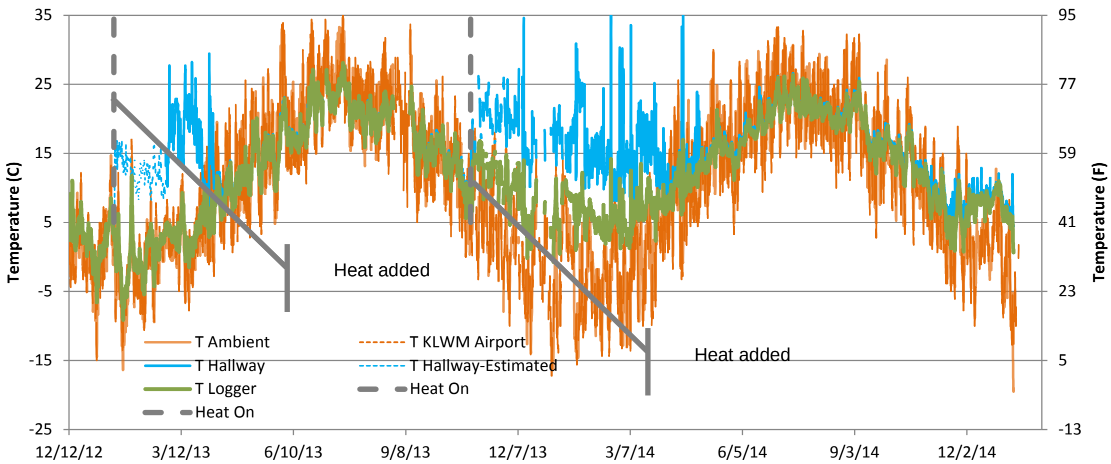

Figure 8: Exterior and interior temperatures; with airport (KLWM) temperature data

Interior temperature and RH conditions were used to generate dew point temperatures (absolute air moisture content), which were compared with outdoor dewpoints. Interior dewpoints mostly track exterior conditions, given the lack of airtightness at the active jobsite, and the lack of interior moisture generation. Summertime interior RH levels are in the 60-90% range (high dewpoint and cool conditions). Wintertime RH levels are in the 30-70% range in unheated spaces, and 10-50% in the intermittently heated spaces.

JOIST MOISTURE CONTENT MEASUREMENTS: BASEMENT TEMPERED SPACES

This section covers the joist ends on the basement level in the tempered/unheated wing of the building, which includes BSMT-N1/N2/N3, BSMT-E2, and BSMT-S. The graphs below plot moisture content (on the left-hand axis) for the lower and upper joist end locations, and the "cheek" moisture content measurement (as a comparison point). No wood species correction factor is used. The relative humidity measured in the joist pocket is plotted on the right-hand axis. The introduction of construction heating in winter 2013-2014 is plotted.

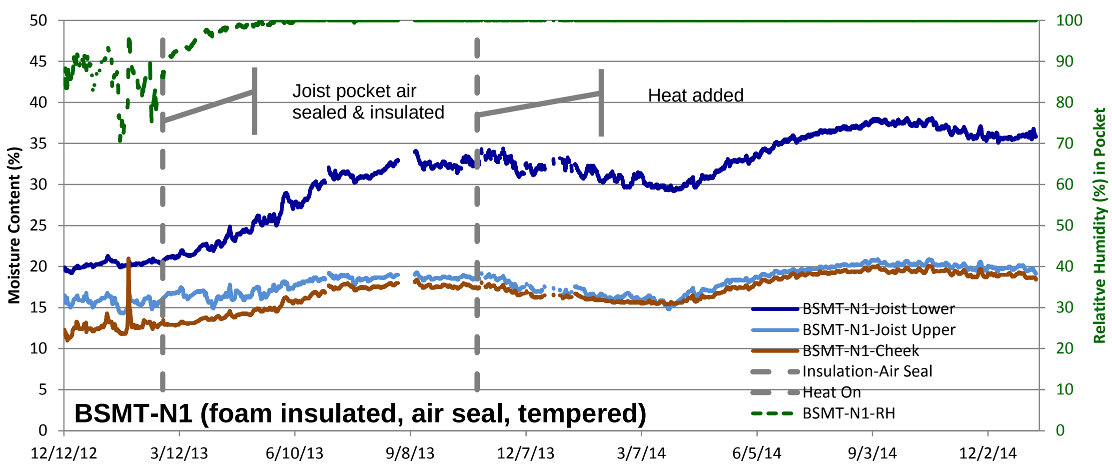

Figure 9: Basement North 1 (insulated) joist end moisture contents and relative humidity

