Arnold Schwarzenegger
Governor

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DEMONSTRATION HOMES SUMMARY REPORT

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Prepared By:
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Demonstration Homes Summary Report

Task 4.5 Report

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(GTI Project No. 15485)

for

California Energy Commission

Contract No. 500-03-013

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April 2006

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Executive Summary

Overview

The overall goal of the work described in this report was to perform a demonstration of mold-resistant assemblies and construction practices by building production homes containing recommended building components, assemblies, and construction techniques. The project team and participating manufacturers worked with the two participating builders, John Laing Homes Inland Division and Clarum Homes, during the demonstration home planning and construction period to incorporate recommended building assemblies and construction practices into seven production homes, six in Southern California, and one in Northern California. Both builders differentiate their companies as high quality, energy efficient builders. Clarum builds only Zero Energy Homes, and John Laing Homes Inland Division builds Energy Star® Homes. They have mature construction practices aligned with industry best practices, and each builder markets energy efficiency features to their customers.

Construction of the demonstration homes provided:

- Lessons learned based on actual construction practices,
- Guidance on best practices for the Builder's Guide and training sessions, and
- Construction costs, potential cost savings, and builder benefits from improved construction techniques and materials.

John Laing Homes Inland Division built a total of eight demonstration homes as a part of the Secret Garden development in Chino, California (Figure 1). Two included only modifications to the concrete slabs, and four included only modifications to the wall assemblies and selected interior spaces. Two baseline concrete slab homes were also included to provide data on the impact of concrete slab installation procedures and materials on concrete slab performance and cost.

Clarum Homes built a single demonstration home as a part of the Pajaro Vista Zero Energy Home development in Watsonville, California (Figure 2). The home was joist construction on built up foundation, and did not include any concrete slab construction features. It was predominantly open frame construction, and incorporated selected innovative assemblies that were compatible with Zero Energy Home construction materials and practices used by the builder.

Long term data acquisition systems were installed in two of the innovative assemblies demonstration homes (one in Chino, and one in Watsonville). Data acquisition for these two homes included temperature, relative humidity, and wood moisture content in wall cavities below windows in each of the four sides of the home, as well as outdoor air temperature and relative humidity. In the Chino demonstration home, an additional moisture pin and temperature sensor was installed in the bathroom floor at the shower to evaluate the impact of incidental water from shower activity on OSB flooring moisture content.

Concrete Slab Demonstration Homes

Two concrete slab demonstration homes (Lot No. 25 and 40) were built and monitored as a part of the John Laing Homes Inland Division Secret Garden development in Chino, California. In addition, two similar homes with standard concrete installation practices (Lot No. 39 and 42) are being monitored to help evaluate the impact of concrete slab installation procedures and materials on concrete slab performance.

Concrete slabs for the two demonstration homes were installed in accordance with ACI 302.1R-04 "Guide for Concrete Floor and Slab Construction." Materials used in conjunction with the ACI 302.1 installation method included Class A vapor retarder, evaporation reducer, and curing cover.

The ACI 302.1 method was compared to the builder's standard practice on two baseline homes with similar floor plans. The key differences between the two methods are vapor retarder permeance, and vapor retarder placement relative to the slab. ACI 302.1 calls for a Class A vapor retarder to be installed directly underneath the slab with compactable drainable fill beneath the vapor retarder, rather than having a sand buffer between the vapor retarder and the slab.

Observations from the concrete slab demonstration home construction include the following:

- Vapor retarder was not applied under interior grade beams or exterior footings using the builder's conventional method, but was applied in the demonstration homes to provide full coverage.
- ACI 302.1-04R installation methods and materials increased the cost and labor content of slab installations significantly. The key benefit of this installation method is reduced risk of mold growth from slab moisture. Long term relative humidity data will be critical to assess the magnitude of this benefit.
- Slab cracks occurred as expected with the ACI 302.1-04R installation method, but not with the standard method in the Secret Garden development. The builder has had slab cracks in other developments, and viewed the demonstration home cracks as a tradeoff for the perceived benefits.
- A capillary break may not be required in many installations with Class A vapor retarders, but is typically a code requirement. Research is recommended in this area to explore technically justified cost reduction options for vapor retarder installation.
- Based on the experience gained in this project, the builder is implementing Class A vapor retarders in all future developments. They are also revising their post-tensioned slab designs to eliminate interior grade beams by using thicker slabs. This will enable them to provide full vapor retarder coverage under the slab more easily.

Innovative Assembly Demonstration Homes

Four innovative assemblies demonstration homes, Lot No. 76 through 79, were built as a part of the John Laing Homes Inland Division Secret Garden development in Chino, California. The homes are wood frame construction with predominantly oriented strand board (OSB) exterior sheathing and wall cavity insulation. Wall cladding is three-coat stucco.

One innovative assemblies demonstration home, Lot No. 24, was built as a part of the Clarum Homes Pajaro Vista development in Watsonville, California. The home is predominantly open wood frame construction except at shear walls, which have OSB sheathing. Wall cladding is one-coat stucco with exterior insulation and additional wall cavity insulation.

Participating manufacturers provided technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. Data acquisition system specifications for the innovative demonstration home selected for long term monitoring were developed by the project team in conjunction with project advisors and Commission staff.

Innovative materials and installation practices in these homes focused on water-resistive barrier options and construction sequence, window installation methods, mold-resistant sealer and interior gypsum panels, construction drying services, and ventilation control and noise reduction strategies.

Observations from the innovative assemblies demonstration home construction include the following:

- The construction sequence evaluated for the housewrap demonstration homes included installing housewrap before windows and other penetrations were flashed. This sequence was intended to fully integrate self-adhered flashing to the housewrap, providing a continuously sealed water-resistive barrier. This approach was consistent with manufacturers' installation instructions and recommendations by building science consultants on this project. However, because it is more expensive to implement and introduces different risks, this sequence is rarely used in California home construction with stucco cladding. Instead, all penetrations are typically installed and

flashed with mechanically fastened flashing before the water-resistive barrier is installed. The stucco contractor installs the entire water-resistive barrier and cladding, including housewrap, associated flashing integration, building paper, lath, and stucco, after all flashing is installed by various trades. The typical sequence limits the need for trade coordination while reducing labor content compared to the sequence used in the demonstration homes.

- Sources of incremental cost and risk associated with application of the water-resistive barrier before flashings and windows are installed included:
  - Risk of reverse shingle-laps at penetrations
  - Trade coordination and education for construction sequence modifications
  - Incremental labor content
  - Risk of leaks at taped butt joints (e.g., holes, tears, v-cut for head flashing)
- Participating builders and contractors did not consider application of the WRB before flashings and windows are installed to be cost-effective with stucco wall assemblies. While both builders remain open to discussions about housewraps, at this time they intend to continue using double ply building paper for future developments with three-coat and one-coat stucco cladding.
- Window Installation using ASTM E 2112-01R Method A1 and self-adhering flashing went smoothly once the window installation contractor was trained on the procedures. No substantive technical issues were identified. The key difference from the standard installation method was labor content and material cost.
- ASTM E 2112-01R window installation methods are intended to reduce the risk of moisture from window leaks while providing a durable installation, especially at the sill. Since these methods add both cost and time, the builder must make informed risk management decisions before deciding whether to use these options. Both builders are currently evaluating these flashing and installation approaches and may consider them in future developments.
- Total incremental material and labor cost per home with self-adhered flashing ranged from $250 to $700. Despite these increased costs, builder and manufacturer feedback indicates a strong and growing acceptance of self-adhered flashing in California based on perceived advantages over mechanically fastened flashing.
- Application of mold-resistant sealer went smoothly and did not impact the remaining production schedule. Labor content associated with room preparation was a significant cost factor. Careful scheduling of the application that minimizes required taping and sealing (e.g., around tubs) would have a large impact on reducing application cost. The builder remains interested in pursuing this technology option for appropriate situations, and will evaluate it as a part of their risk management strategy for future developments.
- Installation of mold-resistant gypsum panels went smoothly and did not impact the production schedule. The incremental cost of the materials was the only significant difference. The builder remains interested in pursuing this technology option for appropriate situations, and will evaluate both materials as a part of their risk management strategy for future developments.
- Automated bathroom relative humidity control is challenging, but worth investigating as a benign control strategy. Its goal is to remove residual moisture automatically whenever needed and the manual switch is off. Since the user may operate the exhaust fan manually when generating the moisture load (e.g., due to bath or shower), its incremental benefit is variable. Low noise, continuous duty fans are a key element of this strategy. Both builders perceive the low noise fans and relative humidity controller to have potential marketing benefits, and plan to provide future feedback on the value they attach to this feature.

Long Term Data Acquisition

The automated moisture data acquisition system includes a datalogger with 64 channel MUX, punchdown blocks, power supply, and wireless modem. Sensors include temperature, relative humidity, moisture

content, and wood temperature under one window on each side of the home. Outdoor air temperature and relative humidity are also being monitored.

Initial observations based on data collected at the John Laing Inland Division home include the following:

- Wall cavity relative humidity measurements appear to indicate different sensor locations relative to the insulation, especially noticeable when comparing the east and west wall cavities.
    - The east wall cavity temperature and relative humidity profiles are consistent with sensor location on the interior side of the insulation.
    - The west wall cavity temperature and relative humidity profiles are consistent with sensor location on the exterior side of the insulation.
- The north and south wall cavity temperature and relative humidity profiles are consistent with sensor location embedded within the insulation, which was the intended sensor location.
- Wood and OSB moisture content levels ranged from 10 to 13 percent throughout the monitoring period. Dry weather conditions prevalent throughout the construction period appear to have permitted significant wood drying to occur prior to wall enclosure.
- Wood temperature profiles were consistent with sensor locations relative to insulation.
- Wood temperature profiles in the west wall indicate significant solar effect on wall temperatures compared to the other 3 orientations.
- Bathroom floor OSB sheathing readings were consistent with occupancy in early January 2006. OSB moisture content was consistent with readings under windows.

Long term data acquisition is planned for the two concrete slab demonstration homes as well as two similar homes with standard concrete installation practices to evaluate the impact of concrete slab installation procedures and materials on concrete slab performance. Data collection for all four homes will be newly developed in situ relative humidity sensors. Relative humidity probes will be inserted into four cored slab locations in each home subject to homeowner permissions. Long term monitoring for these four homes throughout 2006 will be provided by non-contractual concrete industry participants.

Conclusions and Research Recommendations

The demonstration home planning, construction, and monitoring tasks met all project goals and successfully implemented nearly all recommended assemblies and construction practices. Voluntary builder and manufacturer commitment, cooperation, and input were critical to the success of the demonstration homes tasks. Builder and manufacturer feedback to date indicates mutually beneficial value from their participation. Based on project results, builders and participating manufacturers have expressed willingness to participate in future demonstrations.

Task 4 demonstration home results corroborated research needs identified during the Task 2 situation analysis and Task 3 laboratory evaluations. Research recommendations based on cumulative project results focus on three major initiatives:

1. Expand field demonstration and monitoring of materials and methods with acknowledged energy efficiency, risk reduction, and performance benefits selected for full-scale implementation or further evaluation by builders under this project;

2. Develop and evaluate laboratory and field performance test methods for wall penetrations integrated with cladding and wall assemblies; and

3. Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for window/wall interfaces.

Task 4.5 – Demonstration Homes Planning and Construction Report

1.0 Introduction

1.1 Background

The first technical task (Task 2) of the "Energy Efficient Mold-Resistant Building Assemblies and Construction Practices for California Homes" project was to perform a situation analysis of mold problems and state-of-the-art methods of addressing these problems in the residential new construction market in California. The overall goal of Task 2 was to identify the most challenging mold problems facing California builders and recommend potential solutions for detailed laboratory evaluation and possible use in demonstration homes to be built by the two participating builders. Based on discussions with Commission staff, the project team, Project Advisory Committee (PAC) members, and building industry experts, the highest value areas for this project to address with laboratory testing were water-resistive barrier (WRB) design options around windows, concrete slab installation practices and materials (especially vapor retarder location and fill materials), and drying times for built up wall assemblies.

This focus was intended to provide defensible, repeatable results that advance the understanding of overall wall system performance. Components and subsystems have been tested for mold growth and impact of moisture by building scientists, universities, and manufacturers. The recommended focus built on that testing to provide a better understanding of the behavior of the entire wall assembly as well as collect unique data on the performance of wall cavities and materials as a part of a complete assembly. This approach also allowed flexible and innovative configurations of materials and installation methods to be tested using a combination of available test protocols and new test methods developed specifically to meet project goals.

Specific laboratory tests and protocols developed in conjunction with project team members, builders, PAC members, Commission staff, and industry consultants were summarized in the Laboratory Evaluation Test Plan (Task 3.1). The test plan provided the initial framework for laboratory evaluations. Based on experience gained during the performance of laboratory tests, the project team updated test goals, protocols, facilities, and test matrix to maximize the value of each test. Under Tasks 3.2 through 3.4, the project team performed a systematic laboratory evaluation of conventional and innovative residential building materials, assemblies, and construction practices identified in Task 2.4. Task 3 laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices. These tests generated empirical data using existing and newly developed test protocols intended to permit replication by other testing organizations and to provide a technical basis for demonstration home design recommendations, builder guidelines, and future revisions to Title 24 energy efficiency standards. Under Task 3.7, the project team worked closely with the participating builders and manufacturers to identify and recommend mold-resistant building systems and construction practices that participating builders used in the Task 4 demonstration homes.

1.2 Task 4 Goal

The overall goal of Task 4 was to perform a demonstration of mold-resistant assemblies and construction practices by building production homes containing building components, assemblies, and construction techniques recommended in Task 3. Construction of the demonstration homes provided:

- Lessons learned based on actual construction practices,
- Guidance on best practices for the Builder's Guide and training sessions, and
- Construction costs, potential cost savings, and builder benefits from improved construction techniques and materials.

1.3 Task 4 Scope

The scope of Tasks 4.1 through 4.4 was to work with the two participating builders, John Laing Homes Inland Division and Clarum Homes, during the demonstration home planning and construction period to incorporate recommended building assemblies and construction practices into at least two production homes, one in Northern California, and one in Southern California. Both builders differentiate their companies as high quality, energy efficient builders. Clarum builds only Zero Energy Homes, and John Laing Homes Inland Division builds Energy Star® Homes. They have mature construction practices aligned with industry best practices, and each builder markets energy efficiency features to their customers.

Based on interactions with John Laing Homes Inland Division, a total of eight demonstration homes were built in Southern California. One demonstration home was built by Clarum in Northern California.

The scope of each subtask was as follows:

Task 4.1: Provide input to participating builders as they develop plans and specifications for the demonstration homes that incorporate innovative assemblies and construction techniques into the demonstration homes.

Task 4.2 Work with John Laing Homes Inland Division during the construction of eight demonstration homes to ensure that construction proceeded according to the Task 4.1 plan.

Task 4.3 Work with Clarum Homes during the construction of one demonstration home to ensure that construction proceeded according to the Task 4.1 plan.

Task 4.4 Perform an engineering analysis of demonstration home construction costs and issues.

Task 4.5 Prepare a summary report including text, tables, graphics, drawings, and photographs of the construction process for each home.

1.4 Task 4 Approach

The project team worked with John Laing Homes Inland Division and Clarum Homes staff, PAC members, and non-contractual participating manufacturers and building scientists to incorporate innovative assemblies and construction practices identified in Task 3.7 into each demonstration home, and to identify any necessary changes to the builder's current drawings and specifications. Based on interactions with the participating builders, all demonstration home recommendations were able to be handled in the field without modifying architectural drawings and specifications or changing engineering reports. Builders coordinated with code inspectors, contractors, and product manufacturers to obtain the necessary materials and detailed installation instructions, integrate into construction schedules, and provide sufficient information for code compliance. Each participating manufacturer provided sufficient technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. The final as built drawings reflect field changes as required by the building officials.

John Laing Homes Inland Division built a total of eight demonstration homes as a part of the Secret Garden development in Chino, California (Figure 1). Two included only modifications to the concrete slabs, and four included only modifications to the wall assemblies and selected interior spaces. Two baseline concrete slab homes were also included to provide data on the impact of concrete slab installation procedures and materials on concrete slab performance and cost.

Clarum Homes built a single demonstration home as a part of the Pajaro Vista Zero Energy Home development in Watsonville, California (Figure 2). The home was joist construction on built up foundation, and did not include any concrete slab construction features. It was predominantly open frame construction, and incorporated selected innovative assemblies that were compatible with Zero Energy Home construction materials and practices used by the builder.

Long term data acquisition systems were installed in two of the innovative assemblies demonstration homes (one in Chino, and one in Watsonville). Data acquisition for these two homes included temperature, relative humidity, and wood moisture content in wall cavities below windows in each of the 4 sides of the home, as well as outdoor air temperature and relative humidity. In the Chino demonstration home, an additional moisture pin and temperature sensor was installed in the bathroom floor at the shower to evaluate the impact of incidental water from shower activity on OSB flooring moisture content.

In-situ relative humidity sensors were installed in both of the concrete slab demonstration homes in Chino and in two similar homes with standard materials and methods to help evaluate the impact of concrete slab installation procedures and materials on slab performance. The project team developed data acquisition system specifications for the concrete slab demonstration homes in conjunction with non-contractual participants from the concrete industry that provided, installed, and will monitor the sensors.

John Laing Homes Inland Division staff and Clarum Homes staff were responsible for providing necessary homeowner disclosures and obtaining homeowner permission for long term data acquisition and on site data collection.

