Balanced Solutions Inc.
"Better Buildings by Design"
160 Columbia St. W. Suite 133
Waterloo, ON, Canada N2L 3L3
Tel: 519.741.7920 Fax: 519.885.5193
www.balancedsolutions.com

**Date:** December 14, 2006

**To:** Marquam George, University of Alaska Southeast
John Davies, Alaska Housing Finance Corporation
Michael Musick, Cold Climate Housing Research Center

**From:** Jonathan Smegal, Balanced Solutions Inc.
John Straube, Balanced Solutions Inc.

**Re:** CCHRC Test Trailer at University of Alaska Southeast

This is the final report on the Cold Climate Housing Research Center (CCHRC) funded research project starting April 4, 2005 and finishing August 23, 2006. The objective of this report is to document the experimental design, equipment, results, and to interpret the results. The scope of this report is limited to the current project between April 4, 2005 and August 23, 2006 as well as a brief review of the previous wall testing study. A detailed analysis and comparison of three wetting events will conducted for each test wall.

## Background

Southeast Alaska presents many moisture related construction issues because of its wet climate. Some problems from excessive built-in or stored moisture within a building enclosure include twisting and warping of framing materials, nail popping, paint peeling, and reduced thermal performance of fibrous insulation.

To help understand moisture movement, storage and drying in walls, the CCHRC funded a research project. This project was designed to collect full-scale field performance data from wall systems comprised of different materials and assemblies.

## Previous Study

A previous wall monitoring study was conducted at the University of Alaska Southeast (2003-2004) to evaluate the drying potential of commonly constructed wall assemblies. This was achieved by increasing the initial moisture content of the building materials to simulate construction in a wet environment. The initial moisture content for all common framing materials and structural sheathing were 30% and 10% respectively.

The test wall selection for the previous wall monitoring study consisted of eight standard construction techniques including siding, sheathing membrane, sheathing, wood studs, insulation and drywall. The ninth test wall used an exterior insulated approach with the insulation, vapor barrier, and air barrier all on the exterior of the sheathing. Of the nine

walls tested, the best performing wall was the exterior insulated wall. It offered the most reliable approach to drying of built-in moisture and had the lowest recorded moisture contents in the sheathing, framing and bottom plate at the conclusion of the testing.

## Current Test – Experimental Apparatus

A nine-panel test trailer with exterior dimensions of 24' long by 8'-6" wide and 8'-10" high was constructed by BulletProof Trailers of North Pole, Alaska for the CCHRC. The trailer was constructed similarly to a structural insulated panel system; 4-inch thick polyurethane foam sheets were sandwiched between 0.5 inch exterior grade plywood and covered with an acrylic coating. The lab has four test bays on each of the two long sides of the trailer, and one test bay on the end of the trailer opposite the door.

Each test wall bay is 45 inches wide by 89 inches high. Temperature for the interior of the lab was controlled with electric resistance heaters to achieve 70°F. A heat recovery ventilator was installed and used to ventilate. Relative humidity was not controlled.

## Purpose

The current (second) study was designed to expand on the results from the previous testing. The goal was to evaluate different combinations of the exterior insulated wall system for both commercial and residential applications

A table summarizing the test wall materials is shown below. A detailed wall drawing showing the construction materials, sensor layout, and sensor codes is shown in the test wall setup section later in the report.

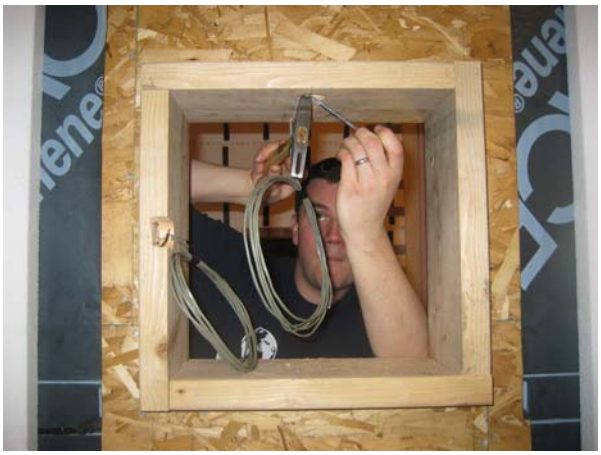
| Wall | Cladding | Drain gap | Drain Plane | Ext Insulation | AB / Drain 2 | Sheathing | Insul/Stud Spc | Framing |
|---|---|---|---|---|---|---|---|---|
| 1 | Fiber Cement Plank | Drainage Matt | Tyvek | XPS | none | plywood | none | 2x4 |
| 2 | Vinyl Siding | Integral | none | EPS | Bituthane | OSB | none | 2x4 |
| 3 | Fiber Cement Plank | PT furring strips | none | XPS | ruffco polyethylene | OSB | none | 2x4 |
| 4 | Vinyl Siding | Integral | none | XPS | #30 Asphalt Paper | plywood | none | 2x4 |
| 5 | Fiber Cement Plank | Drainage Matt | none | XPS | P&S Strips | OSB | none | 2x4 |
| 6 | Vinyl Siding | Integral | Tyvek | EPS | P&S Strips | plywood | none | 2x4 |
| 7 | Vinyl Siding | Integral | none | XPS | Sto-Guard | OSB | 2" PU | metal |
| 8 | Fiber Cement Plank | Drainage Matt | none | none | none | none | ICF | ICF |
| 9 | Fiber Cement Plank | Drainage Matt | Tyvek | XPS | none | plywood | 3.5" batt | 2x4 |

## Instrumentation

Each of the test walls is outfit with a series of temperature, relative humidity and wood moisture content sensors. These sensors were continuously monitored and recorded throughout testing and data was recorded using a data acquisition system. The sensor package for each wall was similar and can be seen in the wall drawing further in the report. Photographs of the individual sensors are shown below.

Moisture content pins were installed in the framing lumber and the sheathing in most wall systems. The wood moisture content pins were installed in combination with a temperature sensor in all locations. This temperature was used to correct the wood moisture content readings.

The relative humidity sensor is always installed in combination with a temperature sensor, both of which are protected by a vapor permeable, water resistant cover. Relative humidity and temperature sensors were installed in the stud space as well as the drainage gap.



To better understand the temperature gradients and heat flow through the window buck, moisture content pins and a temperature sensor were installed near the exterior surface in all the window bucks.

**Wetting System**

Two wetting systems were installed to simulate leaks from the window on the interior and on the exterior side of the sheathing. This allowed an addition of a known amount of water at a known location into the stud space or drainage gap. Injecting water into the wetting system provides a method of evaluating and comparing the response of wall systems to a carefully controlled simulated leak.

The interior wetting system in the stud space consists of a plastic tube, and water storage medium to hold the water against the sheathing as shown in the photograph below. It is possible for the wetting apparatus to hold a maximum of 100 mL of water but because of imperfections in the wetting apparatus, and uncontrollable moisture paths, it is possible for a fraction of the water to miss the wetting apparatus and collect at the bottom plate.

The exterior wetting system consisted of a tube passing through the sheathing membrane to the exterior drainage plane, and was well sealed to avoid moisture or air movement into the stud cavity. In some cases, it was difficult to push water through the plastic tube as there was very little space on the exterior of the sheathing where the insulation was pressed up against the sheathing.

Wetting systems were installed in all wall systems except for the Wall 8 (ICF), and were wetted as per a wetting schedule. The wetting apparatus is monitored with two sets of moisture content pins. One set was installed very close to the bottom of the window and is referred to as mid sheathing moisture content (MENM). The second set was installed near the bottom of the wetting apparatus and is referred to as lower sheathing moisture content (MENL).

The wetting schedule, determined based on previous wetting experiments, is designed to allow some time to dry between wettings. In Juneau rain leaks can occur at any time of the year, so some wetting events occurred before complete drying had occurred. In some cases water was added on two consecutive days to imitate a slower leak over a longer period. There was no wetting apparatus in Wall 8 (ICF Wall) because there was no stud space.

| Date | Int / Ext | Volume |
|---|---|---|
| 3-Jul-05 | Exterior | 30 mL |
| 21-Jul-05 | Interior | 50 mL |
| 22-Jul-05 | Interior | 50 mL |
| 18-Aug-05 | Interior | 50 mL |
| 19-Aug-05 | Interior | 50 mL |
| 27-Sep-05 | Interior | 100 mL |
| 27-Sep-05 | Exterior | 100 mL |
| 10-Nov-05 | Exterior | 90 mL |
| 22-Dec-05 | Interior | 90 mL |
| 06-Feb-06 | Interior | 100 mL |
| 07-Feb-06 | Interior | 100 mL |

The external wetting apparatus showed no response in any of the monitoring sensors, and was difficult to use, because of the positioning of the tube, and the lack drainage space in some of the test walls.

**Trailer Location**

The test trailer was placed outside the main school building. In order to access services the trailer had to be located close to the building. The southwest face (Walls 1-4) is completely exposed. The northeast face (Walls 6-9) may be partly sheltered.

**Weather Station**

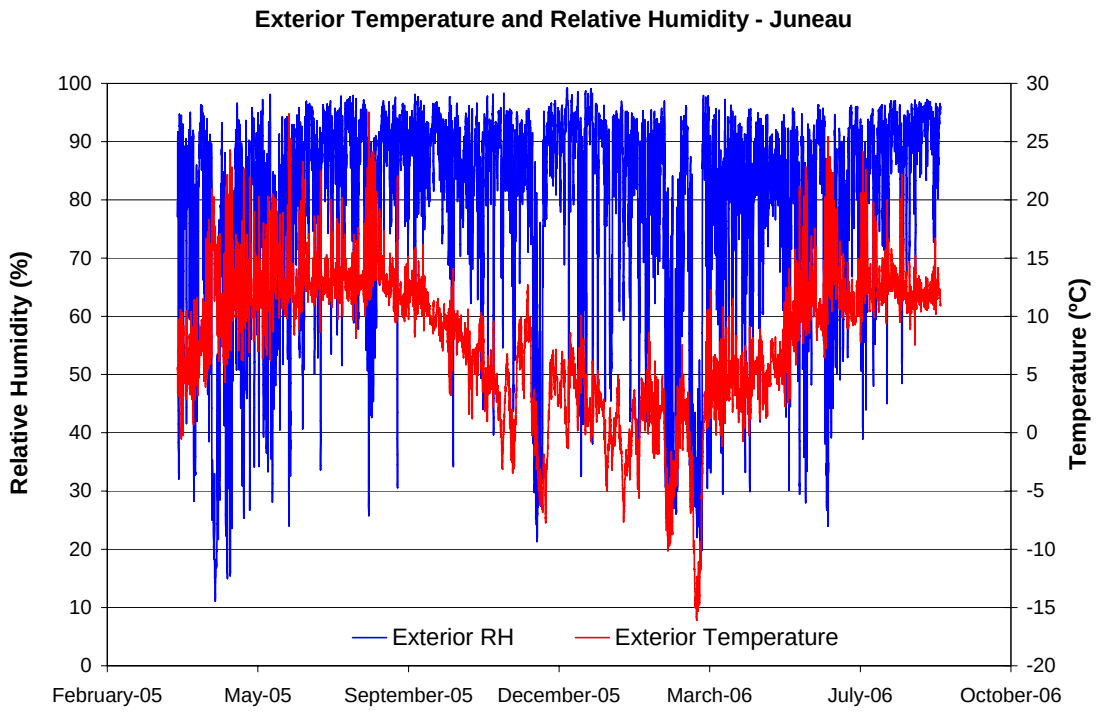
Boundary conditions during testing were monitored with the aid of two weather stations mounted on the test trailer. The weather station included wind direction and speed, horizontal and driving rain, exterior temperature and relative humidity, and a solar radiation sensor.

Weather stations, mounted on the outside of the trailer show that the two wind vanes on the weather stations are not pointed in the same direction. This may have been caused by the interference from neighboring buildings.

