

Topical Report: August 2002 to October, 2003

Developing Innovative Wall Systems that Improve Hygrothermal Performance of Residential Buildings

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Abstract:

This document serves as the Topical Report documenting the first year of work completed by Washington State University (WSU) under US Department of Energy Grant, Developing Innovative Wall Systems that Improve Hygrothermal Performance of Residential Buildings. This project is being conducted in collaboration with Oak Ridge National Laboratory (ORNL), and includes the participation of several industry partners including Weyerhaeuser Company, APA – The Engineered Wood Association, CertainTeed Corporation and Fortifiber. This document summarizes work completed by Washington State University August, 2002 through October, 2003.

WSU's primary experimental role is the design and implementation of a field testing protocol that will monitor long term changes in the hygrothermal response of wall systems. In the first year WSU constructed a test facility, developed a matrix of test wall designs, constructed and installed test walls in the test facility, and installed instrumentation in the test walls. By the end of the contract period described in this document, WSU was recording data from the test wall specimens.

The experiment described in this report will continue through December, 2005. Each year a number of reports will be published documenting the hygrothermal response of the test wall systems. Public presentation of the results will be made available to the building industry by industry partners and the University cooperators.

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Introduction:

Washington State University (WSU) and Oak Ridge National Laboratory (ORNL) have implemented a research protocol to analyze the hygrothermal response of wall assemblies. The protocol utilizes three primary evaluation methods. These include experimental testing of full-scale walls in the natural environment, characterization of building materials response to moisture, and long term predictive evaluation of heat and moisture transport through building components using advanced computer modeling techniques.

During the first year of this project Washington State University has established a facility capable of conducting the experiment, designed and constructed test walls and installed detailed instrumentation that will document the heat and moisture transport characteristics of wall systems.

Executive Summary:

This document serves as the Topical Report documenting the first year of work completed by Washington State University (WSU) under US Department of Energy Grant, Developing Innovative Wall Systems that Improve Hygrothermal Performance of Residential Buildings. This project is being conducted in collaboration with Oak Ridge National Laboratory (ORNL), and includes the participation of several industry partners including Weyerhaeuser Company, APA – The Engineered Wood Association, CertainTeed Corporation, and Fortifiber. This document summarizes work completed by Washington State University August, 2002 through October, 2003.

This project is developing and implementing a unique systems engineering approach to designing wood frame building assemblies that are energy efficient and moisture tolerant in the climate of the Pacific Northwest. The overall impact of successful project completion will be a significantly improved understanding of building component relationships within a wall system and how they influence hygrothermal performance. In addition to developing a systems engineering approach to wall moisture evaluation, this project will test the viability of building materials and assembly methods in the field.

This project is unique because it proposes to apply a number of evaluation methods to a specific end result. Laboratory testing of building material hygrothermal properties, field-testing of full-scale test walls, and evaluation using advanced computer modeling will all lead to the development of durable wall assembly recommendations for a specific climate. This project is specifically targeted at developing results for wood frame construction in the challenging climate of the Pacific Northwest. The results of the project will include:

- an expanded hygrothermal material property data base,
- a fully instrumented natural exposure test facility,
- an implemented systems engineering approach using the most advanced modeling tools and uniform test methods
- specific wall construction recommendations for the Pacific Northwest climate.

WSU's primary experimental role is the design and implementation of a field testing protocol that will monitor long term changes in the hygrothermal response of wall

systems. In the first year WSU constructed a test facility, developed a matrix of test wall designs, constructed and installed test walls in the test facility, and installed instrumentation in the test walls. By the end of the contract period described in this document, WSU was recording data from the test wall specimens.

Design and construction of the Natural Exposure Test Facility (NET) began in September, 02 and was completed June, 03. The NET can accommodate 12 - 4X9' test walls facing South, and 12 - 4X9' test walls facing North. The primary tests are being conducted using the South facing test configuration because this is where the most severe winter weather approaches the site. The NET is equipped with an HVAC system that includes heating, air conditioning, humidification and dehumidification, and ventilation.

Development of the test wall design matrix was an iterative process. Over several months, input was received from research team members and industry partners. The test wall matrix details 12 wood frame test wall designs. Principal differences included in the test wall designs are exterior cladding type (2), cladding ventilation strategies (4), insulation strategies (3), and vapor retarder strategies (4).

Hygrothermal response of the test walls are being monitored using a set of data loggers and an array of instruments. With some variation, each test wall has the following instrumentation.

- Resistance of wood to measure moisture content (6)
- Resistance of gypsum to measure drywall and stucco moisture content (2)
- Leaf moisture sensors to measure occurrence of condensation in wall cavities (2)
- Relative humidity of the wall cavity, exterior cavities behind cladding, or stucco (4)
- Temperature (12).