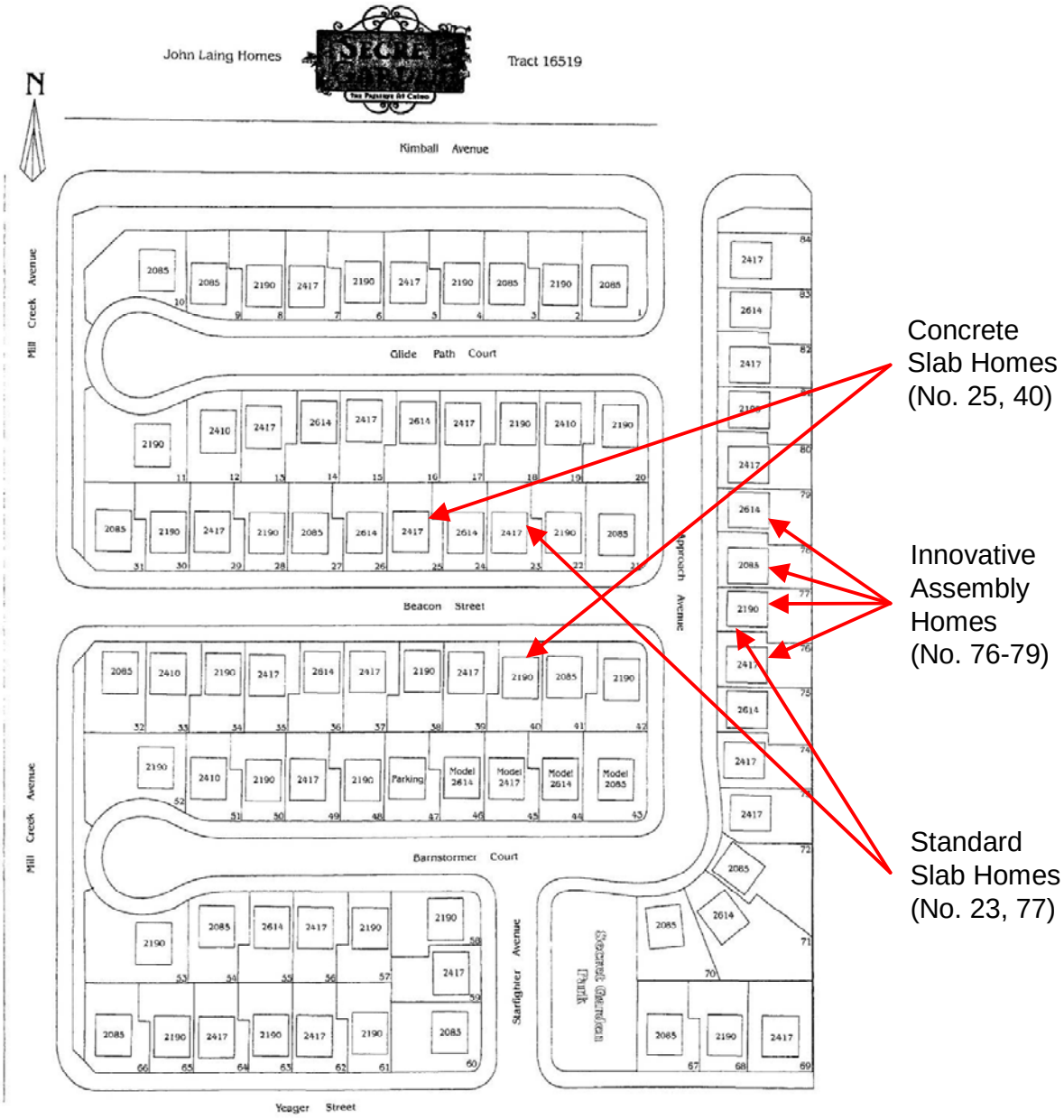
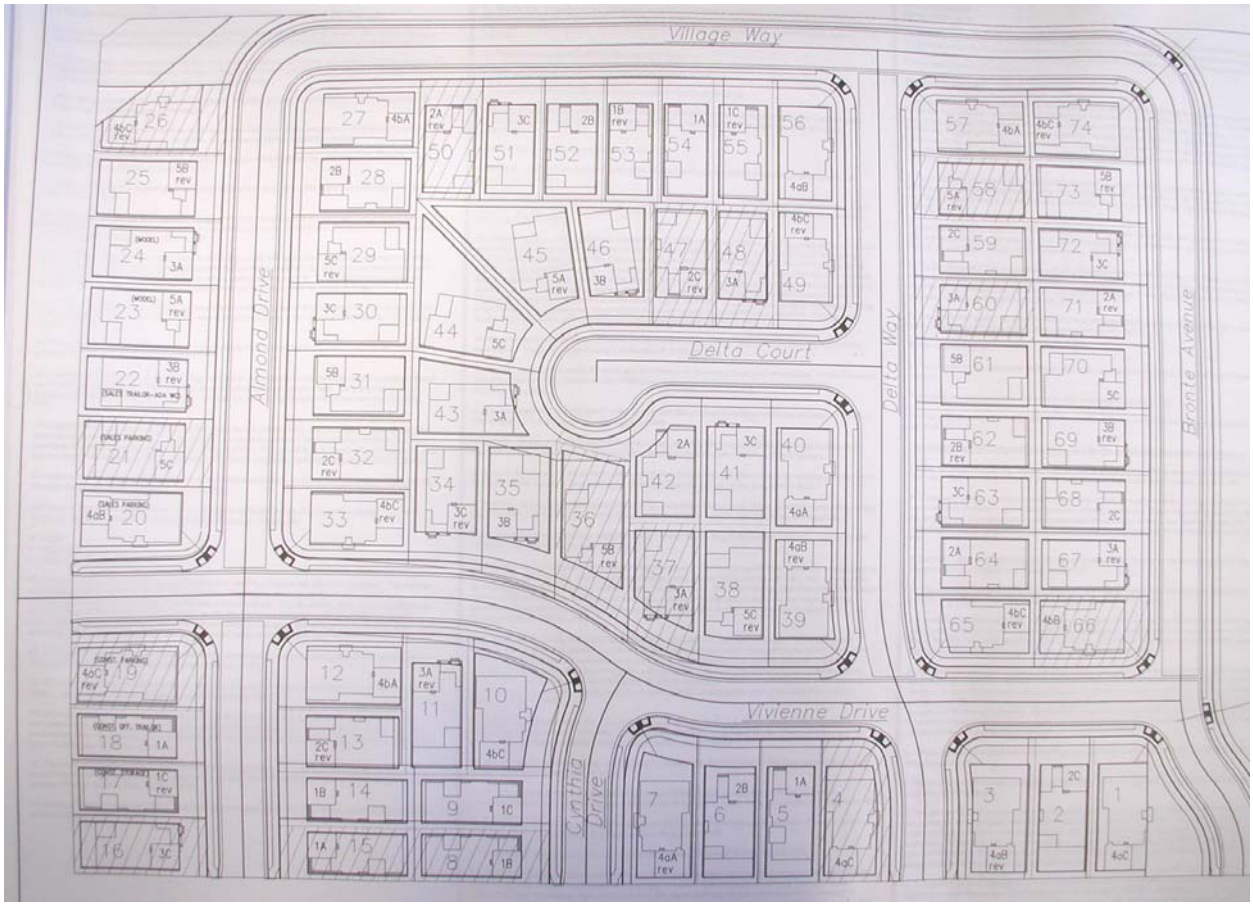
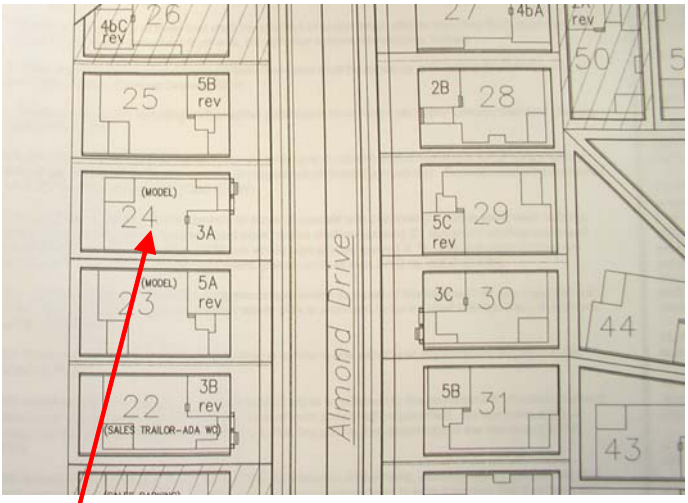


Figure 1 John Laing Homes Inland Division Secret Garden Development



Pajaro Vista Development, Watsonville, CA



Demonstration Home, Lot No. 24

Figure 2 Clarum Homes Pajaro Vista Development

2.0 John Laing Homes Inland Division Concrete Slab Demonstration Homes

2.1 Goal

The goal of this task was to support construction of two John Laing Homes Inland Division Concrete Slab Demonstration Homes in Southern California using materials and procedures contained in ACI 302.1R-04 "Guide for Concrete Floor and Slab Construction."

2.2 Scope

The scope of this task was to work with John Laing Homes Inland Division and participating manufacturers during the construction period to ensure that demonstration home construction proceeded according to plan. John Laing Homes Inland Division used the design information provided by the project team and participating manufacturers and consultants to build the homes containing recommended assemblies and construction practices. The project team also documented costs and recorded construction using videotapes and photographs as appropriate.

2.3 Approach

Two concrete slab demonstration homes (Lot No. 25 and 40) and monitored as a part of the John Laing Homes Inland Division Secret Garden development in Chino, California. In addition, two similar homes with standard concrete installation practices are being monitored (originally Lot No. 39 and 42, now Lot No. 23 and 77) to help evaluate the impact of concrete slab installation procedures and materials on concrete slab performance.

For field modifications, participating manufacturers provided technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. Data acquisition system specifications for the concrete slab demonstration homes were developed by the project team in conjunction with co-funding non-contractual participants from the concrete industry.

The concrete slab construction schedule for these homes was as follows:

June 15-17, 2005	Start Trenching
June 28-July 1, 2005	Install Substrate and Vapor Retarders
July 7-8, 2005	Pour Footings and Slabs
July 14-15, 2005	Remove Curing Cover
July 25, 2005	Post-Tension Slabs
March 18, 2006	Install Slab Data Acquisition System

Data collection for all four homes includes in situ relative humidity sensors.

2.4 Materials and Installation Practices

Table 1 provides information on the materials and installation practices for the two John Laing Homes Inland Division Concrete Slab Demonstration Homes. Demonstration home concrete slabs were installed in accordance with ACI 302.1R-04 "Guide for Concrete Floor and Slab Construction." Based on discussions with concrete industry participants, materials used in conjunction with the ACI 302.1R-04 installation method included:

- Stego® Wrap 15 Mil Class A Polyolefin High Performance Vapor Retarder
- Confilm® Evaporation Reducer
- HydraCure™ Curing Cover

John Laing Homes Inland Division used the ACI 302.1 installation method for vapor retarders and fill materials on two homes with different floor plans and orientations (Lot No. 25 and 40). The ACI 302.1 method was compared to the builder's standard practice on two baseline homes (Lot No. 39 and 42) with similar floor plans. The key differences between the two methods are vapor retarder permeance, and vapor retarder placement relative to the slab. ACI 302.1 calls for a Class A vapor retarder to be installed directly underneath the slab with compactable drainable fill beneath the vapor retarder, rather than having a sand buffer between the vapor retarder and the slab. All installations were by Campbell Concrete of California, Inc. with on site supervision by the builder and participating manufacturers. Holliday Rock provided the concrete in accordance with design specifications provided by the structural engineer based on soils engineering requirements for the specific soil conditions at the site.

Table 1 Concrete Slab Demonstration Homes Materials and Contacts

Item	Purpose	Provider	Contact
ACI 302.1R-04	Installation Guidelines for Vapor Retarder Location, Buffer Materials, Pouring, Curing, and Drying Procedures and Materials.	Concrete Industry Consultants	Scott Tarr, Peter Craig Claudia Lezell
Stego® Wrap 15 mil Class A	Low Perm Vapor Retarder to Address SB 800 Liability Provisions for Slabs	Stego Industries	Bret Houck Matthew Blasdel
Confilm® EMACO® R320 CI Concresive® Paste LPL	Reduce evaporation rate Improved pocket form fillers for long term corrosion protection	Degussa Construction Systems Americas	Robert Gulyas
HydraCure™	Reduce Cracking During 7 Day Curing Period	PNA Construction Technologies	Nigel Parkes Bob Waggoner
Rapid RH™ Relative Humidity Sensor	Long Term Data Acquisition	Wagner/CTL	Scott Tarr Lee Eliseian

2.5 Installation

All homes in the development had post-tensioned slabs due to expansive soil, with 4,500 psi concrete specified for sulfate resistance. Homes included 5" slabs, 18" exterior footings, and 12" interior grade beams for structural support of the 2-story homes (Figures 3 and 4). Slab area under each home was about 1,200 SF, with an additional 450 SF for the garage floor slab. Post tensioning tendons were approximately 3½" below finish floor crisscrossed 3' to 4'-5" apart. Cables were ½" diameter with plastic sheathing. Chairs supported the tendons at the desired elevation above the vapor retarder.

Pouring of the interior grade beams, exterior footings, and 5" slab occurred on the same day for each home. Exact timing of pours were affected by concrete truck arrival schedules, and the 5" slab pour for the garage areas occurred several hours after the grade beam and exterior footings were poured.

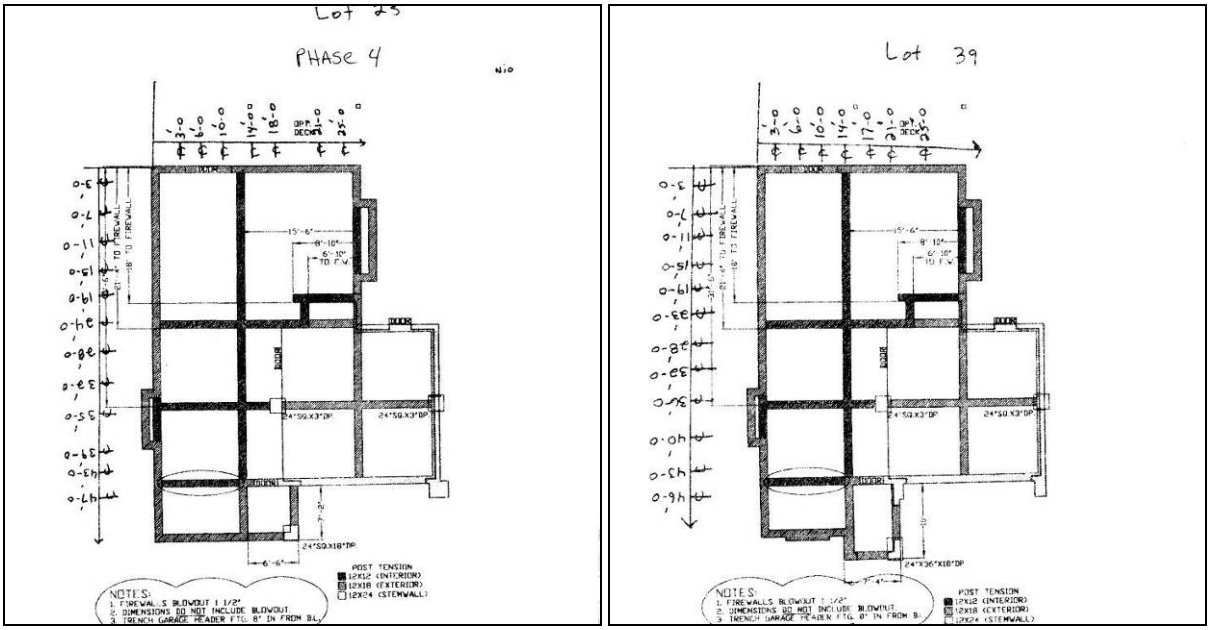
Confilm® was applied after bull floating to retard the bleed water evaporation rate. The HydraCure™ curing cover was placed over the slab in accordance with the manufacturer's installation instructions for a period of seven days to improve the curing process and reduce cracking and curling.

Pocket form fillers for the stressing hardware remaining in the slab after post tensioning were intended to be an acrylic modified dry powder repair material, DeGussa EMACO® R320 CI Pocket Former Filler (in Home No. 40), or an epoxy paste, DeGussa Concresive® Paste LPL Pocket Former Filler (in Home No. 25) packed into the cavity to completely encase the hardware. These materials were provided at no cost to the contract by DeGussa to replace the standard non-shrink grout and were intended to prevent potential ingress of air or chemicals that can cause corrosion of the stressing mechanism. However, these products were not installed by the concrete contractor due to communication and scheduling issues.

For demonstration homes 25 and 40, the 15 mil Stego® Wrap vapor retarder was installed directly under the footing as well as the slab and interior grade beams. Four inches of graded, fine-grained compactable fill were placed on the graded soil to prevent damage to the vapor retarder, to encourage drainage, and to provide a continuous capillary break (Figure 5). No gravel was used under grade beams or footings. The vapor retarder was draped down into grade beams and footings for full coverage, with approximately 12" overlaps (not taped) at seams. Seams were taped on all other floor slab areas, and all penetrations were taped and sealed with mastic (Figure 6). Vapor retarder was not applied on the exterior vertical face of the exterior footings due to post tensioning clip interferences. Wide base support rods with spring clips were used for 2x4 leveling studs to avoid penetration of the vapor retarder (Figure 7). Post tensioning cables were suspended above the vapor retarder using chairs (Figure 8).