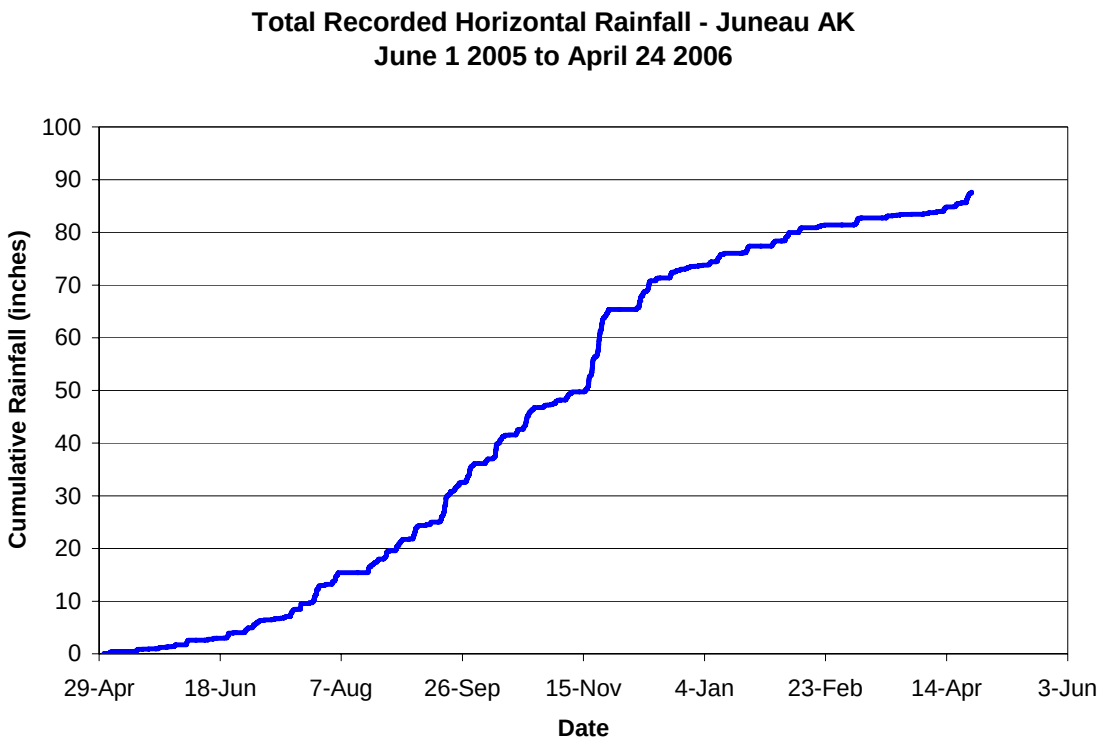
Driving rain gauges were installed on the southwest and northeast sides of the trailer.

## Test Trailer Exterior Conditions

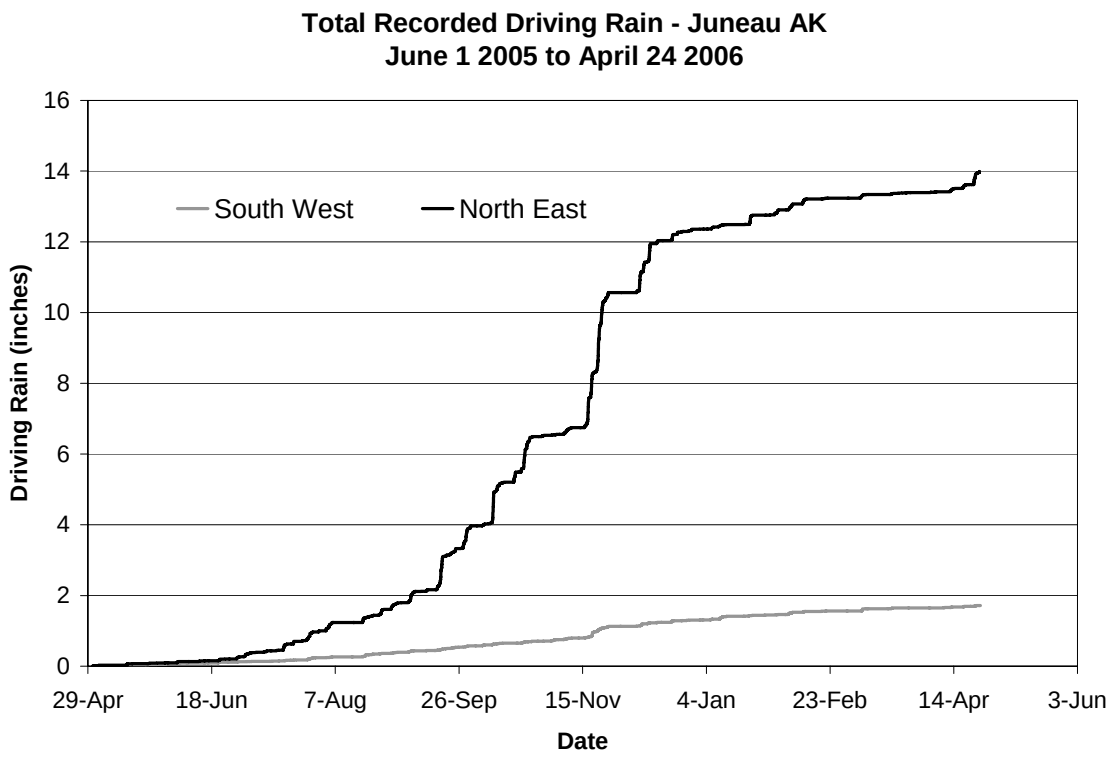
The following graphs show the exterior conditions during the testing period.




Exterior relative humidity and temperature. The relative humidity is between 80 and 95% for most of the year. The exterior temperature generally stays between 20°C and -10°C throughout the year, with peaks of approximately 25°C in the summer and -15°C in the winter.



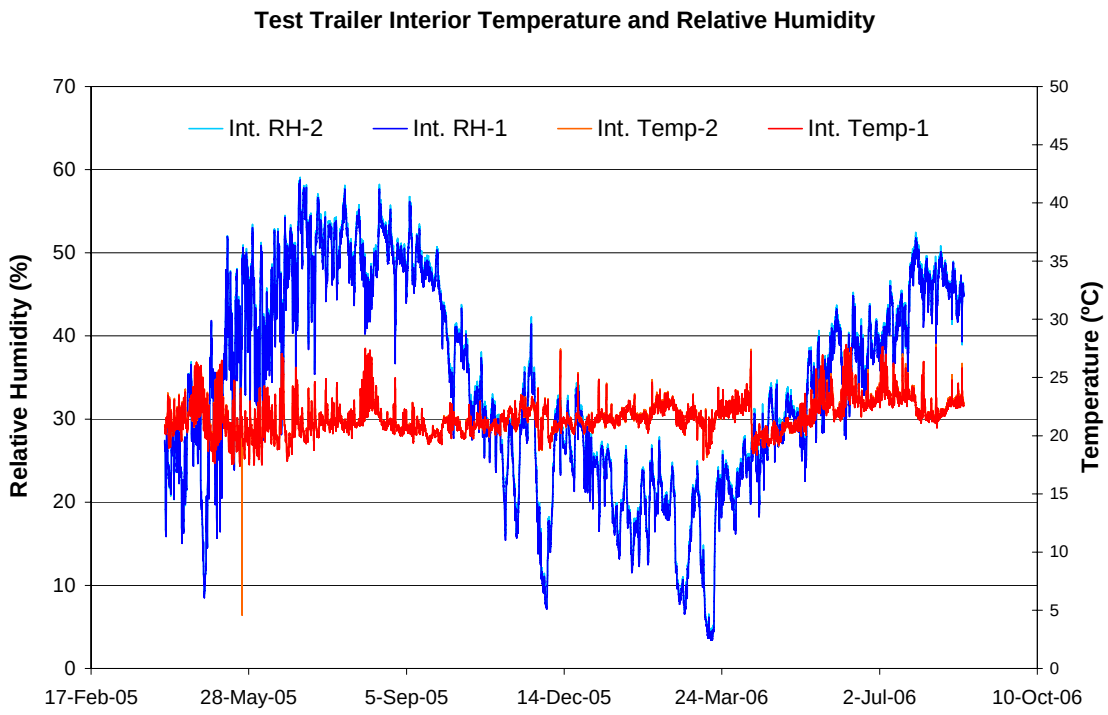

The rainfall on a horizontal surface was almost 90 inches of rain from May 1, 2005 to May 1, 2006. (1 year)



The driving rain amounts varied considerably between the two faces through the year. The partly sheltered walls 6-9 received considerably more driving rain than exposed walls 1-4. This demonstrates that the majority of driving rain comes from the inland direction and is more than experienced by most North American housing.

For ten days between November 17, and November 27, 2005, there was a significant driving rain event on Walls 6-9 as shown on the driving rain graph by the nearly vertical line. The test wall data was examined closely for that time period for any correlation between driving rain and wall moisture. No wetting was observed in that time period.

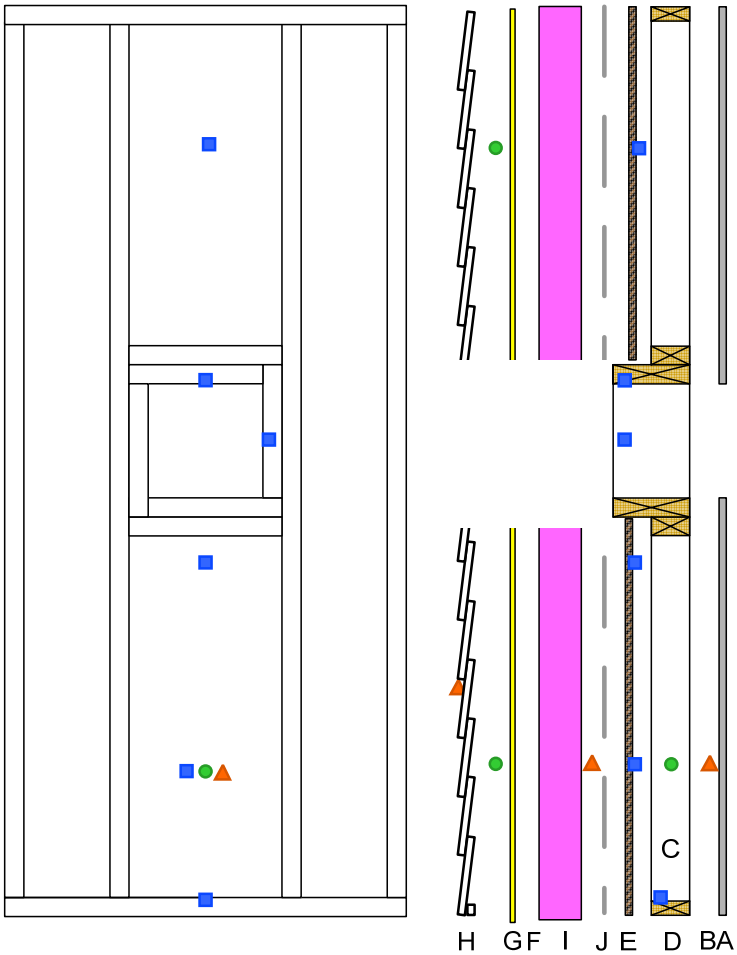
**Test Trailer Interior Conditions**




Temperature and relative humidity were each recorded in the trailer by two different sensors. The temperature was kept fairly constant between 20 and 25°C through the year. The interior relative humidity dropped as low as 10% in the winter and reached a high of approximately 55%.

**Test Wall Setup**

All of the test walls were constructed and instrumented similarly except for Wall 8 (ICF). The sensor locations, sensor codes and layout is shown below in the test wall schematic.




