NAHB RESEARCH CENTER

Initial Study of the Moisture Performance of OSB-Sheathed Walls in Homes in Climate Zones 4 and 5

Interim Report

6/30/2010

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Purpose

This study is designed to document construction practices and obtain performance data for new houses framed in the fall of 2009 in the same geographical areas and by the same builders that experienced buckling of OSB wall sheathing in the winter of 2008-2009. The objective of the study is to attempt to isolate the variables or a combination of variables that are contributing to OSB wall sheathing buckling. In addition, moisture performance information is collected by sensors installed in wall cavities to better understand the in-service moisture conditions of OSB-sheathed walls during the first winter and spring following the construction process.

Background

Field Observations

An apparent increase in OSB wall sheathing buckling was reported during the winter season of 2009 by builders in the Midwestern states and Pennsylvania. The homes with reported OSB buckling are located in cold climate (Climate Zones 5 and 6) or at the boundary between the cold and mixed-humid climate (Zone 4).

Interviews were conducted with several builders that experienced this condition. The problem manifested itself as "wavy" vinyl siding (Figures 1-4). The repairs typically involve removal of the siding and replacing of buckled OSB panels. Evidence of the panels having elevated moisture levels was observed during the repairs, including in some cases observations of a 'mold-like substance' on the interior face of the panel. During repairs made in the winter months, in some cases frost was also observed on the exterior face of the panel.

Figure 1 – Wavy lap siding due to buckled OSB panels on the rear wall of a house

Figure 2 – Wavy siding due to buckled OSB panels on a side wall of a house

Figure 3 – Wall with buckled OSB panels (siding removed exposing water resistive barrier)

Figure 4 – Removed buckled OSB panel

OSB Characteristics

OSB panels are made of wood strands oriented and glued together. Because wood changes dimensions as it loses or gains moisture, the OSB panels expand as the moisture content of wood increases in response to the in-service environment. All OSB panels are required to meet the linear expansion limits of Product Standard PS-2 (1) for a maximum average expansion of 0.5% in either panel direction (machine and cross machine) when subjected to a controlled laboratory moisture content change of about 19%.

OSB panels typically arrive to the jobsite at low moisture content (e.g., 5%). OSB manufacturers require a 1/8-inch gap between the vertical panel joints to allow limited expansion of the panels. If the expansion of the panel exceeds the provided gap, the panels are prone to buckling in the direction perpendicular to the wall's plane. For a 48-inch-wide panel with a linear expansion of 0.5%, installed with a 1/8-inch gap, the calculated maximum moisture content change for panels to come to full contact without additional room to expand is about 10%. As it is observed during this study, moisture contents of OSB above 20 and even above 25 percent are not uncommon in walls in the initial months following the construction process – resulting in a total potential moisture fluctuation of 15 to 20%. (It should be noted that sheathing fasteners help restrain the expansion of panels in a wall assembly. A follow-up laboratory study is planned to investigate the relationship between the panel properties and the panel expansion and buckling behavior when attached to wall framing.)

Research Methodology

The research methodology includes the following primary steps:

(1) identifying new homes built in the Fall of 2009 by the same builders in the same geographical areas that experienced OSB buckling in the Spring of 2009,
(2) observing OSB installation on each selected home,
(3) collecting relevant design, construction, and material data for each selected home,
(4) installing sensors in walls to measure temperature, dew point, and relative humidity inside the cavity and moisture content of OSB sheathing

(5) measuring air exchange rates through blower door testing for each selected home,
(6) collecting and analyzing data, and
(7) developing conclusions based on the documented performance.

This report summarizes results of Steps 1 through 5 on a total of six homes. Preliminary analysis of measured moisture performance data collected through May 31, 2010 is also included. A more-detailed analysis of the conditions in the wall cavity is planned as a follow-up study using conterminous heating and cooling cycles. Conclusions are drawn based on the analysis completed to date.

Research Homes

A total of six homes/jobsites were made available to the NAHB Research Center by three homebuilders in three different states in climate zones 4 and 5 (Figure 5). A site visit was conducted for each home during the construction process. Form A (see Attachment) was completed for each home/jobsite to document construction details, home design, and material characteristics. Table 1 provides a summary of key characteristics for each home. Table 2 includes wall assembly details.

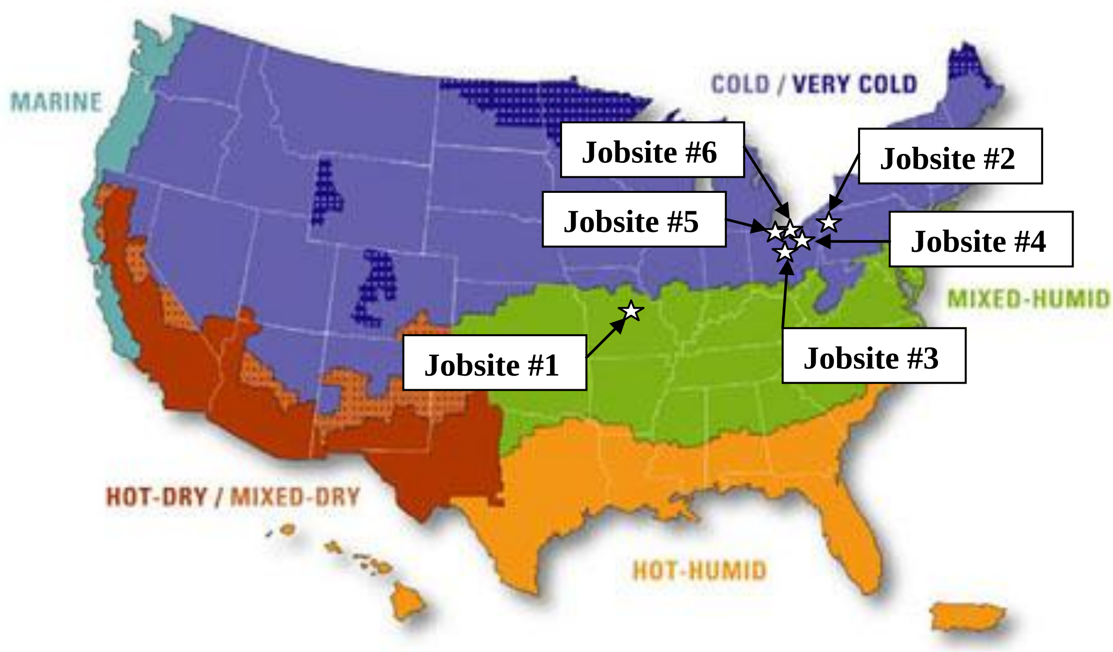


Figure 5 – Jobsite geographical and climate zone locations (2)

Because the building's air tightness is important to its moisture performance, blower door tests were conducted on each home to measure the amount of air changes per hour at 50 Pascal's (ACH_{50}). The blower door tests were performed after completion of construction and before occupancy Results of blower door tests are also included in Table 1.

Table 1 – Jobsite and home details

Jobsite Number	City	State	Climate Zone	Energy Star	Blower Door ACH_{50}[1]	Square Footage[2] (ft^2)	Number of Occupants	Basement		Attached Garage		Heating System	Cooling System	Ventilation	Fire-place
								Cond.	Finish	Cond.	Finish				
1	St. Louis	MO	4	Yes	2.49	5,700	Model Home	Yes	Yes	Yes	Yes	Gas (92.1 AFUE)	Electric (SEER-14)	TBD[3]	*Information on fireplaces is in the process of being assembled*
2	Valencia	PA	5	Yes	2.41	5,300	3	Yes	No	No	Yes	Electric (8.0 HSPF)	Electric (SEER-13)	Kitchen/ Bathrooms	
3	Mansfield	OH		No	2.12	4,000	4	Yes	No	No	Yes	Electric (8.1 HSPF)	Electric (SEER-13)	Kitchen/ Bathrooms	
4	Wadsworth			Yes	3.71	3,000	2	Yes	No	No	Yes	Gas (93 AFUE)	Electric (SEER-14)	Whole-house	
5	Lorain			No	3.27	2,800	4	Yes	No	No	Yes	Gas (92.3 AFUE)	Electric (SEER-13)	Kitchen/ Bathrooms	
6	North Ridgeville			No	2.83	3,000	3	Yes	Partial	No	Yes	Gas (92.3 AFUE)	Electric (SEER-13)	Kitchen/ Bathrooms	

1. Depressurization blower door test results reported.
2. Home square footage includes the basement.
3. The information provided by builder on this house is inconsistent with the plan specifications. A follow-up effort is underway.

Table 2 – Wall details

Jobsite Number	City	State	Framed Stories	Framing Size[1,2]	Stud Material/ Grade	Stud Moisture Content[3] (%)	Air Sealing	Wall Insulation/ Vapor Retarder	Water Resistive Barrier (Perms[4])	Finish
1	St. Louis	MO	2	2x4	SPF/Stud	9-17	Sill, Rim Joist	R-13/ Kraft paper	Brand 1 (46.6)	Brick, Cement Fiber Board
2	Valencia	PA	3	2x6	SPF/Stud	11-15	Plates (top, bottom, and sill), Rim Joist	R-19/ Kraft paper	Brand 2 (56)	Vinyl
3	Mansfield	OH	2	2x4	SPF/Stud	9-15	Plates (top, bottom, and sill), Rim Joist	R-13/ Kraft paper	Brand 2 (56)	Vinyl
4	Wadsworth	OH	1	2x4	SPF/Stud	10	Plates (top, bottom, and sill), Rim Joist	R-13/ Kraft paper	Brand 2 (56)	Vinyl
5	Lorain	OH	2	2x4	SPF/2	12-13	Bottom Plate	R-13/ Kraft paper	Brand 3 (63)	Vinyl
6	North Ridgeville	OH	1	2x4	SPF/Stud	8-14	Bottom Plate	R-13/ Kraft paper	Brand 3 (63)	Vinyl

1. Spruce-Pine-Fir typical wood species for all jobsites.
2. Stud spacing of 16 inch on center was used for all jobsites.
3. Framing moisture content was measured during site visit.
4. Perm ratings for water resistive barriers obtained from product specifications physical properties data sheets.

Specific dates for construction of each home are given in Table 3. Framing on all homes occurred primarily during the month of November. Occupancy of the homes began in January and February of 2010. The total precipitation by month during the time of construction is provided for each site in Figure 6, including historic monthly averages for comparison. Generally, total precipitation during the observation period measured below historic monthly averages except for October and January when precipitation levels were higher than average. Table 3 also includes the dates of the NAHB Research Center site visits. NAHB Research Center staff was present at the time of the wall framing only for jobsite 1 (St. Louis, MO). For the other five sites, the visit was conducted a few days after the framing had been completed and the wall framing was still exposed.

Table 3 – Home construction dates

Jobsite Number	Foundation Start	Framing Start	Roof Enclosed	House Enclosed	Occupancy Start	NAHB Research Center Site Visit
1[1]	10/23/09	11/03/09	11/12/09	11/13/09	12/22/2009	11/04/09
2	10/29/09	11/17/09	12/10/09	12/10/09	1/18/10	11/20/09
3	10/22/09	11/10/09	11/11/09	11/12/09	1/6/10	11/12/09
4	10/19/09	11/5/09	11/09/09	11/10/09	2/22/10	11/12/09
5	10/20/09	11/10/09	11/18/09	11/24/09	01/19/10	11/12/09
6	10/14/09	10/30/09	11/12/09	11/19/09	01/25/10	11/12/09

1. Home is a model home, occupancy date is the date the home became open for display.

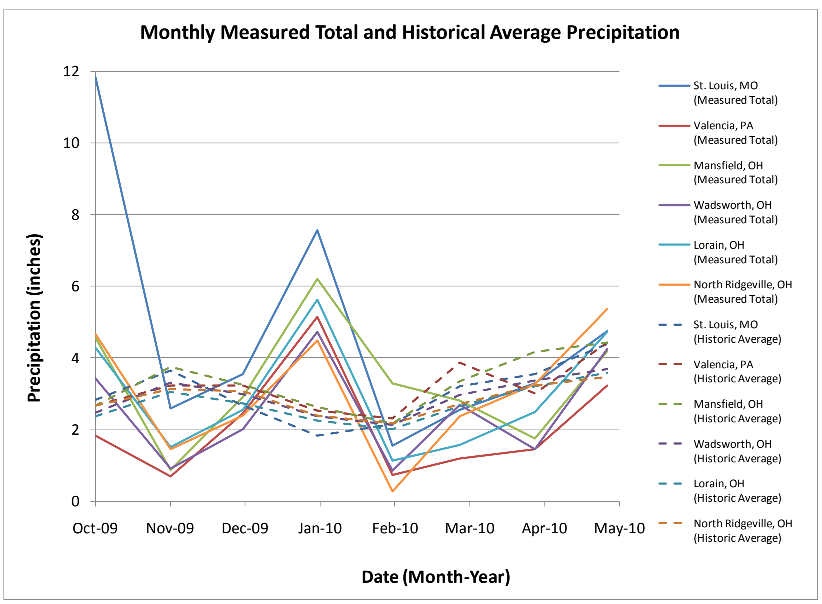


Figure 6 – Comparison of precipitation amounts for each jobsite location

Figures 7-12 show first-story plans and photographs of each home. In each home, a 'test wall' was selected for detailed documentation of the OSB installation process and monitoring of the moisture performance. The test walls were selected based on (1) wall orientation and (2) the amount of openings (i.e., doors or windows) in the wall. Because moisture content in the OSB panels is the driving factor for panel expansion and possibly buckling, sidewalls with a northward orientation were the primary choice for investigation. These walls were selected because of higher expected moisture contents due to reduced sun exposure, thus leading to lower wall temperatures and decreased drying potential. The walls with fewer openings are expected to be more prone to buckling because of increased amounts of sheathing and cumulative expansion across the face of the wall. The test wall is always a first floor side wall (left or right side elevation) with few openings and the majority of the wall adjacent to livable space. Panel dimensions, gapping between installed panels, and panel attachment details were observed and documented for each test wall (Table 4).

The OSB panels used in wall construction of the six homes came from a total of six different mills from five manufacturers. Because panel linear expansion properties vary by mill based on the materials used in panel fabrication (wood species, strand orientation, resin type and content, wax, etc), panels are classified by manufacturer (1 through 5) and mill location (A or B).

OSB samples were taken from wall sheathing panels at each of the jobsites for testing linear expansion properties. The testing was conducted at the NAHB Research Center's laboratory in accordance with PS-2(1). Results from the linear expansion testing are provided in Table 4. Linear expansion in the machine grain direction was substantially below the 0.5% limit for all six mills. Linear expansion in the cross direction varied substantially between the mills from as low as 0.22 to as high as 0.57. Panels from Mill 2-B consistently exceed the PS-2 0.5% limit. Panels from Mill 1 and Mill 5 were at or near the 0.5% limit.