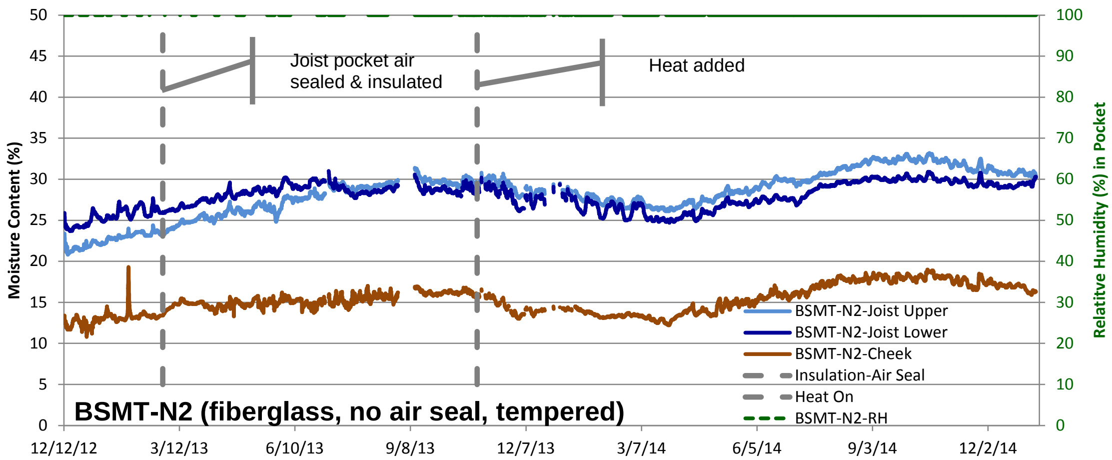

Figure 10: Basement North 2 (fiberglass) joist end moisture contents and relative humidity

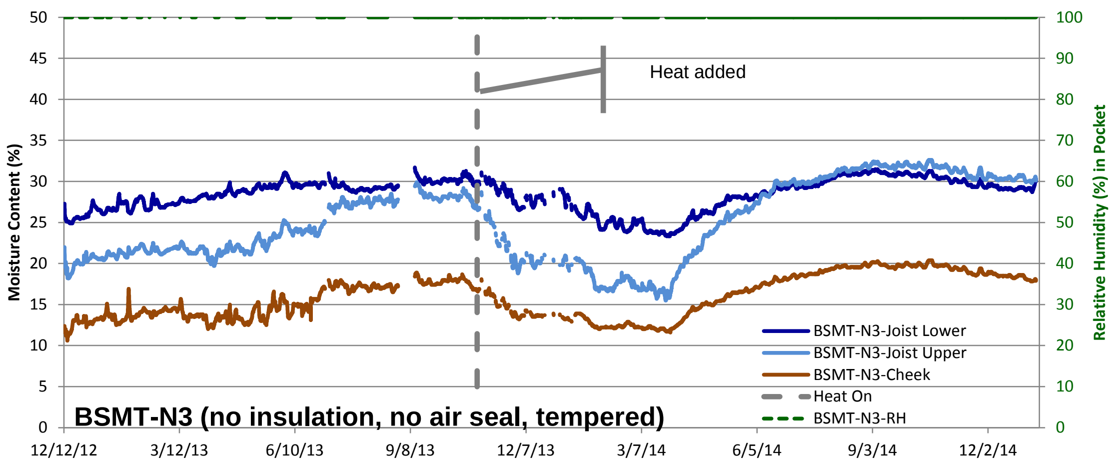

Figure 11: Basement North 3 (uninsulated) joist end moisture contents and relative humidity

The joist pocket RH measurements were either a constant 100% (BSMT-N2 and BSMT-N3), or a quick rise to 100% (BSMT-N1). The reason for the RH difference between BSMT-N1 vs. BSMT-N2/N3 was not evident; temperature differences between joist ends were a maximum of 1°F/0.5°C. Visual inspection of the T/RH sensor installation did not show any significant installation differences between the three joists.

Moisture content measurements consistently showed that the lower joist end was wetter than the upper joist end. This can be attributed to direct contact with the masonry, gravity drainage of bulk water, deeper embedment at the bottom of the beam (greater drying at the top), and/or more of an air pocket at the top of the beam. The cheek measurement was drier than the joist end measurements in all cases.

The joist end moisture contents are higher than typical levels recommended for durability: lower joist ends are mostly in the 25-38% range (N1 joist lower was wettest by far); upper joist ends 15-32%, and joist cheeks 12-20%.