Elevation Section

**Assembly**

| Layer | Function | Variables |
|---|---|---|
| A | Interior Finish | gypsum wall board |
| B | Vapor Control | paint |
| C | Studspace Insulation | FG Batts, 2" PU, ICF, none |
| D | Framing | 2x4 wood stud, metal stud |
| E | Sheathing | OSB, plywood |
| J | Air Barrier/Drain 2 | Bituathane, Ruffco polyethlyne, #30 asphalt paper, P&S Strips, Sto-Guard, none |
| I | Exterior Insulation | XPS, EPS, none |
| F | Drainage Plane | Tyvek, none |
| G | Drainage Gap | Integral, Drainage Matt, PT furring strips |
| H | Cladding | Fiber Cement Plank, Vinyl |

**Sensor Package**

| Layer | Code | Location |
|---|---|---|
| A | tael | Interior finish, exterior face, 16" |
| C | r/tcnl | Studspace, interstitial, 16" |
| D | m/tdfb | Framing, exterior edge, bottom plate |
| D | m/tdfh | Framing, interstitial, window head |
| D | m/tdtj | Framing, interstitial, window jamb |
| E | m/tenu | Sheathing, interstitial, 64" |
| E | m/tenm | Sheathing, interstitial, 40" |
| E | menl | Sheathing, interstitial, 32" |
| G | r/tgnl | Drainage space, interstitial, 16" |
| G | r/tgnu | Drainage space, interstitial, 64“ |
| H | thel | Cladding, exterior surface, 16" |
| I | tiil | Exterior Insulation, interior surface, 16“ |

- ● Relative Humidity and Temperature Sensor Package
- ■ Moisture Content Pins and Temperature Sensor Package
- ▲ Temperature Sensor

## Wall Performance Analysis

The wall performance analysis was complicated by the large number of variables being tested. It was difficult to attribute any differences in wall performance to a single variable.

A preliminary analysis was conducted to evaluate the wall performance under normal climate conditions, without intentional wetting events. This analysis was conducted by examining the wood moisture content in the walls. It is generally accepted that wood moisture contents less than 20% are safe, moisture contents in the 20-30% range are risky, and moisture contents greater than 30% should be avoided at all times. The amount of moisture damage is not only a function of the moisture content, but also a function of the time and temperature at a given moisture content level. Almost all building materials can tolerate wetting provided they are allowed to dry in an appropriate time.

Moisture content calibrations with electrical resistance are a function of both temperature and wood species. It should be noted that the moisture contents used for this analysis are corrected for temperature only. Species correction factors for OSB and plywood have not been determined. Without the species correction factor, the wood moisture content may differ by as much as ±5% moisture content.

No walls exhibited any observed moisture problems under normal operating conditions. Graphs for every wall including temperature, moisture content and relative humidity are attached at the end of this report. None of the moisture content readings exceeded 17% under normal conditions, and most never got as high as 11%. This means that all of the test walls could perform well in Juneau's climate provided that no rain or air leaks occurred and the interior RH was controlled. One anomaly in the moisture content data was Wall 5, which had two spikes in moisture content that are explained further in the Wall 5 analysis.

In the winter months the walls were subjected to a very low interior moisture load. Interior moisture conditions are generally higher due to human occupancy and activities (eg. Bathing, cooking). Increasing the interior relative humidity would increase the moisture damage risk of the test wall systems and more closely simulate normal interior conditions.

Most moisture problems that occur in the building enclosure are caused by detail design and construction deficiencies allowing water into the wall. To simulate a leak, the wetting apparatuses were used to inject a known amount of water. A wetting event in the cavity space should cause an increase in the moisture content of the sheathing and the relative humidity in the stud space. This added moisture will only become a problem if the moisture content stays elevated and does not dry in a timely manner.

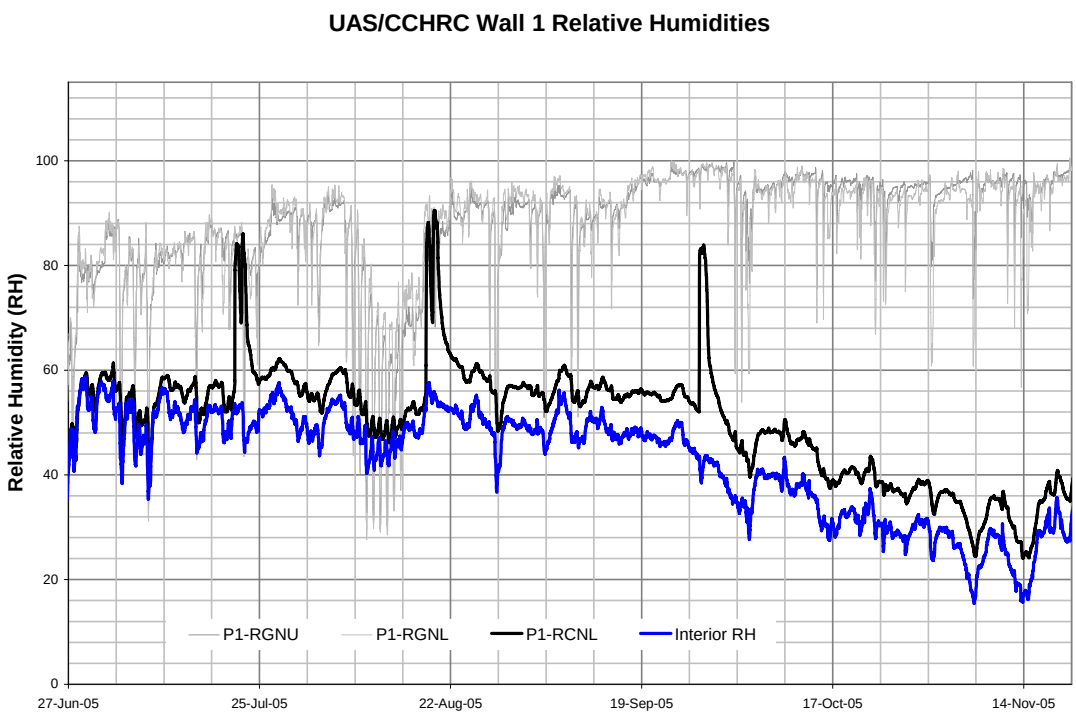
The wetting events and the nature of the subsequent drying will be the main focus for comparison of the different wall systems. Three wetting events will be analysed in detail: July 21-22, August 18-19, and September 27, 2005. In July, 50 mL of water was injected

on both the 21st and 22nd. On August 18th and 19th the procedure was repeated, and on September 27, 100 mL of water was injected into the wetting apparatus. These three wetting events were chosen because they follow each other close enough for easy analysis, and to simulate repeat leakages which are common when leaks do occur.

These three wetting events occurred in the summer months when it is likely that the walls would dry more quickly due to increased temperatures, and slightly lower relative humidities. A wetting event in December was also analyzed for comparison and it was found that the walls did not dry significantly faster during the summer months.

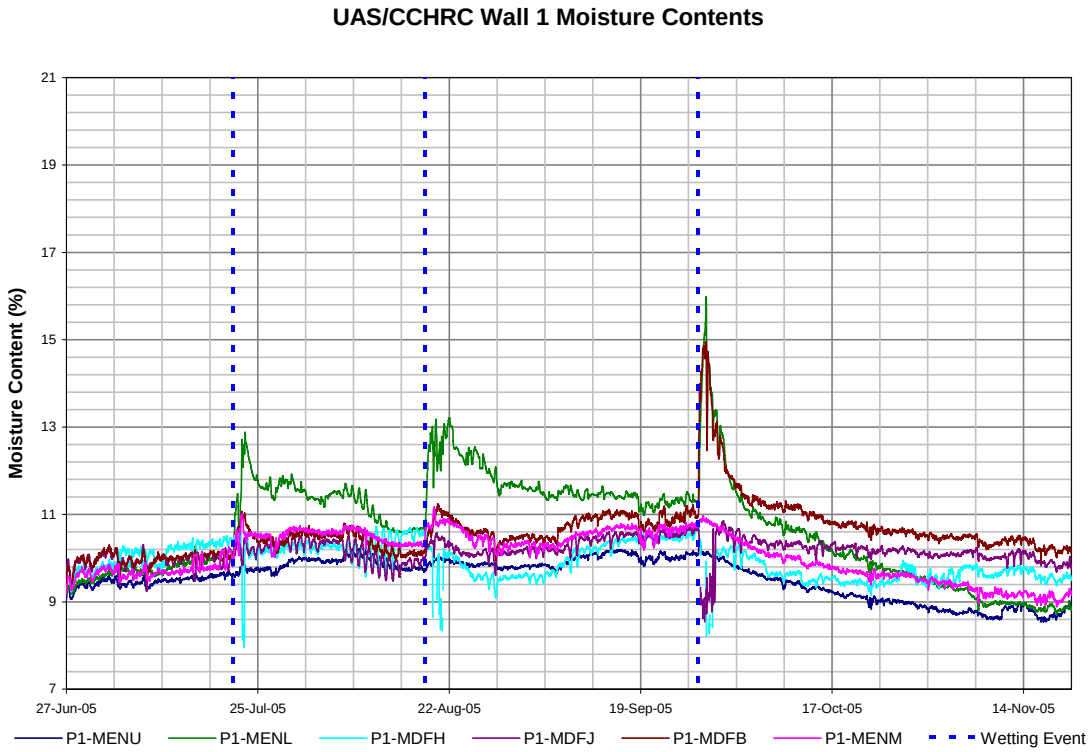
**Wall 1**

The relative humidity (RH) in the cavity space of Wall 1 was typically around 50% (see plot below). Immediately following the wetting events, the RH reached between 84% and 92%. In the case of the two-dose wettings (July and August), the relative humidity decreased to approximately 68% in the first 24 hours and returned to normal relative humidity levels in approximately four days following the end of wetting. During the single-dose wetting event on September 27, it took 48 hours for the relative humidity to fall below 60% RH. All of the relative humidities reached high levels during wetting events (ie. greater than 80%) but declined quickly, so that any risk of moisture problems would be minimal.



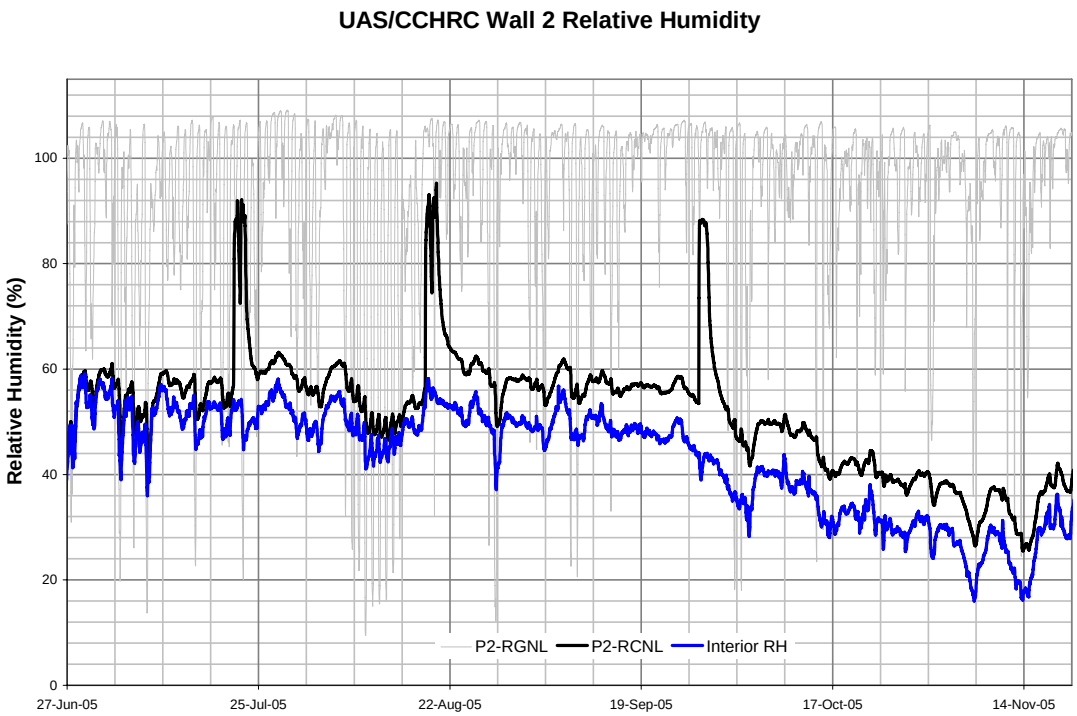

The wood moisture content of the lower sheathing in contact with the wetting apparatus (MENL) increased during all three wetting events. The first two events increased the moisture content from approximately 11% to 13% which is a measureable but insignificant (to moisture risk) increase. The third wetting event increased the moisture content of the sheathing to 16% and also increased the moisture content of the bottom

plate to 15%. During the third wetting event, the amount of water added to the wetting apparatus exceeded the storage of the absorptive layer, and water ran down the sheathing and collected on the bottom plate. The increased moisture content from the first two wetting events decreased relatively slowly, requiring a couple weeks to return to the pre-wetting moisture content. The third wetting event required only half the time to return to normal moisture content conditions, but none of the increased moisture contents result in a durability or performance risk.