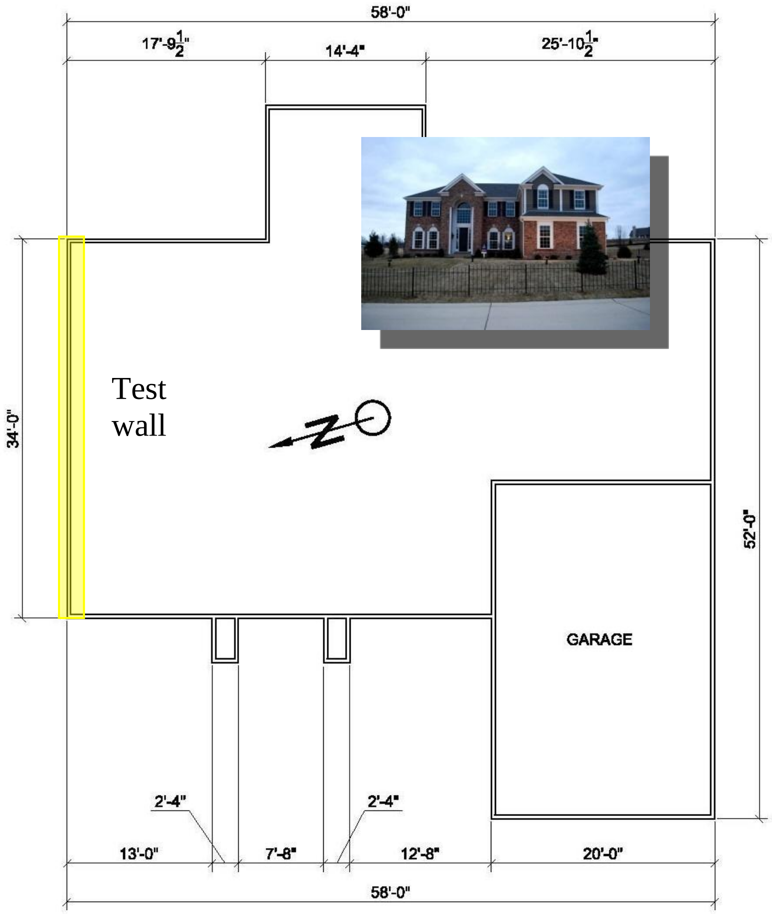


Figure 7 – Jobsite #1 test wall location and orientation

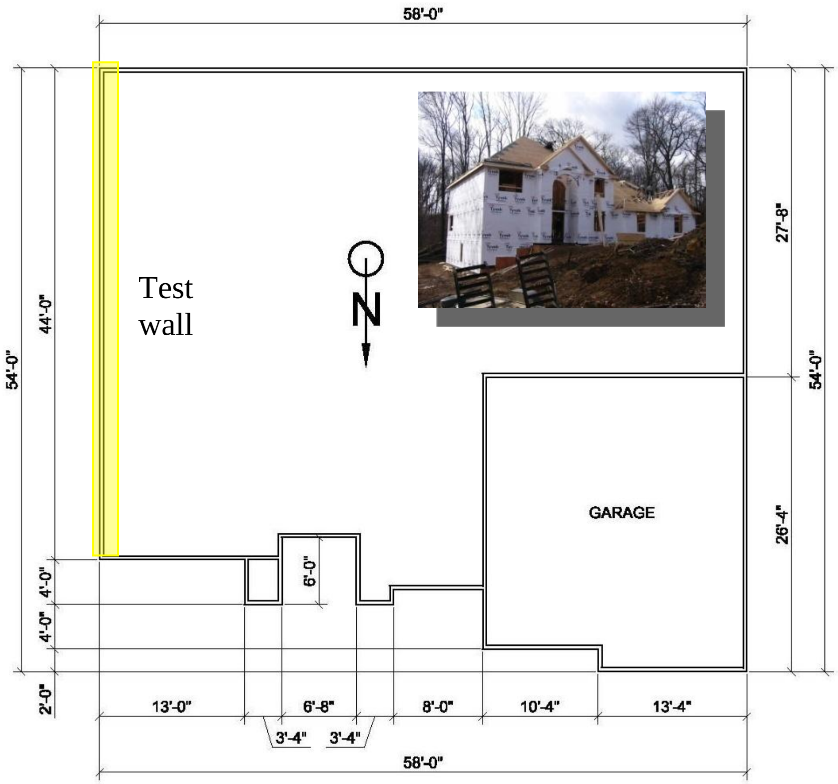


Figure 8 – Jobsite #2 test wall location and orientation

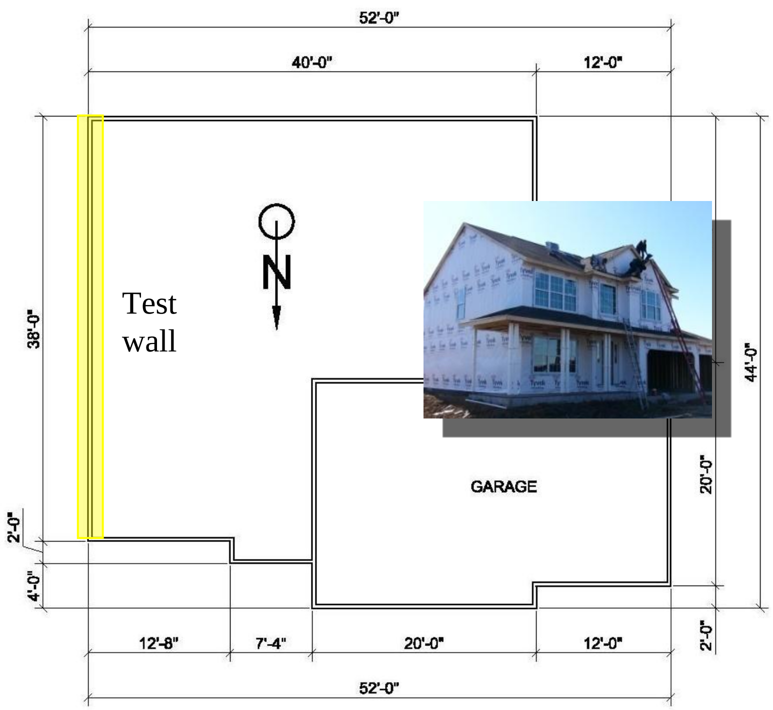


Figure 9 – Jobsite #3 test wall location and orientation

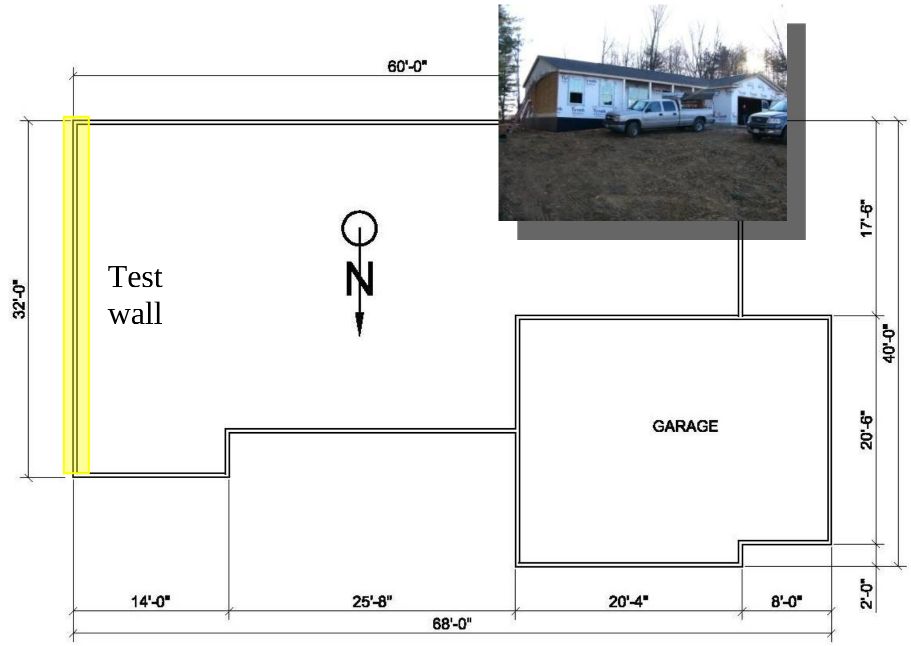


Figure 10 – Jobsite #4 test wall location and orientation

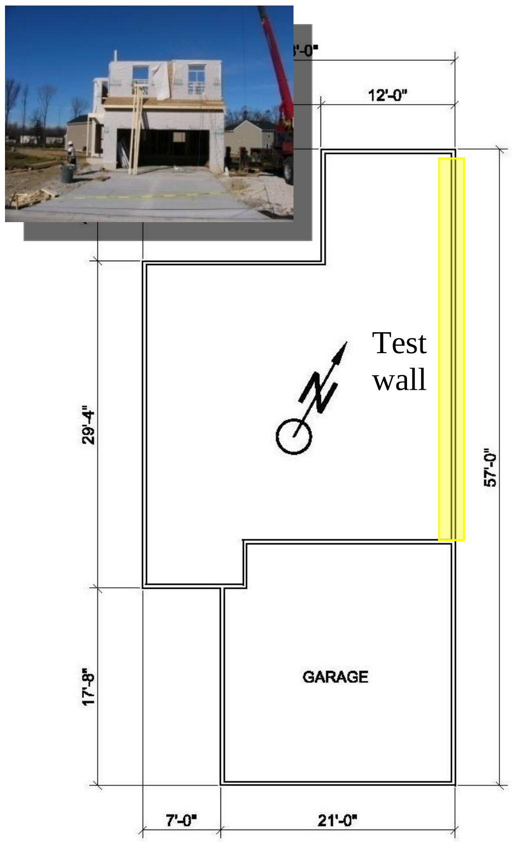


Figure 11 – Jobsite #5 test wall location and orientation

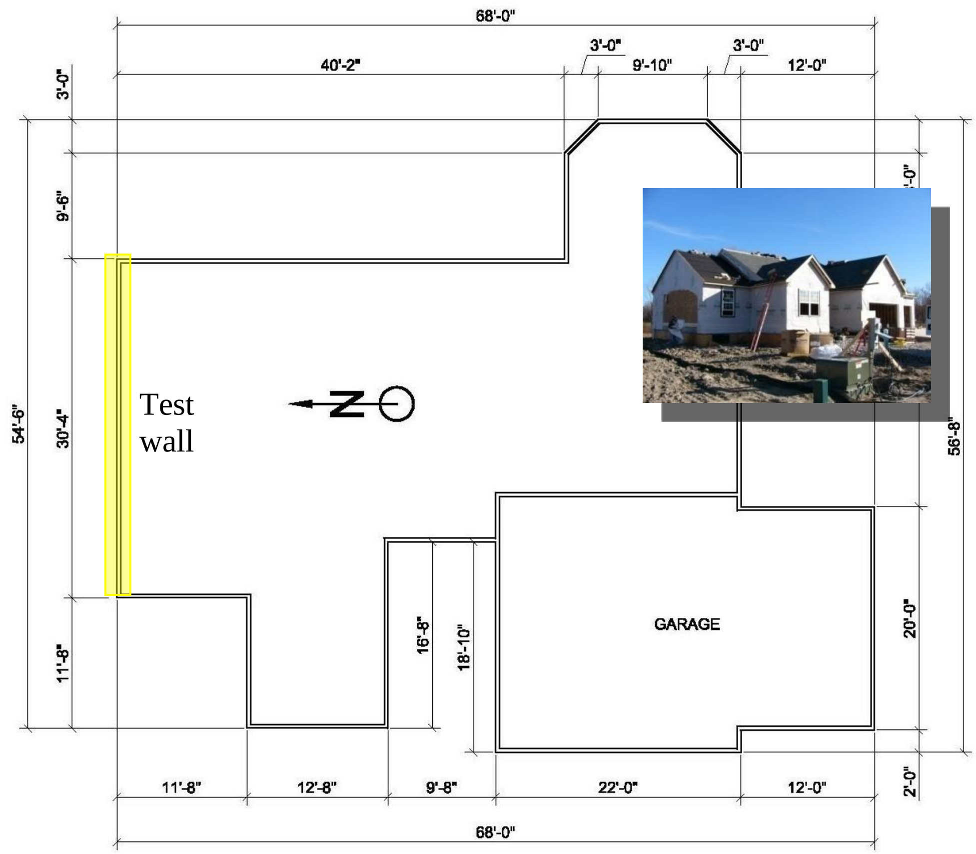


Figure 12 – Jobsite #6 test wall location and orientation

Table 4 – OSB panel properties and installation details

Jobsite	OSB Mill	Floor	Average Moisture Content at Inspection	Panel Dimension		Installed Vertical Edge Gap	Panel Orientation	Fasteners			Linear Expansion	
				Mean	Dev.			Edge Distance	Orientation to Adjoining Panel Edge	Over-driven	Grain Direction	Mean
1	Mill 1	1	<6%	47.910	0.027	0-3/16”	Vertical	0-1/2	Perpendicular	Partial	Machine	0.13
											Cross	0.50
	Mill 2-A	2	<6%	47.934	0.023	-		-	-	-	Machine	0.07
											Cross	0.22
2	Mill 3	1	11%	48.036	0.048	0-1/8”		Footnote 1			Machine	0.10
											Cross	0.25
	Mill 2-B	2	10%	47.881	0.013	-		-	-	-	Machine	0.16
											Cross	0.56
3	Mill 4	1	9%	47.948	0.0210	0-5/32”		1/16-1/2	Parallel	Yes	Machine	0.16
											Cross	0.27
	Mill 2-B	2	8%	47.931	0.0342	-		-	-	-	Machine	0.23
											Cross	0.49
4	Mill 3	1	7%	47.972	0.025	1/32-1/8”		1/2	Parallel	Yes	Machine	0.13
											Cross	0.28
5	Mill 5	1	9%	48.060	0.009	1/16-1/8”		0-1/2	Varies	Partial	Machine	0.20
											Cross	0.47
	Mill 2-B	2	<6%	47.866	0.026	-		-	-	-	Machine	0.16
											Cross	0.57
6[2]	Mill 2-B	1	9%	95.938	0.030	0-1/8”	Horizontal	>1/2	Parallel	No	Machine	0.16
											Cross	0.57

1. At the time of the jobsite visit, OSB sheathing was covered with WRB and sheathing fasteners were not accessible for detailed inspection.
2. Linear expansion results from OSB sheathing obtained at Jobsite #5 (panels used were from the same mill and had the same manufacture date).

The home located in Valencia, PA (Jobsite #2) had a wood framed walk-out basement such that one end of the home had three framed stories. The test wall for this home was at the second level as shown in Figure 13.

Figure 13 – Jobsite #2 east wall (test wall highlighted) three stories framed

The framing on Jobsites #4 and #6 was completed before the visit of NAHB Research Center staff. As a result, all excess OSB sheathing panels were removed from the site prior to the visits. For Jobsite #4 the builder was able to obtain OSB panels from their supplier of the same manufacturer and mill; the unique difference between panels installed on the walls and the panels used for linear expansion testing was the manufacture date (installed panels - Sept. 9, tested panels - Sept. 3). No linear expansion samples were obtained from Jobsite #6 because OSB panels were identical to the OSB panels used on Jobsite #5.

In-Service Environmental Conditions Monitoring

Because increased moisture in the OSB panels is the primary driver for panel expansion, sensors were installed inside the wall cavity of the test wall and in several other reference locations of each house to measure the moisture content of the OSB panels and environmental conditions inside the wall cavity. In addition, one or two sensors were installed inside of each home to monitor the temperature and relative humidity inside the house. The ambient weather data was obtained from local weather stations. This section discusses details of the environmental monitoring system and presents preliminary results based on measurements through May 2010.

Monitoring System

Small wireless sensors (Omnisense S-900-1-- Figure 14) were installed in walls in the home to measure the following parameters:

Temperature (-40 to 185 °F)

Relative Humidity (0 to 100%)

Dew Point

Wood Moisture Content (7 to 40%)

The temperature (T) and relative humidity (RH) are measured by an internal sensor located inside the plastic housing. The wood moisture content (MC) is measured through two screws driven into wood based on resistivity of the OSB material. The sensors transmit measurements at set intervals (30 minutes) wirelessly to a gateway (router). The gateway then uploads the measurements to a central location for storage and acquisition on the Omnisense website. Figure 15 shows a typical installation of a sensor before enclosing with insulation.

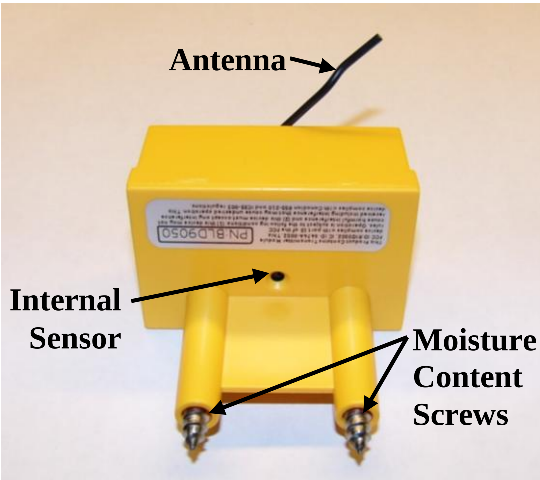


Figure 14 – Omnisense S-900-1 sensor

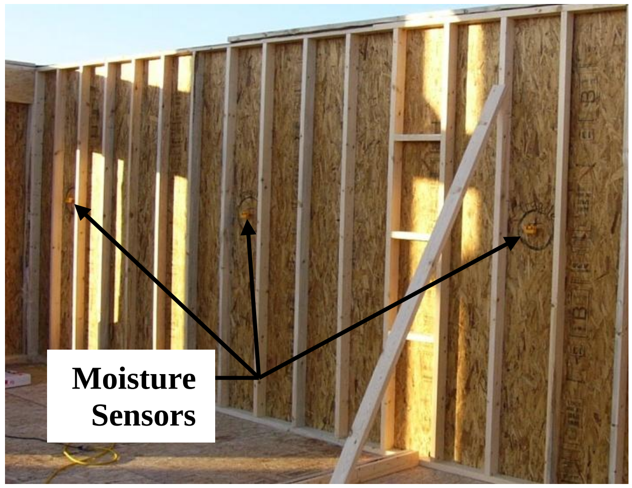


Figure 15 – Installed test wall moisture sensors

Monitoring Sensor Locations

On average, eight sensors were installed in the one-story homes and fourteen sensors were installed in the two-story homes. Sensors were attached to the inside face of the exterior OSB panel in the center of the wall cavity. The sensors were located at an elevation of 5 feet above the subfloor. A minimum of one sensor per wall orientation (i.e., north, west, east, and south) was installed except that three sensors were installed in each test wall, and in two story homes a minimum of three sensors were installed in the second floor exterior wall above the test wall. Table 5 provides individual sensor locations and associated wall orientation for each of the six jobsites. During the planning stages of this study based on discussions with builders it was determined that there was no consistency between OSB buckling and interior room use (e.g., bathrooms with higher humidity). Therefore, sensor locations were not predetermined based on adjacent interior room use.

One sensor was located in the interior of the home to monitor temperature and relative humidity inside the house. Although the intention was to have the interior sensor located as near to the home's thermostat as possible, due to aesthetics and home owner preferences, the interior sensors in five of the six homes were located in the kitchen above cabinets. Daily average ambient temperature, relative humidity, and dew point were obtained from weather stations located near each home.

Table 5 – Sensor locations by jobsite

Adjacent Interior Room Use	Number of sensors (wall orientation)					
	Jobsite #					
	1	2	3	4	5	6
Kitchen	2 (Interior, East)	1 (Interior, East)	1 (Interior, West)	1 (Interior, South)	1 (Interior)	1 (South)
Full Bath	1 (South)	1 (East)			1 (East)	
Half Bath			1 (East)		1 (East)	
Living room	3 (2-North, West)		2 (North, East)			
Family room	1 (North)		2 (East, South)			
Dining room		2 (North, East)			1 (East)	
Great room				1 (North)	2 (North, West)	1 (Interior)
Bedroom/Office	5 (3-North, West, South)	5 (1-North, West, 2-East, South)	4 (North, 2-East, South)	4 (West, 3-East)	4 (North, West, East, South)	5 (3-North, East, South)
Breakfast		1 (South)			1 (East)	
Laundry					1 (East)	1 (South)
Closet/Pantry	1 (East)	2 (East)	2 (West, East)		1 (East)	
Garage	1 (North)	1 (North)	1 (West)	1 (East)	1 (East)	1 (North)

1. Indicates location of interior sensor in the home.

Results of In-Service Environmental Conditions Measurements

The measurements through May 31, 2010 for each home are presented by jobsite, floor level, and exterior wall orientation. All results are reported as daily averages calculated based on the measurements recorded every half hour. Because the primary observation is the OSB moisture content levels, relative humidity and temperature plots are only provided for the first floor locations. The measurements recorded by the sensors installed in garage walls are included for each home. However, it should be noted that garages are constructed as unconditioned space in five of the six homes.