There is a distinct seasonal cycle in moisture contents: peaks occur during late summer/early fall (September). It is more telling to note that there is a drop in MCs when heat was introduced in October 2013, especially in N3 (uninsulated). An outward temperature gradient would result in outward drying of the beam end; summer conditions have an inward water vapor gradient.

There is not a distinct moisture difference between the three joist ends: although N1 (insulated) has very high “lower” MCs, measurements at other parts of the joist are drier than N2 and N3. In addition, high moisture contents are experienced by all three joist ends.

The moisture contents were plotted with driving rain deposition on the north wall, calculated using methods from Straube and Burnett (2005). Individual rain events showed no distinct responses in the measured data.

BSMT-E2 showed generally similar patterns: it is in unheated conditions, and is not insulated or air sealed. The pocket remained at 100% RH throughout the monitoring period, with joist end moisture contents in the 20-30% range.

The south-facing basement joist is plotted in Figure 12; moisture contents are substantially lower (~10-16%) than the north- and east-facing basement joists, and the relative humidity is markedly lower (seasonal rise and fall between ~75-100%). This is attributed to the warmer temperatures (due to solar gain) on this orientation. These drier conditions are a function of solar heating, which is evident if north and south temperatures are compared. The BSMT-S joist end measurements are a left/right pairing, not an upper/lower pairing.

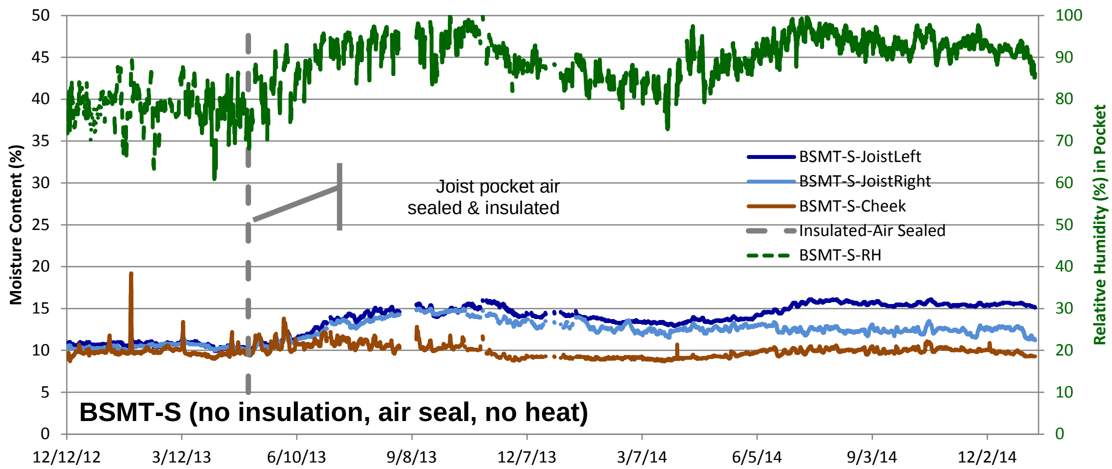

Figure 12: Basement South joist end moisture contents and relative humidity

JOIST MOISTURE CONTENT MEASUREMENTS: FIRST FLOOR

There are three joists monitored on the first floor, which include FIRST-N, FIRST-E, and FIRST-S. These joists are primarily installed in hollow clay block backup wall. Temperatures were generally warmer than basement conditions.

FIRST-N showed generally similar patterns to basement north and east measurements, with joist end MCs in the 20-30% range, and continuous 100% RH conditions.

FIRST-E showed much drier conditions (9-15% MC) throughout the monitoring, and RH levels rising and falling seasonally between 50 and 90% (high in summer); it is in unheated, uninsulated, and unsealed conditions. It has higher summertime temperatures (solar gain) than the east-facing joists on the basement level.

FIRST-S also had low moisture contents (9-12%), with RHs cycling between 50-90%.

JOIST MOISTURE CONTENT MEASUREMENTS: HEATED WING BASEMENT

There were three joist ends on the basement level that received intermittent wintertime construction heat (BSMT-W1, BSMT-W2, and BSMT-E-1).

At the beginning of monitoring, the joists were uninsulated and unsealed. Joist pocket RHs started near 100%; when heat was added, RH and MCs drop sharply (Figure 13 and Figure 14, "Heat added"). Going into spring and summer (following sealing/insulation of the joist ends), RH rises to a constant 100%, and moisture contents rise (peak joist lower MCs 25-30%). However, in the autumn, both of these levels fall in tandem. The drop coincides with both seasonal temperature changes (colder conditions outdoors), and the re-activation of the heating system ("Heat added"). This shows that even with insulation and air sealing, interior heating can cause drying at joist pockets.