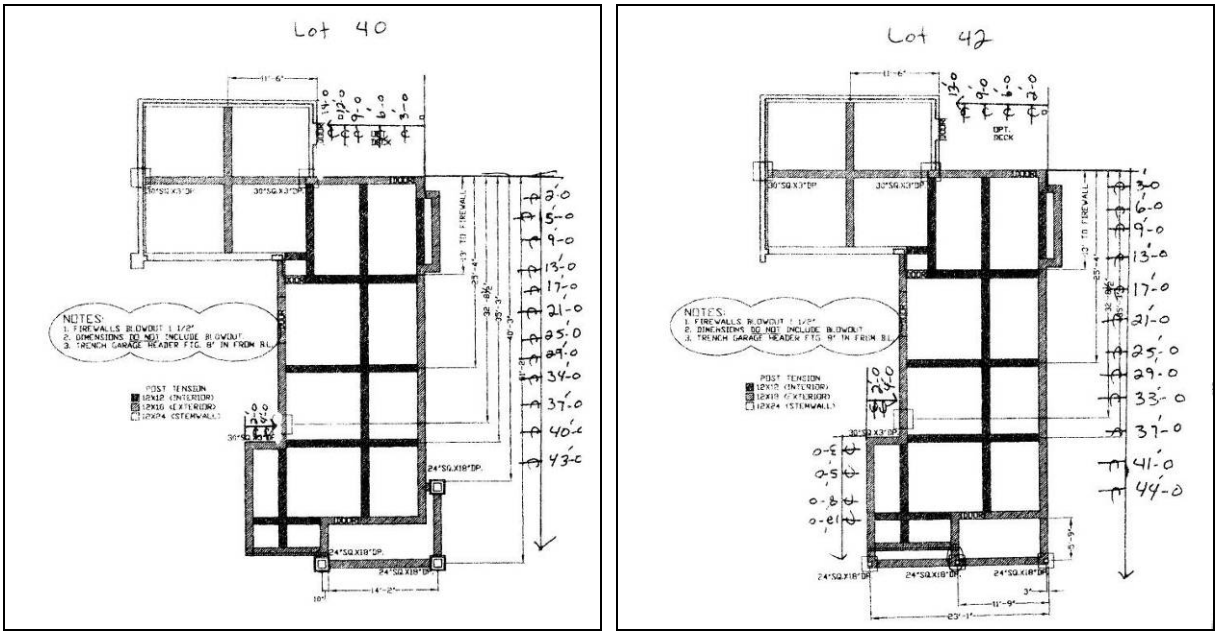
For conventional method homes 39 and 42, 10 mil polyethylene was applied over a 2" layer of sand and an additional 2" of sand then covered the vapor retarder as a buffer. Vapor retarder was not applied below the interior grade beams or the exterior footings (Figure 9). Immediately prior to pouring concrete, the sand buffer was sprayed with water (Figure 10). Stakes were driven through the vapor retarder for the 2x4 leveling studs and bracing as necessary. Post tensioning cables were suspended above the vapor retarder using chairs.

Demonstration home 25 slab was poured from 9 AM to 11:30 AM on July 7, 2005 (Figure 11). Degussa Confilm® Evaporation Reducer was applied 3 times on the main house slab (manufacturer's installation instructions call for one-time application after bull floating is complete) due to lack of familiarity with the concrete installer's repeated wood bull floating and steal troweling sequence, with the first Confilm® application starting about 10:30 AM. The house slab was wetted and covered with Hydracure™ about 4 PM (Figure 12). The garage slab was poured at about 2 PM, with Confilm® applied only one time at about 3 PM. Curing agent was sprayed on at about 6 PM, and the garage slab was wetted and covered with Hydracure™ at about 6:30 PM. The entire slab was pre-stressed to 2000 LB. on July 8 at 8 AM (Figure 13). Baseline Slab 39 was also pre-stressed at about 8:15 AM to evaluate the impact of pre-stressing alone. Slab 25 was subsequently uncovered July 14.



a) Lot 25, ACI 302.1-04R Method b) Lot 23, Conventional Method

Figure 3 Post Tension Layout, Slabs 25 and 39



a) Lot 40, ACI 302.1-04R Method b) Lot 77, Conventional Method

Figure 4 Post Tension Layout Slabs 40 and 42

a) Crushed Stone for Capillary Break

b) Bracing

c) Hand Application

d) Finishing and Leveling

Figure 5 Crushed Stone Capillary Break Installation, Slab 25

a) Unrolling Sheet

b) Fitting Sheet to Interior Grade Beam

c) Overlapped Joints under Grade Beams, not Taped

d) Taped Slab Joints

e) Mastic at Plumbing and Electrical Penetrations

f) Post Tension Cables on Chairs

Figure 6 Fifteen Mil Stego® Wrap Installation Sequence, Slab 25

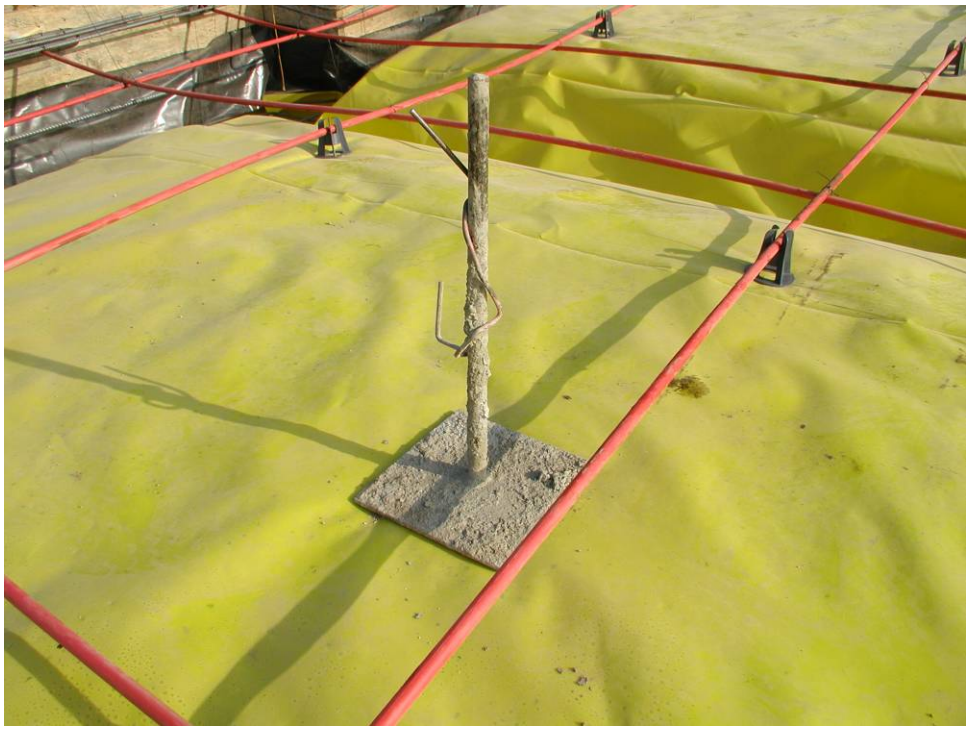


Figure 7 Support for Leveling Studs, Slab 25

Figure 8 Post-Tensioning Tendon Support Chair, Slab 25

Figure 9 Ten Mil Vapor Retarder Installation Below Sand Buffer, Slab 39

Figure 10 Soaking Sand Buffer Prior to Concrete Pour, Slab 42

a) Interior Grade Beam and Footings Pour

b) Initial Slab Pour and Leveling

c) Slab Pour and Tamping

d) Bull Float

e) Supplemental Bracing Removed

f) Garage Slab Pour

Figure 11 Concrete Pour, Slab 25

Figure 12 PNA Construction Technologies Hydracure™ Cover, Slab 25

Figure 13 Pre-Stressing Slab 25

Demonstration home 40 slab was poured from 7 AM to 9 AM on July 8, 2005 (Figure 14). Confilm® was applied one time on the main house slab at about 9:45 AM after final bull floating. Curing agent was sprayed on at about 1:30 PM, and the house slab was wetted and covered with Hydracure™ starting at about 2 PM. The garage slab was poured at about noon, with Confilm® applied at about 1:15 PM. Curing agent was sprayed on at about 3:30 PM or so, and the garage slab was wetted and covered with Hydracure™ at about 4:15 PM. The slab was not pre-stressed. The slab was uncovered July 15.

2.6 Observations

Bleeding on slab 25 appeared to be similar to bleeding on slab 39 (conventional methods), which was poured after this slab on July 7. Based on previous experience with this procedure in commercial slabs, the participating manufacturer had expected more visible bleeding. It is possible that the bleeding evaporated quickly, but the ultimate cause remains a question. Several cracks appeared in the house slab between 12 PM and 1 PM, some with relatively large width, (e.g., 0.7 mm) and several that were more than 6 feet long (Figures 15 and 16). The hypothesis by concrete industry participants based on the quick crack formation is these were heat restraint cracks rather than shrinkage cracks. No cracks were observed in the garage slab. No cracks were observed anywhere on conventional slab 39.

Visible bleeding on slab 40 was greater than bleeding on slab 25 (Figures 17 and 18) and also greater than slab 42 (conventional methods), which was poured after this slab on July 8. The amount of visible bleeding was more in line with a priori expectations. Slab 40 had only a few cracks that were shorter in length and narrower (0.1 to 0.3 mm) than cracks in slab 25. These cracks started to appear about 3 hours after the pour was finished, as would be expected with shrinkage cracks. The garage slab had no visible cracks. Slab 42 had no visible cracks anywhere. Some discoloration was observed on both slabs after the Hydracure™ cover was removed. Visible cracks in slabs 25 and 40 remained after pre-stressing and post tensioning (Figures 19 through 22).

It appears that virtually all cracking occurred before the application of the Hydracure™, and the 2 slabs behaved very differently from each other, and additionally behaved differently than the garage slabs. The first slab was poured about 2 hours later in the day than the second slab, with warmer and somewhat windier conditions. Each garage may have cold joints between the grade beams and slab due to the intentional delay of about 3 hours between the grade beam pour and the garage slab pour. This may have contributed to the lack of cracks in the garage slabs. The garage slabs had troweled joints, but no visible cracks appeared in these joints before the cover was applied.

Labor content of each of these additional processes was also of interest. Application of the Hydracure™ cover took approximately 2 person-hours. Confilm® application and pre-stressing took little incremental time. Application of the Stego® Wrap took approximately 6 person-hours, compared to 1 person hour for the conventional vapor retarder. The increased labor content included labor to fill in the interior grade beams and exterior footings by cutting and fitting sheet sections. In addition, great care was taken to seal all penetrations. Additional framing was required above the garage slab area to brace house floor slab forms while not puncturing the continuous vapor retarder. In the conventional homes, stakes were used to brace these forms and were either driven through the vapor retarder or driven into the ground in the footing area that did not have any vapor retarder.

The concrete contractor estimated that it would take 2 to 3 person-hours in production to apply the ACI 302.1-04R method. The expected benefit of this method is to provide full vapor protection under the entire slab (see Section 2.8 Stego Industry Observations). Long term relative humidity data will be critical to assess the magnitude of this benefit. Also noted in the Stego Industry observations is the questionable value of the capillary break when using Class A vapor retarders. If the vapor retarder can be placed directly on soil, the cost and schedule benefits would be significant.

Overall, the builder was very pleased with the installation, and is looking forward to implementing the procedure as soon as possible on a more conventional 4” slab with 2500 PSI concrete and no post

tensioning. Moisture problems have become a major concern in the past two years, and this project has provided excellent information and product options to address these concerns. Based on the experience gained in this project, the builder is implementing the Class A vapor retarders in all future developments. They are also revising their post-tensioned slab designs to eliminate interior grade beams by using thicker slabs with sloped transitions to beams whenever interior beams are required for structural strength. This will enable them to provide full vapor retarder coverage under the slab much more easily.

2.7 Long Term Data Acquisition

Long term data acquisition is planned for the two concrete slab demonstration homes (Lot No. 25 and 40) as well as two similar homes with standard concrete installation practices (Lot No. 39 and 42) to evaluate the impact of concrete slab installation procedures and materials on concrete slab performance. Data collection for all four homes will be newly developed Wagner Rapid RH ™ in situ relative humidity sensors (Figure 23). Relative humidity probes will be inserted into four cored slab locations in each home (Figures 24 and 25) subject to homeowner permissions. Long term monitoring for these four homes throughout 2006 will be provided by non-contractual concrete industry participants.