Based on visual observations of the siding in the spring of 2010, none of the six homes exhibited buckling. However, the OSB moisture content increased from less than 6% to 11% at the time of site visit to anywhere from 10% to 25% at the time of first measurements after initial occupancy that started in the months of January and February. Based on these changes in moisture contents and the results of the linear expansion tests, the calculated OSB panel expansions are provided in Table 6. OSB buckling potential is highest for Jobsite #5 with installed panel gaps of 1/8-inch and a maximum calculated expansion of 5/16-inch. Maximum potential panel expansions in the other homes all are in the range of the provided gaps and therefore buckling potential is low. In all homes, the moisture content started trending down in the spring months as the average daily temperature increased. A typical observed drop of OSB moisture content ranged from 5 to 10 percent.

Table 6 – Potential OSB Panel Expansion

Jobsite	OSB Mill	Maximum Moisture Content Increase[1]	Maximum Calculated Panel Expansion	Vertical Edge Gap as Installed
1	Mill 1	16	3/16”	0-3/16”
	Mill 2-A	14	1/16”	-
2	Mill 3	14	1/16”	0-1/8”
	Mill 2-B	13	3/16”	-
3	Mill 4	8	1/16”	0-5/32”
	Mill 2-B	6	1/16”	-
4	Mill 3	-	-	1/32-1/8”
5	Mill 5	23	5/16”	1/16-1/8”
	Mill 2-B	20	5/16”	-
6	Mill 2-B	9	1/16”	0-1/8”

1. The maximum moisture content increase reported in this table is estimated relative to the moisture content at the time of the visit to allow for direct comparison of the calculated expansion with the gap measured at the time of the visit. It is likely that the OSB moisture content at the time of panel installation was lower and the overall change in moisture content was greater.

The daily average OSB moisture contents for each jobsite are provided in Figure 16 through Figure 24. In-service home interior and wall cavity measurements of temperature, relative humidity, and a comparison of dew point versus temperature are provided in Attachment 1. In-service conditions are provided through May 31, 2010 for five of the six homes (data for Jobsite #4 is not yet available due to issues with the homeowner's internet connection). The initiation date of in-service condition monitoring and peak OSB moisture contents for each jobsite are provided in Table 7. Also included in Table 7 is the range of interior relative humidity over the monitoring period. Daily average interior temperatures were approximately 70°F over the monitoring period for each jobsite.

Table 7 – Recorded peak OSB moisture contents and associated wall orientation

Jobsite Number	Initial Measurement Date	Average Interior Relative Humidity (%)	Peak OSB Moisture Content (%) (Floor Level)			
			Wall Orientation			
			North	West	East	South
1	**1/28/2010**	**32**	**20 (2)**	**22 (1)**	**15 (1)**	**12 (2)**
2	**3/22/2010**	**51**	**20 (1)**	**18 (1)**	**25 (1)**	**12 (1)**
3	**3/16/2010**	**48**	**14 (1 and 2)**	**14 (2)**	**17 (1)**	**14 (1)**
4[1]	**-**	**-**	**-**	**-**	**-**	**-**
5	**1/29/2010**	**48**	**24 (2)**	**18 (2)**	**32 (1)**	**18 (1)**
6	**1/13/2010**	**42**	**15 (1)**	**-**	**13 (1)**	**18 (1)**

1. In-service conditions for Jobsite #4 are not yet available due to issues with the homeowner's internet connection.

The trends in OSB moisture contents demonstrate that during the initial stages of home occupancy moisture contents are elevated or elevating. However, as ambient temperatures increased in the spring, a decrease in moisture contents in OSB panels occurred. This 'drying-out' of the panels was most accentuated during the first week of April with a drop in OSB moisture content observed in each of the homes during this period.

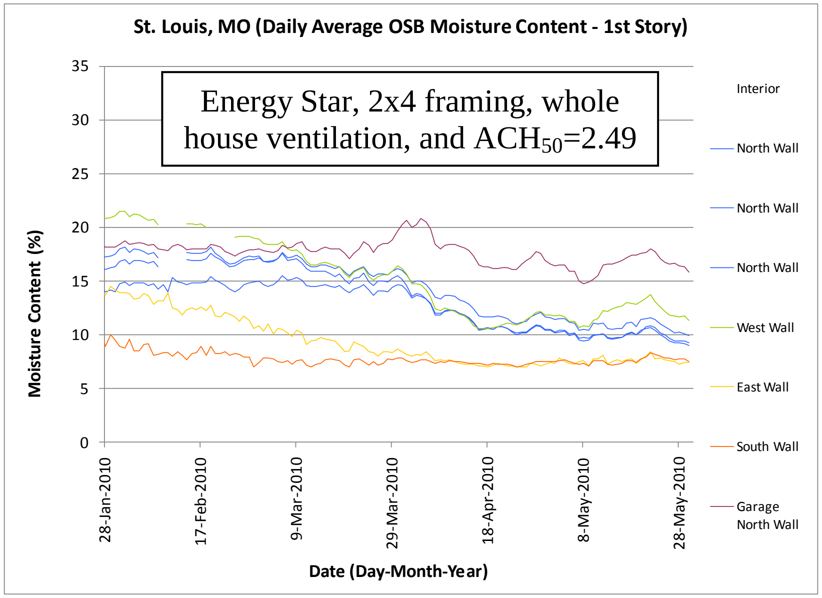


Figure 16 – Jobsite #1 1st floor OSB moisture contents

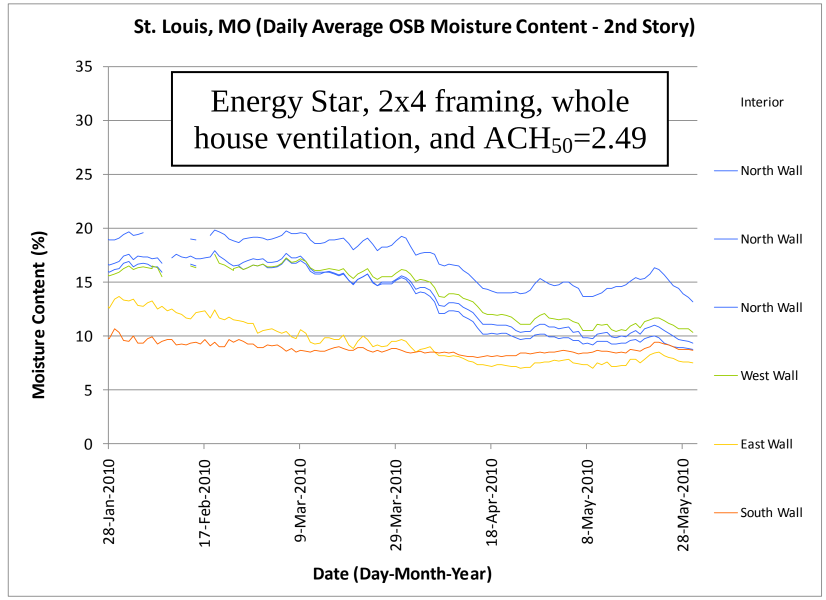


Figure 17 – Jobsite #1 2nd floor OSB moisture contents

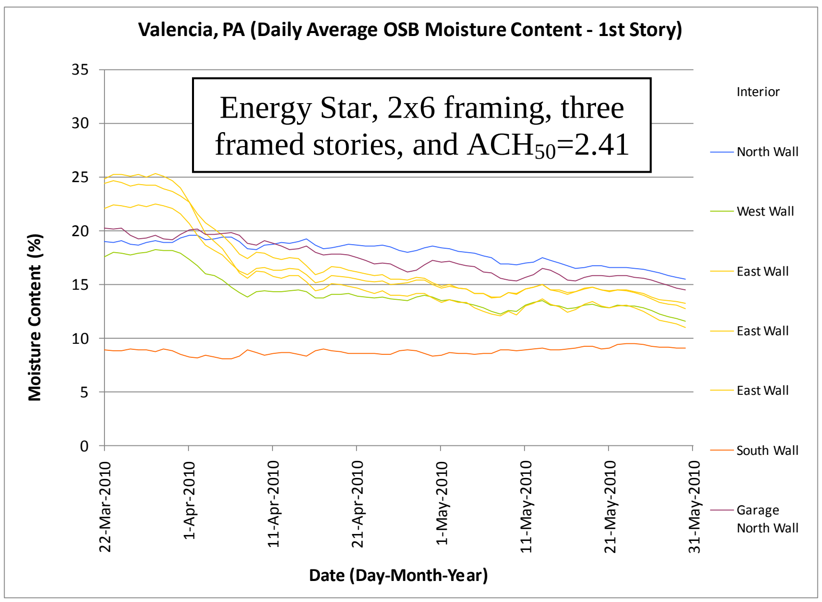


Figure 18 – Jobsite #2 1st floor OSB moisture contents

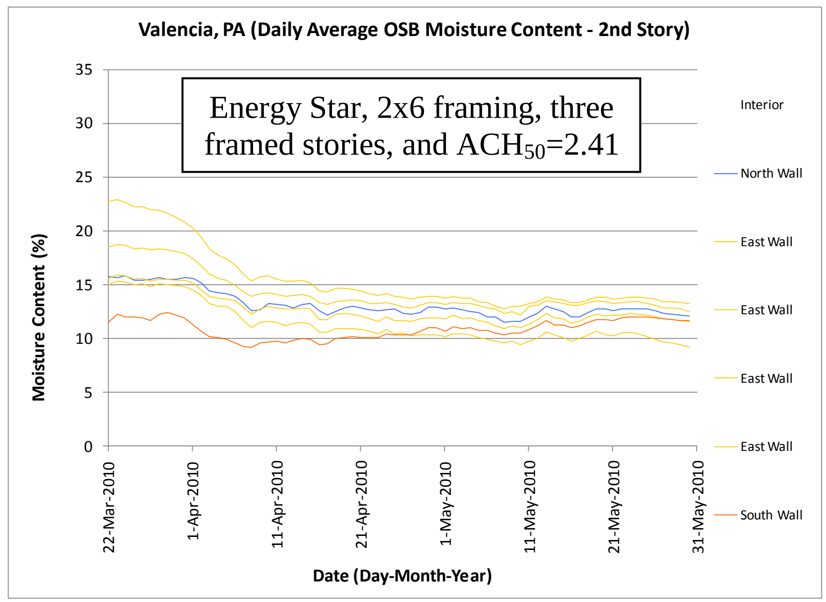


Figure 19 – Jobsite #2 2nd floor OSB moisture contents

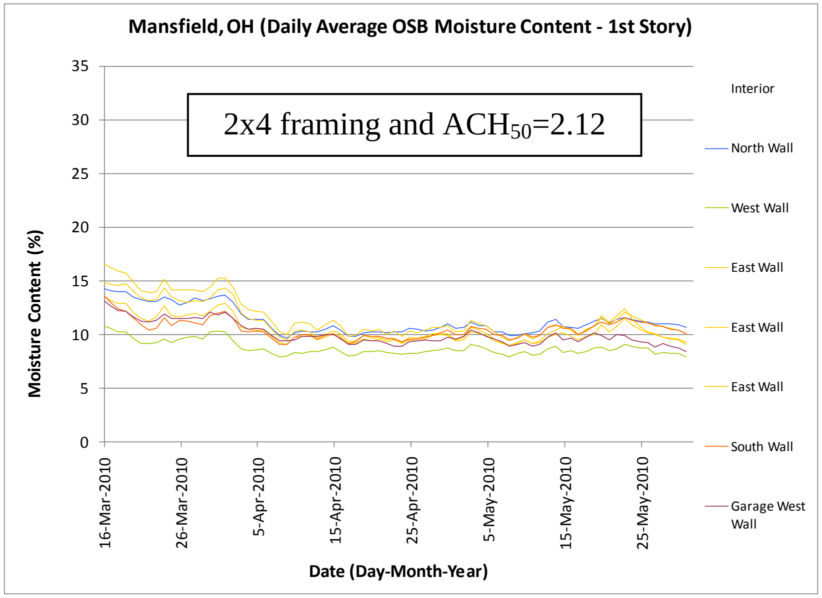


Figure 20 – Jobsite #3 1st floor OSB moisture contents

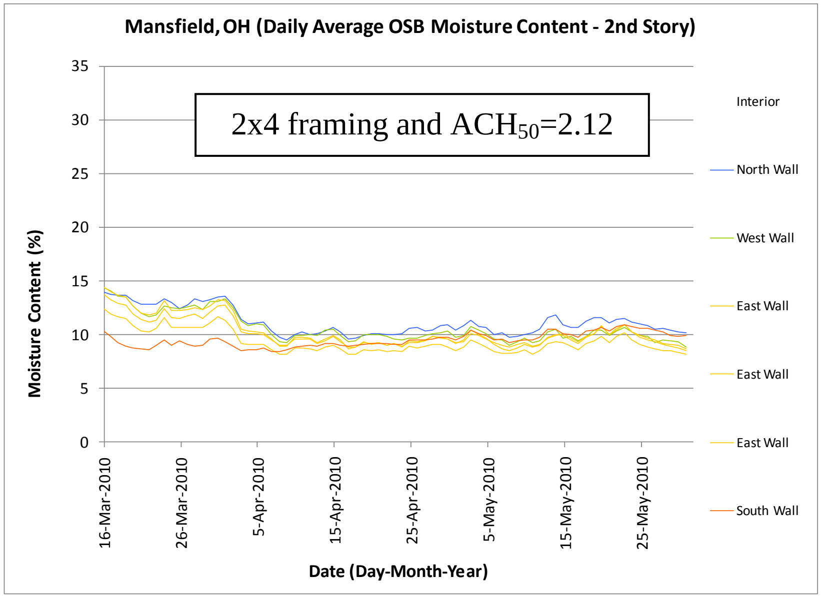


Figure 21 – Jobsite #3 2nd floor OSB moisture contents

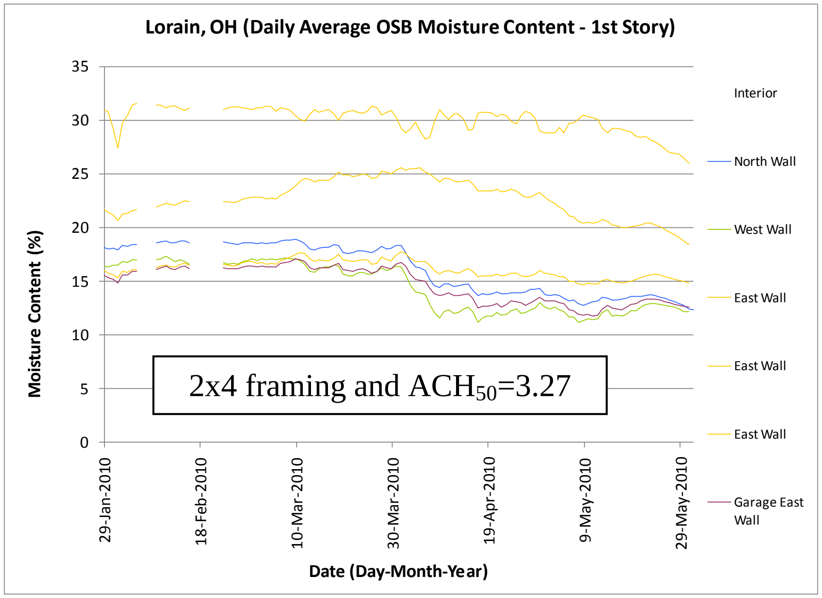


Figure 22 – Jobsite #5 1st floor OSB moisture contents

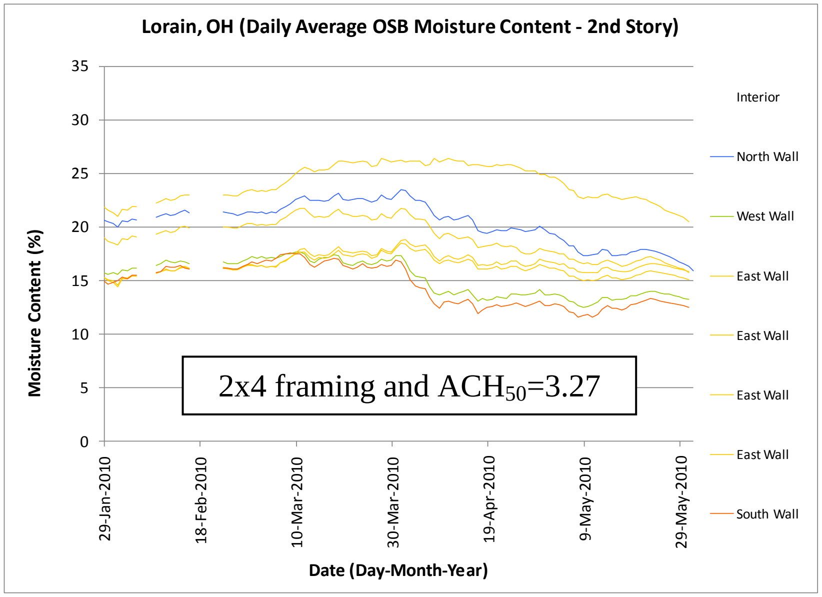


Figure 23 – Jobsite #5 2nd floor OSB moisture contents

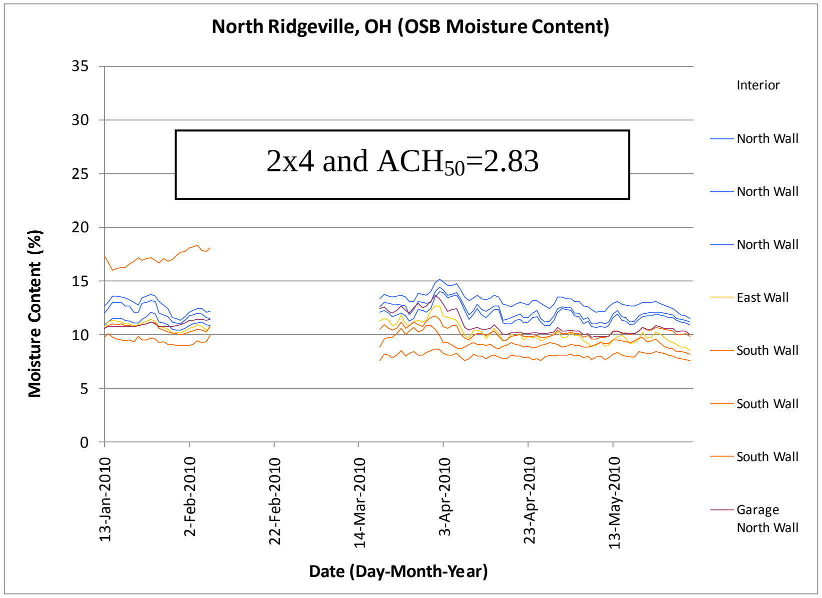


Figure 24 – Jobsite #6 OSB moisture contents

As relative humidity increases in a wall cavity, the potential for condensation of water on the interior surface of OSB panels also increases. Figure 25 and Figure 26 are comparison plots for the test wall cavity temperatures and dew point cavity temperatures for Jobsite #1 and Jobsite #5, respectively. The dew point temperatures and the cavity temperatures are converging during the winter months and diverging in the spring months in each of the two homes. Condensation potential is highest in Jobsite #5 as shown in Figure 26 where the cavity temperature is consistently approaching the cavity dew point throughout the monitoring period.