In addition the data system will collect interior temperature and relative humidity. The system also includes a weather station collecting temperature, relative humidity, wind speed, wind direction, and solar radiation. By the end of the reporting period documented in this report, the data acquisition system was recording data and storing it for analysis in the coming months of the project.

The experiment described in this report will continue through December, 2005. Each year a number of reports will be published documenting the hygrothermal response of the test wall systems. Further reporting will provide wall system recommendations based on the experimental results and computer simulations. Public presentation of the results will be made available to the building industry by industry partners and the University cooperators.

Project Background:

This project is developing and implementing a unique systems engineering approach to designing wood frame building assemblies that are energy efficient and moisture tolerant in the climate of the Pacific Northwest. The overall impact of successful project completion will be a significantly improved understanding of building component relationships within a wall system and how they influence hygrothermal performance. With this understanding, building professionals and component manufacturers will be able to scientifically design buildings and products that are directly responsive to natural and conditioned environments. This will provide builders with a higher degree of confidence in the durability of their structures. This will also allow the advocates for

energy efficiency to maintain and advance the market for highly energy-efficient buildings.

In addition to developing a system engineering approach to wall moisture evaluation, this project will test the viability of new materials and assembly methods developed by industry partners. Industry proposed testing proprietary solutions that are designed to limit the entry of exterior moisture and to accommodate needed drying cycles. The test assemblies represent new technologies that are appropriate and cost effective in the current building production environment. These proprietary solutions should provide the durability assurances needed to move the market toward improved energy efficient construction methods.

This project is unique because it proposes to apply a number of evaluation methods to a specific end result. Laboratory testing of building material hygrothermal properties, field-testing of full-scale wall samples, and evaluation using advanced computer modeling will all lead to the development of durable wall assemblies for a specific climate. This project is specifically targeted at developing results for wood framed construction in the challenging climate of the Pacific Northwest. The results of the project will include:

- an expanded hygrothermal material property data base,
- a fully instrumented natural exposure test facility,
- an implemented systems engineering approach using the most advanced modeling tools and uniform test methods
- specific construction solutions for the Pacific Northwest climate.

Following conclusion of the project the model, some material property data and the results of all nonproprietary analyses will be disseminated.

Research Team

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APA – The Engineered Wood Association

CertainTeed Corporation

Fortifiber

Natural Exposure Test Facility:

The Natural Exposure Test facility (NET) is located on Washington State University property located in Puyallup WA. This location is representative of a Pacific Marine climate, receiving on average 40 inches of rainfall per year.

The NET is designated a commercial structure under the state's building code. The foundation is slab on grade. The permanent walls are 5.5 structural insulated panels protected by two layers of building paper and vinyl siding. The roof is constructed of 8.5" structural insulated panels with roofing felt and a steel roofing system. Openings for test walls are created by supporting the roof system with large continuous headers on the North and South walls.

The NET can accommodate 12 - 4X9' test walls facing South, and 12 - 4X9' test walls facing north. Each test wall is independently installed in the NET. This provides flexibility in test wall configuration, and accommodates future plans to gravimetrically measure wall moisture content of the test walls.

Currently there are 12 test walls installed facing South, with immediate plans to complete 3 test walls facing north. Most of the wet winter weather originates from the South, increasing the interest in utilizing this part of the building first.

The NET has been divided into two rooms. Each room has a separate HVAC system that includes heating, air conditioning, humidification and dehumidification and ventilation systems. The ventilation system can be set up to provide either a positive or negative pressure on the building interior to simulate different ventilation strategies. Including two rooms with independent HVAC systems provides the capability to create different interior environmental conditions, when the experimental design calls for it.

NET Construction:

A key task in completing WSU's contract requirements to DOE was the design and construction of the NET. The construction followed the schedule below. Completion in June allowed the research team to proceed with the installation of test walls early in July.

Design	8/02 to 9/02
Permits	9/02 to 2/03
Foundation	2/03 to 4/03
Structure	4/03 to 6/03
Electrical	6/03
HVAC and completion	6/03

1 Net Construction Schedule



2 NET Construction Photographs

Test Wall Selection:

The selection of test wall designs was an iterative process. Over several months, input was received from research team members and industry partners. Several decisions on the test wall construction were made early in the process. Others came rather late in the process, as purchasing decisions were made based on input from materials suppliers in the Puget Sound region. One of the most challenging aspects of selecting test wall designs was balancing the almost unlimited number of possibilities with the limited test wall space in the NET. In the end, the research team chose test wall construction methods that would allow analysis of construction methods thought to have significant impact on heat and moisture transport performance. Additional wall construction alternatives will be tested in the next test year based on the results of the first test cycle.