a) Interior Grade Beam and Footings Pour

b) Initial Slab Pour and Leveling

c) Slab Pour and Deaerating

d) House Slab Pour after Initial Bull Float

e) Finish Floating

f) Garage Slab Control Joints

Figure 14 Concrete Pour, Slab 40

Figure 15 Slab Crack on Day of Pour at Plumbing Penetration, Slab 25

Figure 16 Slab Crack on Day of Pour above Grade Beam, Slab 25

Figure 17 Bleed Water after Bull Floating, Slab 40

Figure 18 Bleed Water after Bull Floating, Slab 25

Figure 19 Slab Crack after Removal of Curing Cover, Slab 25

Figure 20 Slab Crack after Removal of Curing Cover, Slab 40

Figure 21 Slab Crack after Post Tensioning and Enclosure, Slab 25

Figure 22 Slab Crack after Post Tensioning and Enclosure, Slab 40

Figure 23 Wagner Rapid RH ™, In Situ Relative Humidity Sensor

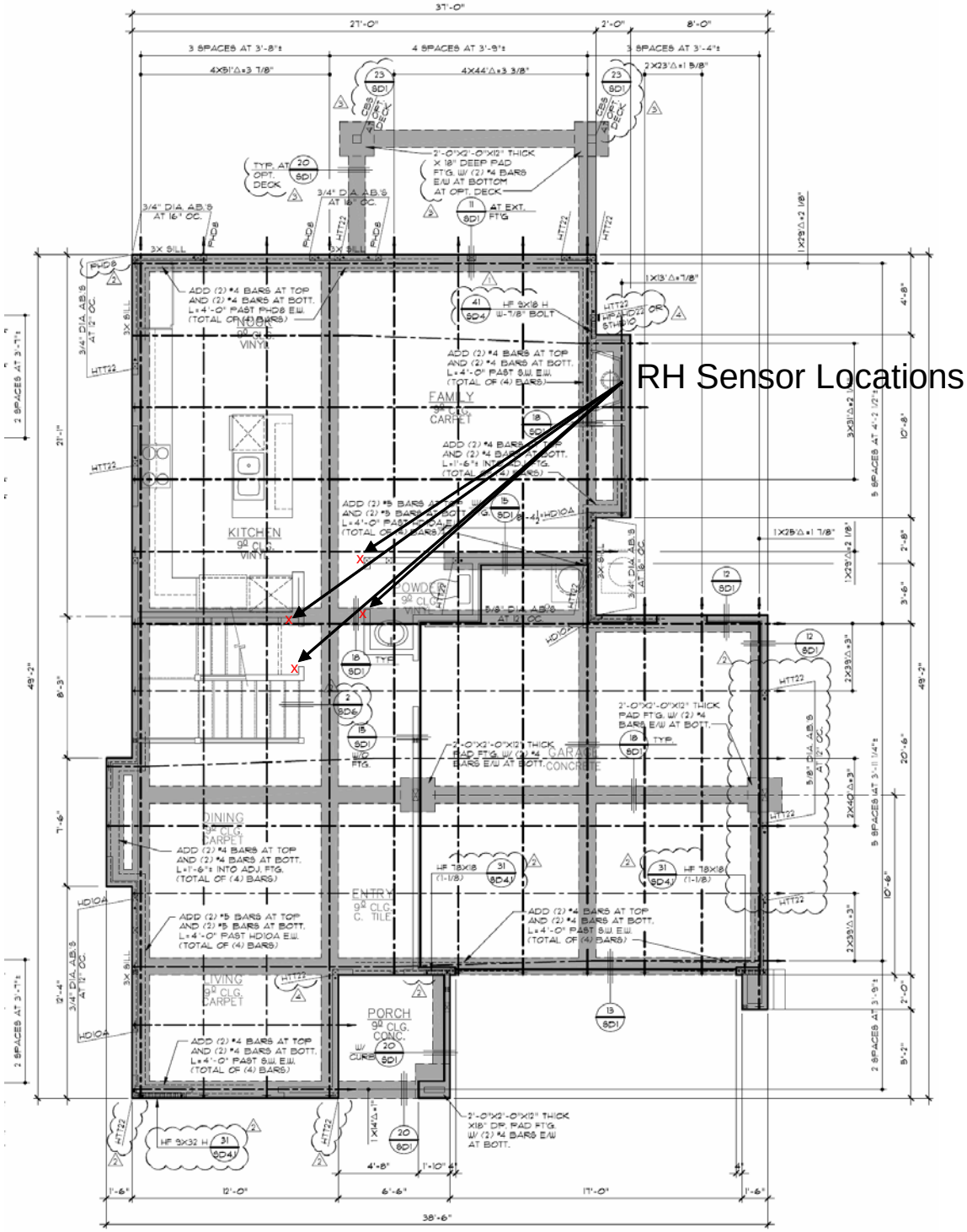


Figure 24 RH Sensor Locations, Slab 25 and 39

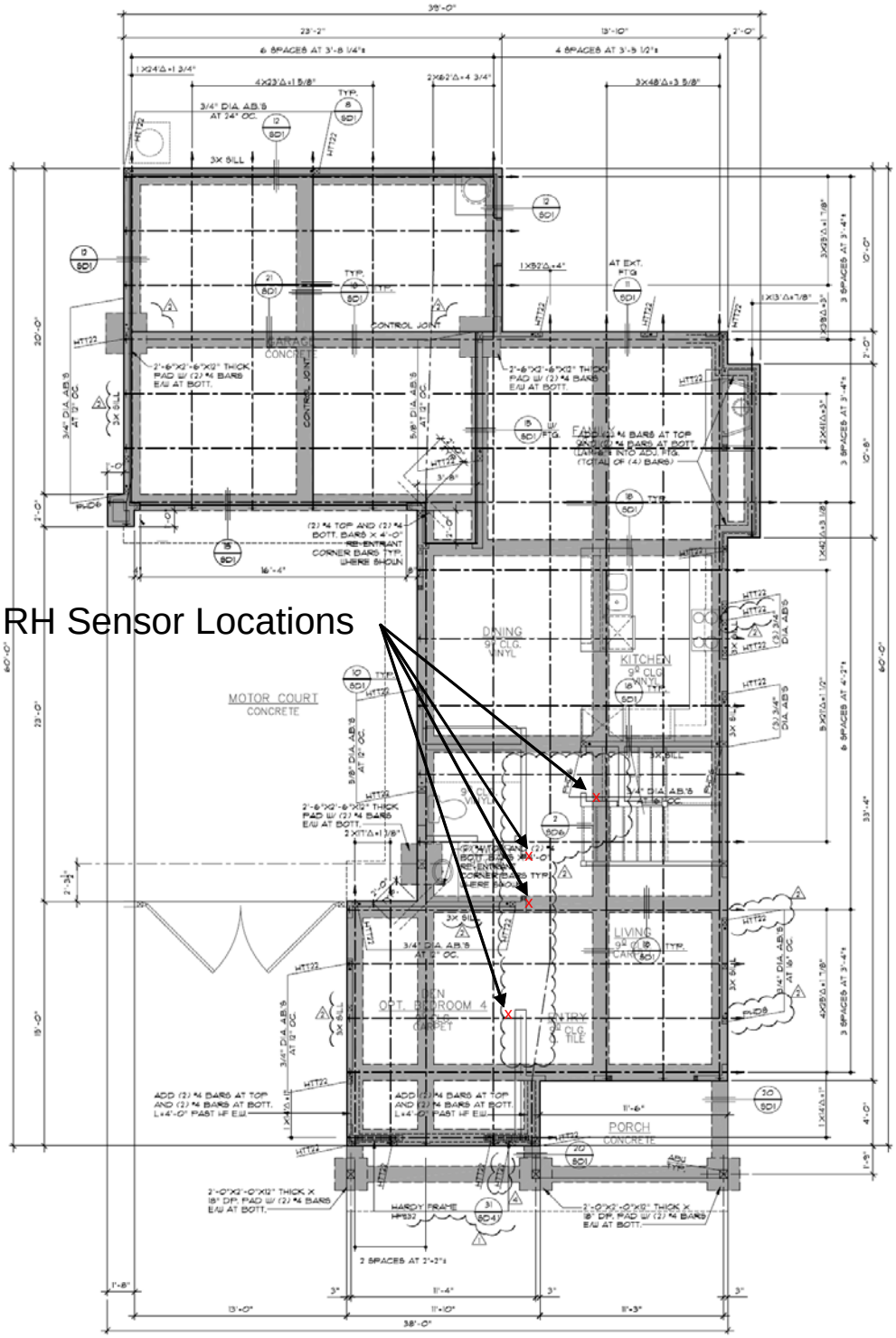


Figure 25 RH Sensor Locations, Slab 40 and 42

2.8 Stego Industries Observations

STEGO INDUSTRIES, LLC

Matthew Blasdel CSI CCPR
Technical Director – Product Development
Stego Industries LLC
27442 Calle Arroyo; Suite A
San Juan Capistrano, CA 92675

July 18, 2005

Neil Leslie
Gas Technology Institute
1700 S. Mount Prospect Road
Des Plaines, IL 60018

Subject: Vapor Barrier Installation
(GTI Project No. 15485)

Neil-

First off, let me start by thanking you for allowing us to be involved with this project. Since the beginning, we at Stego have taken a technical approach to our understanding of this industry, and it was a pleasure to coordinate that type of effort with other dedicated professionals on this job. Regardless of what fruits are produced by our being a part of this experiment, I feel like we were able to greatly increase our peripheral understanding of residential construction. So again, thank you.

One of the first major issues that we encountered was that of the exterior installation of the vapor barrier such that it would extend all the way under the footer and tie into the exterior side of the slab to prevent the horizontal migration of liquid water from irrigation. As I discussed with you on site, this sort of installation is very close to impossible because of the interference from the anchor bolt supports. On jobs where we do completely encapsulate the slab and footer, we need the luxury of being able to lap excess vapor barrier up and over the exterior forms. Then, once the concrete is poured, the excess vapor barrier can be cut off or lapped under wooden framing that sits on the slab.

With anchor bolts in place, our only option would have been to nail, glue, or otherwise terminate the plastic to the top of the wooden form. While this installation is possible, knowing what I know about the construction abuse during concrete pours I would envision a very high percentage that, even if attached to the footing, the integrity of the plastic would be compromised during the pour because of foot traffic, screeding, and troweling.

In addition, a plastic vapor barrier is not the best selection when trying to mitigate problems created by horizontal liquid water migration. Plastic is without a doubt waterproof, but it is susceptible to problems where other bona fide waterproofing materials are not. One small hole in a plastic material will potentially expose and entire face of concrete to water, whereas a liquid or peel-and-stick waterproofing membrane only allows a liquid access to the damaged area.

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The second issue was that of vapor barrier placement over dirt pads in-between interior footers. As we discussed with you, Stego Wrap 15-mil (or most any Class A vapor barrier) can be placed directly on top of compacted earth. Such products do not require a cushion layer to ease the potential for puncture due to foot traffic and other construction abuses. The only other reason that we are aware of for the placement of such a layer below the plastic is to act as a capillary break in instances where there is a very high water table. However, on the vast majority of residential applications the interior footers will extend deeper into the ground than will the capillary break, defeating the entire purpose (concrete is an excellent capillary for water). Most contractors have estimated that the cost of placing this two-inch sand layer is around twenty cents per square foot. That number is close to the entire installation cost of most vapor retarders. In terms of an overall cost benefit analysis, a cushion or capillary break provides very little utility on jobs with interior footings.

Lastly, we arrive at the issue of varying levels of performance provided by different types/thickness' of plastic, as well as the level of utility provided by traditional installation practices vs. current industry standards/more proactive installation techniques. The minimum level of plastic protection is a 6-mil or 10-mil polyethylene. Both of these are commodity products, are not manufactured for use below concrete slabs, do not meet the current industry standard (ASTM E 1745 "Standard Installation Practices for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs"), and provide almost no long term protection against moisture migration from below slab. The majority of the time these materials are manufactured with a high content of recycled plastic, and as a result lack the protective anti-oxidants needed to remain intact for the life of the building.

A step up from low grade polyethylene would be a product like Stego Wrap 10-mil Class C (as in, it meets the minimum of three classes set forth by ASTM E 1745). Products like this are considered "high performance vapor retarders", and while they don't take the ground completely out of play they have a low enough permeance that they can reliably extend the healthy life of a moisture sensitive floor covering. Most good vapor retarders have a permeance between 0.04 and 0.02 perms and have enough puncture resistance to be placed directly on top of compacted earth. This is more true with Class A materials and less true with those meeting Class C. Most experts agree that high performance vapor retarders are satisfactory for use under semi-breathable types of flooring (example: carpet, ceramic tile). For comparison, a standard recycled polyethylene will have a permeance as tested by the parameters of ASTM E 1745 of about 0.3 perms, and is not endorsed for use to protect any type of floor covering.

To be considered a vapor barrier, most experts agree a product must have a permeance down in the range of 0.01 perms (or 0.009 WVTR, if you'd like an explanation of the difference please let us know). On the surface, this would not seem like a great difference. An obvious question is "why would someone bump up from a high performance retarder to a vapor barrier in a residential application". The reason is two-fold: dew point and floor covering type, and mold.

Many experts agree that the only effective way to take the ground completely out of play is to use a vapor barrier. They have defined a barrier at 0.01 perms because that is same permeance as the most sensitive types of floor coverings. A quarter inch thick piece of rubber (one of the most impermeable floor coverings possible) has a permeance just under 0.01 perms. The thought process is that if the

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floor covering has a permeance that is equal to or higher than that of the vapor barrier, then there is no potential for buildup of water vapor below the floor covering. Consequently, if a retarder is used and the inverse is true, over the life of the building humidity levels within the slab will inch up until the point where they approximate 100%. At that point, only a small dip in the temperature underneath the floor covering would create a dew point condition, and put liquid water in contact with flooring adhesives forcing them to re-emulsify and fail.

While it is true that a vapor retarder can successfully keep a breathable floor covering down, there is still a risk of mold. It is commonly known that mold needs three things to survive: temperature levels between approximately 50 and 120 degrees Fahrenheit, a cellulose or organic based food source, and a relative humidity of 65% and above. The only one of these three factors that we have a chance of preventing in a building interior is the humidity. Without a barrier, the same conditions that create a failure under impermeable floor coverings will also be created when moisture builds up under furniture or other impermeable materials sitting on the floor. Because of this, and especially in light of all the recent multi-million dollar settlements/awards surrounding mold, a barrier has become necessary under all types of floor coverings.

The vapor barrier/retarder installation method can play an equally important role in preventing failures. Before 2004, at least 90% of residential applications in CA would only install plastic over the dirt pads in-between interior footers, leaving the base and sides of the footers completely unprotected from water vapor. At present, that is still the most wide spread installation technique. In the last two years, either as a means of reducing liability, or to prevent failures altogether, some builders have adopted installation practices that completely encapsulate the concrete from below slab vapor sources. As you know, this is what we provided on site for you on this job. With such a system, the ground is taken out of play, and the only concern (aside from horizontal liquid water migration) is the water that was in the concrete itself, or whatever water is trapped in the sand blotter layer that was placed on top of the vapor barrier.

Hopefully you were able to learn at least a small amount from us during this process, but either way we at Stego appreciated the opportunity to contribute. Thank you again for your time and consideration. Please feel free to use us as a resource if anything comes up, and know that we'll be more than happy to coordinate a similar effort on any future testing opportunities.

Sincerely,

Matthew M Blasdel

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3.0 John Laing Homes Inland Division Innovative Assemblies Demonstration Homes

3.1 Goal

The goal of this task was to support construction of four John Laing Homes Inland Division Innovative Assemblies Demonstration Homes in Southern California.

3.2 Scope

The scope of this task was to work with John Laing Homes Inland Division and participating manufacturers during the construction period to ensure that construction of the four innovative assemblies demonstration homes proceeded according to plan. John Laing Homes Inland Division used the design information provided by the project team and participating manufacturers and consultants to build the homes containing recommended assemblies and construction practices. The project team also documented costs and recorded construction using videotapes and photographs as appropriate.

3.3 Approach

Four innovative assemblies demonstration homes, Lot No. 76 through 79 (Figures 26 through 29), were built as a part of the John Laing Homes Inland Division Secret Garden development in Chino, California. The homes are frame construction with predominantly OSB exterior sheathing and wall cavity insulation. Wall cladding is three-coat stucco. For field modifications, participating manufacturers provided technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. Data acquisition system (DAS) specifications for the innovative demonstration home selected for long term monitoring (Lot No. 76) were developed by the project team in conjunction with project advisors and Commission staff.

3.4 Materials and Installation Practices

Table 2 provides information on the materials and installation practices for the four John Laing Homes Inland Division Innovative Assemblies Demonstration Homes.

Concrete slab seats (¾" deep) were designed into the footings at sliding doors and were intended to be installed in one demonstration home to determine the cost and installation issues associated with providing a back dam for door sills. However, due to construction schedules and coordination with the concrete slab installers, the seats were not installed in the demonstration homes at this site. Nonetheless, based on the design information provided in this project, the builder plans to use concrete slab seats in future production homes.

Different housewrap options were used on each of the demonstration homes. In all housewrap installations, ASTM E 2112-01R Method A1 was used, with alternative sill pan flashing options installed. Caulking with backer rods was planned for installation around all windows. However, no caulking or backer rod was installed due to schedule constraints and stucco contractor preference. Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals.

Housewraps provided for the demonstration homes by participating manufacturers included DuPont Tyvek® HomeWrap™, Tyvek® StuccoWrap™ (5 foot roll) and DrainWrap™ (9 foot roll), and Dow Styrofoam® Weathermate Plus®. Double ply building paper was installed on Lot No. 79. This approach allowed comparison of installed cost, including materials, taping, labor, and trade coordination. Different window flashing systems were used, including Dupont™ FlexWrap™, Dupont™ StraightFlash™, Pella® SmartFlash™, Fortifiber Moistop® E-Z Seal®, Moistop® Corner Shield™, and FortiFlash® flashing.