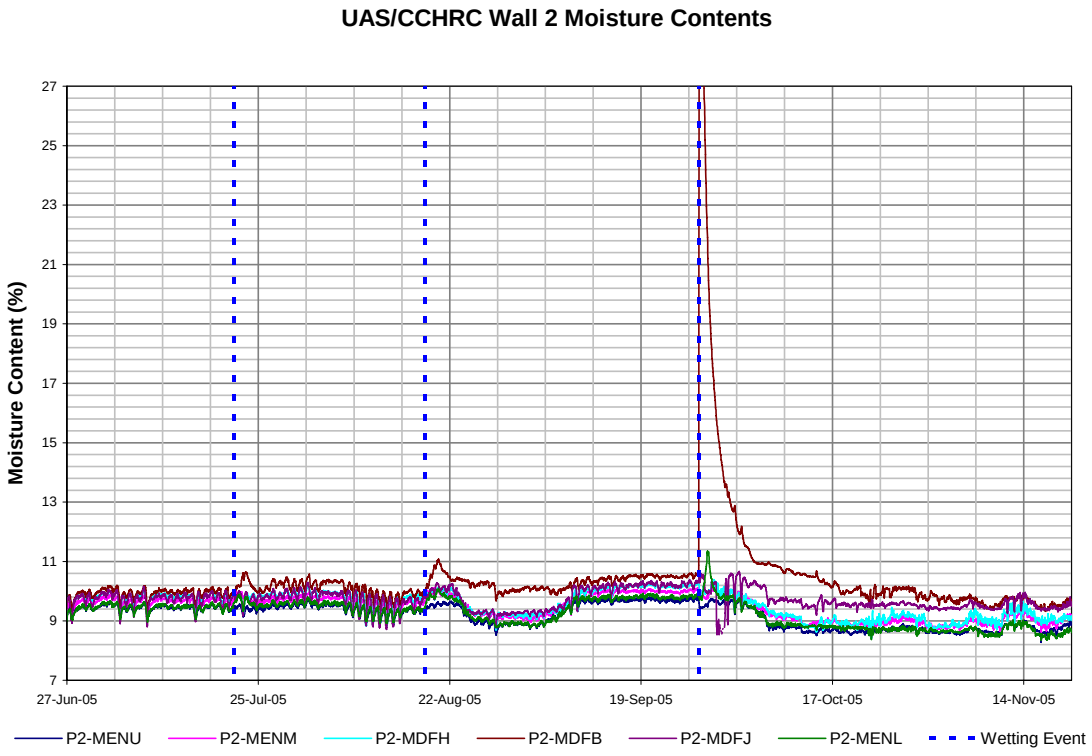



## Wall 2

The relative humidity graphs for Wall 2 look very similar to Wall 1. The relative humidity achieves slightly higher values (88-96%) after wetting, but the walls still dry most of the injected water in a short period of time (eg below 60% in less than 48 hours). The relative humidities decrease quickly enough that minimal risk is associated with the wetting events.

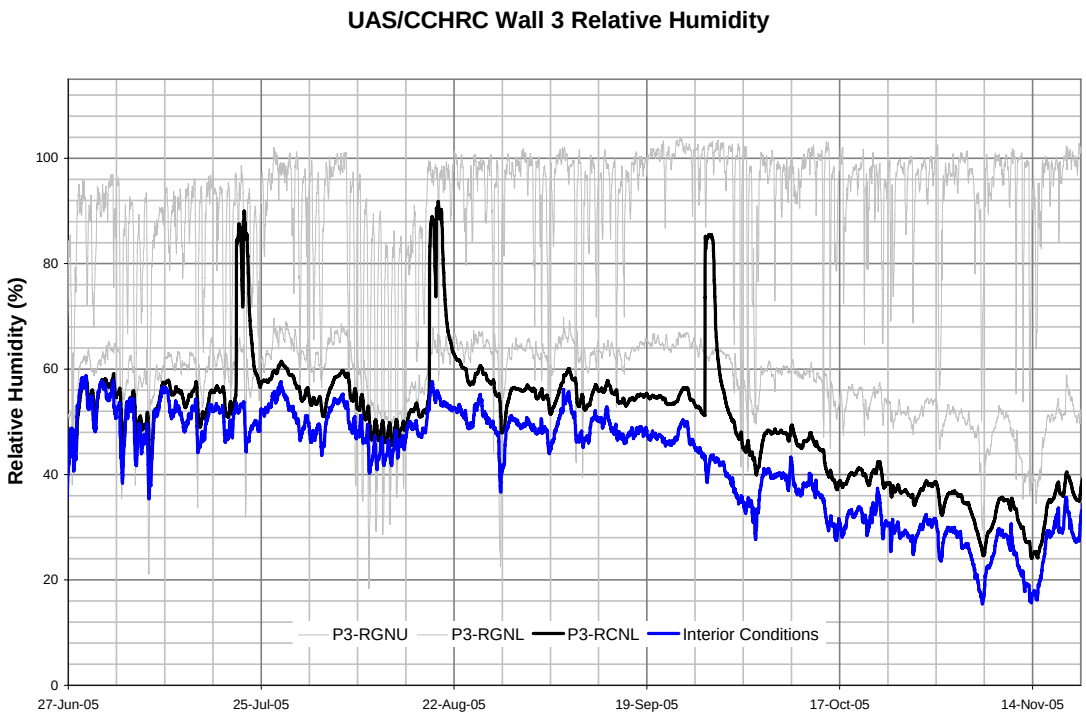



The moisture content curve for Wall 2 shows that the only increased moisture content during the wetting events was the bottom plate (MDFB). The wetting apparatus may have been overloaded and allowed liquid water to drain to the bottom plate rather than be retained in the storage media. The cause may be determined when the drywall is removed and the walls are analyzed visually for moisture damage. The first two wetting events resulted in a barely noticeable spike in the moisture content of the bottom plate, indicating that some water was likely held in the wetting apparatus. The third wetting event resulted in a maximum of 32%MC in the bottom plate. In 24 hours the moisture content decreased to 24% and under 20% in 48 hours. One week later, the moisture content had returned to the normal moisture content. The third wetting event caused the moisture content of the bottom plate to reach critical levels (over 30%), but the wall dried quickly enough to avoid serious risk.

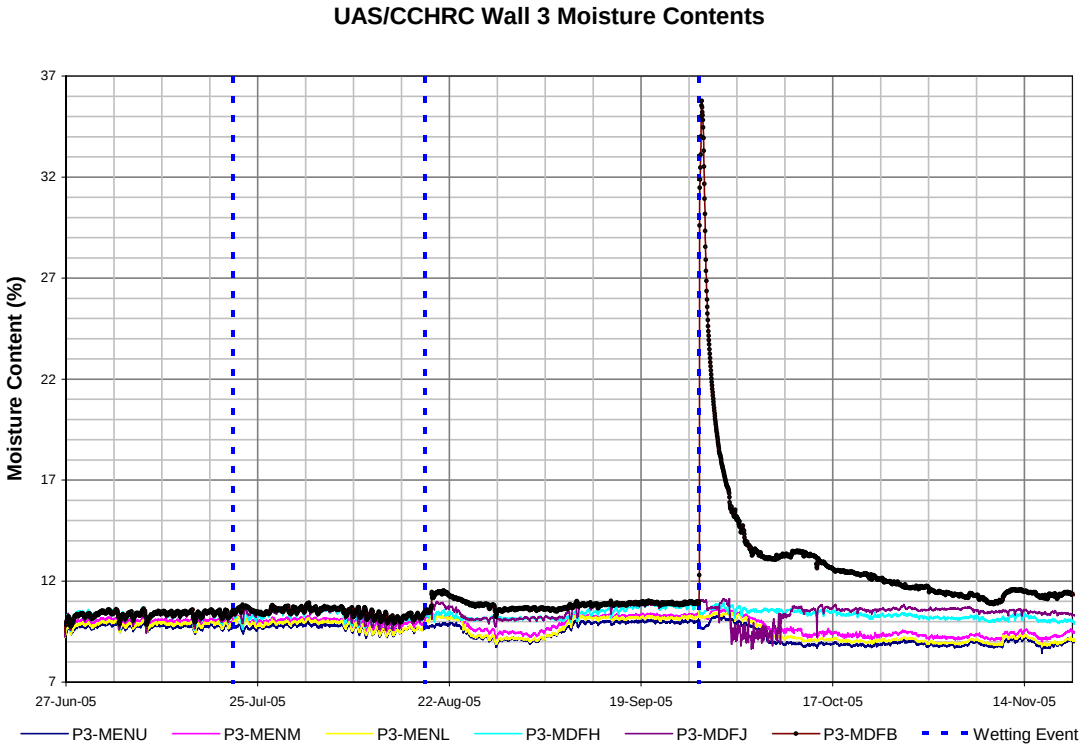



## Wall 3

The relative humidity during the wetting events for Wall 3 are very similar to Walls 1 and 2. The RH increased to between 84% and 92% during wetting, but dried very quickly, showing significant drying to less than 80% in 24 hours, and a return to normal in four days.

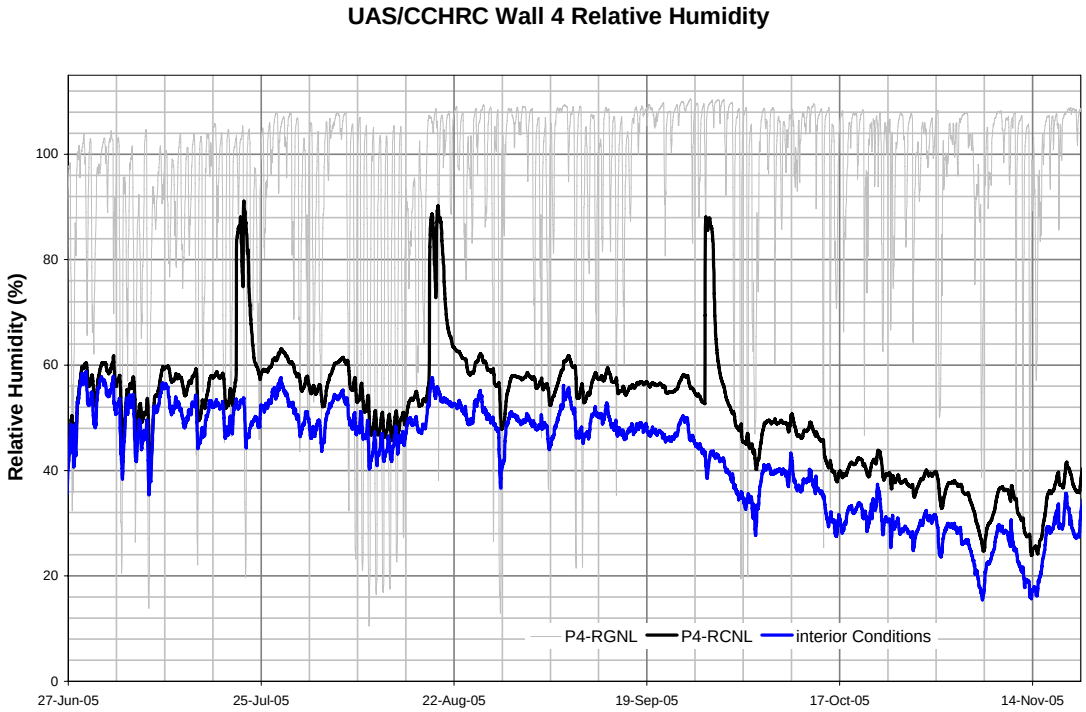



The wetting events for Wall 3 did not increase the moisture content of the sheathing in the vicinity of the moisture content sensor. The bottom plate showed a small amount of wetting during the second wetting event, and significant wetting during the third wetting event. The moisture content of the bottom plate during the third wetting event reached a maximum of 35%, decreasing quickly to 27% in 24 hours, and to less than 22% in 48 hours. When testing is complete, and the drywall is removed, it may be possible to determine the reason the sheathing was not wetted as expected. As with the previous walls, Wall 3 was able to dry small amount of moisture quickly.