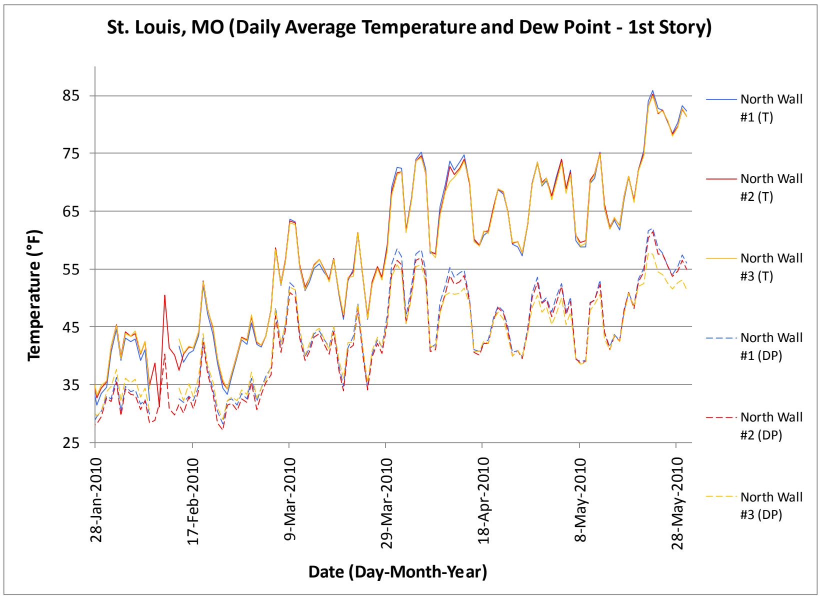


Figure 25 – Comparison of Jobsite #1 1st floor test wall cavity temperatures and dew points

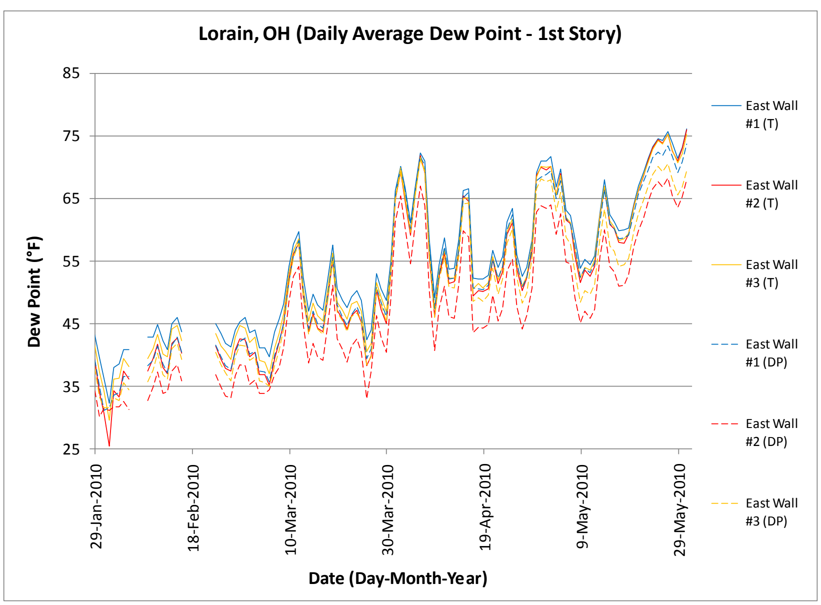
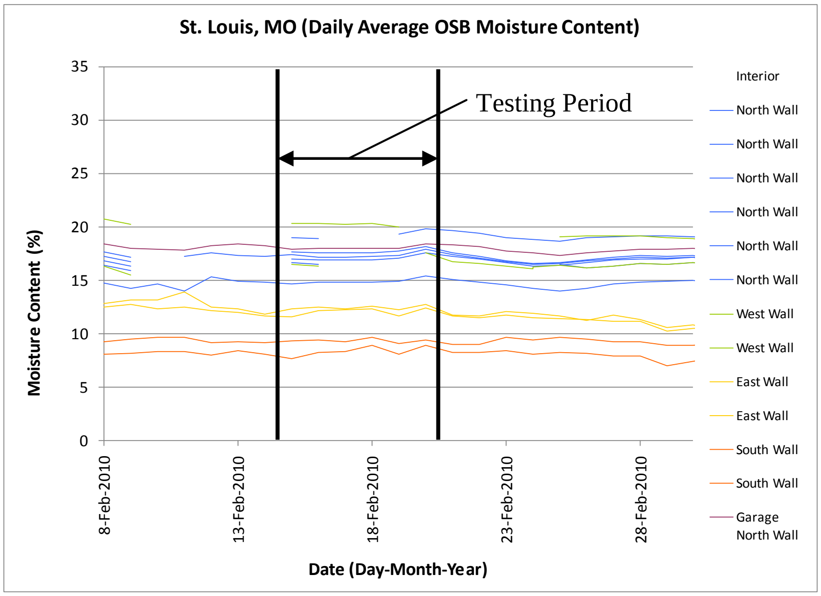


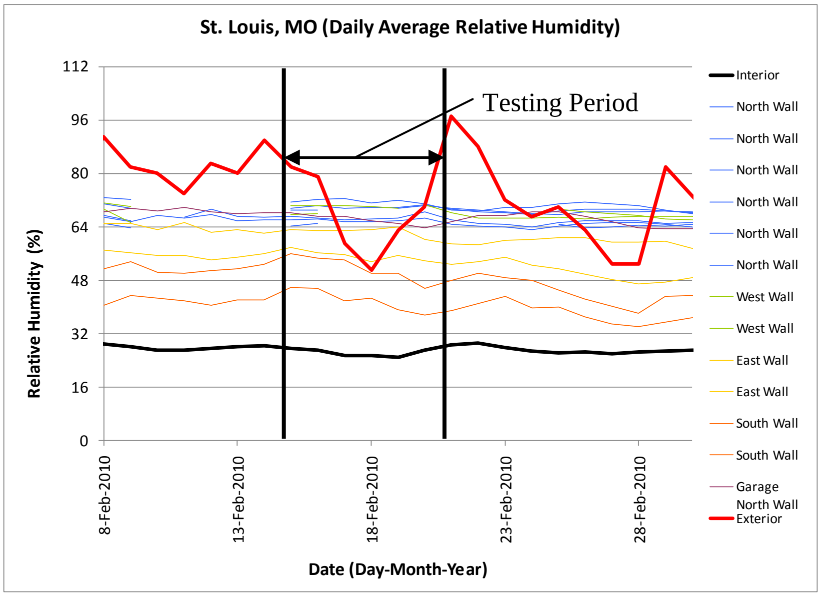
Figure 26 – Comparison of Jobsite #5 1st floor test wall cavity temperatures and dew points

Elevated moisture content in the garage wall OSB panel for Jobsite #1 is attributed to the use of the garage as an office space while the home is being used as a model home.

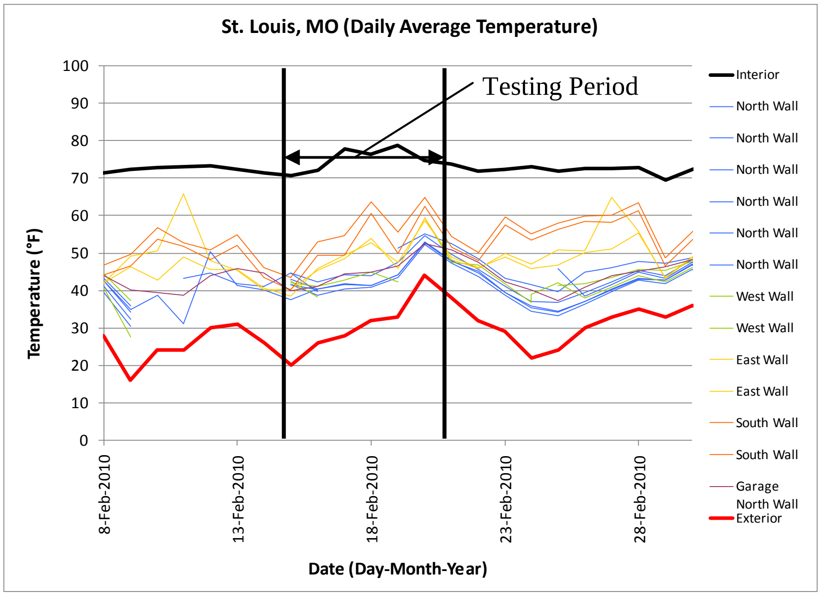
During the first week of obtaining measurements for Jobsite #1, elevated relative humidity and moisture content levels were observed. To determine the effect of interior relative humidity on OSB moisture content, the home contractor was requested to turn on bathroom fans and keep the fans running continuously for one week. No definite reductions in interior relative humidity, cavity relative humidity, or OSB moisture content were observed during the time the fans were continuously operating (Figure 27). While following the fan testing period a slight decline of moisture content and relative humidity occurred, it is observed that during this period the ambient relative humidity reduced as well (Figure 27c) and could have been the primary cause for minor reductions in OSB moisture content measurements.



(a) OSB Moisture Content



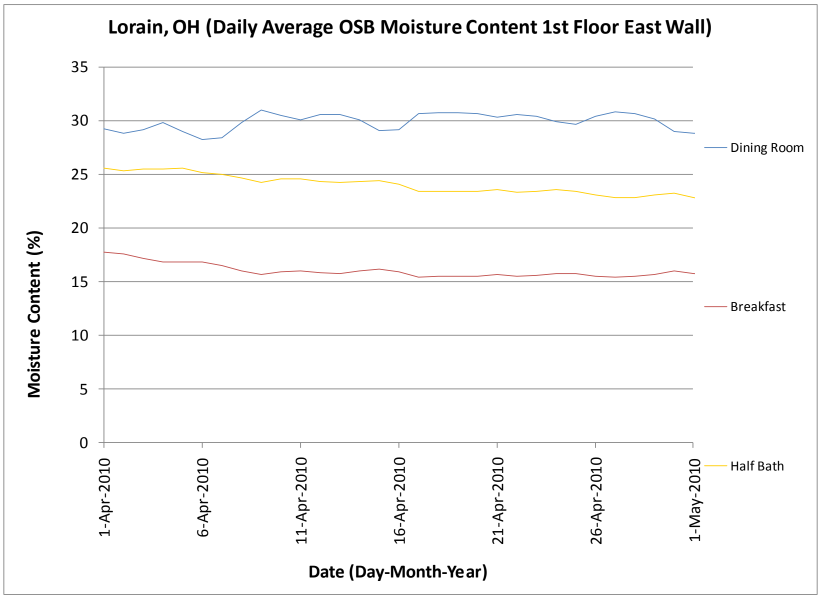
(b) Relative Humidity



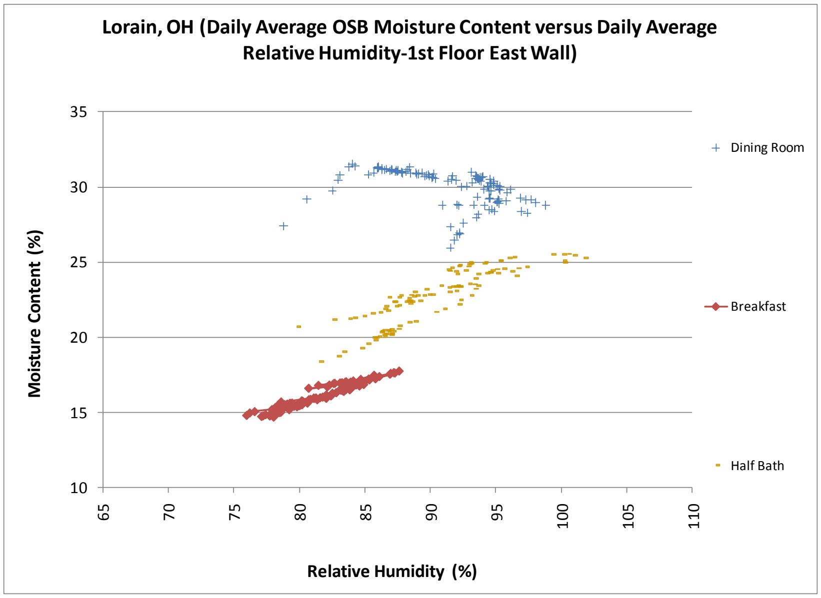
(c) Temperature

Figure 27 – Jobsite #1 continually running fan test observations

The sensor in the dining room of the first floor east (test) wall of the Lorain Home (Jobsite #5) measuring 30% OSB moisture content (Figure 28.a) does not follow the trends of the other sensors in the same wall. Based on Figure 28.b plots, a correlation between relative humidity in the wall cavity and OSB moisture content is observed for the sensors located in the breakfast and half bath wall sensors, whereas the sensor in the dining room does not show a correlation. Moisture content readings of the dining room sensor will continue to be monitored in order to determine the cause of apparent inconsistency.



(a) Moisture Content April 1st through May 1st



(b) Moisture Content versus Relative Humidity

Figure 28 – Jobsite #5 1st floor east wall measurements

Discussion

This section analyzes trends between OSB moisture content, wall cavity conditions, home interior relative humidity, and blower door test results. In addition, the relative humidity measurements are evaluated using criteria for mold growth.

The test wall OSB moisture contents through the month of May are provided in Figure 29 for each home. The legend of Figure 29 provides the calculated ACH_{50} along with the jobsite location and test wall orientation. A total of three sensors are considered for each jobsite except for the Lorain, OH jobsite, where only the two sensors that follow general trends for the home are used. There is not a definitive relationship between the moisture content and ACH_{50} (which serves as a measure of building's tightness). While the home with the lowest ACH_{50} has the lowest moisture content and the home with the highest ACH50 has the highest moisture content, the remaining three homes do not align with the same trend. It should be noted that ACH_{50} for each of the homes is relatively low and the range between all six homes is relatively narrow.

Figure 30 plots relative humidity in the wall cavity versus OSB moisture content. There is a definitive trend for all homes indicating an increase in moisture content with an increase in relative humidity. It should be noted that the trend in Jobsite #1 is several percentage points above the trend observed for the rest of the homes. Further analysis will be conducted to investigate reasons for an apparently different correlation observed in Jobsite #1.

Figure 31 shows relative humidity levels inside each home over the monitoring period with the legend showing the associated ACH_{50}. With one exception of Jobsite #1 (St. Louis, MO), interior relative humidity readings for all homes are clustered together indicating no distinctive trend due to the building tightness for the given range of ACH_{50} values. The interior relative humidity in Home #1 is about 10 percent lower than interior relative humidity in the other homes throughout the reporting period[1]. This trend will be monitored throughout the summer to investigate the impact of the warmer and more humid ambient air.

As the last point of comparison, the wall cavity relative humidity is plotted versus the home interior relative humidity. None of the homes exhibit a trend between these two variables. These results indicate that, at least over a short period following the construction process, other factors besides interior relative humidity alone influenced the conditions inside the wall cavity.

Future monitoring of the walls' conditions over the next winter season will provide additional insights with regard to the impact of the different sources of moisture including construction moisture, vapor drive, condensation, bulk air, and bulk water.

[1] The information submitted by the builder with regard to the provided ventilation system is inconsistent with the plan specifications for the home. A follow-up effort is underway to obtain accurate information on the installed ventilation system.