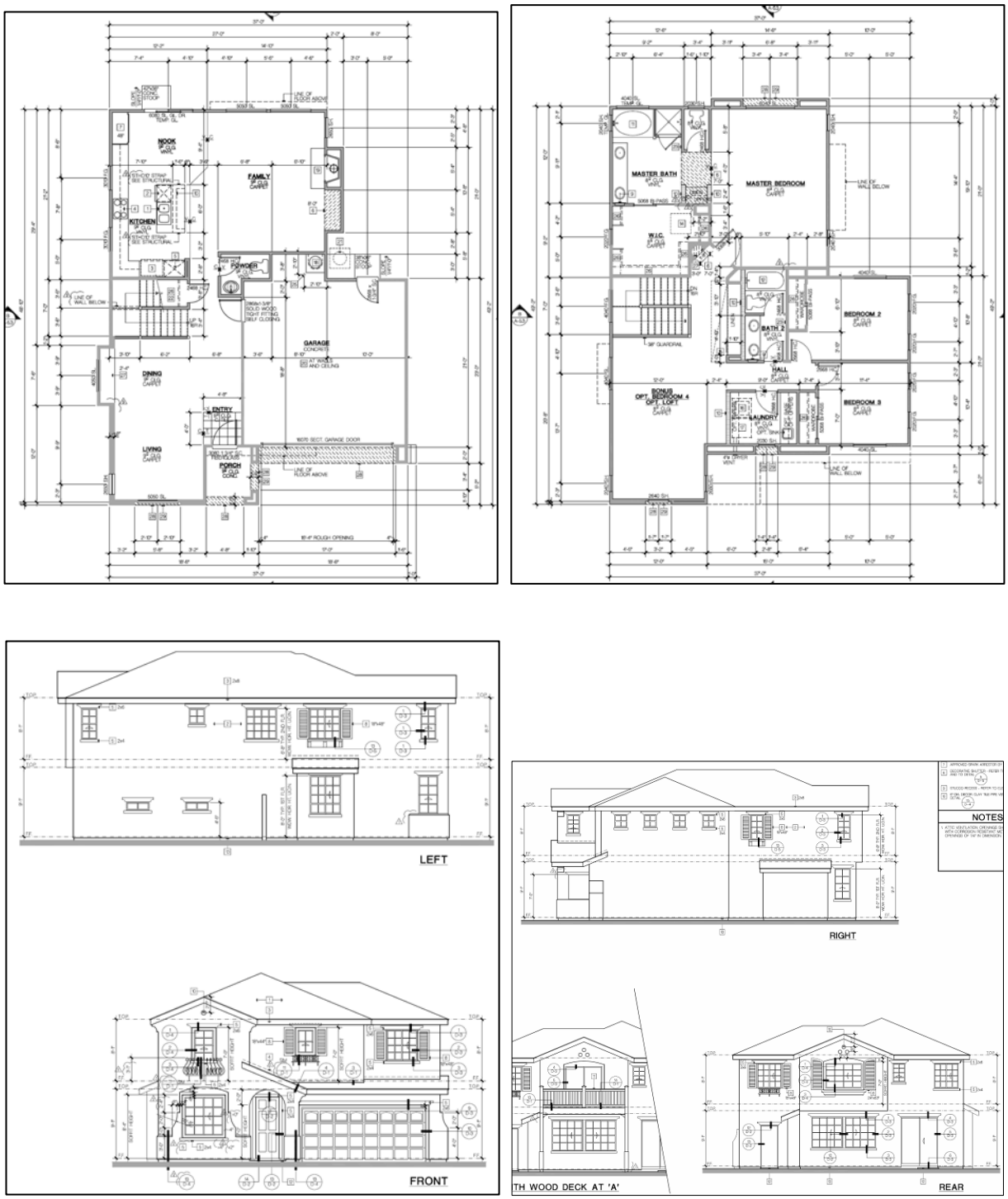


Figure 26 Lot No. 76 Mirror of Floor Plans and Elevations

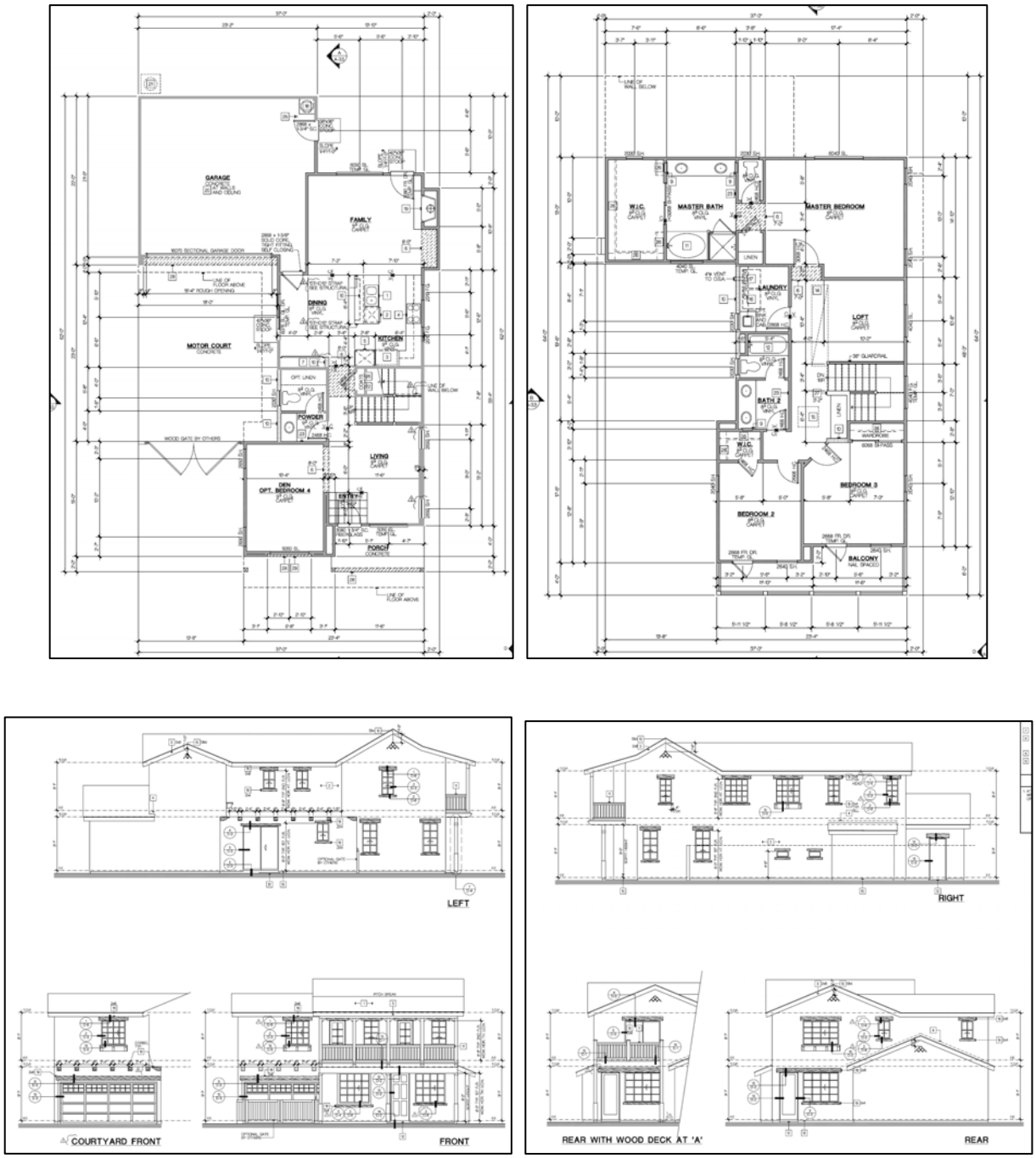


Figure 27 Lot No. 77 Mirror of Floor Plans and Elevations

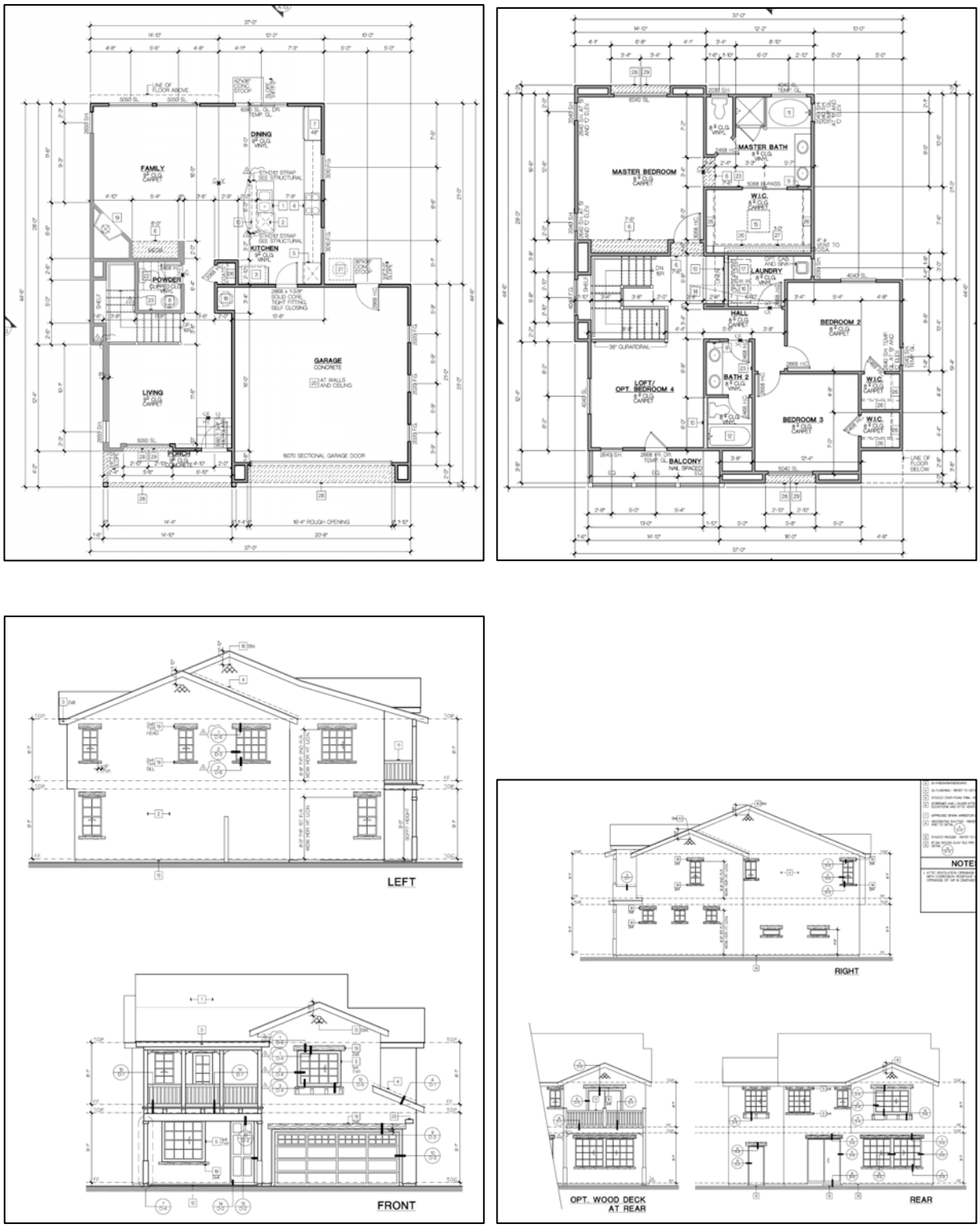


Figure 28 Lot No. 78 Mirror of Floor Plans and Elevations

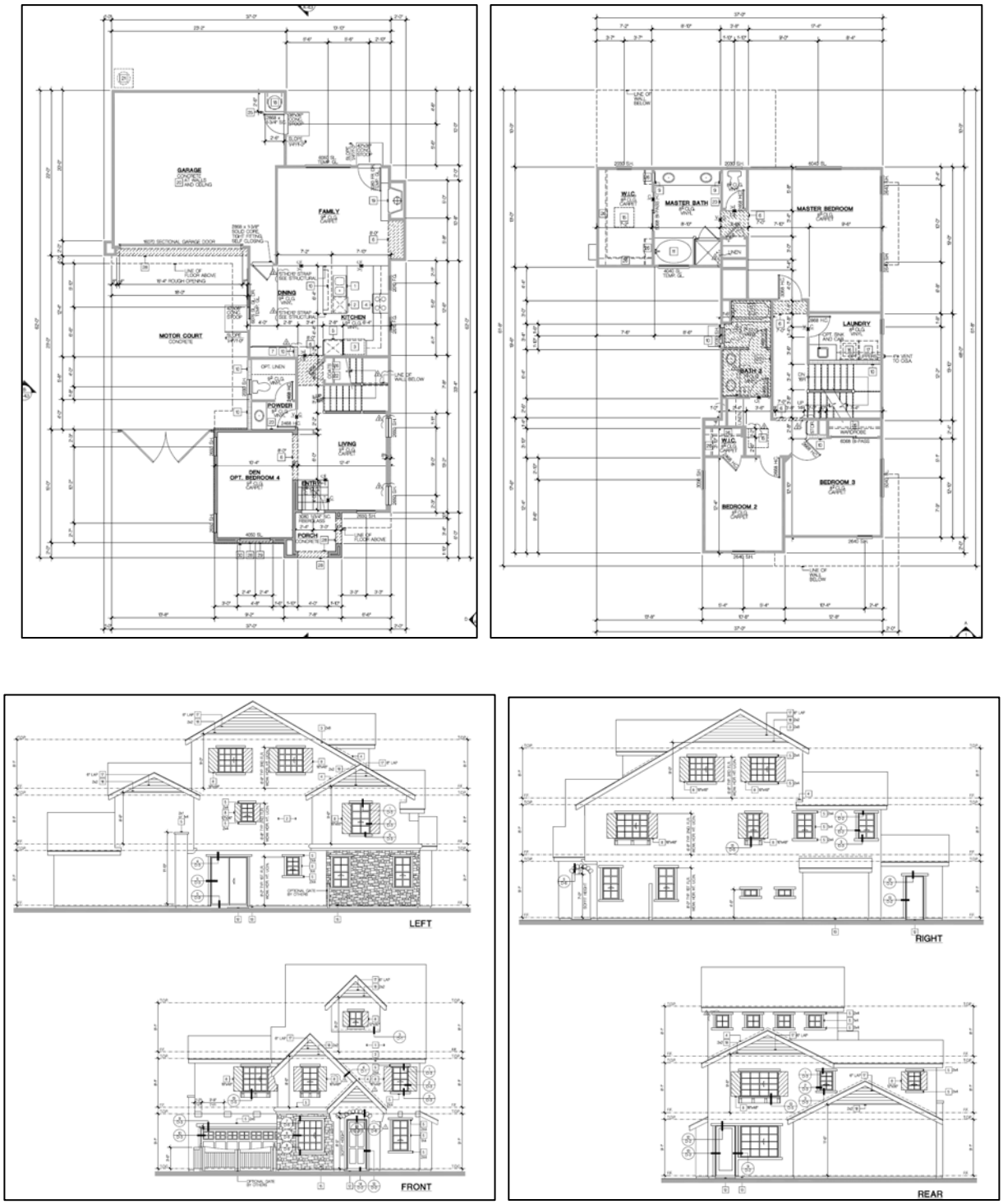


Figure 29 Lot No. 79 Mirror of Floor Plans and Elevations

Table 2 John Laing Inland Division Demonstration Homes Materials and Contacts

Supplier	Product/Service	Contacts
Broan-Nutone LLC	Continuous Duty Bath Fan/Lights	Terry Pond, Kevin Morris
Dow Chemical	Housewrap, Tape, Foam Sealant, Engineering Support	Doug Bibee, Mel Rasco, Bob Braun
Dri-Eaz	Construction Drying System, Engineering Support	Darren Hudema
DuPont Nonwovens	Housewrap, Tape, Flashing, Engineering Support	Theresa Weston, Brett Lubsen
Fortifiber Building Systems Group	Building Paper, Flashing, Engineering Support	David Olson
Foster Products	Fungicidal Protective Coating, Engineering Support	Troy Anderson
Pella Corporaton	Flashing, Engineering Support	Cordell Burton
SureSill	Sill Pan, Engineering Support	Mishko Teodorovich
Tamarack Technologies, Inc.	Ventilation Fan Controllers, Engineering Support	Paul Raymer
USG	Mold-Resistant Gypsum Panels, Engineering Support	Paul Shipp

Installation of SureSill™ sill pan flashing was attempted in one demonstration home, but due to dimensional interferences with the installed windows, a decision was made not to install this product in the demonstration home.

WD-40® bond break was sprayed on weep screeds on one demonstration home. The intent was to help liquid water drain more effectively at the weep screed/stucco interface. Installation method and materials were developed in conjunction with the Lath and Plaster Institute of Northern California.

Dri-Eaz intends to provide construction drying services to at least one additional demonstration home in Winter 2006, but had not completed this effort by the time this report was prepared. Energy usage, schedule impacts, and site conditions will be monitored during the drying process to determine the benefits and costs and reported separately to the participating builder by Dri-Eaz.

Foster® 42-42™ mold-resistant sealer was applied to two of the demonstration homes on selected concealed shear walls and studs to evaluate the incremental cost and impact on construction schedule.

USG HUMITEK™ mold-resistant gypsum panels were installed in the utility room and bathrooms of one demonstration home. The International Residential Code (IRC) no longer approves greenboard as a tile backer in wet areas and instead recommends cement-based backer boards or other moisture-resistant products. USG Fiberock® gypsum panels were installed in bath and shower areas of one demonstration home to compare their cost and ease of use to paper-faced greenboard previously used by the builder.

Two of the demonstration homes incorporated demand ventilation strategies using Broan-Nutone LLC Model QTXE080FL continuous duty low sone fan/lights controlled by Tamarack Humitrak™ AS dehumidistat or Airetrak™ timed controller in Bath 2 on the second floor. This strategy focused on the bathroom and automatically operated the exhaust fan whenever humidity conditions exceed the setpoint in one home, and on a timed ventilation strategy in the other home. The incremental cost of this technology was evaluated and homeowner acceptance will be evaluated by the participating builder.

3.5 Installation

Housewrap, building paper, and window flashing options were installed on all four homes between September 8, 2005 and September 25, 2005. Mold-resistant coatings were applied on September 19-20, 2005. Mold-resistant gypsum panels were installed during October 2005.

3.5.1 Water-Resistive Barrier Construction Sequence

The stucco contractor installed housewraps using two-person crews (Figure 30). After installing weep screeds (Figure 31), nine foot high rolls were wrapped around the perimeter of each house, including over window and door openings (Figures 32 – 34). Tyvek® StuccoWrap™ (5 foot rolls) and DrainWrap™ (9 foot rolls) were installed on Lot No. 76. DuPont Tyvek® HomeWrap™ was installed on Lot No. 77. Dow Styrofoam® Weathermate Plus® was installed on Lot No. 78. Trim pieces were applied to posts, eaves, and other envelope features (Figures 35-36). The stucco contractor used staples rather than capped nails to fasten the housewraps to reduce labor content and cost. Supplemental housewrap pieces were installed below pre-installed penetrations and flashings to avoid reverse shingle-laps (Figure 37). Vertical and horizontal seams were overlapped at least 9" and taped.

Following window installation, a second layer of Grade D 60 Minute building paper was installed over housewraps. Double ply building paper was installed on Lot No. 79. Immediately prior to stucco application, WD-40® bond break was sprayed on exposed metal weep screeds in Lot No. 79. One 12 oz. can was sufficient for the home, and incremental labor content was approximately 10 minutes. All subsequent installation materials and methods, including metal lath, stucco, and stucco finish, were applied according to the builder's standard installation practices.

3.5.2 Window Installation Methods

The window installation contractor installed all window flashing and windows. For Lots No. 76-78, ASTM E 2112-01 R Method A1 protocols (Figure 38)were followed (windows installed after housewrap), using Dupont™ FlexWrap™ flexible self-adhering sill flashing, with ⅜" backer rod beneath the length of flashing on the sill at the interior side of the window frame to create a backdam (Figure 39). The backer rod was flexible enough to compress when the windows were installed. The interior sides of window head and jamb flanges were fully caulked. Window sill flanges were not caulked. This design was intended to allow any water collected by the sill flashing to drain back outdoors. Exterior sides of window flanges were not caulked. Instead, jamb and head flashing was self-adhering flashing, Dupont™ StraightFlash™ for Lot No. 76 and 77 (Figure 40), and Pella® SmartFlash™ for Lot No. 78 (Figure 41).

SureSill™ sill pan flashing was applied to one window frame to determine its compatibility with the windows installed throughout the development (Figure 42). However, the 1½" depth of the pan flashing did not match the 1⅝" depth of the window frame, so a decision was made not to proceed further with the installation.

For Lot No. 79, Fortifiber Moistop® neXT™, Moistop® E-Z Seal®, Moistop® Corner Shield™, and FortiFlash® flashing (Figures 43 and 44) were installed in accordance with Fortifiber installation instructions, with windows and flashing installed before building paper. Caulk was applied to the interior side of all window flanges, including head, jamb, and sill flanges. Exterior sides of window flanges were not caulked. Jamb, head, and sill flashing were Moistop® neXT™ mechanically fastened flashing supplemented by FortiFlash® self-adhering flashing. Corner shields were installed at the sill/jamb interface for additional sill protection.

In three of the demonstration homes (Lot No. 76-78), housewrap is the critical WRB. All flashing was either shingle-lapped or self-adhered to this layer. A layer of building paper was then applied over this integral layer and acts as a partial WRB as well as a substrate for stucco. In Lot No. 79, the double ply building paper is the WRB, with all flashing shingle-lapped to the outer ply of building paper in a similar fashion to the builder's standard construction practice.

Prior to application of stools or other window treatments, Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals to provide a continuous air barrier in conjunction with the ASTM E-2112-01R installation method. The goal was to reduce air pressure differential across the window and minimize the risk of leaks due to wind-driven rain.

A key design difference between the housewrap/window flashing option and the builder's standard construction practice is the location of the WRB. The goal of the demonstration home WRB design was to provide a capillary break between the stucco and WRB that provides enhanced liquid drainage capacity (Figure 45) compared to the builder's standard practice of double ply building paper for the WRB (Figure 46). To achieve this goal, the entire WRB must be able to drain freely by gravity flow rather than capillary-dominated drainage through the stucco. The other key goal of the design was to provide drainage to outdoors in the event of a window frame leak. The use of sill flashing with backdam and no caulk between the flashing and window sill flange was intended to collect and drain water leaking behind the window frame. The bond break at the weep screed was intended to ensure drainage space between the stucco and weep screed. This approach was used in Lot No. 76-78.

In Lot No. 79, the full flange seal (similar to the builder's standard practice) prevents any water leaking behind the window frame from draining to outdoors at the sill. The use of a corner shield and self-adhering flashing covering the entire sill was intended to protect the sill and contain the leak or drain the leak to the interior wall where it would be more likely to be detected and repaired by the homeowner.

3.5.3 Mold-Resistant Sealer

Foster Products staff applied Foster® 42-42™ mold-resistant sealer (42-42) to selected areas in two of the homes (Lot No. 76 and 77) to demonstrate some typical application procedures. In each home the areas in which the product was applied were first prepped to eliminate the product from getting in areas that were not meant to be coated. Once all prep work had been completed the designated areas were then sprayed with 42-42™ sealer.