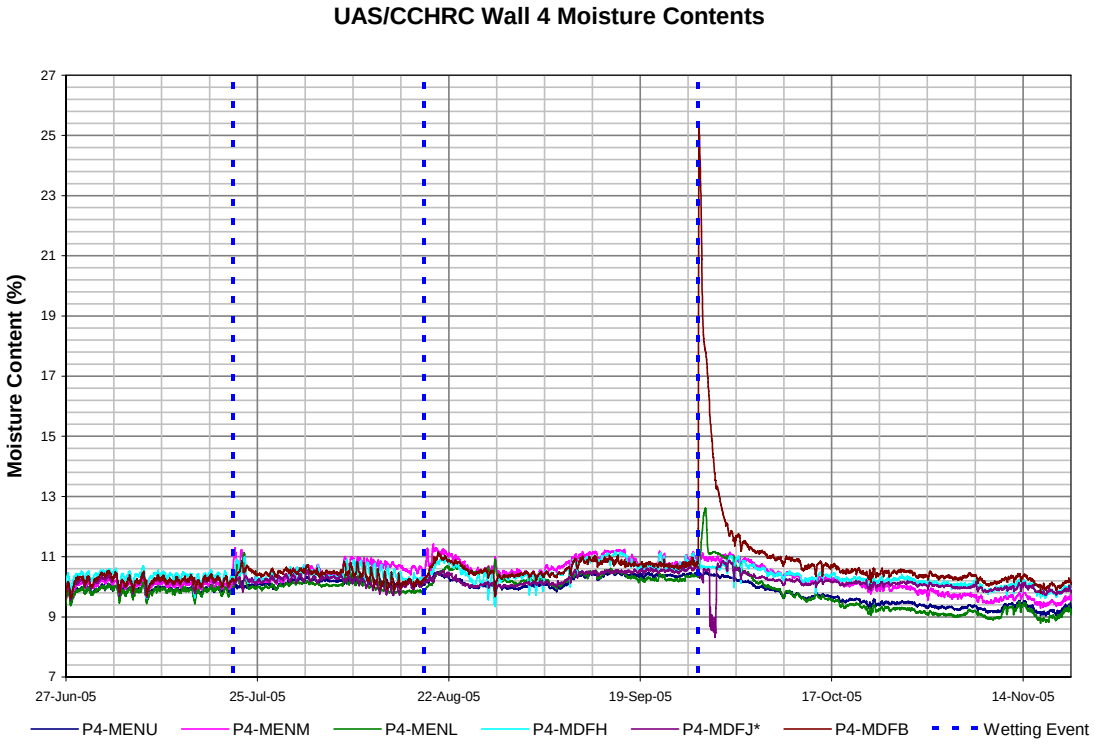



## Wall 4

The relative humidity during the wetting events for Wall 4 is very similar to Walls 1, 2, and 3. The RH increased to between 84% and 92% during wetting, but dried very quickly, showing significant drying to less than 80% in 24 hours, and a return to normal in four days.

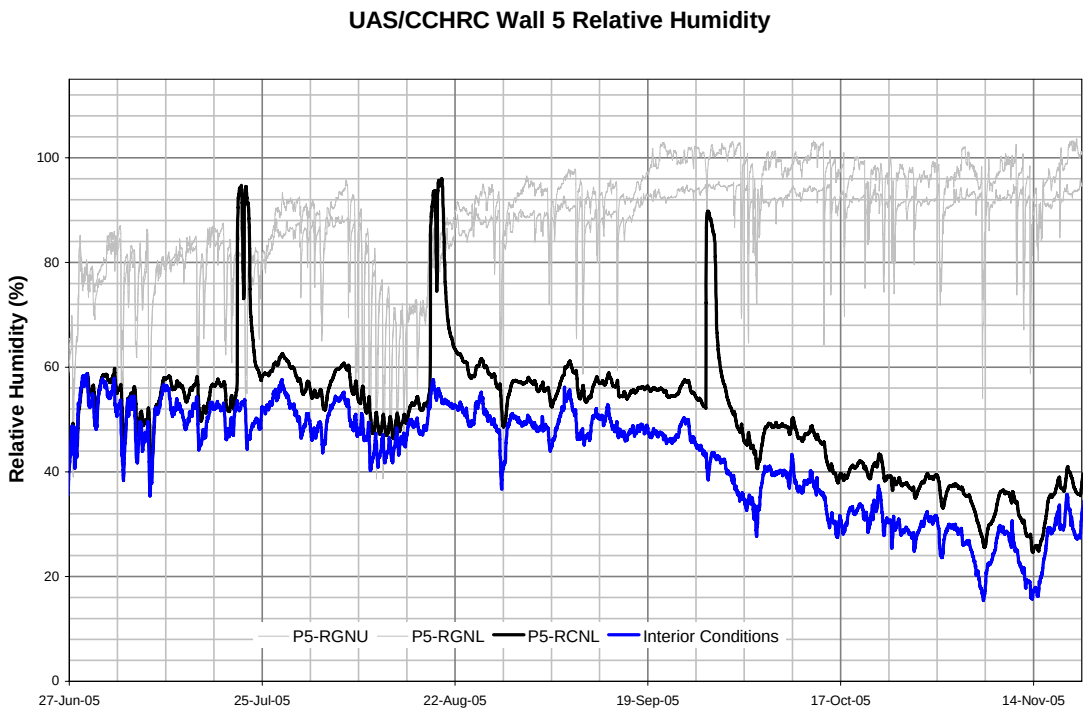



The moisture content did not increase at any location above the level of background noise for the first two wetting events. The third wetting event caused an increase of moisture content in the bottom plate to 25% and an increase in the sheathing to almost 13%. The bottom plate decreased to a moisture content of 18% in 24 hours. Similarly to the previous walls, no serious risks to the wall durability occurred from wetting events. The water may not be wetting the sheathing as expected because of the lack of cavity insulation, such as batt insulation, which would press the wetting apparatus against the sheathing.



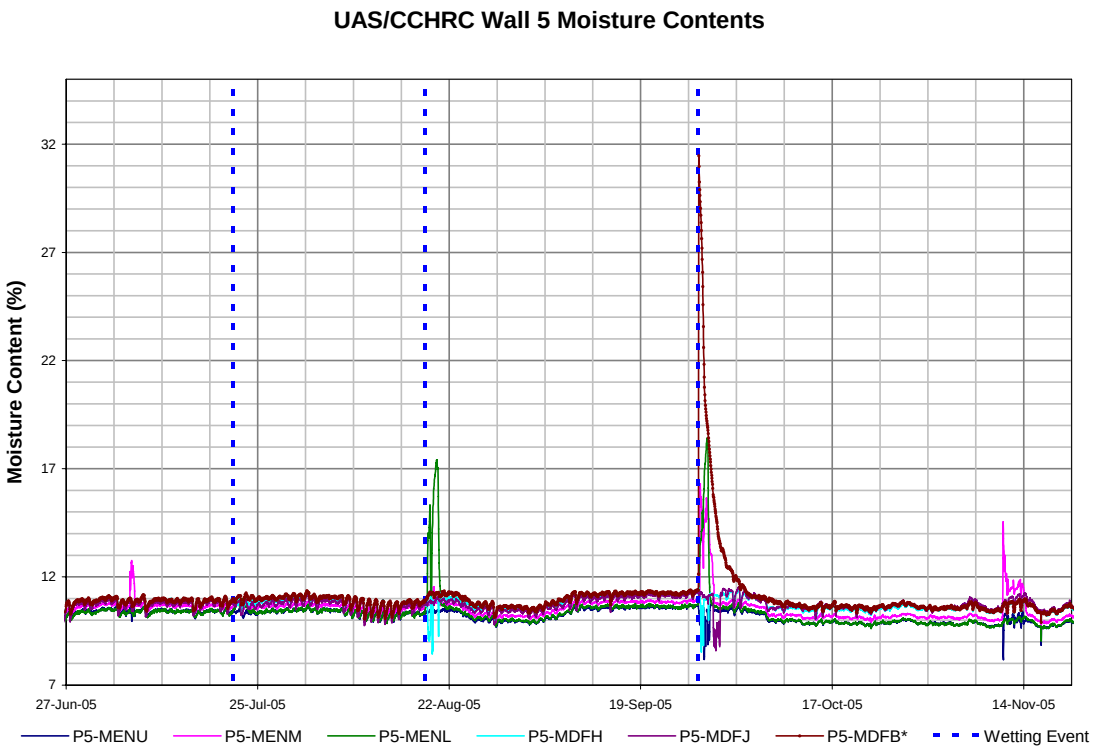

## Wall 5

As with all the previous uninsulated cavity walls, the relative humidity curves look nearly identical, increasing to 88-96% and then decreasing quickly avoiding moisture damage risks.



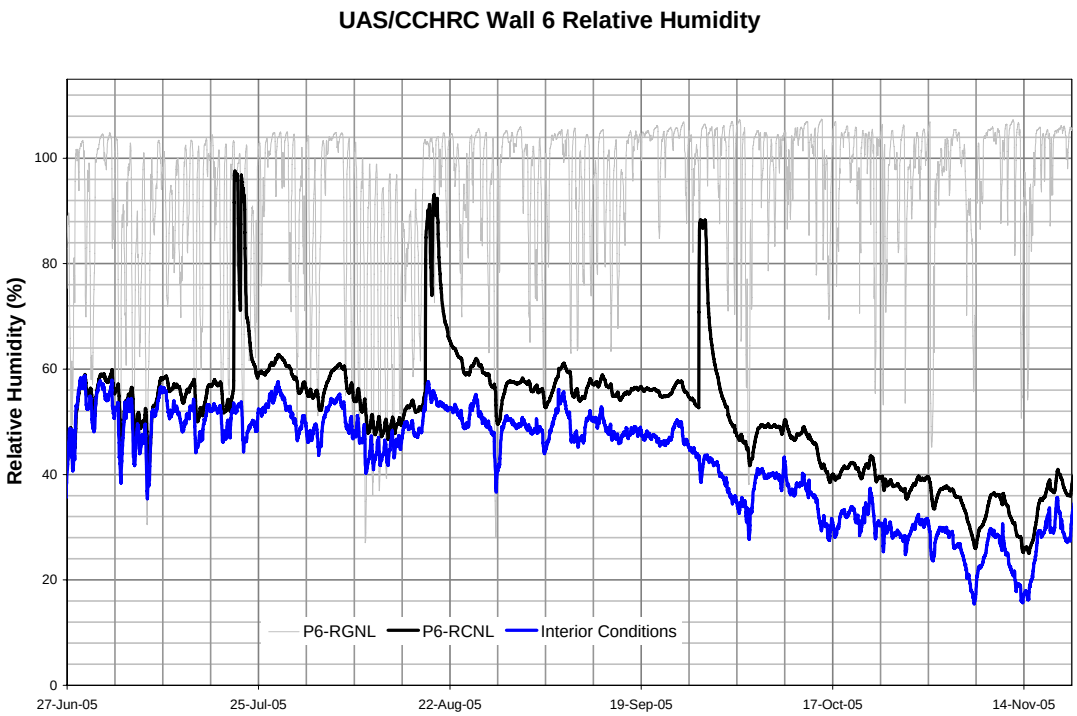

The moisture content graph shows increases in moisture content corresponding to wetting events two and three. The second wetting event increased the lower sheathing moisture content to 17%, and the third wetting event increased the moisture content at the bottom plate, and two locations on the sheathing. The lower (MENL) and middle (MENM) sheathing moisture contents both increased in Wall 5 to approximately 17%. The bottom plate moisture content increased to 32%, and dried to 20% in 24 hours.

The unexpected peaks were investigated by analyzing the temperature data for the specific times, but no correlation could be found for the moisture content peaks. The rainfall data was also examined, and it was found it almost always rains, so it's difficult to correlate any increased moisture content to rain events. Wall 5 is on the end of the trailer facing southwest, so is subject to different rain patterns than the other eight walls, but no reasons could be found for the unexpected peaks in moisture content. The peaks are minimal and present no risk to wall durability.