The summertime rise and fall in RH and MC is consistent with the temperature-driven inward vapor drive issues found in one-dimensional hygrothermal simulations by Ueno (2012).

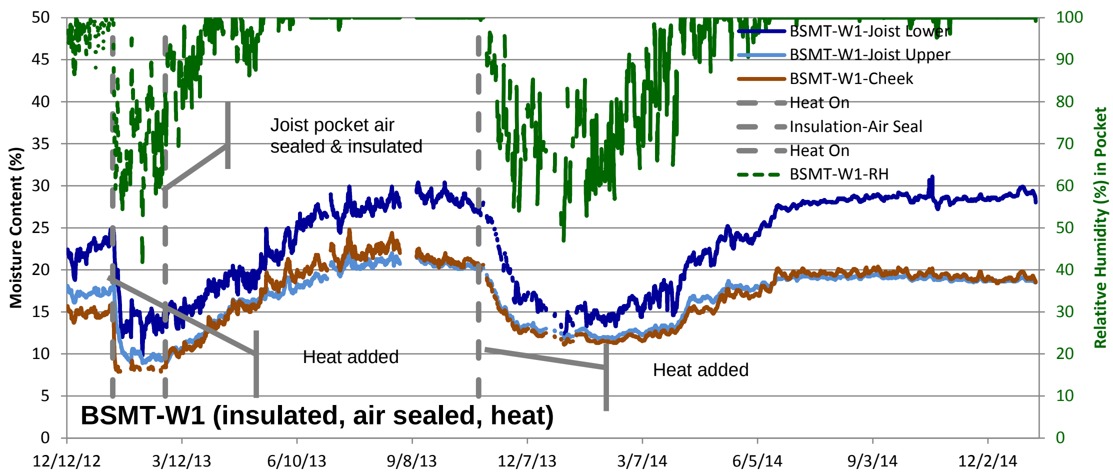

Figure 13: Basement West-1 joist end moisture contents and relative humidity

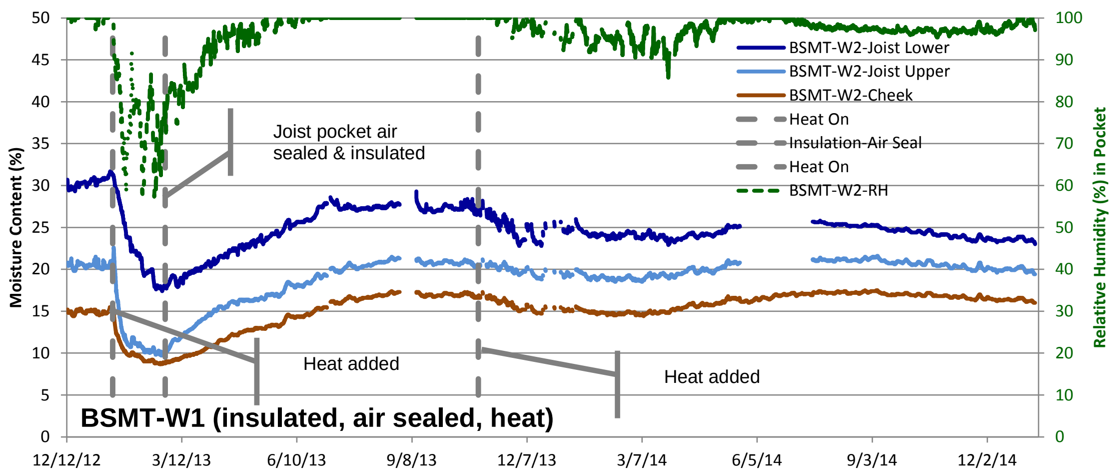

Figure 14: Basement West-2 joist end moisture contents and relative humidity

One expected difference between BSMT-W1 and BSMT-W2 was increased wetting of W-2 due to rain exposure; no pattern was apparent.

Joist BSMT-E1 had somewhat similar behavior; however, moisture contents were higher and pocket RH remained at 100% throughout the monitoring. This was explained by temperature differences: the east joist pocket was consistently colder in the winter than the west joist pockets. Solar exposure and proximity to the wintertime heat source may both play a role.

JOIST END “STUB”

Two joist ends remained embedded in the masonry wall from a joist that was removed, in the rear addition (southeast and southwest corners). These samples were removed for inspection: one joist end (southeast) was damp to the touch, and had a distinct odor of mold. However, when the wet joist end was probed with a screwdriver, it was structurally intact, with no evidence of rot, decay, or punkiness. Both joist ends had evidence of earlier water staining.