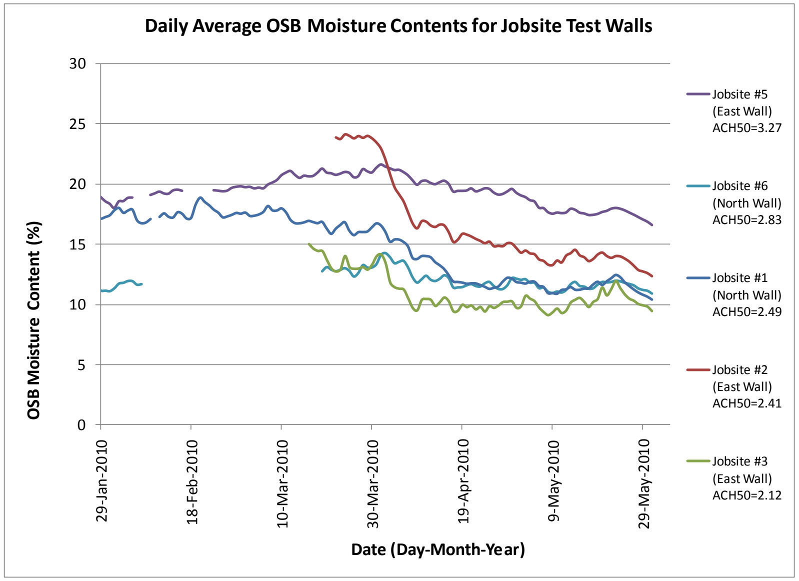


Figure 29 – Jobsite test wall daily average OSB moisture contents

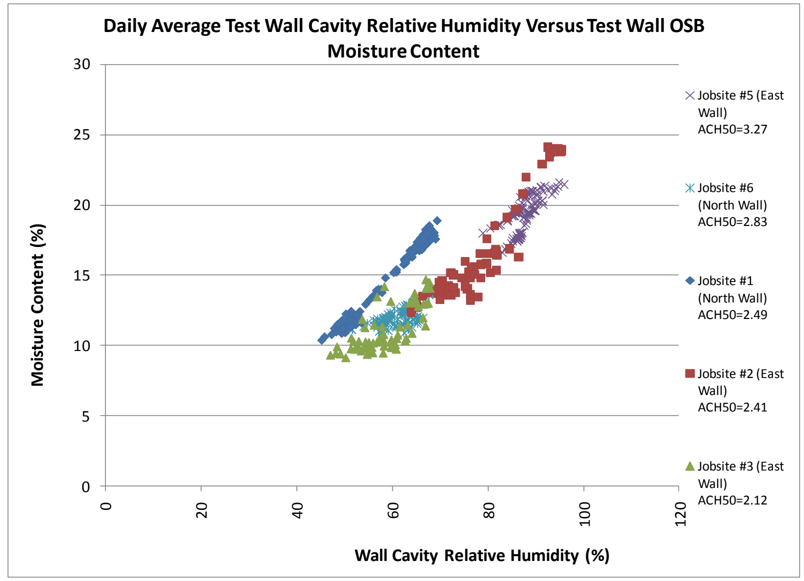


Figure 30 – Jobsite test wall relative humidity and OSB moisture content comparison

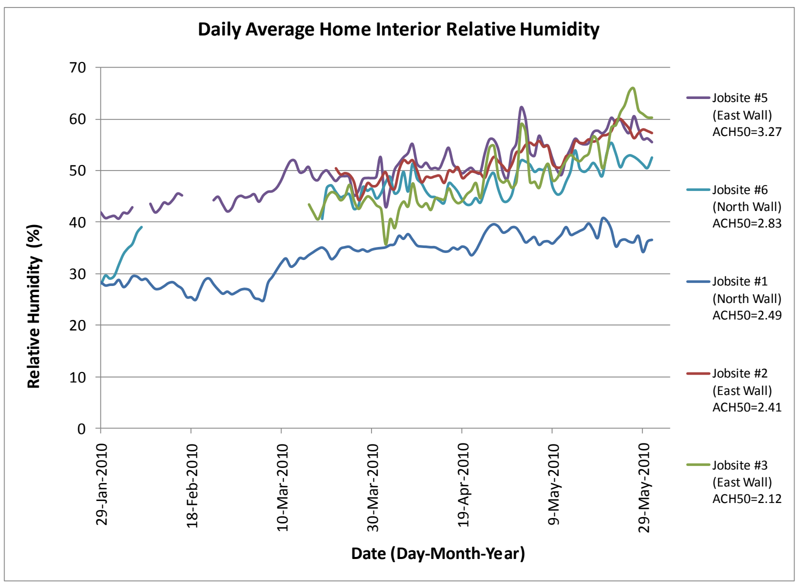


Figure 31 – Jobsite daily home interior relative humidity

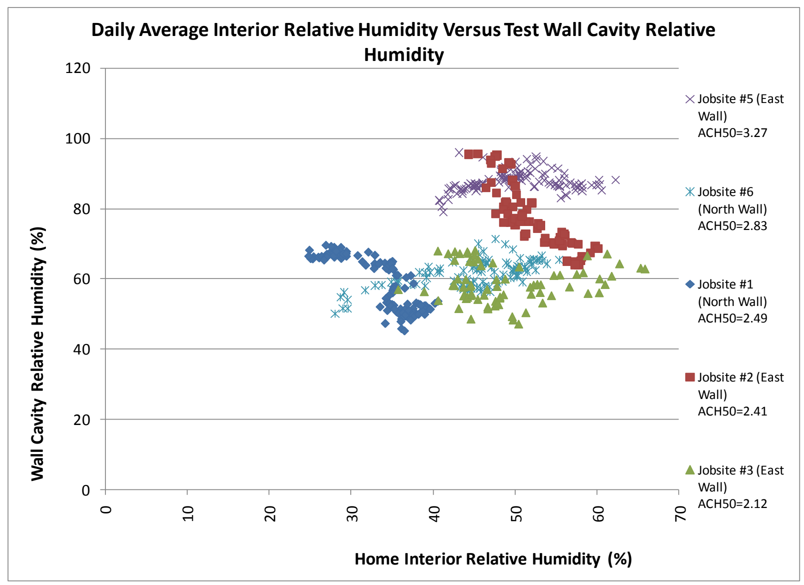


Figure 32 – Jobsite home interior and test wall relative humidity comparison

One of the home builders in Ohio reported that while repairing walls with buckled OSB following the winter of 2009, a 'mold like substance' was often present on the interior face of the OSB panels. To investigate the potential for mold growth in the test homes monitored in this study, the observed environmental conditions of the wall cavity are evaluated using the threshold established by ASHRAE Standard 160-2009 "Criteria for Moisture-Control Design Analysis in Buildings" (3). Standard 160 provides temperatures and associated relative humidity ranges that minimize mold growth on the surfaces of components of building envelope assemblies (Table 8).

Table 8 – Conditions necessary to minimize mold growth [after (2)]

Condition	Duration	Temperature	Relative Humidity
A	**30 days**		**< 80%**
B	**7 days**	**41°F < T < 104°F**	**< 98%**
C	**24 hours**		**< 100%**

According to these criteria, the wall cavity relative humidity levels for two of the homes exceed the specified limits. Five of the fourteen sensors in the home located in Valencia, PA did not meet Condition A (i.e., 30 day running average of relative humidity > 80%). These levels were maintained through March and April of 2010. Relative humidity in this home during the measuring period did not exceed the 98% trigger of Condition B.

The home located in Lorain, OH presented the greatest potential for mold growth. Thirteen of the fourteen wall sensors installed in the wall cavities have experienced a running average relative humidity exceeding 80% for thirty or more continuous days. Whereas these levels have reduced, four of the sensors continue measuring relative humidity > 80% at the end of May. Two of the thirteen sensors that exceed Condition A also exceed the relative humidity threshold of Condition B. Lastly, one of these two sensors exceeds Condition C. Based on the criteria provided in ASHRAE Standard 160-2009 there is potential for mold growth under such conditions.

Summary and Continuing Efforts

This study documents construction methods and materials used by builders that experienced OSB buckling problems in the winter of 2008-2009. A total of 6 new homes built in the fall and winter of 2009 by three different builders are included in the study. The focus of the study is on the construction practices that affect the moisture performance of exterior walls. Blower door testing was conducted to measure air-tightness characteristics of each home. In addition, moisture and temperature sensors are installed in wall cavities of all six homes. The data collected by the sensors provides objective moisture performance information for the OSB panels and the wall cavity.

Over the first 6 months of the study (November 2009 through May 2010), buckling of OSB wall sheathing has not been observed in any of the six homes (visual inspection of walls have been performed in April or May of 2010). However, periods of elevated moisture content in OSB panels have been recorded in each of the homes. The OSB moisture content increased from less than 6% to 11% at the time of panel installation or jobsite visit to anywhere from 10% to 25% or higher at the time of first measurements taken after the beginning of occupancy that started in the months of January or February. In three of the homes, the OSB moisture content levels exceeded 15% for an extended period of time. In two of those three homes, moisture content peaked at over 25% with the highest measured moisture content at around 30% (one sensor only). An analysis of the wall cavity conditions against a set of mold growth criteria based on temperature, relative humidity, and their duration suggests that in two of the six homes there were periods when there was potential for mold growth.

In all homes, the moisture content started trending down in the spring months as the average daily temperature increased. A typical observed drop of OSB moisture content ranged from 5 to 10 percent. The largest drop in OSB moisture content in each of the homes occurred during the period of April 1 through April 9 and was associated with increased ambient temperatures and decreased ambient relative humidity leading to increased cavity temperatures and drying potential.

Analysis of the expansion of OSB panels based on the measured linear expansion properties and the measured peak moisture content levels suggests a significant potential for OSB buckling in the period following the construction process for one of the test homes (jobsite #5). Based on calculations of expected linear expansion, the provided gapping and panel expansion properties for the other four homes are adequate to prevent OSB buckling. As the “wavy” siding has not been observed in home #5, it should be noted that limited amount of buckling would not show through vinyl siding as the siding strips are capable of spanning over minor imperfections in the wall sheathing.

Analysis of a correlation between the results of blower door tests and the OSB moisture content in walls does not indicate a strong trend. To draw more definitive conclusions, this study needs to be expanded to include homes with a wider range of air tightness characteristics.

Among other observation, the walls with a southern orientation had the lowest OSB moisture contents due to the higher cavity temperatures from the longer period of exposure to direct sunlight leading to higher drying potential.

The following continuing efforts of this research are planned:

1. In depth analysis of results through cooling and heating cycles.
2. Continued monitoring of OSB moisture contents, relative humidity, temperature, and dew point in all instrumented homes to collect data over a minimum 12-month period in order to understand seasonal variations and the impact of construction moisture.
3. Maintaining contact with builders to be informed if OSB buckling occurs on any of the research homes or if any new OSB buckling issues occur.
4. Instrumenting and monitoring of new homes and retrofitted homes built to higher energy efficiency standards including walls with exterior rigid foam insulation.
5. Laboratory testing of full-size wall sections in an environmental chamber to simulate buckling of OSB as part of a wall assembly under controlled conditions (RH and T).

References

1. **National Institute of Standards & Technology.** *Voluntary Product Standard PS2-04, Performance Standard for Wood-Based Structural-Use Panels.* Washington, DC : U.S. Government Printing Office, 2004.
2. **U.S. Department of Energy.** U.S. Department of Energy: Energy Effeciency and Renewable Energy. *U.S. Department of Energy.* [Online] June 6, 2006. [Cited: June 22, 2010.] http://www1.eere.energy.gov/buildings/residential/printable_versions/climate_zones.html.
3. **ASHRAE.** *ANSI/ASHRAE Standard 160-2009, Criteria for Moisture-Control Design Analysis in Buildings.* Atlanta, GA : American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2009.
4. **DuPont.** DuPont Tyvek HomeWrap Physical Properties Data Sheet. *DuPont.* [Online] 2007. [Cited: June 25, 2010.] http://www2.dupont.com/Tyvek_Weatherization/en_US/assets/downloads/K-05031_HW_Prod_Prop.pdf.
5. **The Dow Chemical Company.** North America - Weathermate Plus - Housewrap. *DOW Building Solutions.* [Online] 2010. [Cited: June 28, 2010.] http://www.dow.com/webapps/lit/litorder.asp?filepath=styrofoam/pdfs/noreg/179-07168.pdf&pdf=true.