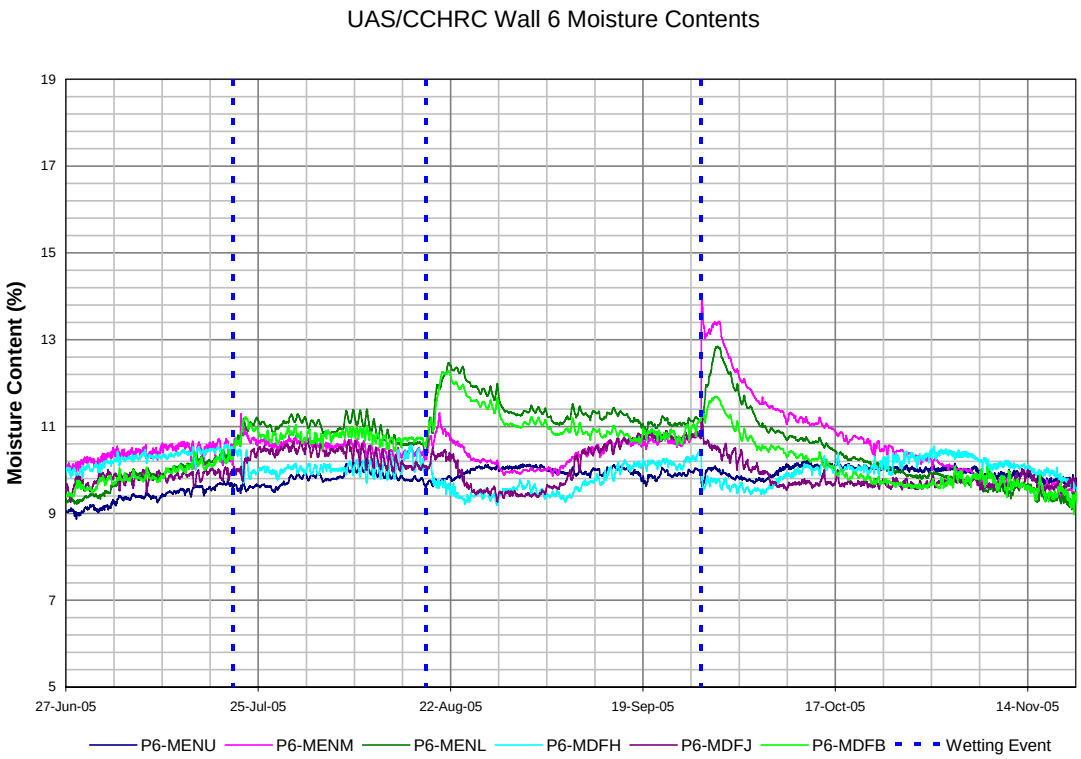



## Wall 6

Wall 6 showed the same relative humidity patterns as all walls with uninsulated cavity spaces. The relative humidities reached maximums of 88-94% during the wetting events, but dried quickly with minimal moisture damage risk.

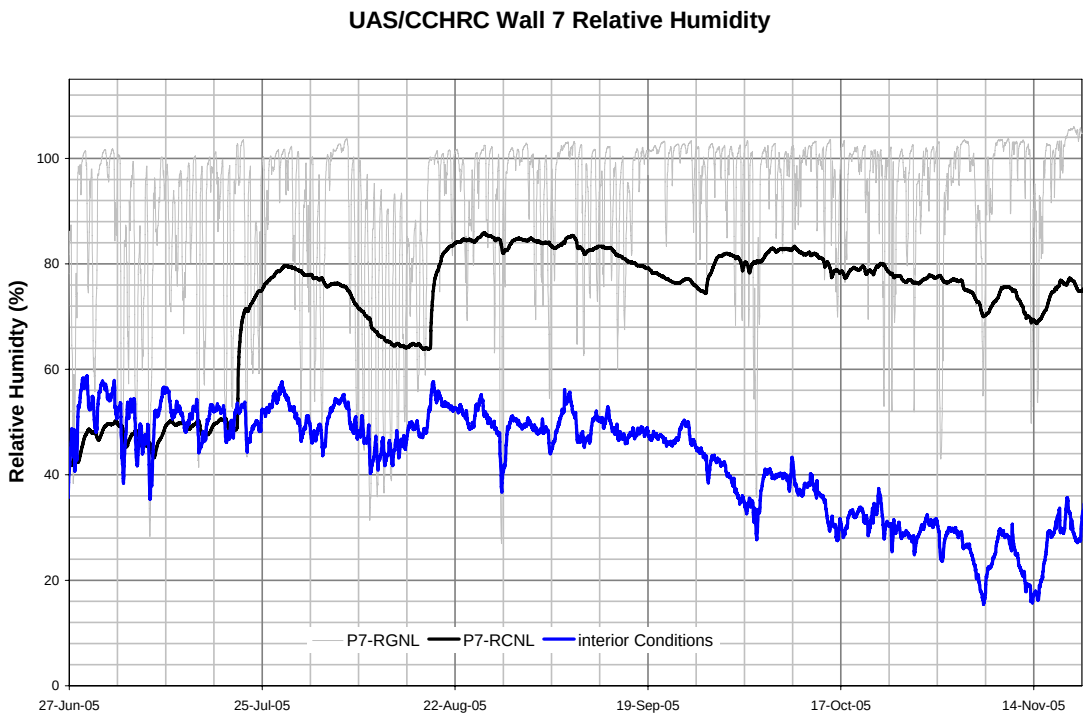



The wetting events in Wall 6 caused increases in moisture content of the sheathing and bottom plate in wetting events two and three. During the second wetting event the moisture content in the bottom plate and the lower sheathing increased to 12%. The middle sheathing moisture content had a small barely noticeable peak. The third wetting event increased the middle sheathing moisture content to 14%, the lower sheathing moisture content increased to 13% and the bottom plate only increased to 12%. All of the increases in moisture content were insignificant to the durability risk of the test wall.



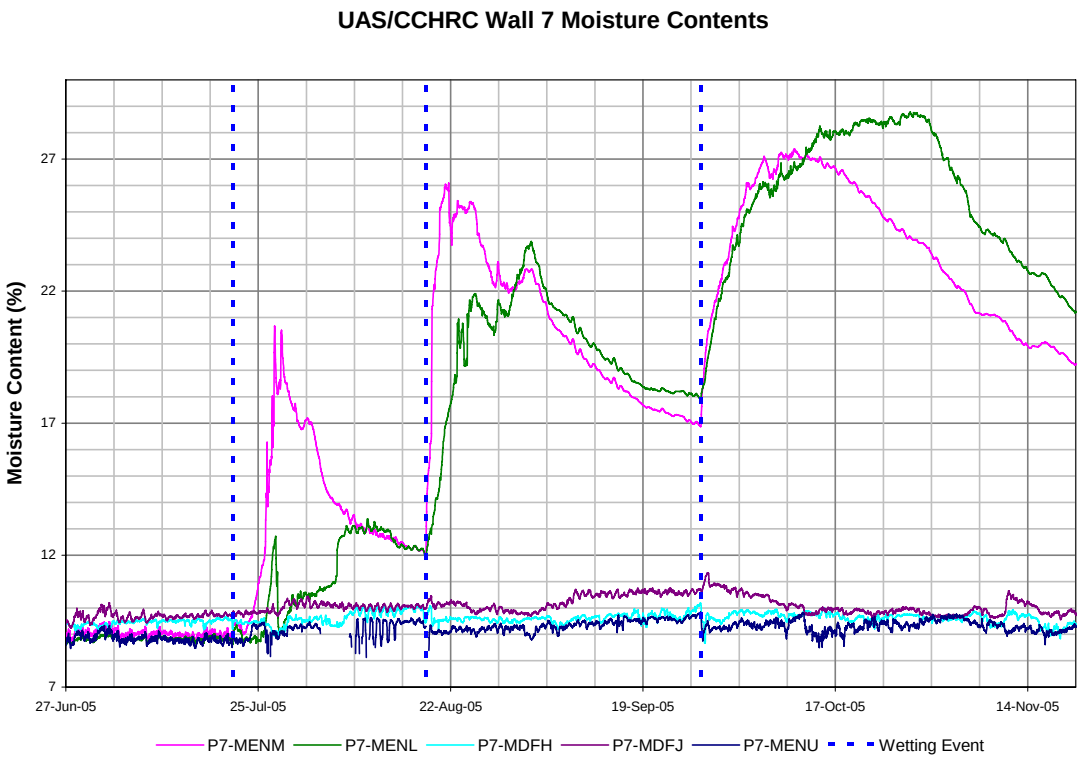

**Wall 7**

Wall seven contains polyurethane spray foam in the cavity space, which significantly affected the relative humidity and moisture content results. The first wetting event increased the relative humidity in the middle of the spray foam to a maximum of 80%. The RH increased quickly at first and then continued to increase gradually for several days. The movement of vapor is assumed to have been slowed by the spray foam insulation. After three weeks, the RH had not returned to the starting level, and remained at approximately 65% until the second wetting event. After the second wetting event the RH reached a maximum of 85% and maintained an RH of 80% for one month. The RH had decreased to 76% immediately before the third wetting event and even though the third wetting event did not increase the relative humidity considerably, it did sustain the relative humidity at approximately 80% for another month. These relative humidities are high enough and occurred long enough to present a risk of moisture damage to the wooden components.




The immediate response of the wood moisture content sensors was different than other walls, likely because of the presence of insulation. After the first wetting event, the sheathing moisture content at the mid sheathing level (MENM) rose for five days before it peaked at 21%MC. This was followed by an eventual increase in the lower sheathing (MENL) moisture content (13%MC) as the water slowly moved down the storage media. The sheathing moisture content did not return to the starting level before the second wetting event a month later.

The second wetting event resulted in a much quicker response from the moisture content sensors, likely because paths for water movement had been formed in the previous wetting. The middle moisture content sensor responded almost immediately, and reached a maximum of 26%. The lower sheathing moisture content sensor reached a maximum of 24% 12 days later. Thirty days later the moisture content had decreased to about 18%. After the third wetting, the moisture contents increased to 27% and 29% for the middle and lower sheathing sensors respectively. Two months later, the sheathing moisture content was still at approximately 20%. The sustained high moisture content indicates that if a leak occurred in this wall system, allowing moisture into the stud space against the sheathing, there is considerable risk for moisture damage.

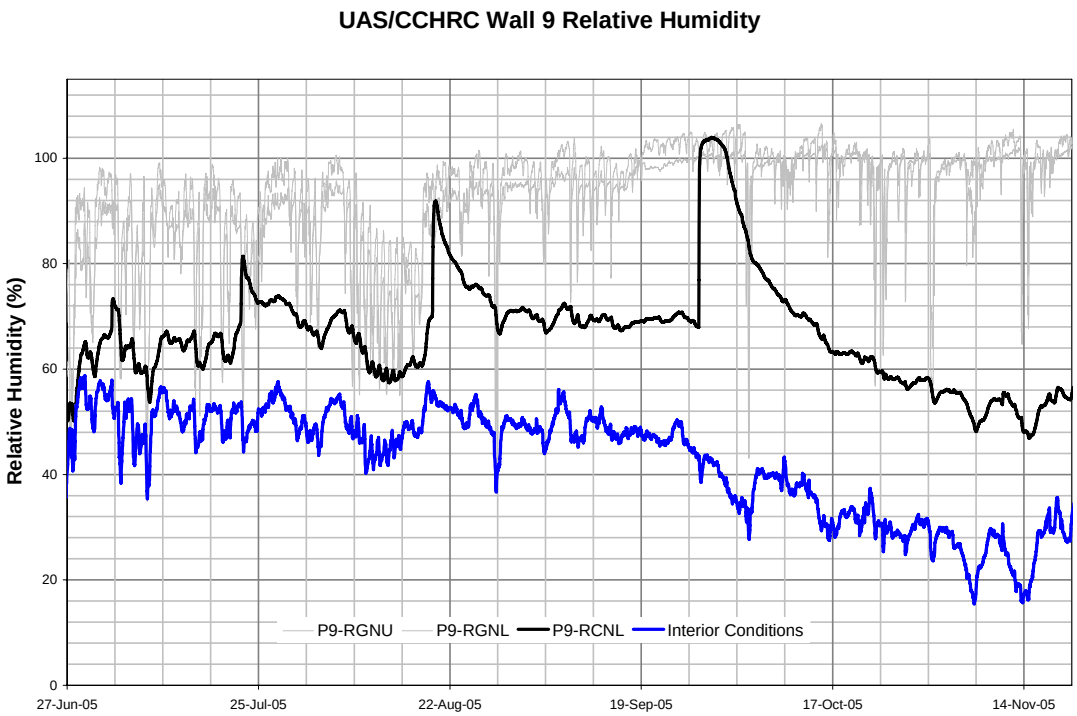



## Wall 8

Wall 8 was difficult to evaluate because it was made with insulated concrete forms (ICF). After sixteen months the relative humidity of the concrete was still greater than 85% from the original concrete moisture. This is a potential moisture source for moisture problems in the wall if the wall is not designed to properly deal with sustained elevated internal moisture loads. The RH, temperature, and wood moisture content graphs are included at the end of the report. There were no observed moisture problems for Wall 8 during testing.