It is important to note that the wall designs chosen were selected to demonstrate specific heat and moisture transport principles. While detailed comparisons between test walls can be made, the test walls selected can also be used to demonstrate more general heat and moisture transport characteristics. For example, stucco represents a high mass moisture storage cladding system and lap siding represents a low mass system. Specific comparisons between these systems can be made, while studying more general principals of construction.

In addition, the test wall designs were chosen to meet calibration requirements for the hygrothermal computer models created by ORNL. Under this contract, verifying the ORNL model is a primary deliverable.

The following discussion outlines the selection of materials and the test wall construction (*Test Wall Matrix* below) for the first test cycle of the project.

Test Wall Framing Design:

Test walls are constructed to simulate a typical 8' frame over a floor system. Two cavities 16" on center are located in the center of a 4X8 foot wall section. These cavities contain the interior instrumentation. The outer edges of the frame create a 7 ½ inch cavity, and provide a buffer space between the primary area being tested and the outer edge of the test walls.

Framing

All test walls are constructed with wood framing systems. In most cases 2X6 frames were selected as representative of the majority of residential construction in Washington and Oregon. This framing type was selected to accommodate the R-21 insulation typically employed to meet the energy codes in the two states. 2X4 framing was selected for a few test walls. Wall 5 represents a wall constructed prior to the implementation of contemporary energy codes. Wall 13 represents a contemporary wall that utilizes 2X4 framing.

Cladding:

The research team selected stucco to represent a high mass storage cladding system. Lap siding was chosen to represent low mass cladding systems. Within these systems specific materials and finishes were selected.

All of the stucco cladding was a 7/8 inch trowel applied cement stucco with a natural cement finish coat. A natural cement finish was selected rather than an acrylic, because

it will have the most dynamic wetting and drying characteristics and better represent a true storage cladding system. The research team does recognize the large market penetration of acrylic finishes, and acknowledge that utilizing this material in the next test cycle will be important.

Lap Siding was selected because of the large market penetration and as a representative material for a low mass cladding system. Lap siding is designed to shed rain water, however, standard assembly methods may allow small amounts of water intrusion during significant weather events. The lap assembly also creates a small cavity behind the siding that may change the drying characteristics of the wall. Cement lap siding was selected because of its growing popularity in the Pacific Northwest. All of the lap siding test walls were painted with one coat of exterior latex paint over the factory applied primer. Wood siding or wood composite siding materials are also of interest to the research team. However, because of limited test space in the NET, including wood lap siding was not an option the first year. Further consideration of wood siding products will be included in selection of next year's test specimens.

Ventilation of Cladding:

A number of test walls will incorporate a $\frac{3}{4}$ inch space between the exterior cladding and the weather resistive barrier. This space is passively ventilated with outdoor air. Two systems were utilized. One system includes an opening to the exterior at the bottom and is closed at the top of the test wall and is called a *vented* system. Walls constructed with openings to the exterior at the bottom and top of the wall are noted in this report as *ventilated*. The computer modeling summarized in "Building Enclosure Hygrothermal Performance Study Phase I", by Achilles Karagiozis, Oak Ridge National Laboratory, April 2002, concludes that ventilation strategies are very promising methods for reducing wall moisture content. In addition, this is a building method frequently employed in Vancouver BC.

Weather Resistive Barriers:

The research team selected a single weather resistive barrier system for the first year of testing. Two layers of 60-minute building paper were selected for all of the test walls. Previous research (Appendix D of "Building Enclosure Hygrothermal Performance Study Phase I, by Achilles Karagiozis, Oak Ridge National Laboratory, April 2002) suggests that a two layer system provides an effective barrier to rainwater penetration. While it will be important to study other weather resistive barriers, this variable was not included in the first year of study due to limited space in the NET.

Structural Sheathing:

Structural sheathing for the test walls includes oriented strand board (OSB) and Plywood. OSB was used for a majority of the test walls. Plywood was installed as a distinct variable. Specifically, Test Wall 6 is identical to Test Wall 1 and Test Wall 9 is identical to Test Wall 12 in every respect except structural sheathing. This will allow direct comparison between the two exterior sheathing products. Additional sheathing methods that were considered but not included because of limited space. This includes a variety of exterior gypsum sheathing products. They will be considered again in next year's test plan.

Insulation:

The dominant insulation method for exterior walls in the Pacific Northwest is R-21 fiberglass batts in the cavity of a 2X6 frame. An acceptable insulation alternative is a

2X4 frame with R-13 batts and R-5 exterior foam sheathing. This alternative has the potential to significantly change the heat and moisture transport characteristics of the wall system. The R-13 + R-5 method is represented by Test Wall 9. Wall systems constructed prior to modern energy codes are represented by Test Wall 5 which incorporates a 2X4 frame insulated with an R-11 batt only.