Attachment 1 – Temperature, Relative Humidity, and Dew Point Plots by Jobsite

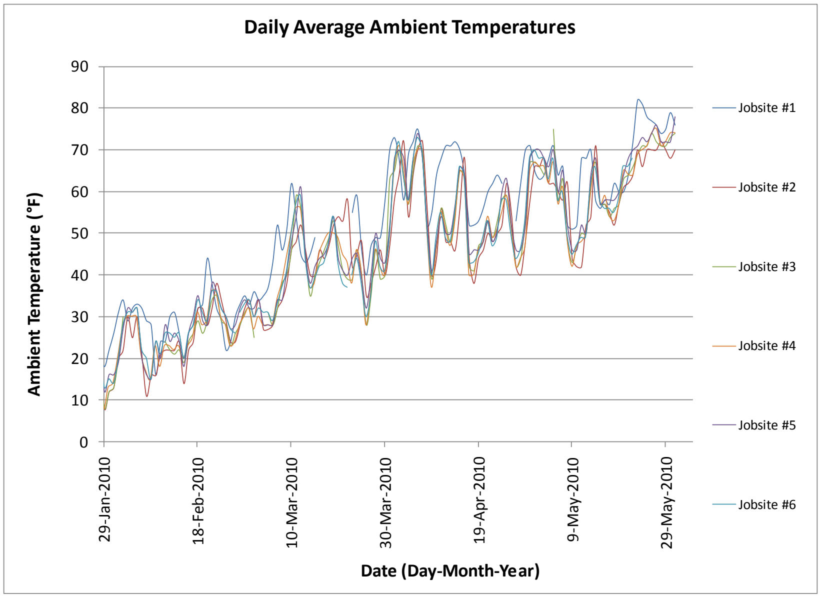


Figure A1- 1 – Jobsites ambient temperature

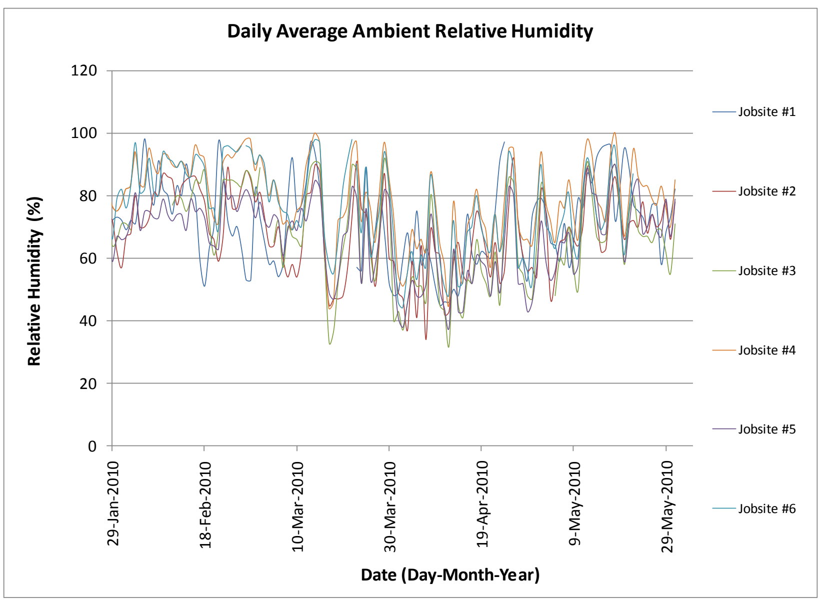


Figure A1- 2 – Jobsites ambient relative humidity

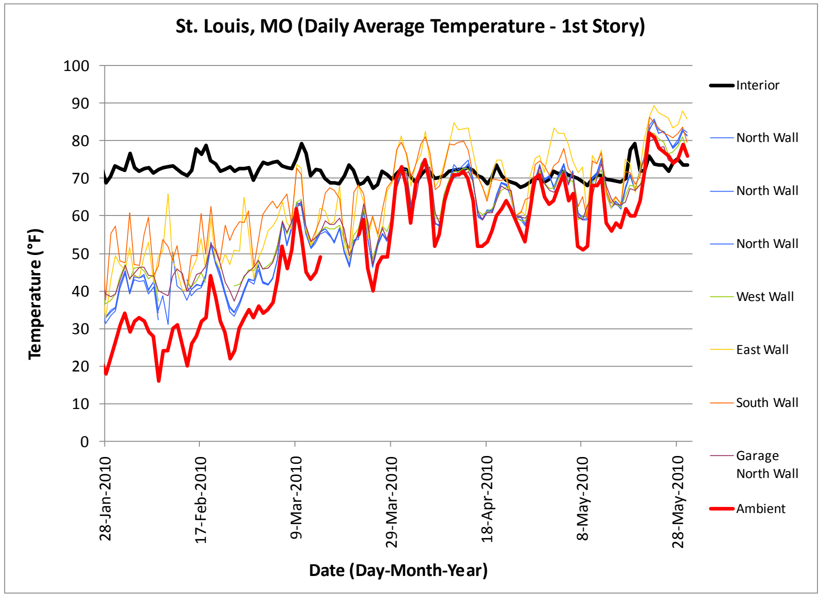


Figure A1- 3 – Jobsite #1 1st floor temperature

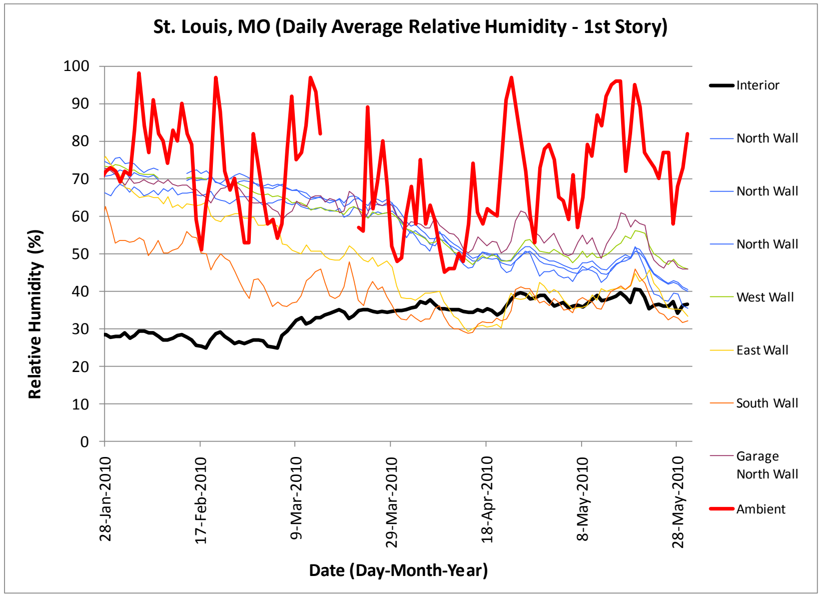


Figure A1- 4 – Jobsite #1 1st floor relative humidity

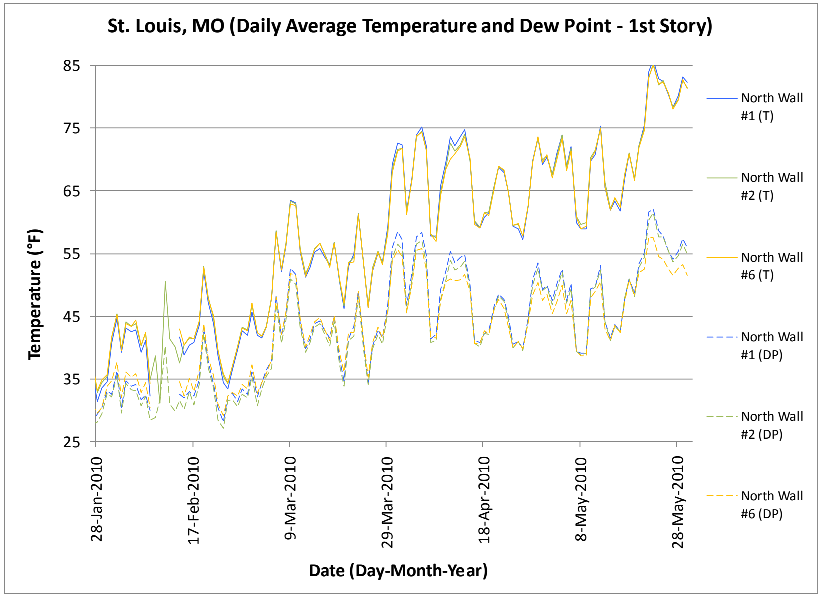


Figure A1- 5 – Jobsite #1 1st floor test wall temperature and dew point

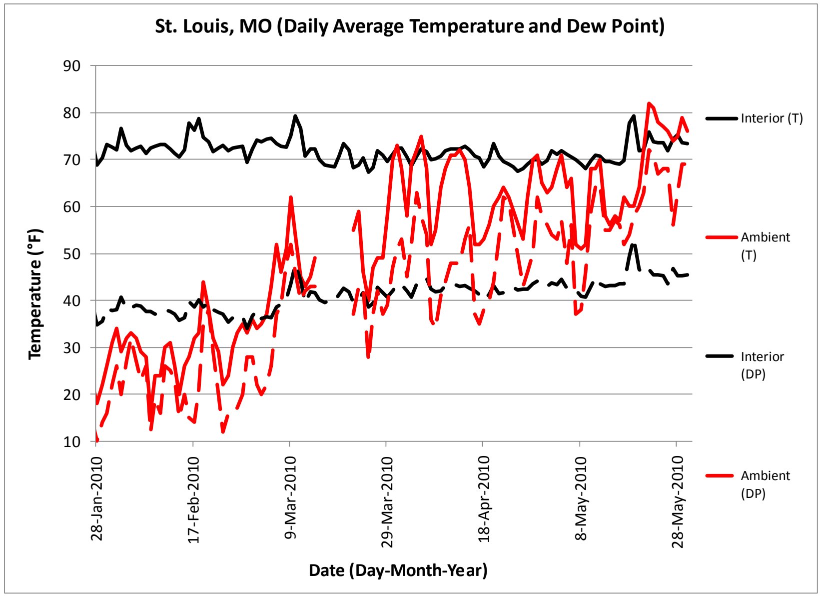


Figure A1- 6 – Jobsite #1 interior and ambient temperature and dew point

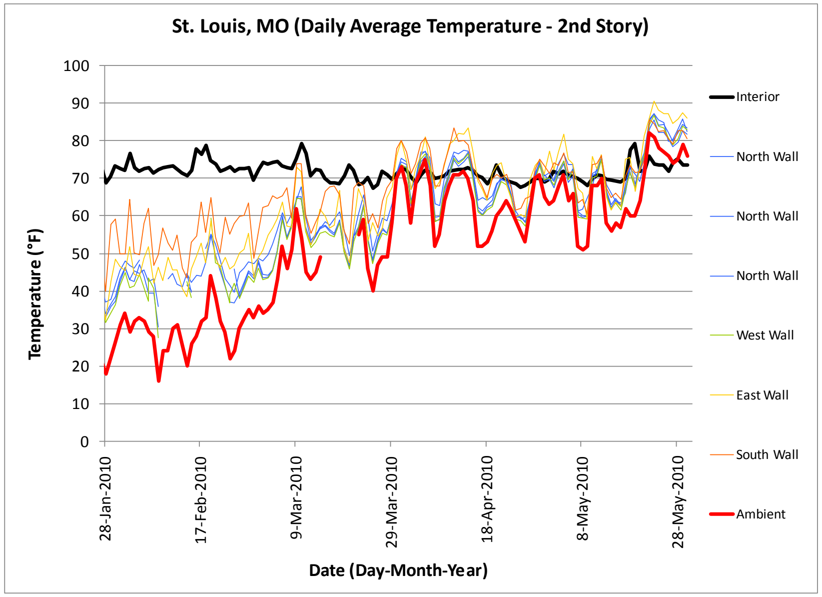


Figure A1- 7 – Jobsite #1 2nd floor temperature

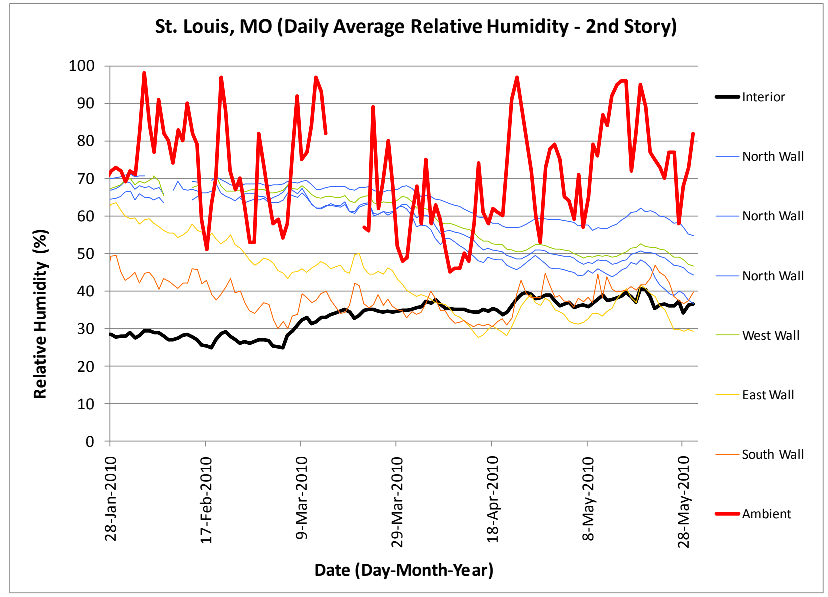


Figure A1- 8 – Jobsite #1 2nd floor relative humidity

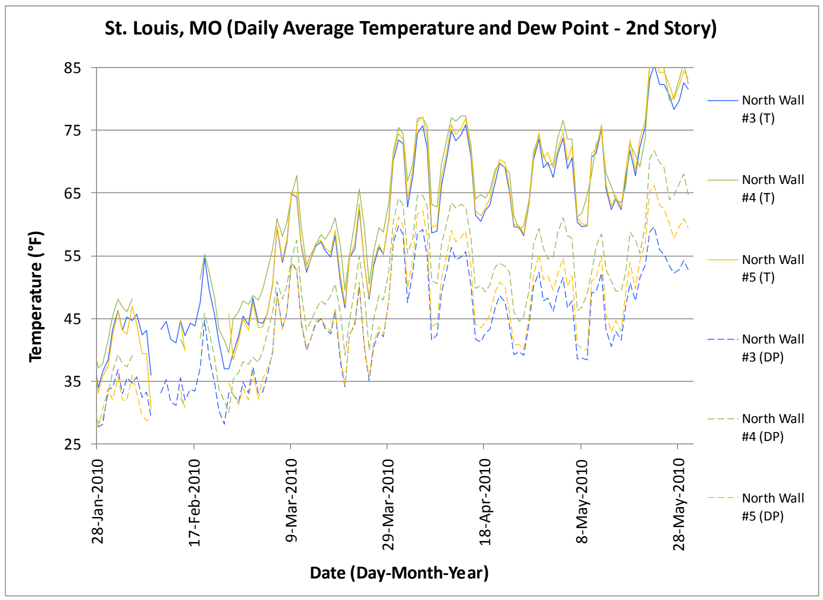


Figure A1- 9 – Jobsite #1 2nd floor north wall temperature and dew point

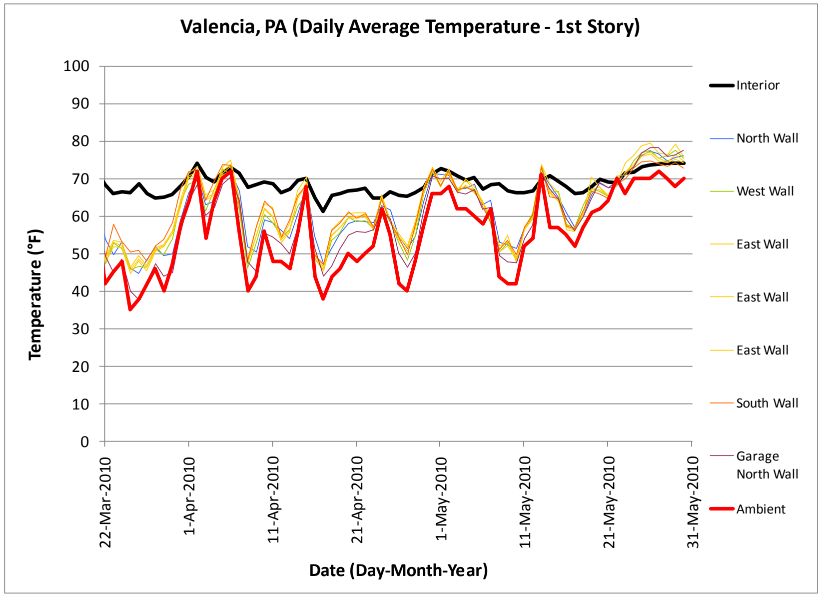


Figure A1- 10 – Jobsite #2 1st floor temperature

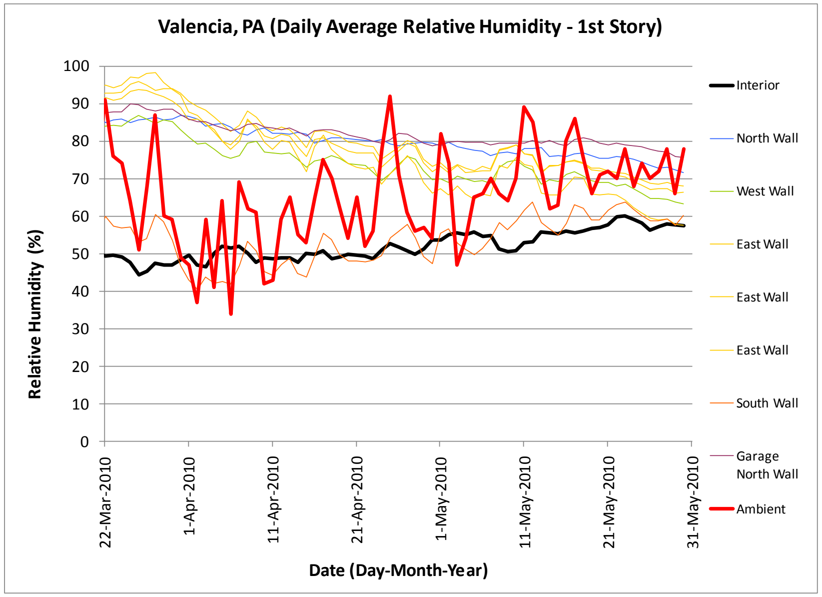


Figure A1- 11 – Jobsite #2 1st floor relative humidity

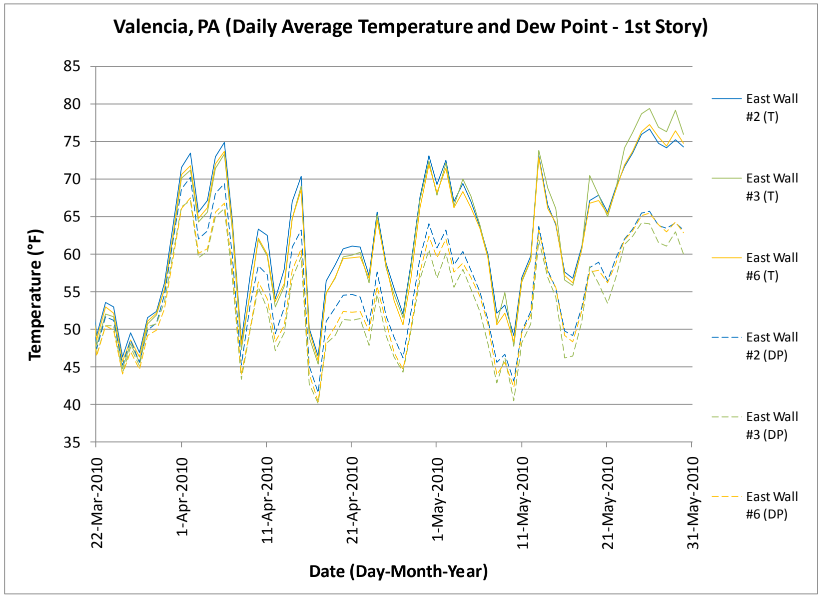


Figure A1- 12 – Jobsite #2 1st floor test wall temperature and dew point

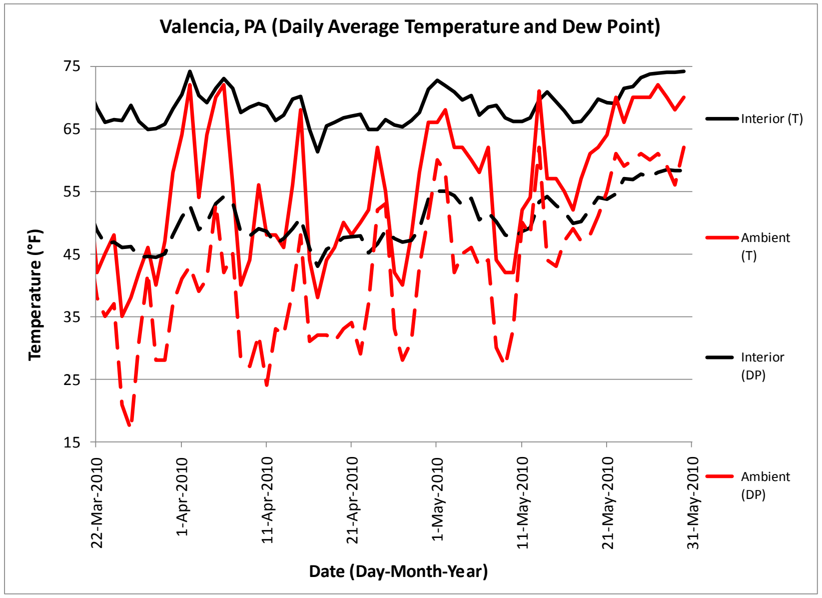


Figure A1- 13 – Jobsite #2 interior and ambient temperature and dew point

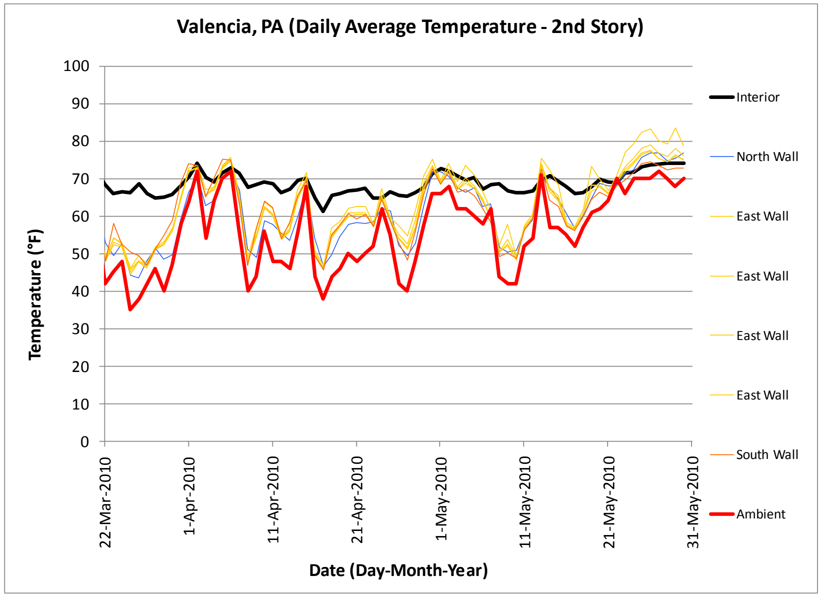


Figure A1- 14 – Jobsite #2 2nd floor temperature

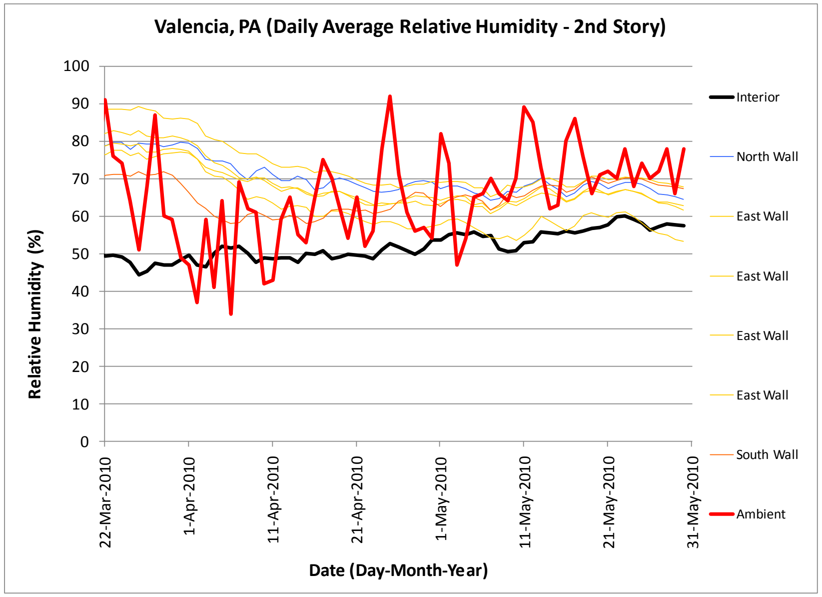


Figure A1- 15 – Jobsite #2 2nd floor relative humidity

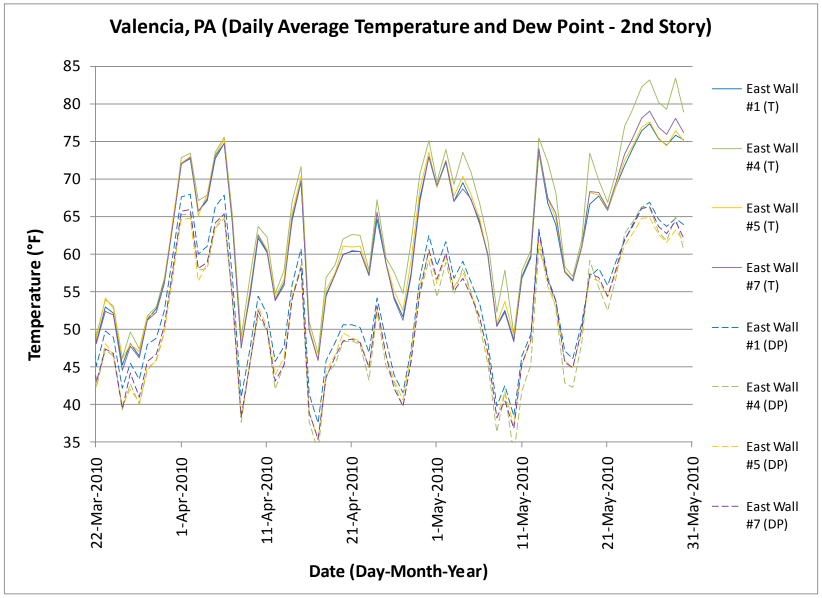


Figure A1- 16 – Jobsite #2 2nd floor east wall temperature and dew point

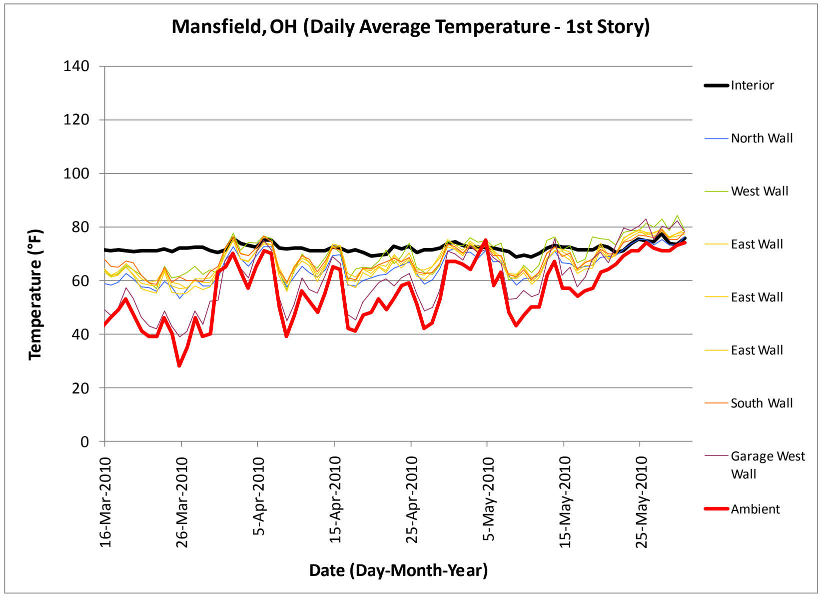


Figure A1- 17 – Jobsite #3 1st floor temperature

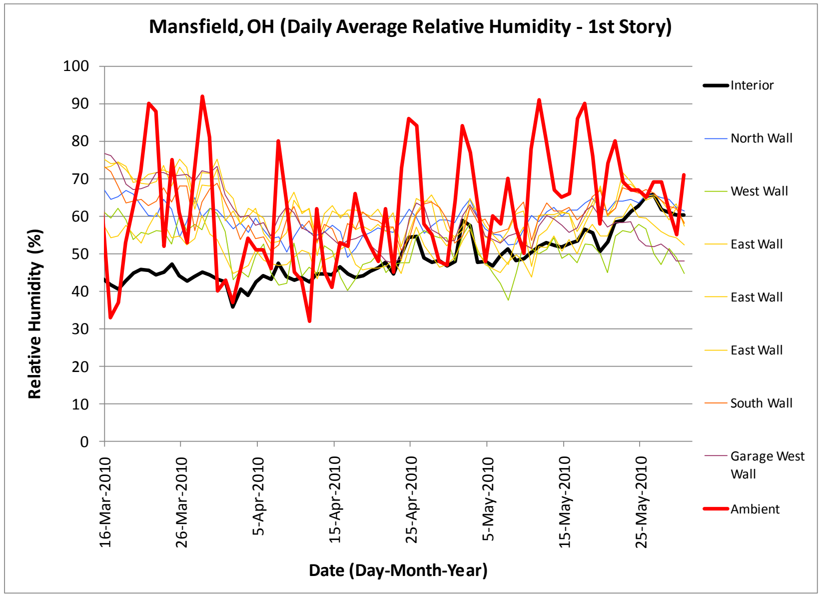


Figure A1- 18 – Jobsite #3 1st floor relative humidity

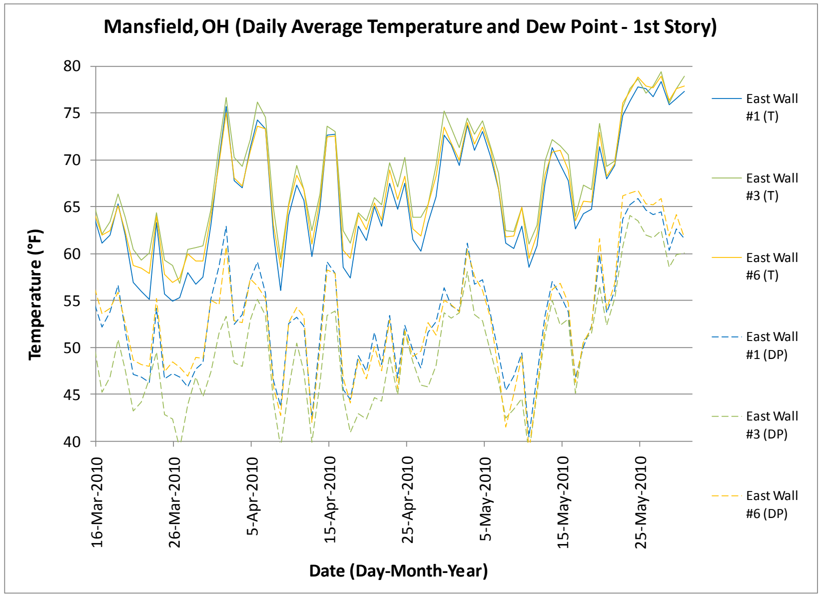


Figure A1- 19 – Jobsite #3 1st floor test wall temperature and dew point

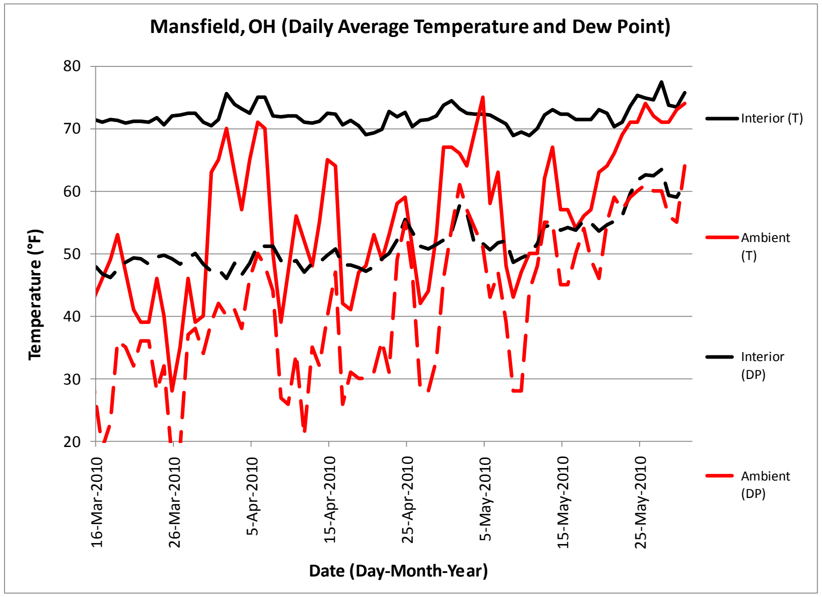


Figure A1- 20 – Jobsite #3 interior and ambient temperature and dew point

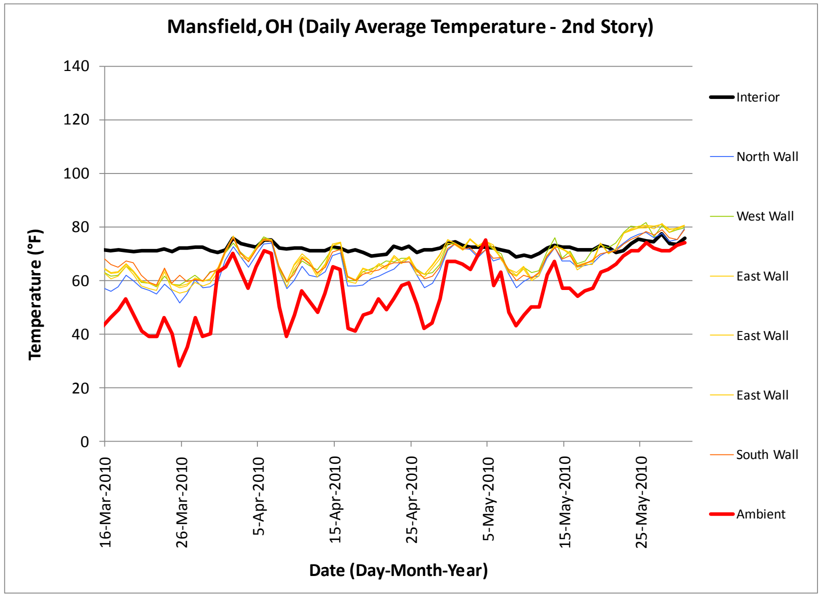


Figure A1- 21 – Jobsite #3 2nd floor temperature

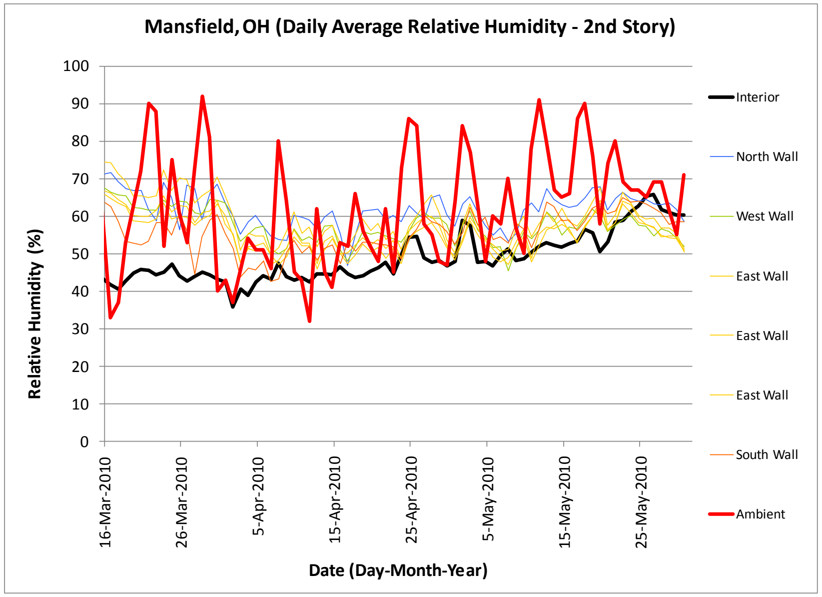