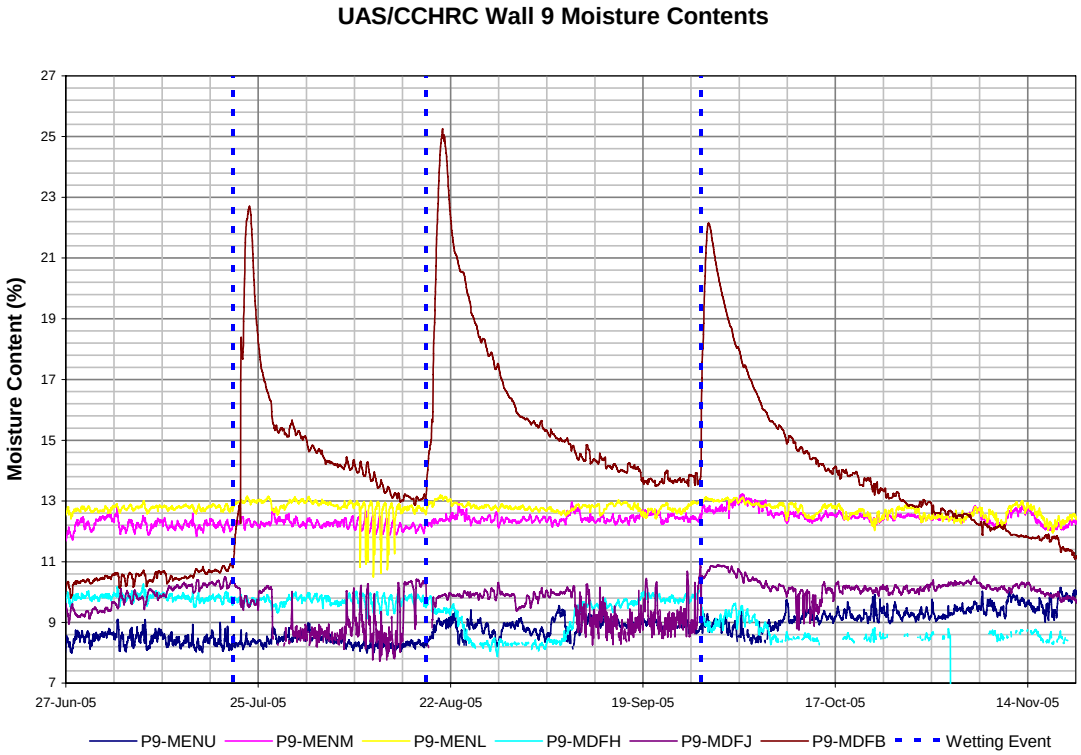
## Wall 9

The relative humidity shown for Wall 9 was elevated before the first wetting event when compared to Walls 1-6. The first wetting event reached a maximum of 80% RH but did not dry as quickly or as far as Walls 1-6. The second wetting event reached a maximum of 92% RH but was sustained above 80% for four days. It decreased only as far as 70% where it was steady until the third wetting event, which reached a maximum of 100%. The RH was sustained above 80% for nine days. This may have resulted in moisture damage that will be inspected once the walls are opened. The increased relative humidity in Wall 9 was sustained for longer periods than Walls 1-6 increasing the moisture damage risk to the wall system.




The moisture contents in the sheathing were not affected at all by the wetting events. The only moisture content sensor indicating higher moisture content was the bottom plate moisture content. Throughout the full scale wall tests, the moisture content readings of the middle and lower sheathing were elevated by approximately 2% over the rest of the moisture content readings. Analyzing the temperature data showed that the sheathing temperatures were lower than the drywall temperature for almost the entire year because of the thermal gradient formed in the cavity space by the batt insulation. Occasionally for a few hours in the summer, the effect was reversed, but in the colder months, the difference in temperature between the drywall and the sheathing could reach 5 or 6°C. The increase in moisture content is kept minimal by the exterior insulation on the wall system. The absence of exterior insulation would increase the temperature gradient between the drywall and sheathing and increase the moisture damage risk to the sheathing.

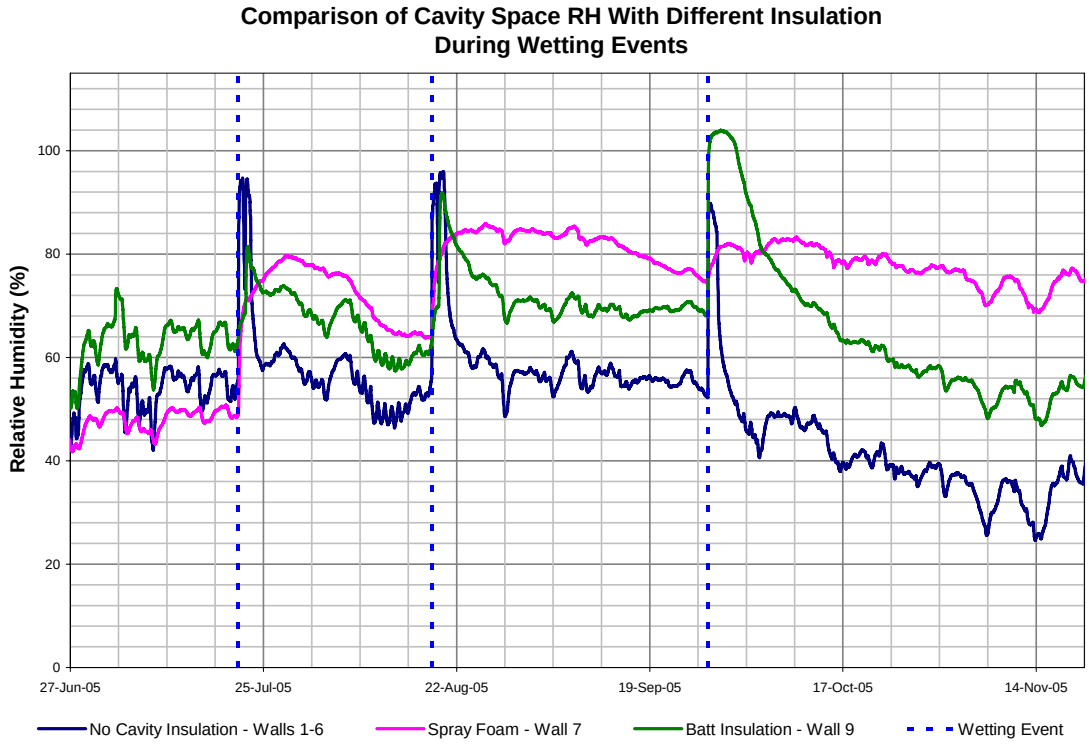
The first wetting event increased the moisture content of the bottom plate to approximately 23%. It took two days for the moisture content to drop below 20%. The second wetting event reached a maximum of 25% in the bottom plate, and the moisture content was sustained above 20% for four days. The third wetting event reached a maximum of 22% and was sustained above 20% for three days. Including the batt insulation in the cavity space increased the time required to dry following a wetting event, and increased the moisture damage risk.




The following table shows a comparison of the relative humidities during the wetting events. It can be seen that for Walls 7 and 9, the drying time for wetting events 2 and 3 was significantly higher, an order of magnitude in most cases. The time above 80% was used for analysis since 80% is generally accepted as a critical relative humidity for possible moisture damage.

| | Wetting Event 1 | | Wetting Event 2 | | Wetting Event 3 | |
|---|---|---|---|---|---|---|
| | Max RH (%) | time above 80% | Max RH (%) | time above 80% | Max RH (%) | time above 80% |
| Wall 1 | 84 | 14 hours | 90 | 17 hours | 84 | 22 hours |
| Wall 2 | 90 | 19 hours | 92 | 19 hours | 88 | 32 hours |
| Wall 3 | 88 | 18 hours | 90 | 25 hours | 86 | 30 hours |
| Wall 4 | 88 | 18 hours | 90 | 24 hours | 88 | 29 hours |
| Wall 5 | 94 | 20 hours | 96 | 25 hours | 90 | 32 hours |
| Wall 6 | 96 | 18 hours | 94 | 25 hours | 88 | 27 hours |
| Wall 7 | 79 | 0 hours | 86 | 683 hours | 83 | 585 hours |
| Wall 9 | 82 | 7 hours | 92 | 81 hours | 100 | 200 hours |

A direct comparison of the drying ability of walls with different cavity insulation is shown below. The relative humidity graphs of Walls 1-6 were plotted as one line since they were nearly identical in every case. Walls 1-6 were compared to Wall 7 with PU foam, and Wall 9 with batt insulation.

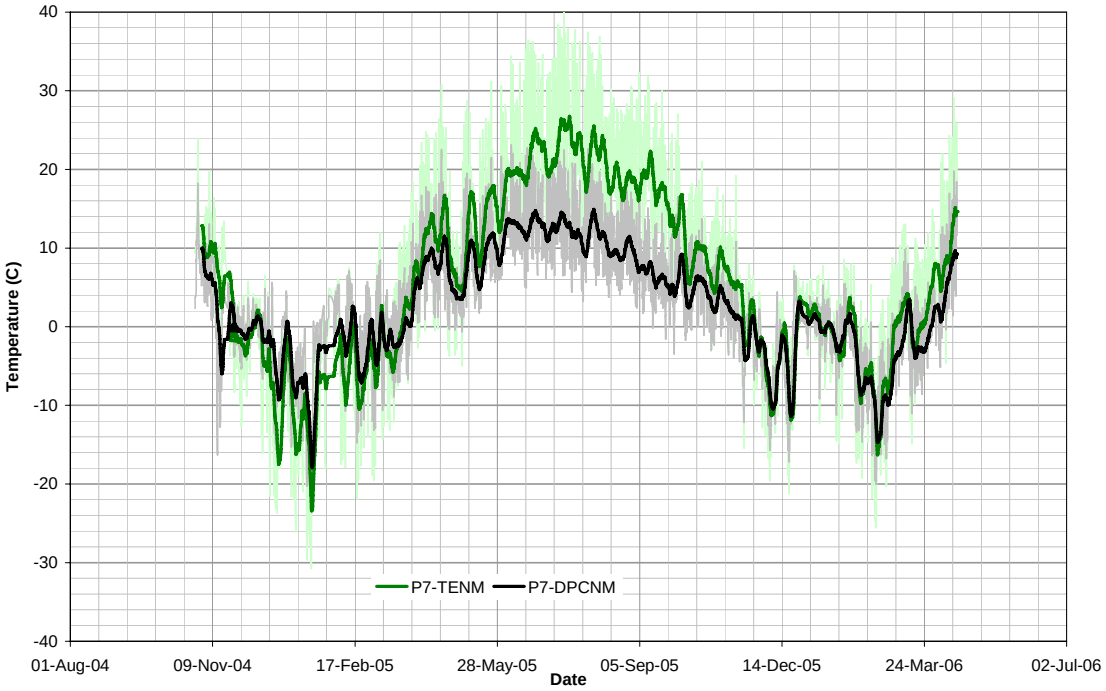



All of the relative humidities are approximately the same previous to the wetting events. Following the first wetting, the relative humidity become stratified, although both Walls 1-6 and Wall 9 appear to return to normal. After the second wetting, it is shown that Walls 7, and 9 had increased relative humidities until after end of the analysis time period.