Vapor Retarder, Drywall, and Interior Paint:

A number of vapor retarders have been included in this year's test walls. 6 mil polyethylene is included in most wall systems because of its dominant use in the Pacific Northwest since 1991. Kraft paper faced R-11 batts is utilized in Test Wall 5 to demonstrate methods typically used before modern energy codes were implemented. A new product, MemBrain[®], has been included in the study because of its promising characteristics. MemBrain[®] meets the code requirement for a vapor retarder with less than one perm dry cup test permeability. However, when the building cavity RH increases, the vapor permeability increases, allowing increased drying to the interior. This material is included in Test Walls 2 and 9. Test Wall 7 was constructed without a vapor retarder and will test the hazard and benefits of using no vapor retarder at all.

Drywall is identical in all cases; ½ inch interior gypsum wallboard.

Two types of interior paint were used in the year one test cycle. Test Wall 5, which represents older construction, utilizes an oil based primer and a finish coat of oil paint. All other test walls used a PVA primer and one coat of interior latex. The research team will consider adding an interior paint rated as a vapor retarder in future test cycles.

Test Wall Location.

Test walls numbered 1 through 12 are located on the south face of the NET. Most wet winter weather originates from the south. This orientation will maximize the test wall exposure to wind driven rain. Test wall 15 has been installed on the north face of the NET. Wall 15 is identical to wall 1, and will provide a north-south exposure comparison.

Additional information on test wall materials

ORNL is conducting materials property testing on test samples selected from this project. This includes material property tests for vapor permeability, liquid permeability (both uptake and redistribution) sorption isotherm, absorption, desorption and pore size distribution for each material. A report on these tests is expected to be available early in 2004.

3 Test Wall Matrix
WSU Natural Exposure Test Facility, First year testing.

Wall#	Ext Finish	Siding	Ext. Venting	WRB	Sheathing	Ext Insulation	Cavity Insulation	Frame	Vapor Retarder	Int Board	Int Paint	Location
1	Cement	Stucco 7/8"	Unvented	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 1
2	Cement	Stucco 7/8"	Unvented	2x 60 min	OSB		R-21	2X6	MemBrain®	Drywall	Latex	South 2
3	Cement	Stucco 7/8"	Vented	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 3
4	Cement	Stucco 7/8"	Ventilated	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 4
5	Cement	Stucco 7/8"	Unvented	2x 60 min	Plywood		R-11	2X4	Kraft	Drywall	Oil	South 5
6	Cement	Stucco 7/8"	Unvented	2x 60 min	Plywood		R-21	2X6	Poly	Drywall	Latex	South 6
7	Cement	Stucco 7/8"	Unvented	2x 60 min	OSB		R-21	2X6	None	Drywall	Latex	South 7
8	Cement	Stucco 7/8"	Unvented	2x 60 min	OSB	Foam - 1"	R-13	2X4	MemBrain®	Drywall	Latex	South 8
9	Latex	lap	Unvented	2x 60 min	Plywood		R-21	2X6	Poly	Drywall	Latex	South 9
10	Latex	lap	Vented	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 10
11	Latex	lap	Ventilated	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 11
12	Latex	lap	Unvented	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	South 12
15	Cement	Stucco 7/8"	Unvented	2x 60 min	OSB		R-21	2X6	Poly	Drywall	Latex	North 6

OSB	7/16	Aspen
Plywood	15/32	4 Ply Doug Fir
Unvented		Siding direct applied over sheathing and weather resistive barrier.
Vented	3/4"	Cavity behind exterior sheathing open at the bottom of the panel only
Ventilated	3/4"	Cavity behind exterior sheathing open at the top and bottom of the panel
WRB		Weather Resistive Barrier
2x 60 min		2 layer 60 minute building paper.
MemBrain®		CertainTeed smart vapor retarder
Drywall	1/2"	Standard drywall taped and finished
Foam	1"	Expanded Poly Styrene R-5

Instrumentation:

A sophisticated level of data collection equipment has been installed to continuously monitor the hygrothermal performance of the test walls. Outdoor environmental conditions are monitored by a high quality weather station located on site. Interior environment is being monitored using instruments meeting the same standards.

The sensor placement in the test walls is based on output from computer modeling conducted by ORNL. The computer modeling identified critical areas of interest in the wall systems. Based on this modeling ORNL selected sensors and directed their placement. The instruments are connected to state-of-the-art data logging equipment. Since mid September 2003, data has been recorded for the 12 south facing test walls. Data for most instruments is collected every 15 minutes, and recorded every hour. The following paragraphs document the installation of instruments in the test walls located at the NET.