For Lot No. 76, the master bathroom was coated with 42-42 sealer. Before application, the area was taped and sealed. Since the windows and bathtub had been installed prior to the application, both were taped off to prevent the product from getting on the surfaces (Figure 47). In addition to the tub and windows, all open electrical boxes were taped off as well. Total preparation time for the bathroom was approximately 30 minutes. After all preparation work was completed, 42-42™ sealer was applied using an airless spray system (Figure 48). The application took approximately 45 minutes and used just over one half gallon of product to cover approximately 200 square feet. The majority of that time was spent getting the sprayer prepared and cleaning up after the application. Actual spray time was less than 15 minutes. All open studs were coated, as well as around the tub and windows. In addition, the walls of the bathroom were coated with 42-42™ sealer. Costs were as follows:

- Total Labor: 2 hours @ $60/hr = $120.00
- Product used: 0.5 gallons @ $55/gallon = $27.50

For Lot No. 77, 42-42™ sealer was applied to the entire first floor using similar procedures as for Lot No. 76. All windows, sliding glass door, fireplace, electrical boxes and main fuse box were taped off. The total prep time for the first floor was 90 minutes for two people. The application took approximately 90 minutes and used three gallons of product to cover approximately 1,200 square feet. The bottom four feet of the interior building envelope was coated with 42-42™ sealer (Figure 49). One sidewall area was not treated due to an interfering stack of drywall. In addition to the building envelope, an entire half bathroom on the first floor was coated, including the open studs (Figure 50). 42-42™ sealer was also applied completely around all windows and doors. Costs were as follows:

- Total Labor: 6 hours @ $60/hr = $360.00
- Product Used: 3 gallons @ $55/gallon = $165.00

3.5.4 Mold-Resistant Gypsum Panels

Following application of mold-resistant sealer in Lot No. 76, USG HUMITEK™ mold-resistant gypsum panels were installed in all walls with plumbing chases in the utility room and bathrooms. USG Fiberock® gypsum panels were installed behind bathtubs and showers instead of greenboard (Figure 51). Incremental cost of these products was about $20 per bathroom. No incremental labor content was required for either material.

3.5.5 Bath Fan and Controls

Broan-Nutone LLC QTXE080FL continuous duty low sone fan/lights controlled by a Tamarack Humitrak™ AS dehumidistat were installed in Bath 2 on the second floor of Lot No. 76. QTXE080FL fan/lights controlled by a Tamarack Airetrak™ timed controller were installed in Bath 2 on the second floor of Lot No. 77 (Figure 52). The list price of the QTXE080FL fan/light is $278. The Humitrak™ AS dehumidistat costs about $140. The Airetrak™ timed controller costs approximately $90. Incremental labor content for the controllers in a normal installation would be minimal, as the controllers would replace the conventional on-off switch. However, in these homes, the controllers were installed in parallel with the on-off switch to enable the homeowner to manually operate the fan/light independent of the controller.

Figure 30 Weep Screed Installation, Lot No. 77

Figure 31 Two-Person Crew for Housewrap Application, Lot No. 76

Figure 32 Housewrap Application, Lot No. 76

Figure 33 Housewrap Application, Lot No. 77

Figure 34 Housewrap Application, Lot No. 78

Figure 35 Housewrap Trim Application, Lot No. 76

Figure 36 Housewrap Application around Fireplace Vent, Lot No. 78

Figure 37 Housewrap Trim Pieces below Bath Exhaust Vent, Lot No. 76

Figure 38 Window Installation, ASTM E 2112-01R Method A1, Lot No. 76

Backer Rod Underneath FlexWrap™

Figure 39 Flexible Sill Flashing with ⅜" Backer Rod Backdam, Lot No. 78

Figure 40 Jamb and Head Flashing, Lot No. 76 and 77

Figure 41 Jamb and Head Flashing, Lot No. 78

Figure 42 Sill Pan Flashing Installation, Lot No. 78

a) Corner Shield and Self- Adhering Sill Flashing

b) Mechanically Fastened and Self-Adhering Sill and Jamb Flashing

Figure 43 Flashing Installation, Lot No. 79

Figure 44 Window Installation, Lot No. 79

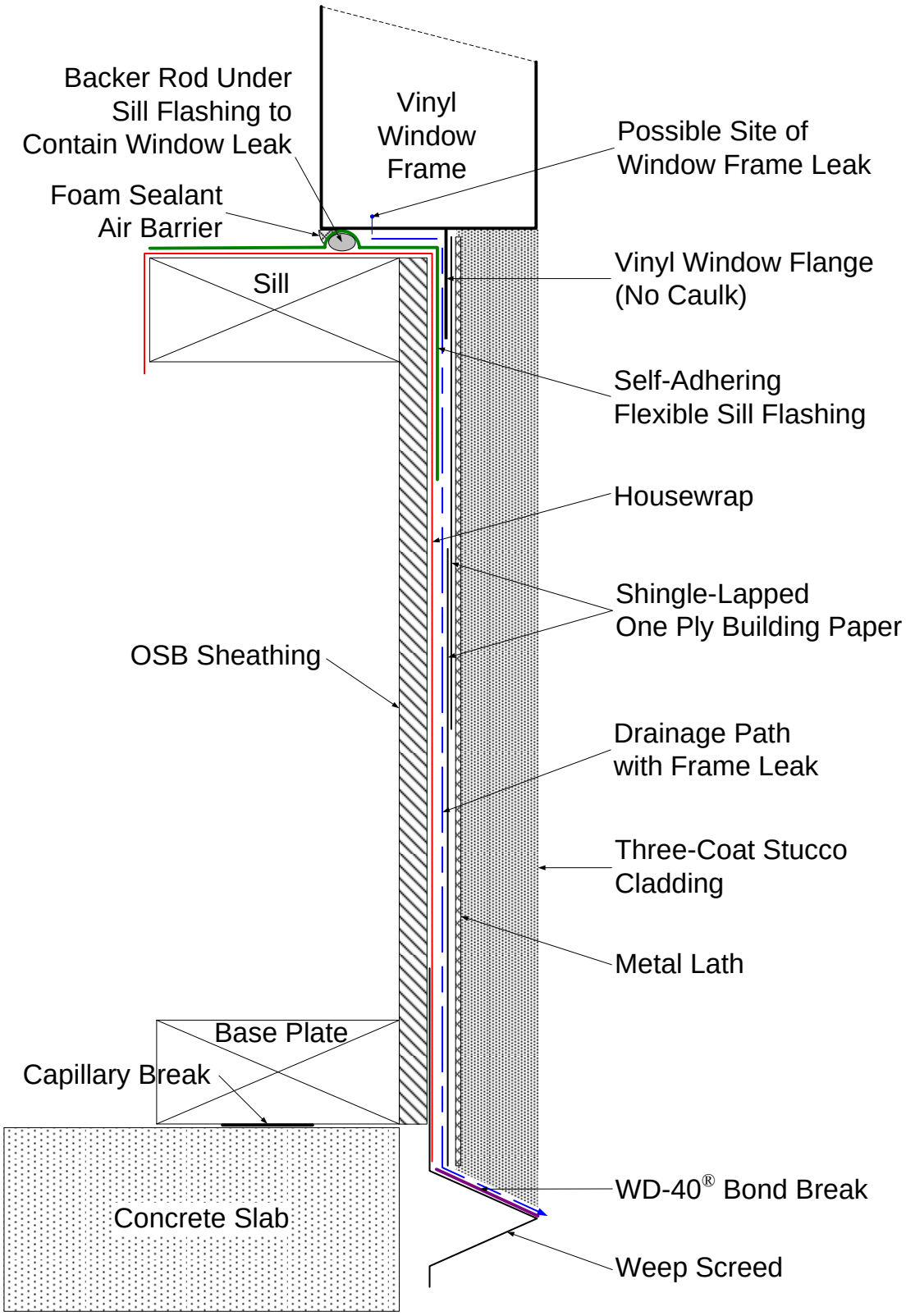


Figure 45 Housewrap/Sill Flashing Schematic with Drainage Path

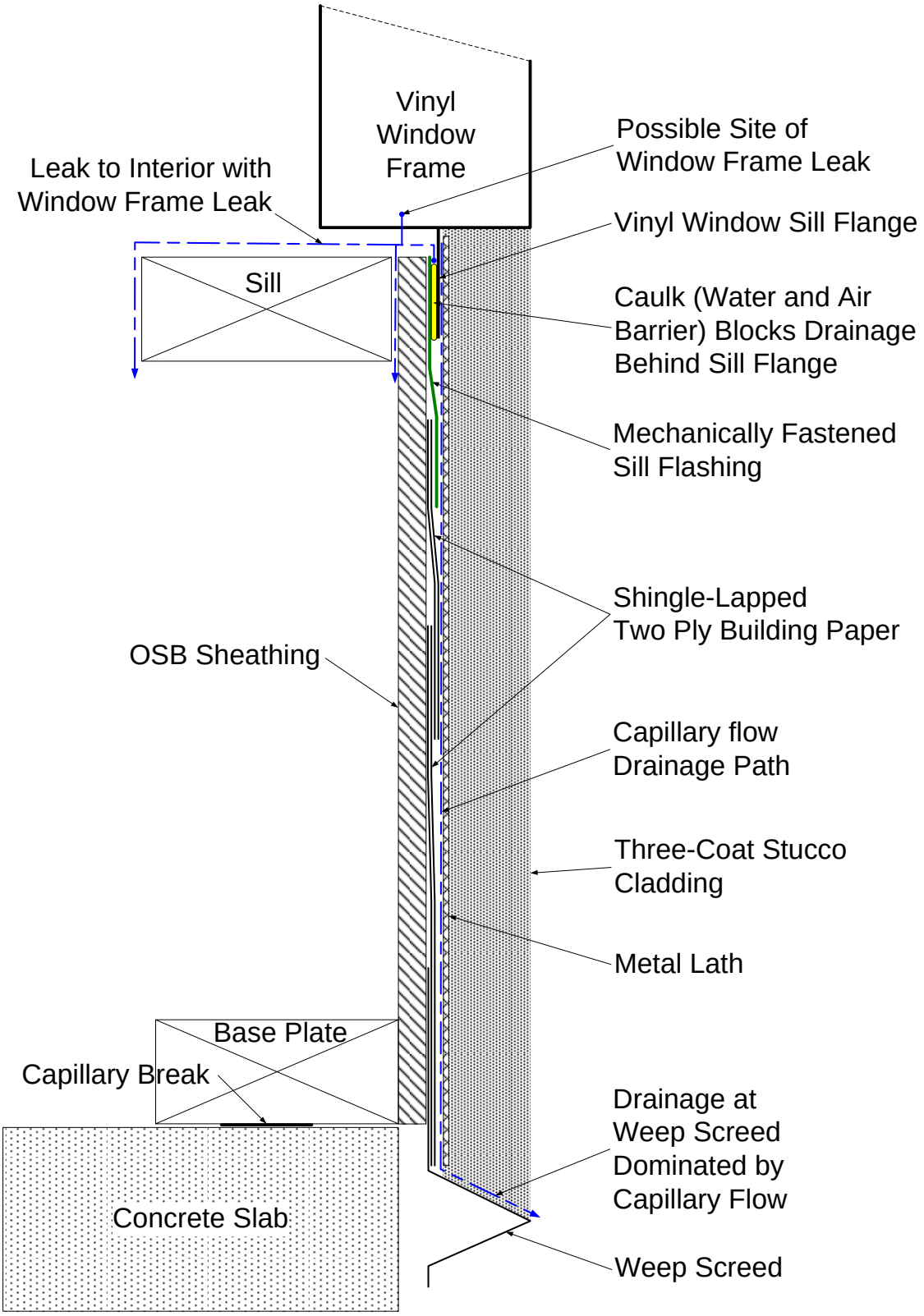


Figure 46 Two-Ply Building Paper and Sill Flashing Schematic with Drainage Path

Figure 47 Second Floor Bathroom Preparation for 42-42 Application, Lot No. 76

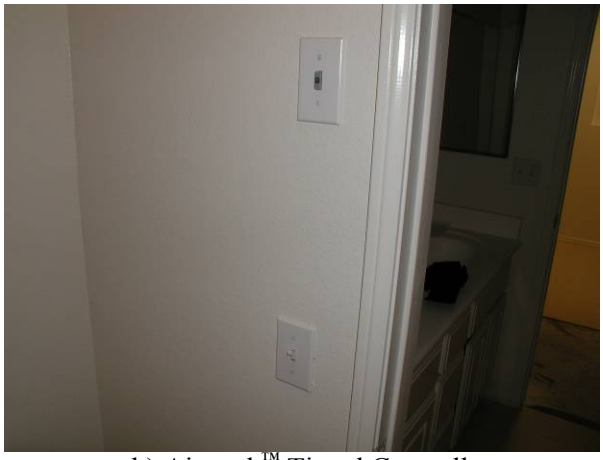
Figure 48 Application of 42-42 in Second Floor Bathroom, Lot No. 76

Figure 49 Application of 42-42 in First Living Area, Lot No. 77

Figure 50 Application of 42-42 in First Floor Bathroom, Lot No. 77

Figure 51 HUMITEK™ and Fiberock® Gypsum Panels after Installation, Lot No. 76

a) Model QTXE080FL Fan/Light



b) Airetrak™ Timed Controller

Figure 52 Continuous Duty Bath Fan/Light and Timed Controller Installation, Lot No. 77

3.6 Observations

3.6.1 Water-Resistive Barrier Construction Sequence

The construction sequence evaluated for the housewrap demonstration homes included installing housewrap before windows and other penetrations were flashed. This sequence was intended to fully integrate self-adhered flashing to the housewrap, providing a continuously sealed WRB. This approach was consistent with manufacturers' installation instructions and recommendations by building science consultants on this project. However, because it is more expensive to implement and introduces different risks, this sequence is rarely used in California home construction with stucco cladding. Instead, all penetrations are typically installed and flashed with mechanically fastened flashing before the WRB is installed. The stucco contractor installs the entire WRB and cladding, including housewrap, associated flashing integration, building paper, lath, and stucco, after all flashing is installed by various trades. The typical sequence limits the need for trade coordination while reducing labor content compared to the sequence used in the demonstration homes.

Due to trade coordination and division of responsibility for flashing installation, the only areas in the demonstration homes that used self-adhering flashing in conjunction with the housewraps were the windows. Doors, vents, and other penetrations had mechanically fastened flashing applied by the installing contractor (e.g., heating contractor for fireplace vent flashing). This construction sequence required cuts in the housewrap to shingle-lap mechanically fastened jamb and sill flashing.

Builder and contractor feedback on housewrap installations for all three demonstration homes was mixed. The builder supports the energy efficiency of housewraps as air retarding wraps and is keenly interested in this approach to saving energy. In addition, housewraps may have excellent durability and performance when subjected to moisture events. However, applying the WRB before window installation, with a layer of building paper applied at a later date, involved additional labor content and trade coordination compared to a single application of double ply building paper after all penetrations are installed. The incremental material cost and construction steps impacted overall construction cost, schedule, and risk profile. Observed sources of incremental cost and risk associated with installing the WRB before windows included:

- Risk of reverse shingle-laps at penetrations
    - Previously installed
    - Subsequently installed
    - Flashing by other contractors
- Trade coordination and education for construction sequence modifications
    - Roofing contractor
    - Holes and tears
    - Scaffolding
- Incremental labor content
    - Cutting and placing small pieces
    - Installing second layer of building paper
- Risk of leaks at taped butt joints (e.g., holes, tears, v-cut for head flashing)
    - Full tape seal required
    - Risk of tape not adhering over time

Increased risk of reverse shingle-laps arose from previously installed penetrations and flashing such as vents, piping, and wiring access hole (Figure 53). The housewrap installer employed two methods to avoid reverse shingle-laps in these cases: Additional housewrap flashing under the penetration flashing (see Figure 34 above), and cutting and inserting housewrap under the flashing (Figure 54). Risk of reverse shingle-lap also occurred when an electrical panel was installed after the housewraps (Figure 55). The electrical contractor was responsible for installing the panel and associated flashing, but usually was

not responsible for integrating the flashing because the building paper typically was installed after all other flashing was complete (Figures 56 and 57). The housewrap contractor (who also installed the second layer of building paper on the demonstration homes) was responsible for the additional effort to ensure that the housewraps in the three demonstration homes were properly integrated with all penetrations and associated flashing.

Other trades also impacted housewrap installation. For example, the roofing contractor typically installed roof flashing before building paper was installed. However, the housewrap was installed before the roof flashing, and the roofing contractor created a reverse shingle-lap when installing the roof flashing (Figure 58). The roofing contractor repaired the reverse shingle-lap (Figure 59), but tore the housewrap in several places when removing the nails and staples. However, the roofing contractor did not have housewrap tape to effect repairs. In this case, the tears were benign since they occurred below the level of the roof flashing. Any remaining repairs were the responsibility of the housewrap contractor before installing the layer of building paper.

The electrical contractor also tore the housewrap to run electrical wiring (Figure 60). This tear was at a window, but extended below the frame, and affected the integrity of the housewrap at the window flashing. In this case, the tear was taped by the window installer before installing window flashing.

Scaffolding was necessary on each home to install housewrap as well as building paper and stucco on the second and third floor walls. The housewrap contractor was responsible for erecting the scaffolding, but did not erect sufficient scaffolding to complete housewrap installation for the entire house (Figure 61). This resulted in housewrap hanging loose until the available scaffolding was relocated to the rest of each house. Both the housewrap contractor and the window contractor needed to return to the houses, impacting both cost and schedule. All scaffolding was subsequently removed and erected again when the building paper and stucco were installed later. Scaffolding was required only once on Lot No. 79 for application of 2-ply building paper and stucco.