Figure A1- 22 – Jobsite #3 2nd floor relative humidity

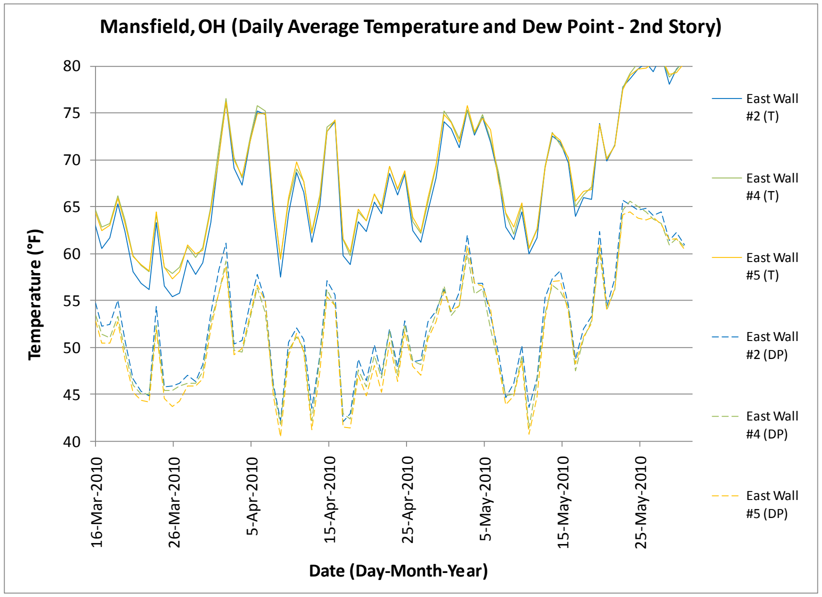


Figure A1- 23 – Jobsite #3 2nd floor east wall temperature and dew point

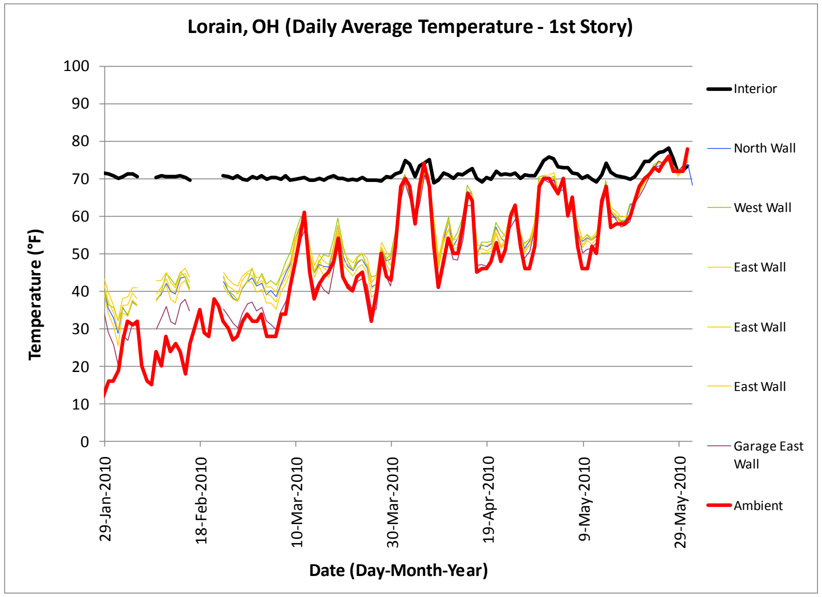


Figure A1- 24 – Jobsite #5 1st floor temperature

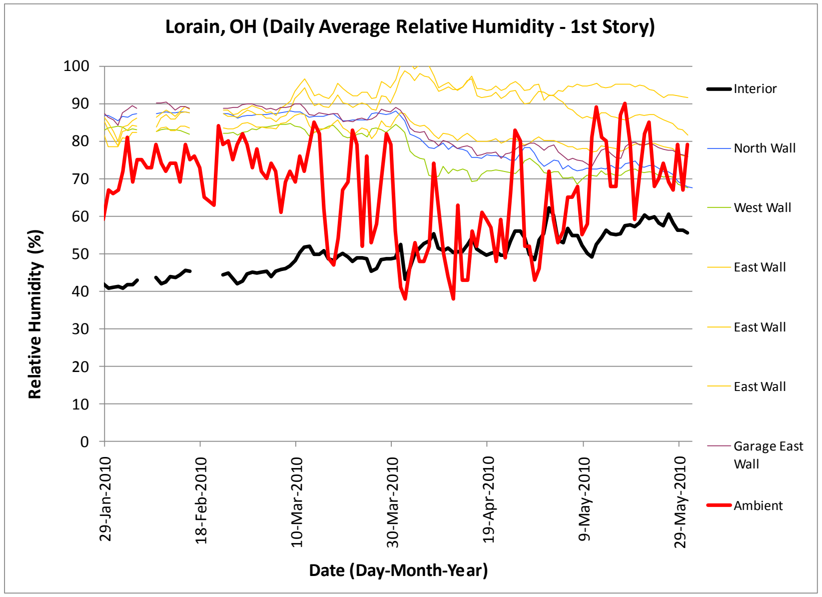


Figure A1- 25 – Jobsite #5 1st floor relative humidity

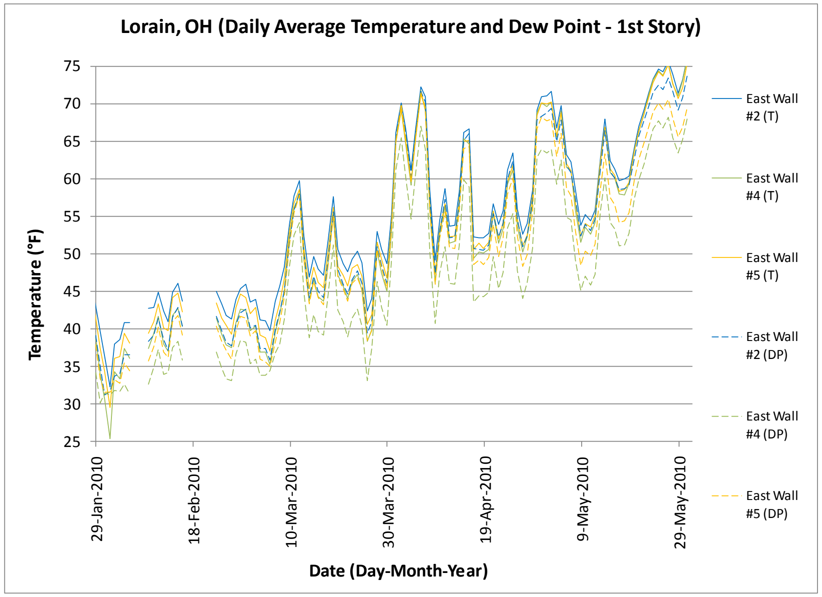


Figure A1- 26 – Jobsite #5 1st floor test wall temperature and dew point

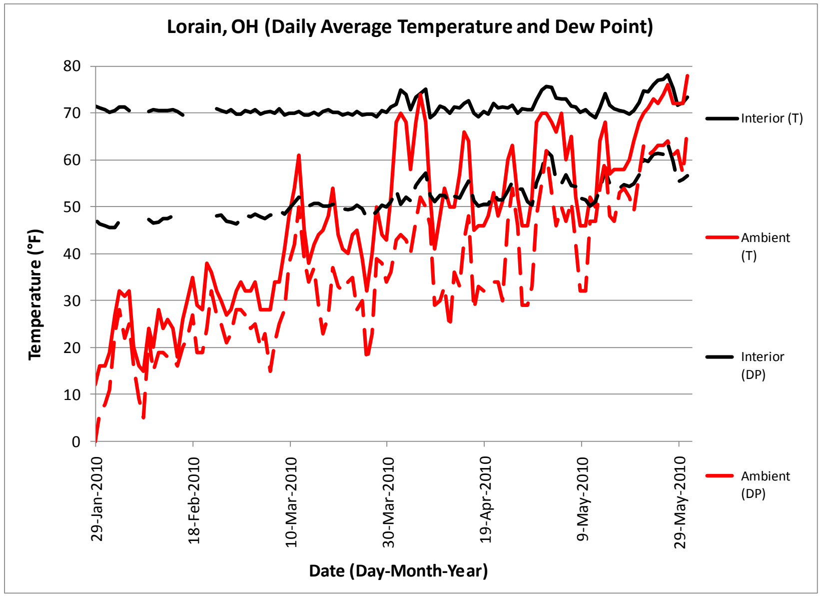


Figure A1- 27 – Jobsite #5 interior and ambient temperature and dew point

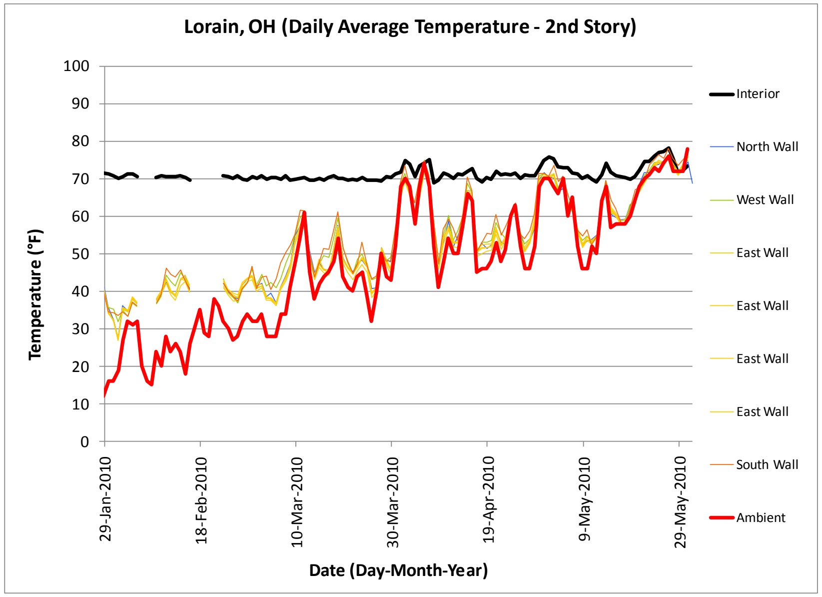


Figure A1- 28 – Jobsite #5 2nd floor temperature

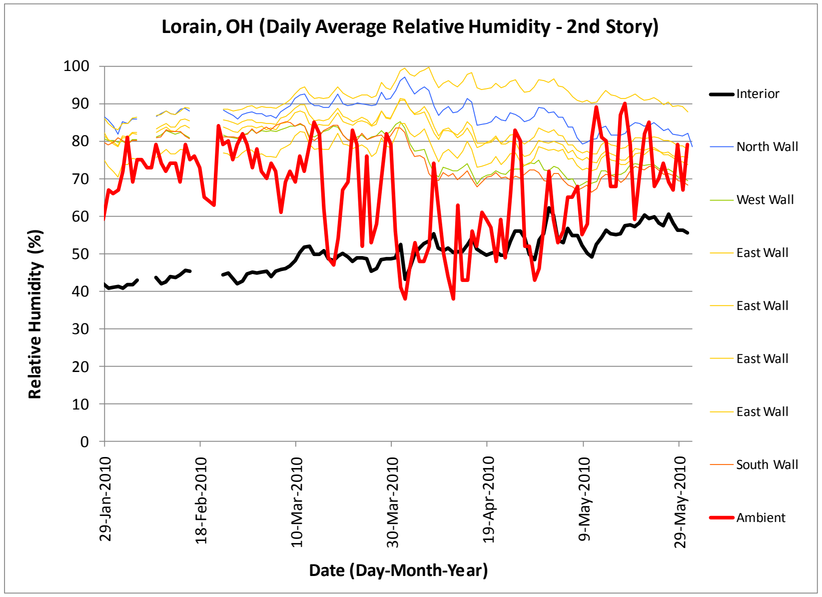


Figure A1- 29 – Jobsite #5 2nd floor relative humidity

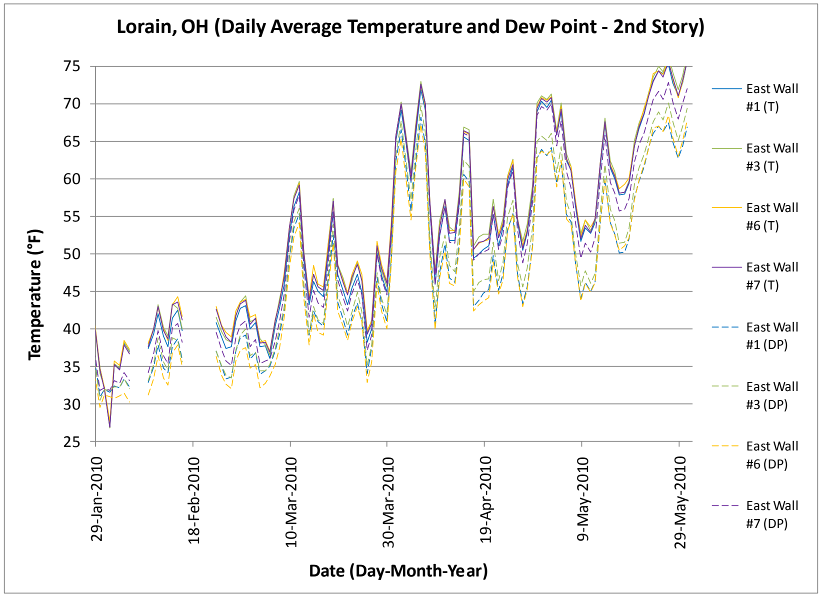


Figure A1- 30 – Jobsite #5 2st floor east wall temperature and dew point

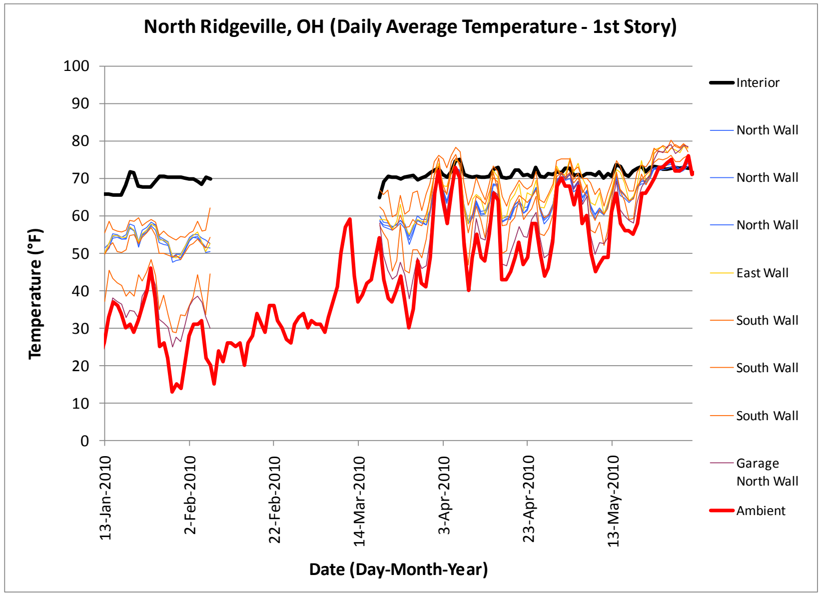


Figure A1- 31 – Jobsite #6 1st floor temperature

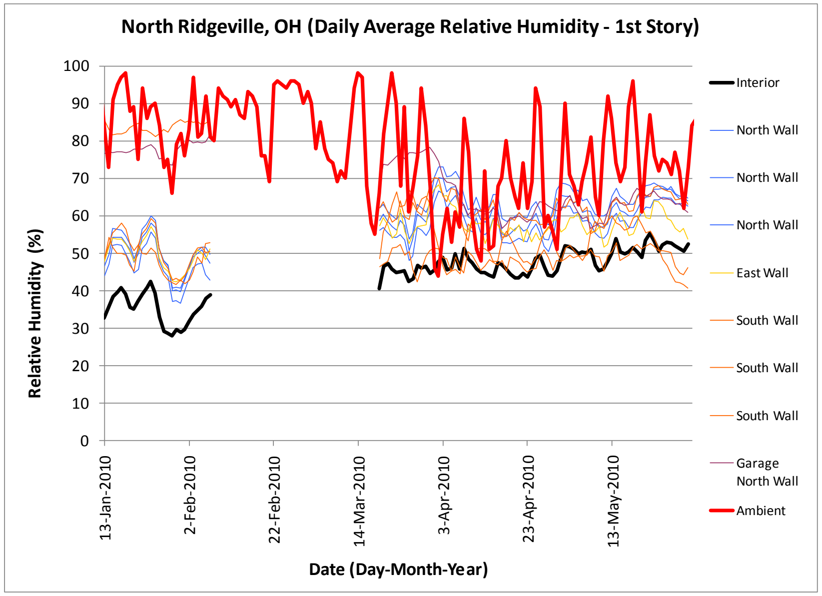


Figure A1- 32 – Jobsite #6 1st floor relative humidity

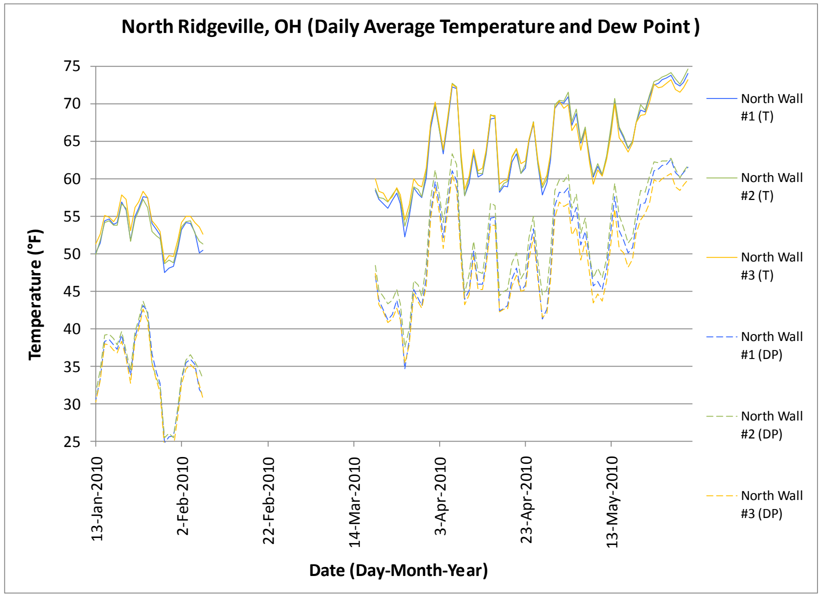


Figure A1- 33 – Jobsite #6 1st floor test wall temperature and dew point

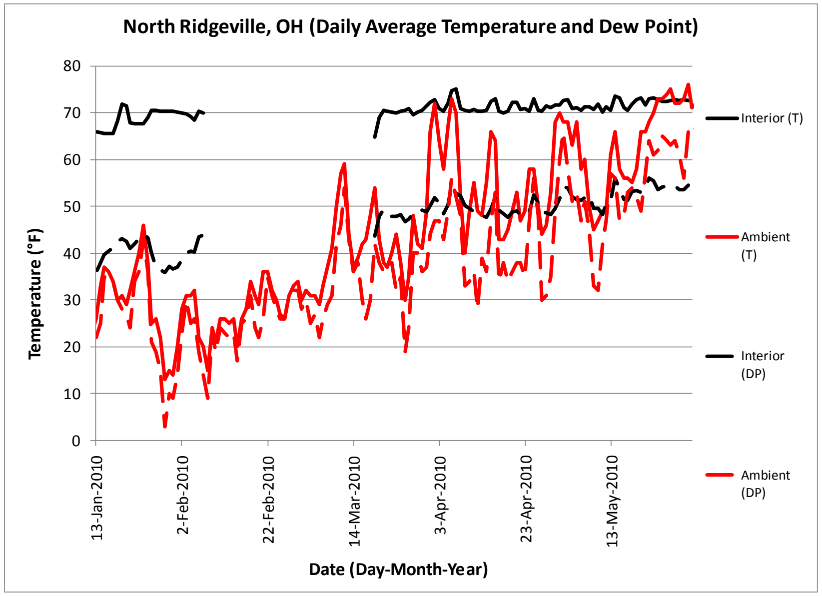


Figure A1- 34 – Jobsite #6 interior and ambient temperature and dew point

Attachment 2 – Site Inspection Datasheet

Project #: (internal use only)

1. Site Location

Street	City	State
Zip	**Climate Zone**	**Local Weather Station**
Notes:		

2. Dates of Construction/Weather

	Date	Rain data (total inches)
Foundation Start		
Framing Start		
Roof enclosed by		
House enclosed by		
Occupancy start on		

3. House

Number of Stories (do not include basement)	

Basement	Yes☐	No☐	
Basement Conditioned/Unfinished	Yes☐	No☐	N/A☐
Basement Finished	Yes☐	No☐	N/A☐
Attached Garage	Yes☐	No☐	
Garage Finished	Yes☐	No☐	N/A☐

Ventilation System:		
Code minimum (bathrooms, kitchen)	Yes☐	No☐
Whole-house ventilation	Yes☐	No☐

ERV HRV Whole-house humidifier Whole-house dehumidifier	Yes☐ No☐ Yes☐ No☐ Yes☐ No☐ Yes☐ No☐

Heating System Type	

Heating System: Electric (HSPF) Gas (AFUE) Other	 ☐ ____________ ☐ ____________ ________________

Cooling System Type	

Cooling System: Electric (SEER) Other	 ☐ ____________ ________________