Condensation: (Cond)

In each wall two condensation sensors have been placed in critical areas of the insulated wall cavity. One sensor is placed on the plane of the exterior sheathing high in the cavity. This location was noted as an early condensation point in the heating season when the vapor drive is to the exterior. The second condensation sensor is placed low in the insulated cavity on the plane with the interior vapor retarder, or drywall. This is typically the first area to be effected by inward vapor drive.

Gypsum Moisture Content (GMC)

Gypsum based moisture content sensors have been placed in the exterior stucco and in the interior drywall. This will record change in moisture content in these materials.

Moisture Content (MC)

Moisture content is measured using two pins placed in the wood building materials. The conductivity between the pins is recorded and converted into a moisture content reading. Each moisture content pin set is accompanied by a thermocouple. This will allow researchers to perform temperature correction to the sensor reading. The temperature sensors can also be used to monitor heat flow across wall sections.

Moisture content is being measured in the framing at the following locations: top plate near the exterior sheathing, bottom plate near the exterior sheathing, and vertical stud at mid-height.

Moisture content is also being monitored in the center of the insulated cavity in the following exterior sheathing locations: interior of the sheathing 12 and 48 inches down from the top plate and on the exterior surface of the sheathing, 48 inches down from the top plate.

Relative Humidity and Temperature: (RH)

Two relative humidity sensors have been installed in the insulated cavity 12 inches from the top plate. One sensor is installed on plane to the exterior sheathing, one on plane to the interior drywall. This placement will allow researchers to study moisture movement across the insulated cavity. Each sensor is accompanied by a temperature sensor to measure heat flow across this cross section.

Relative Humidity and Temperature sensors have also been placed in the exterior stucco, in ventilated cavities high and low, and behind lap siding. This will add to the description of the

moisture content of these materials, and will track the accumulation and distribution of moisture through the ventilated cavities.

Exterior Cladding Temperature Sensor (T)

Temperature sensors have also been placed in the exterior stucco and lap siding to monitor temperature of the exterior surface of the wall system.

Pressure (P)

Pressure will be periodically measured at rapid intervals to profile the effect of specific wind or temperature events on cavity ventilation performance. Rubber tubing has been placed in interior cavities, exterior cavities, and on the exterior surface of some walls to accommodate this measurement.

Methods to increase the moisture content of wall systems.

To assure robust testing of the drying capability of the test walls, two locations for moisture introduction have been added to the wall systems to allow the research team to increase the moisture content of the insulated cavity.

First, each insulated wall cavity has a $\frac{3}{4}$ inch opening through the drywall to the interior of the NET. This opening has a cap that can be opened or closed. Opening the cap will simulate a air leakage pathway in the wall system, and can be used to increase the moisture loading through this location.

A controlled method for introducing bulk water into the insulated wall cavity has also been included. A tube from the exterior feeds an absorbent cloth placed on the interior plane (adjacent the vapor barrier or wallboard) of the wall cavity. This cloth can readily hold 150 ML of water. Research staff will load the cloth when the exterior temperature is relatively cold. Moisture from the cloth will be distributed into the cavity and ultimately to the exterior sheathing. A study of the drying cycle of interest can then begin.

Weather Station

A high quality weather station that records wind speed, wind direction, solar radiation, temperature, relative humidity has been installed on the building and is integrated with the data collection system.

Data acquisition system

The data acquisition system can accommodate 250 channels of input. It is modular in design and can be built up further to accommodate additional requirements. The system is hooked directly to the University network, which allows direct access for programming and sampling from most any location