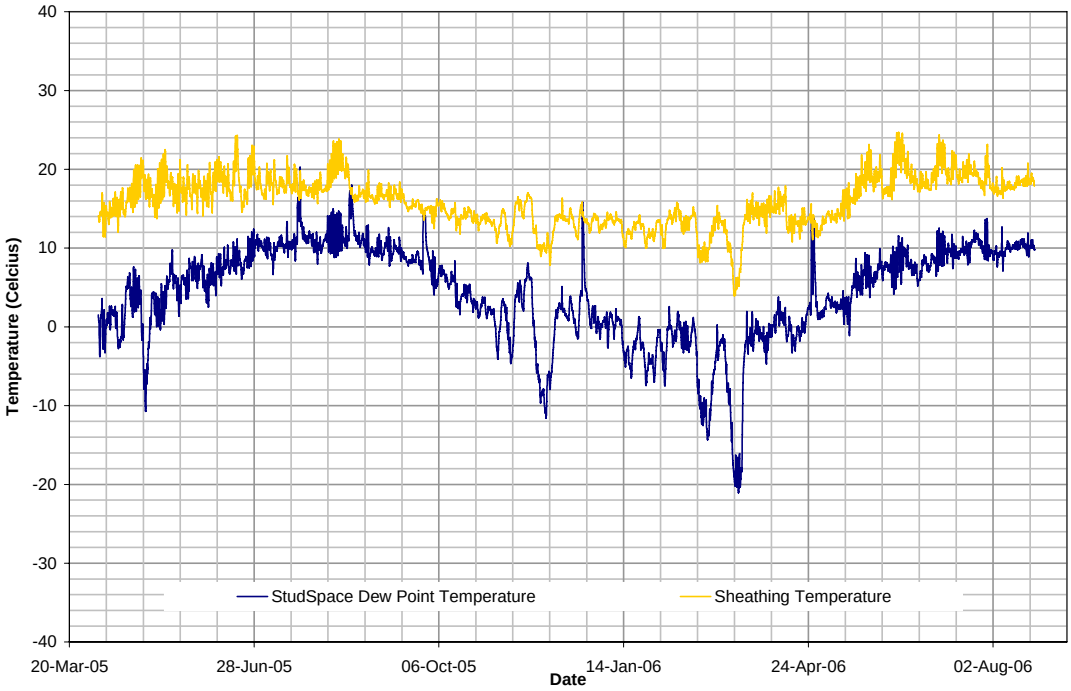
## Condensation Analysis

Another common method to evaluate wall performace during full scale wall testing is to determine the number of hours of possible condensation on either the sheathing or drywall/poly. This is done by calculating the dew point temperature in the cavity space from the relative humidity and temperature sensor and comparing it to the surface temperatures of both the sheathing and the drywall for every hour of the year. In most common wall assemblies, condensation may occur on the interior surface of the sheathing in the winter, or the exterior surface of the drywall/poly in the summer.

During a recent full scale wall test in climate zone 6, a similar wall was tested, constructed with fiber cement plank, tyvek, sheathing, 5.5” batt, and drywall. This wall had over 1000 hours of winter condensation in one year. This is shown in the the graph below every time that the green line (sheathing temperature) falls below the black line (dew point temperature in the studspace).




These results can be compared to a similar wall construction in the CCHRC/UAS test trailer. Wall 9 is constructed with fiber cement plank, drainage matt, tyvek, EPS, sheathing, 3.5" batt and drywall. With the addition of the exterior insulation, the number of condensation hours was decreased to zero because the temperature of the sheathing was increased during the winter months. The graph for CCHRC/UAS Wall 9 is shown below. The temperature of the interior surface of the sheathing does not drop below the dewpoint temperature once during the year of monitoring.



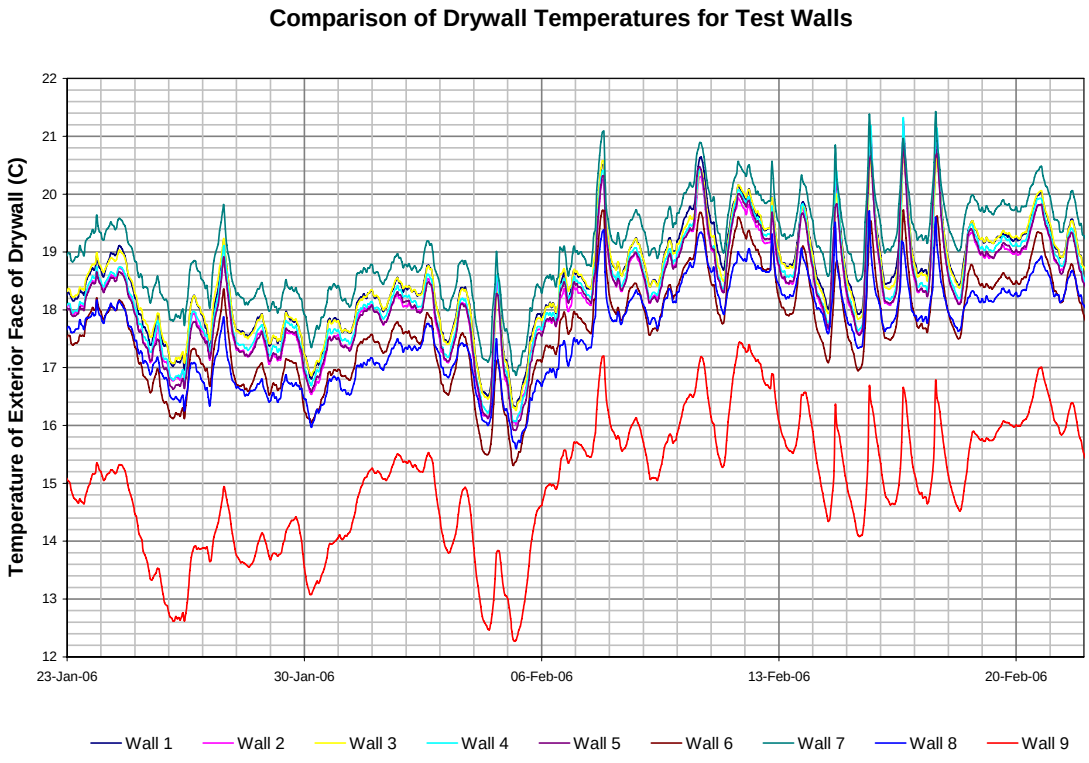
All of the CCHRC test walls were anyalyzed for condensation potential and it was found that none of the test walls had any hours of condensation throughout the period of the testing. All of the graphs are included in the appendix.

**Temperature Analysis**

A temperature analysis of the exterior surface of the drywall was conducted to analyze any differences in drywall temperatures caused by different wall construction and insulation techniques. The temperatures were examined during the winter months for the largest temperature gradient across the wall system (Dec – Mar).

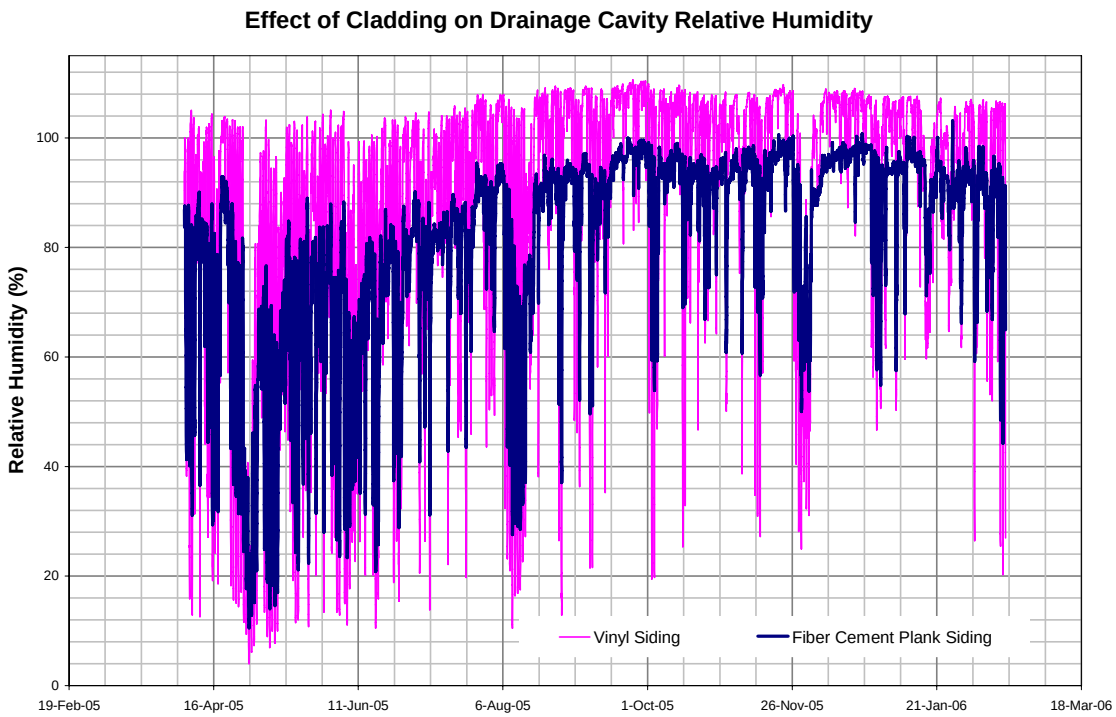
Wall 7 had the highest temperature readings through the winter, but by only 0.5°C over Wall 3. Wall 3 was the second highest, followed very closely by Walls 1,4,5, and 2. There were no significant differences in the drywall temperatures of Walls 1,2,4 and 5. Walls 6 and 8 were approximately 0.5°C colder than the middle walls, and the coldest wall through the winter by 1-2°C was Wall 9.

It is likely that Wall 7 was the warmest because of the excellent air sealing of both the STO Guard and the PU foam, and the increased R-value from the PU Foam. There does not seem to be a reason for Wall 9 to have the coldest drywall temperature during the winter. The difference in Wall 9 drywall temperature may be caused by sensor error. Except for Wall 9, there were no significant differences in temperature on the exterior surface of the drywall caused by different insulation techniques.



## Cladding Analysis

The choice of cladding on the exterior of the test walls appears to have an affect on the relative humidity in the drainage gap. The fiber cement's moisture storage capacity acts as a buffer, dampening the relative humidity changes in the drainage space. The relative humidity behind the fiber cement siding does not rise as high or fall as low as the relative humidity behind the vinyl siding as shown in the following graph.




## Conclusions

This research project generated the following conclusions:

- All of the test walls can perform well in a climate similar to Juneau's. This was shown by the absence of moisture problems, caused by the local climate.

- The external wetting apparatus showed no response in any of the monitoring sensors, and was difficult to use, because of the positioning of the tube, and the lack drainage space in some of the test walls.

- Wetting of the stud space (by 100 mL doses of water) increased the relative humidity, and in some cases, the moisture content to risky, or dangerous moisture levels inside some the test walls.

- Walls 1-6, with no insulation in the cavity space dried the most quickly, avoiding any serious moisture related risks..

- Wall 9, insulated with batt insulation, dried slower than Walls 1-6. The lower sheathing temperature in combination with vapor open insulation could be a risk for moisture damage. This was shown by the measured elevated moisture content levels of the sheathing.

- Wall 7, insulated with spray foam in the stud space also dried very slowly, and held water between the spray foam insulation and the sheathing. This resulted in the highest risk to moisture damage of the test walls.

- Examining the test walls for condensation potential in the cavity space showed that none of the wall systems had sheathing temperatures or drywall temperatures that fell below the dew point temperature of the cavity space. This lack of condensation potential is directly linked to the use of exterior insulation.

- The relative humidity in the drainage gap of vinyl walls coincided closely with the relative humidity of the exterior environment, while the relative humidity in the drainage gap of the fiber cement walls, was buffered by the storage capacity of the cladding.

**Recommendations**

It was determined from previous testing that the exterior insulated wall outperformed all other test walls. During these tests, all of the externally insulated walls were shown to perform well in Juneau's climate. The next step is to develop a wall system that can be built quickly and cheaply, with very low risk to moisture problems.

Any further testing should focus on the least expensive, easiest to build wall systems that will decrease moisture damage risks as well as maximize the energy efficiency to decrease energy costs in the future.