The moisture contents of these joist ends were measured with a resistance (pin-based) MC meter, to examine the spatial MC pattern (Figure 15). The MCs are color coded (red high risk, green safe) in these diagrams. The MCs of the underside (horizontal bearing surface) of the joist ends are signified by the rotated text.

Inboard Face | Outboard Face | Outboard Face | Inboard Face

Figure 15: Joist end moisture contents for southeast (left) and southwest (right) corners

One significant observation is that embedded joist ends—at least the species/samples taken at this building—can withstand sustained high moisture conditions (40% MC) without suffering structural damage or rot. These high moisture contents were observed in a joist end with no insulation present, showing that there are important risk factors to joist ends other than insulation/no insulation; it was an unheated portion of the building.

There is a strong effect of orientation on joist end MCs: the southwest joist end had dry MCs, well within the safe range, while the southeast joist had MCs that would be considered at risk of failure. The spatial MC measurements show that the joist end portions most deeply embedded in the wall had the highest moisture contents, in particular, the bottom portion of the joist. Both of these observations corroborate monitoring data.

CONCLUSIONS AND FURTHER WORK

Overall, the relative humidity and moisture content conditions measured in joist pockets are higher than the range considered conducive to long-term durability. Most the joist pockets have sustained 100% RH conditions, and many moisture contents remain are in the 20-30% (or higher) range for extended periods.

Traditional guidance is to keep wood MC below 20%; decay fungi are inhibited below this level (Carll and Highley 1999), with optimum growth occurring in the 25%–30% MC range. Decay fungi become active at MC levels above 28% (Straube and Burnett 2005). However, the MCs should interpreted with temperatures in mind. Biological activity is inhibited at low temperatures, so high MCs in mid-winter pose less risk than in warmer seasons. Sustained high MCs at moderate temperatures pose the greatest durability risks.

Many of these joists started at high MC levels, before the installation of insulation or air sealing. No evidence of damage was seen at the joist ends, indicating that these wood members—especially dense, old-growth (1906/1930 construction) framing—can survive these moisture contents without damage. This is further corroborated by the joist end “stub,” which was measured at 30-40% MC, with no evidence of structural damage.

The collected data indicate that the introduction of heating causes drying at the joist pockets, even in joists that have been insulated and air sealed. In contrast, peak moisture contents are typically seen during the summer. This is attributed to the direction of the moisture vapor gradient: it is inward in summer, and outward in winter (with heated conditions). However, the moisture response of joists for normal heated and occupied operation (i.e., with interior moisture generation) has not yet been measured.

Orientation has a major effect on RH and MC levels: all south-facing joists had MCs well within the safe range, due to solar heating and drying. The east and west orientations had a mixture of results, but many remained above the 20% MC level, while the north side joists were generally among the wettest.

Another factor in joist pocket moisture conditions is deposition of wind-driven rain on the exterior masonry. MCs were plotted with rainfall, and minimal correlation was seen. Based on previous work (Ueno and Straube 2008), wood moisture contents often have a relative slow response, especially when adsorbing/gaining moisture. Rain impacts are more likely to appear in the data as seasonal effects, rather than in response to individual wind-driven rain events.

There was a repeated pattern of joist end MCs at the upper and lower portions of the pocket. The lower joist end was consistently wetter than the upper joist end, which can be attributed to contact with the masonry pocket, gravity drainage of bulk water to the bottom of the pocket, deeper embedment at the bottom of the beam (greater drying at the top), and/or more of an air pocket at the top of the beam. The cheek measurements were drier than the joist end measurements in almost all cases, due to greater hygrothermal connection to interior space than the masonry pocket. The joist pocket relative humidity measurements match the patterns of wood moisture content measurements.

Another potential explanation for the higher moisture contents at the lower joist location is migration of salts from the masonry into the wood, which would increase apparent moisture content due to electrical conductivity changes. This could be ascertained by analyzing salt content in drilled wood shavings, and/or gravimetric measurements of cut samples.

The comparison between spray foam insulation, fiberglass insulation, and no insulation (BSMT-N1/N2/N3) did not show a significant difference between these cases. Based on other observations, it appears that there are secondary factors—besides insulation—which can have a strong effect on joist end MCs. The introduction of typical interior temperature and humidity levels will provide greater insight into the difference between these conditions, and whether or not the insulated (but non-air sealed) joist pocket has risks of condensation.

There is weak evidence to suggest that joists embedded in hollow clay block on the first floor (as opposed to brick) might have greater drying, but the sample size is too small to draw any conclusions.

Monitoring will continue at this site; upper-floor units are currently complete, and basement-level units will likely be finished winter 2014-2015.

ACKNOWLEDGEMENTS

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