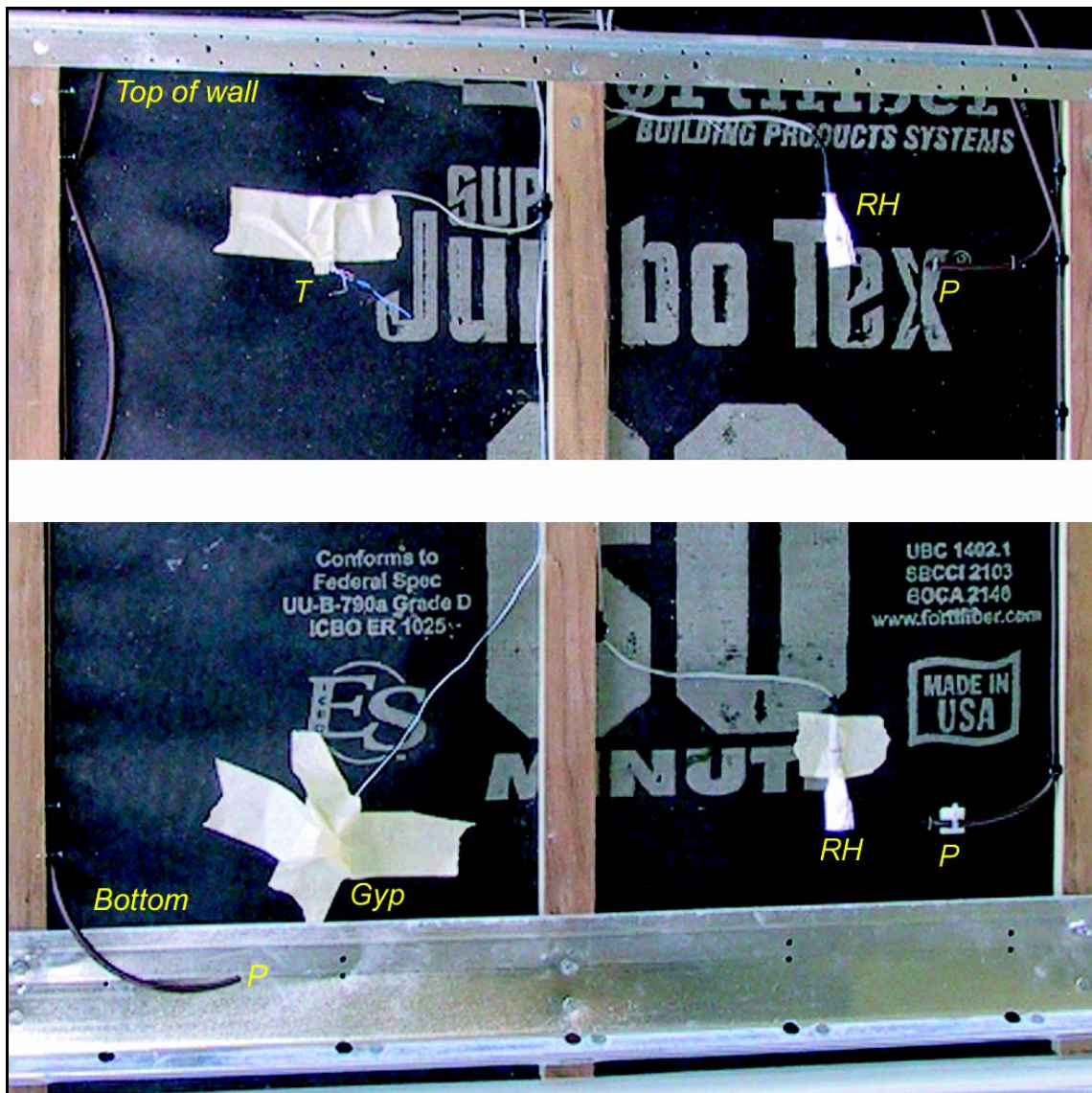
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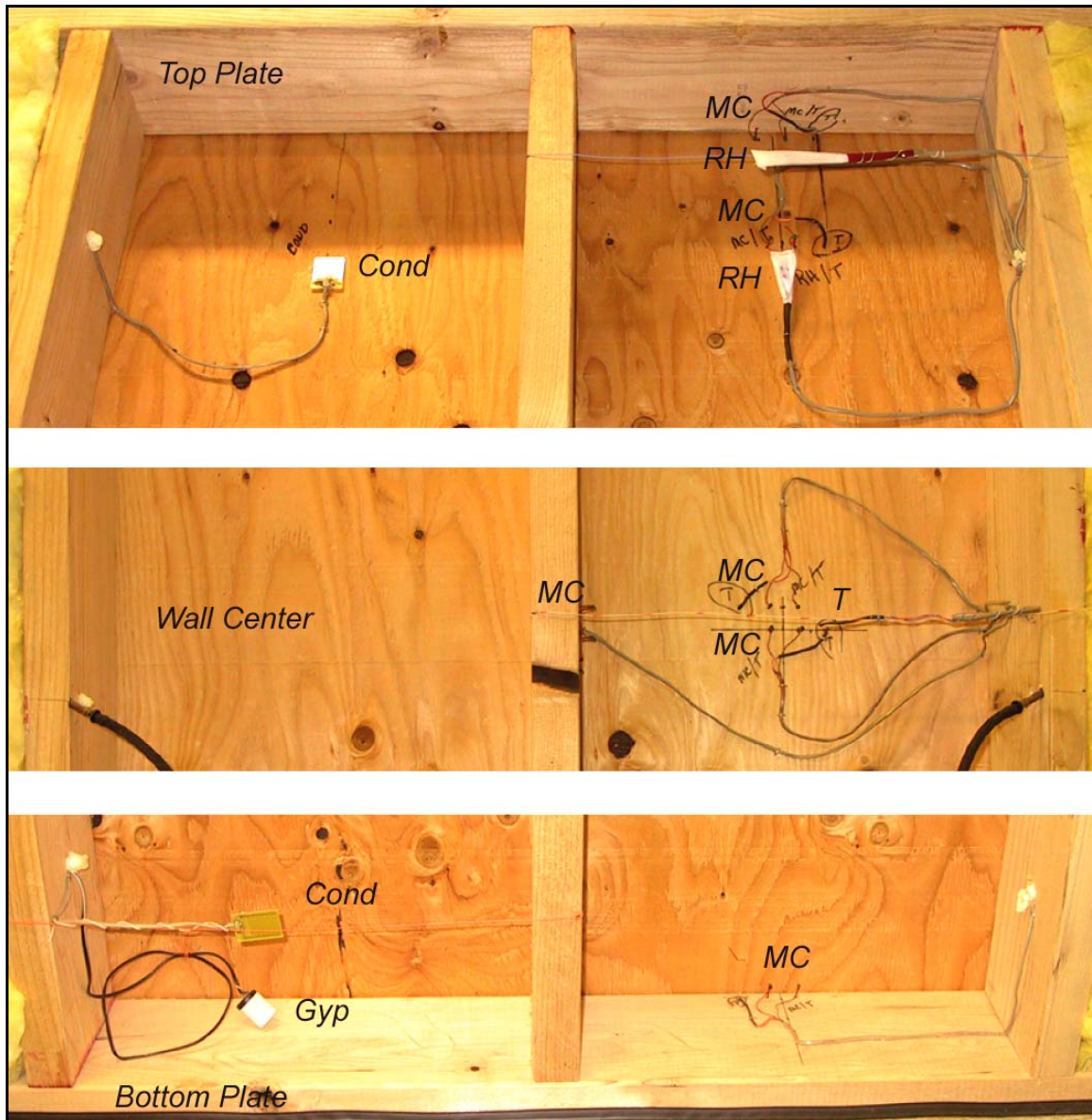
4 Test Wall Cavity