Recessed windows used a self-adhering waterproofing membrane for sill and jamb flashing. In Lot No. 76-78, the self-adhering flexible flashing was attached to the waterproofing membrane (Figure 62), but did not adhere to the full length of flashing. Since the self-adhering flashing was shingle-lapped to the waterproof membrane, failure to adhere was not expected to be a significant risk, and this approach was used on all recessed windows in all 3 housewrap homes. Lot No. 79 used standard installation methods for recessed windows (Figure 63).

Tape for housewrap seams, tears, and cuts was intended to adhere to the full length of the housewrap and maintain its adhesion for the life of the home. In general, the tape performed as well in the field as it did in laboratory experiments. The tape adhered so well to the flat housewraps that care was required to avoid tearing the housewraps when removing the tape after temporary taping at v-cuts above windows. Taped seams and cuts remained well-sealed based on subsequent inspections for these housewraps. However, textured housewrap behaved quite differently. The tape did not adhere well to this housewrap. It was relatively easy to separate the tape from this housewrap at joints, and there were noticeable seal failures, especially in long horizontal runs (Figure 64). It also was difficult to guarantee a full seal at cuts and tears.

This issue may be associated with the designed vertical creases that add material length per lineal foot of installed length. When the tape is applied, especially over longer horizontal seams, there is a mismatch in length between the tape and the housewrap, creating the potential for numerous vertical gaps between the tape and housewrap. An installation technique in which the tape is “pushed into the creases” as it is unrolled may need to be developed. Rolling with a rubber laminate roller has helped when the textured housewrap has been applied over solid substrate. Although reduced tape adhesion may not be a major issue at the seams which are already shingled to facilitate drainage out of the wall, window installation methods may need to be revised to reduce the dependence on tape to seal the diagonal slits at the top corners of the window. One possible approach to address this issue would be to shingle-lap another piece

of housewrap under horizontal or angle cuts and tears extended out a couple feet in both directions below the cut.

Application of a WRB before flashings and windows are installed is not cost-effective with stucco wall assemblies in California. While the builder remains open to discussions about housewraps, at this time they intend to continue using double ply building paper for future developments with 3-coat stucco cladding.

3.6.2 Window Installation Methods

Window Installation using ASTM E 2112-01R Method A1 and self-adhering flashing went smoothly once the window installation contractor was trained on the procedures. No substantive technical issues were identified. The key difference from the standard installation method was labor content and material cost. The extra steps associated with the new method took nearly four times as long to install as the standard method. Some of the incremental time was due to inexperience, but the contractor estimated the new method would take twice as long as the standard method in production mode. Increased labor content included the increased steps associated with the installation method and care required when applying self-adhering flashing (versus stapled flashing).

The material cost was also higher, especially for the flexible sill flashing and sill pan. Metal tape flashing had the lowest incremental cost and sill pans had the highest incremental cost for sill flashing. The window installation contractor estimated that a four man crew can complete four homes per day with mechanically fastened flashing with 25 windows per home, compared to 2 homes per day with the self-adhering flashing. Total incremental material and labor cost per home with self-adhered flashing ranged from $250 to $700. Despite these increased costs, builder and manufacturer feedback indicates a strong and growing acceptance of self-adhered flashing in California based on perceived advantages over mechanically fastened flashing.

Flashing options and related window installation methods are intended to reduce the risk of moisture from window leaks while providing a highly durable installation, especially at the sill. Since these materials add both cost and time, the builder must make informed risk management decisions before deciding whether to use these options. The builder is currently evaluating these flashing and installation approaches and may consider them in future developments.

3.6.3 Mold-Resistant Sealer

Application of mold-resistant sealer went smoothly and did not impact the remaining production schedule. Sufficient slack exists in the overall schedule to accommodate application throughout a development and not affect the critical path. The only issue with the demonstration home installation was interference from installed or stacked items. The bath and shower were installed in Lot No. 76 prior to application of the sealer, which prevented application in the wall areas behind these fixtures. In addition, stacked gypsum panels prevented access to the adjacent wall in Lot No. 77. This is a trade sequence and interference issue that would need coordination to ensure application of sealer in all desired areas.

Labor content for room preparation was a significant cost factor. Careful scheduling of the application that minimizes required taping and sealing (e.g., around tubs) would have a large impact on reducing application cost. The builder remains interested in pursuing this technology option for appropriate situations, and will evaluate it as a part of their risk management strategy for future developments.

3.6.4 Mold-Resistant Gypsum Panels

Installation of mold-resistant gypsum panels went smoothly and did not impact the production schedule. The incremental cost of the materials was the only significant difference. The builder remains interested in pursuing this technology option for appropriate situations, and will evaluate both materials as a part of their risk management strategy for future developments.

3.6.5 Bath Fan and Controls

Bathroom exhaust noise is an increasingly important parameter based on use of bath exhausts as a part of a whole house ventilation strategy or automated bath exhaust approach. A sone level of 3.5 or higher will become less acceptable as fans are operated automatically or cycled to supplement whole house ventilation. While many homeowners may not currently perceive fan noise to be objectionable, a near future education and marketing opportunity exists, as well as a link to improved performance and energy efficiency with 0.6 sone low noise, 6" ducted fans.

Bathroom relative humidity control is challenging, but worth investigating as a benign control strategy. Its goal is to remove residual moisture automatically whenever needed and the manual switch is off. Since the user may operate the exhaust fan manually when generating the moisture load (e.g., due to bath or shower), its incremental benefit is variable. Concerns about dynamic setpoint (ranging from 60% in summer to 30% in winter) to match the interior space needs are valid and worth reviewing prior to broad recommendations on this approach. An alternative strategy of timed cycling may also be a concern due to increased energy consumption associated with ventilation and fan energy, so it is also worth further review. Either strategy will need to be integrated into a whole house humidity and ventilation control strategy, whose objectives need to be carefully crafted to avoid or minimize unintended consequences. The builder perceives the relative humidity controller to be a potential marketing benefit, and plans to provide future feedback on the value they attach to this feature.

3.7 Long Term Data Acquisition

The automated DAS for the innovative demonstration home, shown in Figure 65, is a Campbell Scientific CR10X datalogger with 64 channel MUX, punchdown blocks, power supply, and wireless modem. Sensors include temperature, relative humidity, moisture content, and wood temperature under one window on each side of the home (Figures 66 through 69). Outdoor air temperature and relative humidity are also being monitored.

The DAS was installed in House No. 76 on December 14, 2005, and monitored for this report during the period from December 14, 2005 through February 4, 2006. Long term monitoring for this home is planned throughout 2006.

Table 3 lists DAS sensor codes used in the demonstration homes to distinguish sensor locations. Figures 70 through 81 show results to date of moisture measurements in the demonstration home. Initial observations based on data collected to date include the following:

- Wall cavity relative humidity measurements appear to indicate different sensor locations relative to the insulation, especially noticeable when comparing the east and west wall cavities.
- The east wall cavity temperature and relative humidity profiles are consistent with sensor location on the interior side of the insulation.
- The west wall cavity temperature and relative humidity profiles are consistent with sensor location on the exterior side of the insulation.
- The north and south wall cavity temperature and relative humidity profiles are consistent with sensor location embedded within the insulation, which was the intended sensor location.
- Wood and OSB moisture content levels ranged from 10 to 13 percent throughout the monitoring period. Dry weather conditions prevalent throughout the construction period appear to have permitted significant wood drying to occur prior to wall enclosure.
- Wood temperature profiles were consistent with sensor locations relative to insulation.
- Wood temperature profiles in the west wall indicate significant solar effect on wall temperatures compared to the other 3 orientations.
- Bathroom floor OSB sheathing readings were consistent with occupancy in early January 2006. OSB moisture content was consistent with readings in all other locations.

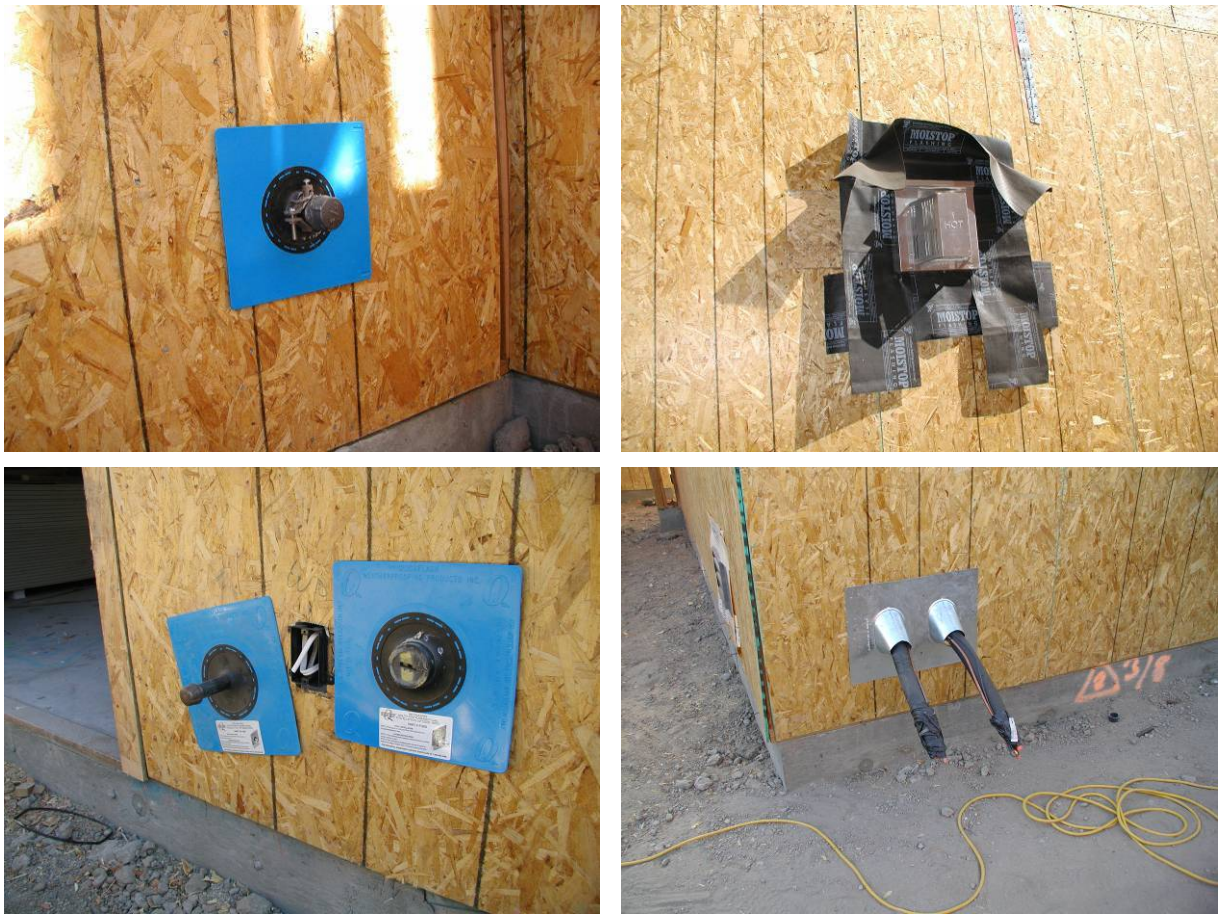


Figure 53 Flashing Installed before Housewraps, Lot No. 76-78

Figure 54 Housewrap Cut and Tucked under Fireplace Vent Flashing, Lot No. 76

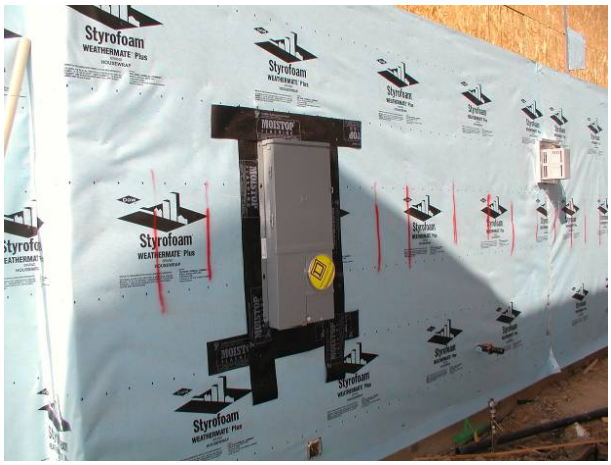


Figure 55 Reverse Shingle-lap at Head Flashing Installed after Housewraps, Lot No. 76-78

Figure 56 Flashing Installed before Building Paper, Standard Construction

Figure 57 Building Paper Shingle-lapped to Flashing, Standard Construction

Figure 58 Reverse Shingle-lap for Roof Flashing Installed after Housewrap, Lot No. 76

Figure 59 Repair for Proper Shingle-lap at Roof Flashing, Lot No. 76

Figure 60 Housewrap Tear by Electrical Contractor, Lot No. 76

a) Incomplete Scaffolding, Lot No. 76

b) No Scaffolding, Lot No. 78

Figure 61 Incomplete Scaffolding Delayed Housewrap Completion, Lot No. 76-78

Figure 62 Recessed Window Flashing Approach, Lot No. 76

Figure 63 Recessed Window Waterproof Membrane Flashing, Standard Construction

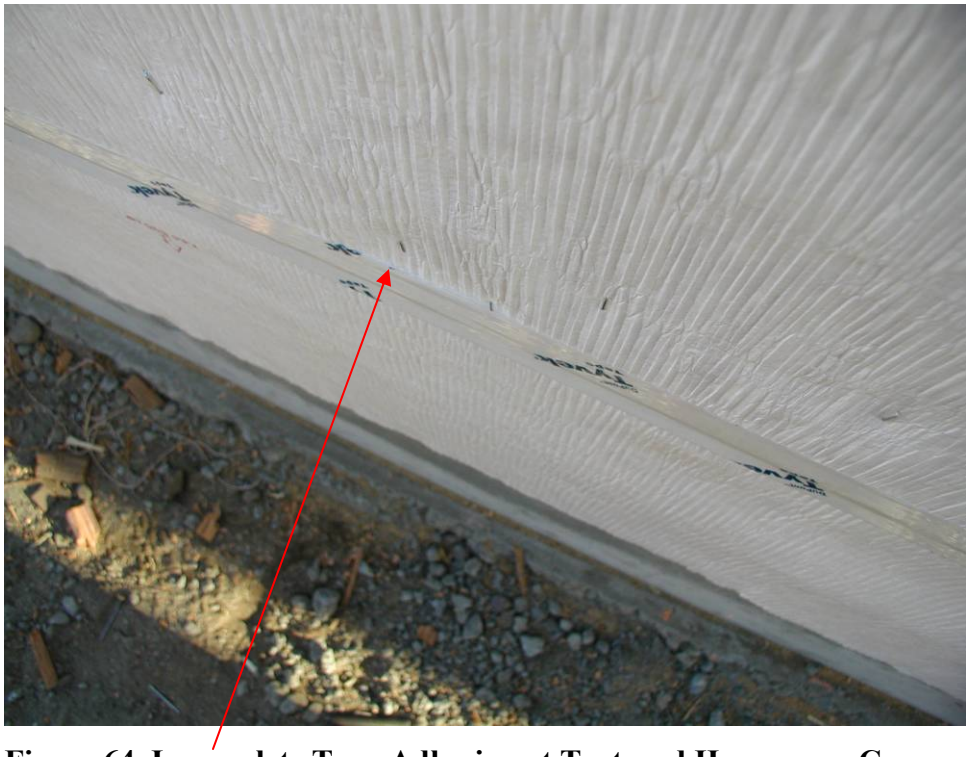


Figure 64 Incomplete Tape Adhesion at Textured Housewrap Creases

Table 3 DAS Sensor Codes

Measurement Value	Location in Wall	Location in Layer	Vertical Location
T-Temperature M-Moisture Content R-Relative Humidity	C-Stud Space D-Framing E-Sheathing	E-Exterior I-Interior N-Interstitial	T-Top U-Upper M-Middle L-Lower B-Bottom