Ducts, duct location, duct insulation:

Hot Water System Type	

Hot Water System: Electric (EF) Gas (EF) Other	 ☐ ______ Tank☐ Tankless☐ ☐ ______ Tank☐ Tankless☐ ________________

Energy Star House	Yes☐ No☐

Other:

4. WALL FRAMING & SHEATHING (ONSITE INSPECTION)

WALL CONSTRUCTION	
Stick-built	☐
Panelized on site	☐
Panelized off site	☐

FRAMING

2 x 4 walls	☐	
2 x 6 walls	☐	
Studs at 16" oc	☐	
Studs at 24" oc	☐	
Framing same all stories	Yes ☐	No ☐ ____________________
Double To Plate	☐	
Single To Plate	☐	
Framing Species and Grade	____________________	
Framing moisture content when being sheathed	____________________	

OSB WALL SHEATHING

> **Note:** all measurements on a min of 5 panels per house

Panel Thickness ______________________

Panel Width ______________________

Panel Length ______________________

Panel Brand and Certification Agency ______________________

Panel Span Rating ______________________

Gap between Panels ______________________

Panel MC at installation ______________________

Continuously Sheathed Yes ☐ No ☐ ______________________

TO BE COMPLETED IN THE LAB:

Linear expansion properties ______________________

5. THERMAL/MOISTURE/AIR BARRIERS

WRB Brand	________________________
WRB Taped	Yes☐ No☐
WRB Perm Rating	________________________
Flashing Material	________________________
Flashing Details	________________________
Exterior Rigid Foam	Yes☐ No☐
Wall Cavity Insulation	________________________
Band Joist Insulation	________________________
Attic Insulation	________________________
Basement Insulation	________________________
Raised Heel Truss	Yes☐ No☐
Attic Eave Baffles	Yes☐ No☐
Wall Vapor Retarder	________________________
Wall Paint	________________________
<u>Air Sealing Details</u>	________________________
Top Plates	________________________
Bottom Plates	________________________
Sill Plates	________________________
Rim Joists	________________________
Roof Heel	________________________
Recessed Lights	________________________
Shower/Tub	________________________
Garage	________________________

Basement Blower Door Test Results (if available)	____________________________________
Fill Out Energy Star Thermal Bypass Checklist as applicable and attach to this checklist	☐Complete ☐N/A