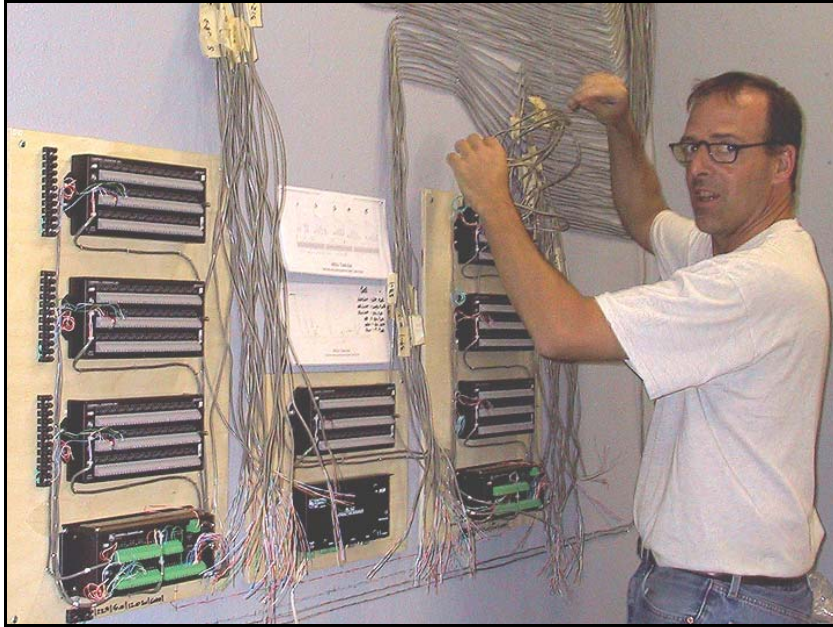
5 Test Wall Cavity with insulation and absorbent material



6 Test wall Instrumentation, exterior cavity



7 Interior wall instrumentation



8 Installation of the data acquisition system



9 Installation of the weather station

Schedule Update:

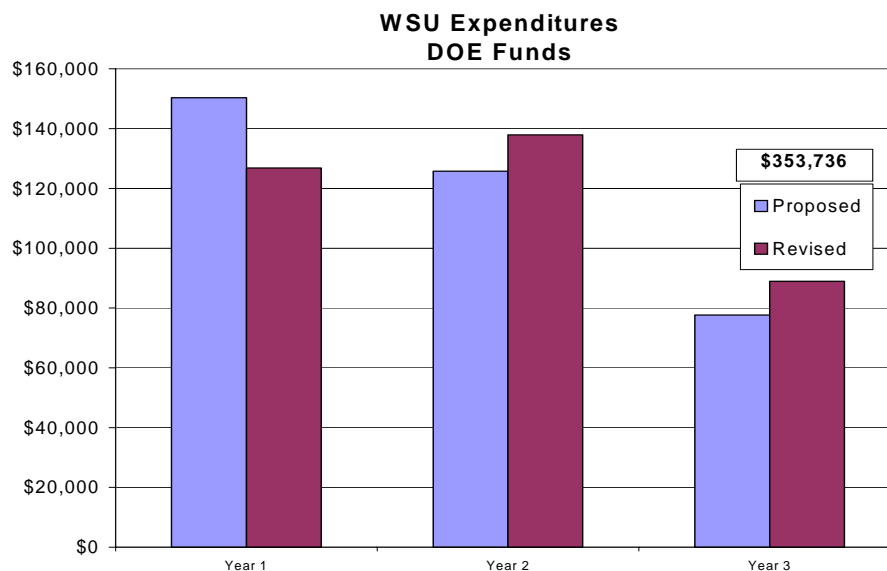
The original schedule developed by the research team assumed a start date of March 2002 and a completion date of September 2004. This schedule accommodated the construction of the NET, and two winter cycles of test wall exposure and data collection. In fact, the award was not received until mid August, 2002. The construction of the NET took longer than originally planned for. This combination has pushed the data collection by one year. Data collection will begin in the fall of 2003 and continue through the fall of 2005. Several months later the research staff will complete their reporting. A comparison between the original proposed and actual schedules are noted in the following table.

Award Date		
Proposed	Mar-02	
Actual	Aug-02	
<hr/>		
Construciton		
Proposed	Mar-02	Jul-02
Actual	Aug-02	Aug-03
<hr/>		
Test Year 1: Year one reports in Dec 04		
Proposed	Aug-02	Sep-03
Revised	Sep-03	Sep-04
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Test Year 2 with Final Reporting		
Proposed	Sep-03	Sep-04
Revised	Sep-04	Dec-05
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10 Schedule Update

Budget Overview:

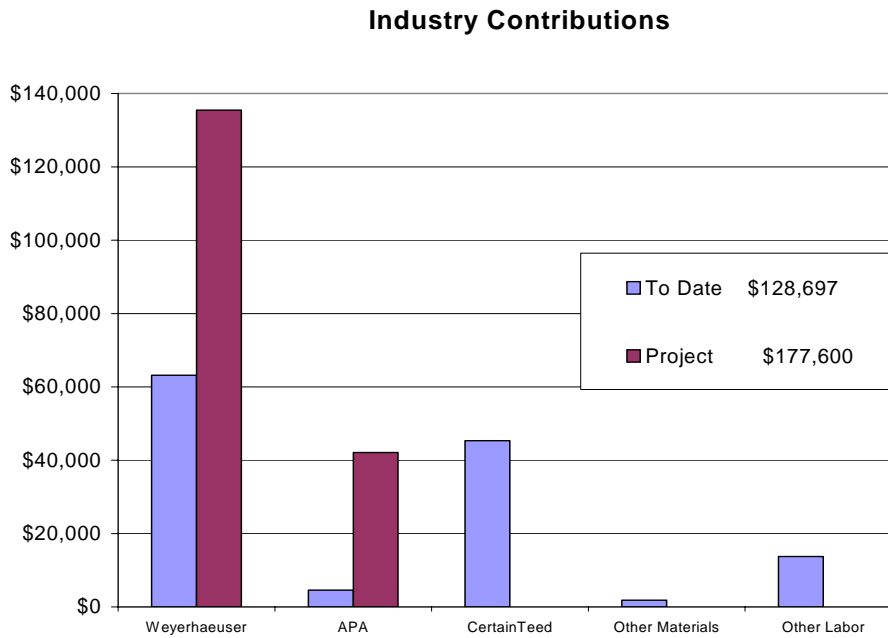
The schedule changes noted above cause a shift in budget. Some funding provided by US DOE will be shifted from year one to future years. No additional USDOE funding request will be required to complete the project beyond the current award amount. For more detail on funding refer to the Financial Status Reports submitted to DOE.



11 Budget Overview

Summary of Industry Contributions:

The chart below documents the contributions of our industry and labor donated to the project. As part of our contract obligation to US DOE, we will continue to solicit the support of industry for this project. For more detail on industry contributions, see the Financial Status Reports submitted to DOE.



12 Industry Contributions

List of Acronyms and Abbreviations

COND	Condensation Sensor
DOE	United States Department of Energy
GMC	Gypsum Moisture Content
MC	Moisture Content
NET	Natural Exposure Test Facility
ORNL	Oak Ridge National Laboratory
OSB	Oriented Strand Board
P	Pressure
RH	Relative Humidity
T	Temperature
US DOE	United States Department of Energy
WSU	Washington State University