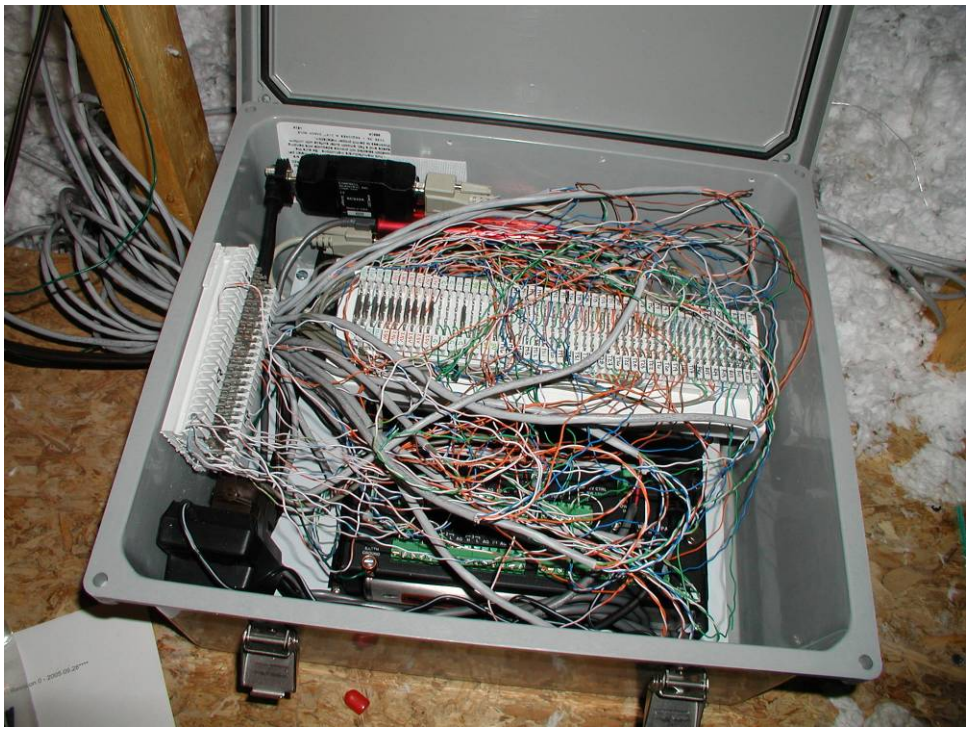


Figure 65 Automated Data Acquisition System

Figure 66 Moisture Sensors in Insulated North Wall Cavity

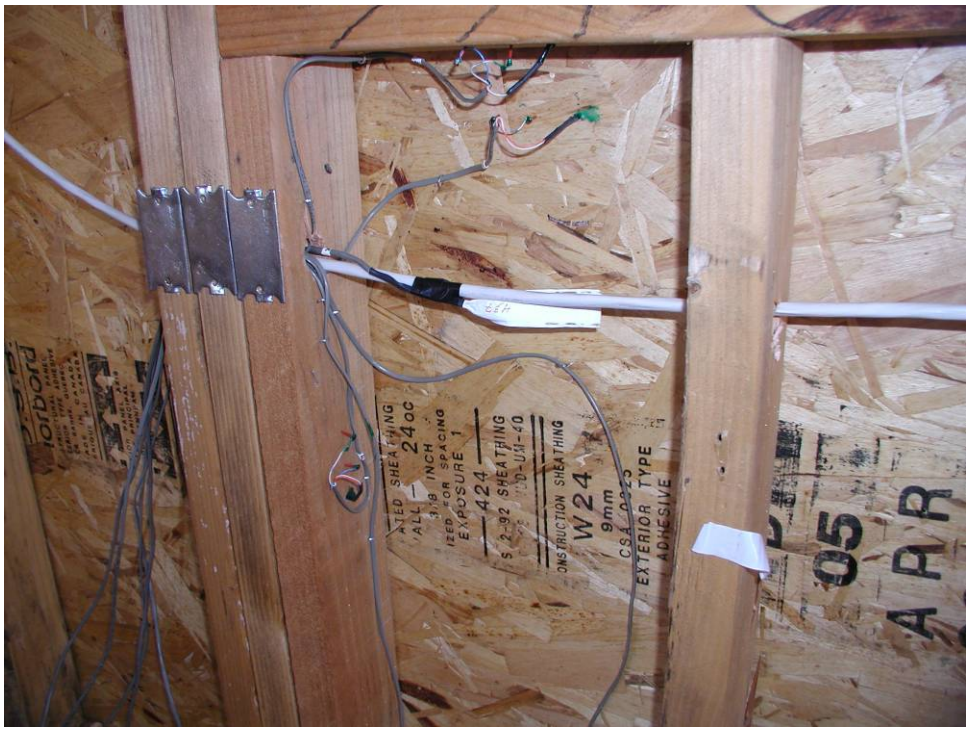


Figure 67 Moisture Sensors in East Wall Cavity

Figure 68 Moisture Sensors in South Wall Cavity

Figure 69 Moisture Sensors in West Wall Cavity

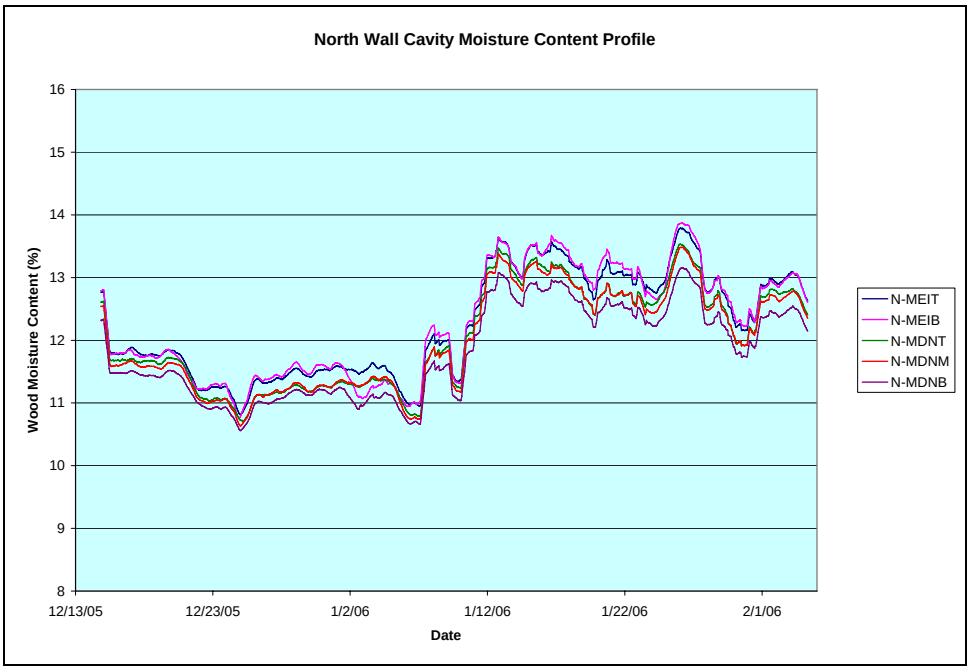


Figure 70 North Wall Cavity Moisture Content Profile

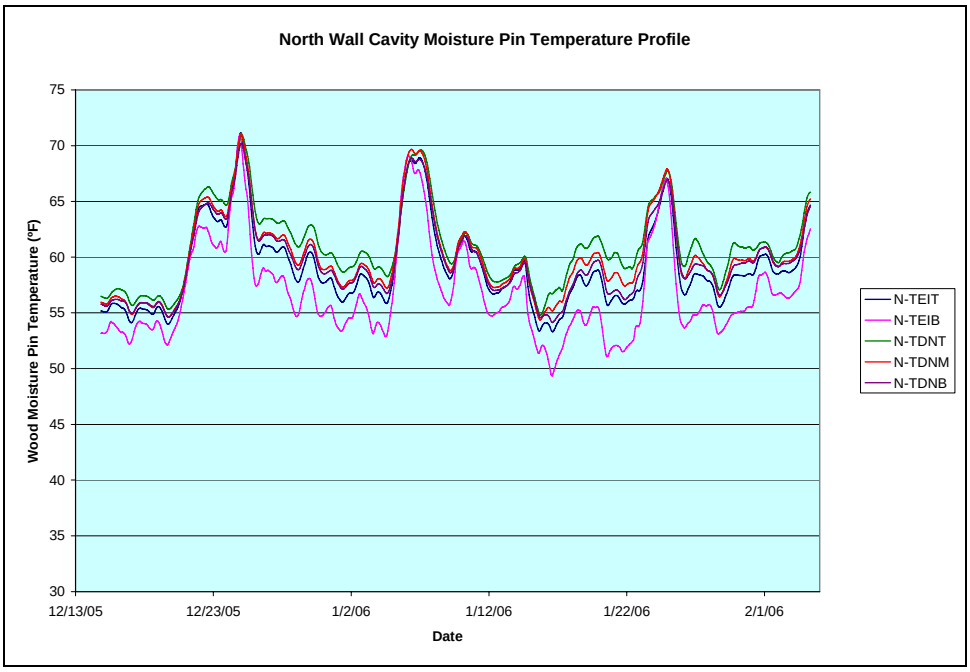


Figure 71 North Wall Cavity Moisture Pin Temperature Profile

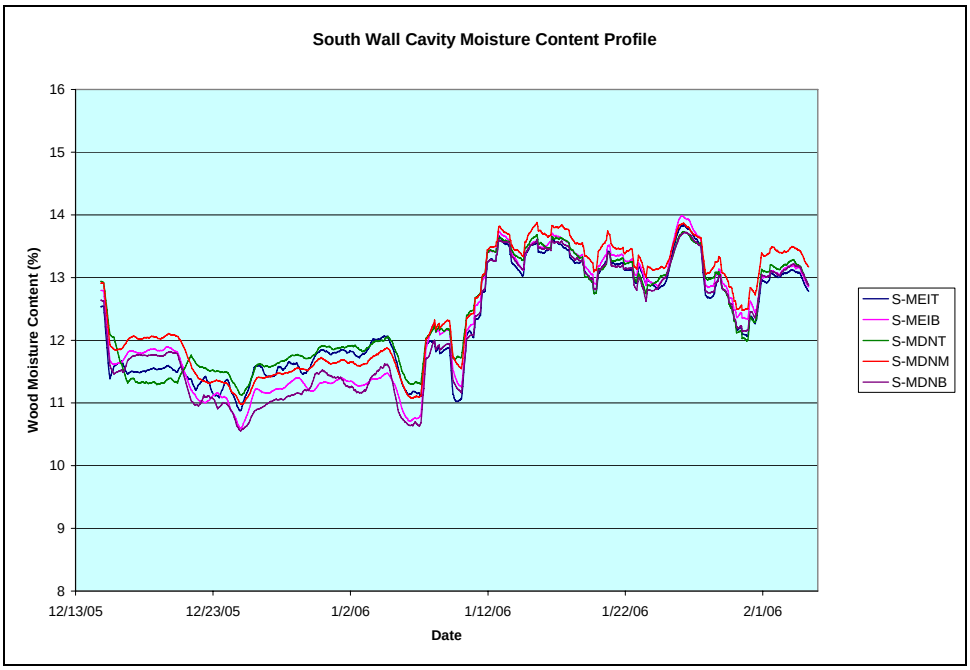


Figure 72 South Wall Cavity Moisture Content Profile

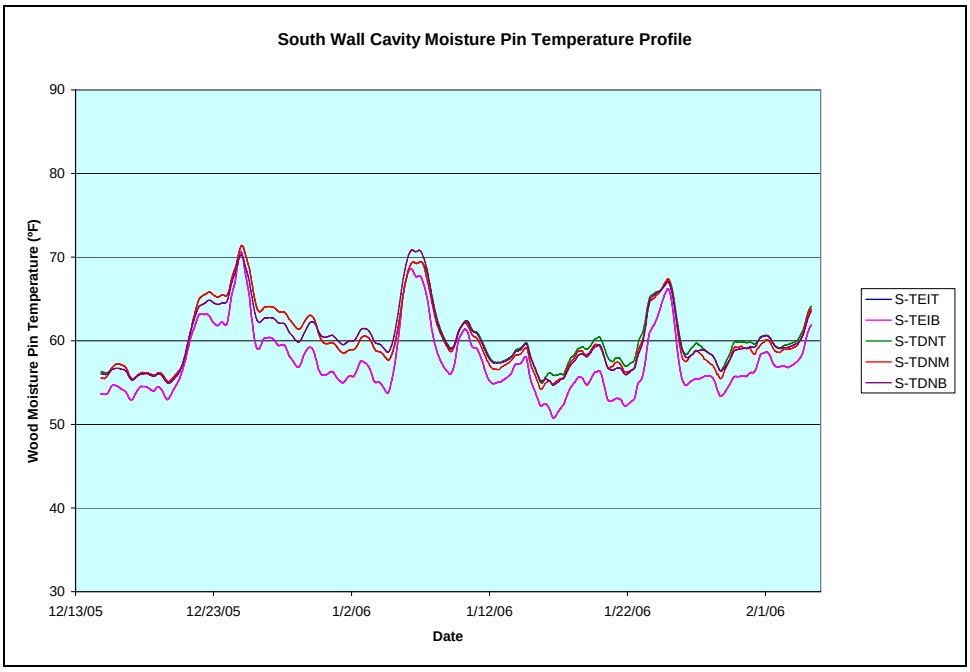


Figure 73 South Wall Cavity Moisture Pin Temperature Profile

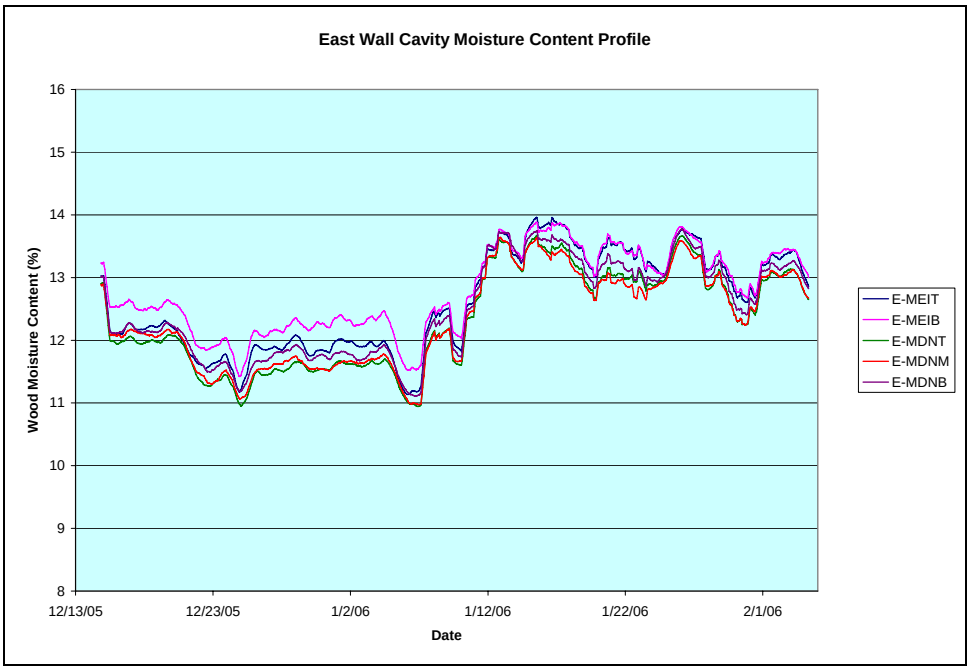


Figure 74 East Wall Cavity Moisture Content Profile

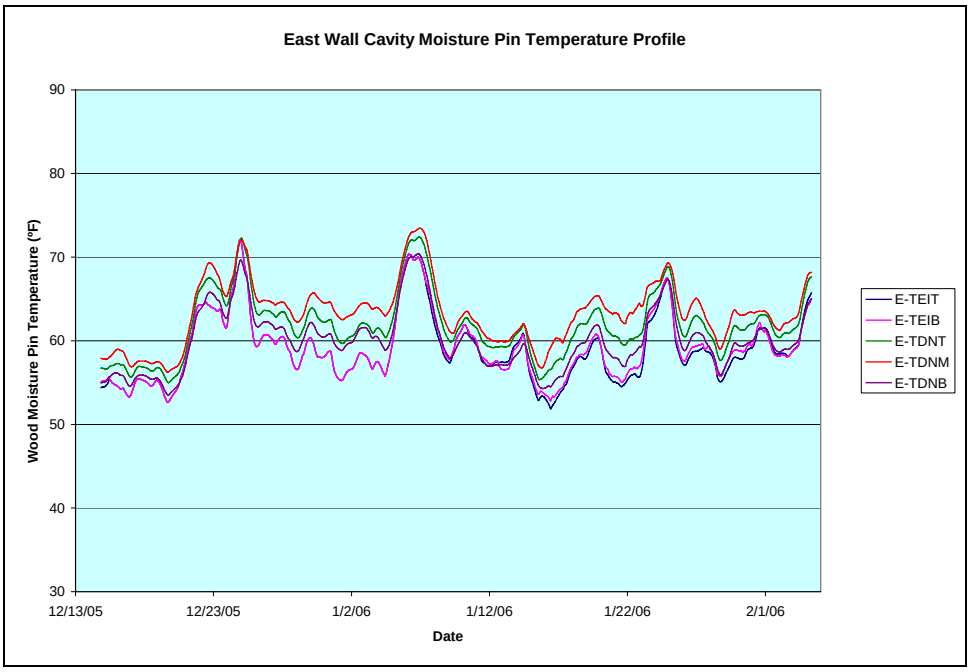


Figure 75 East Wall Cavity Moisture Pin Temperature Profile

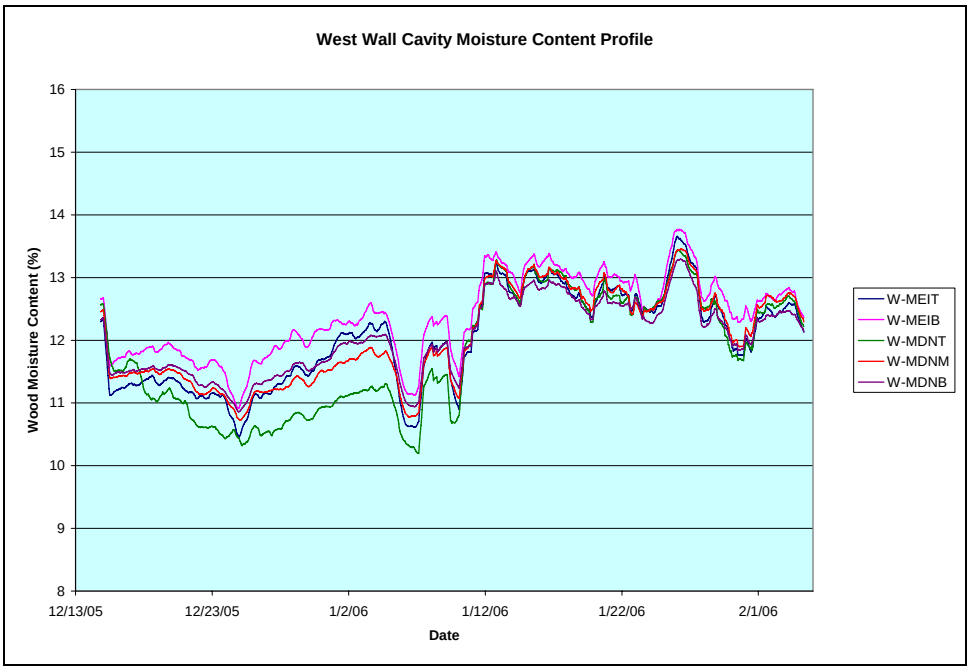


Figure 76 West Wall Cavity Moisture Content Profile

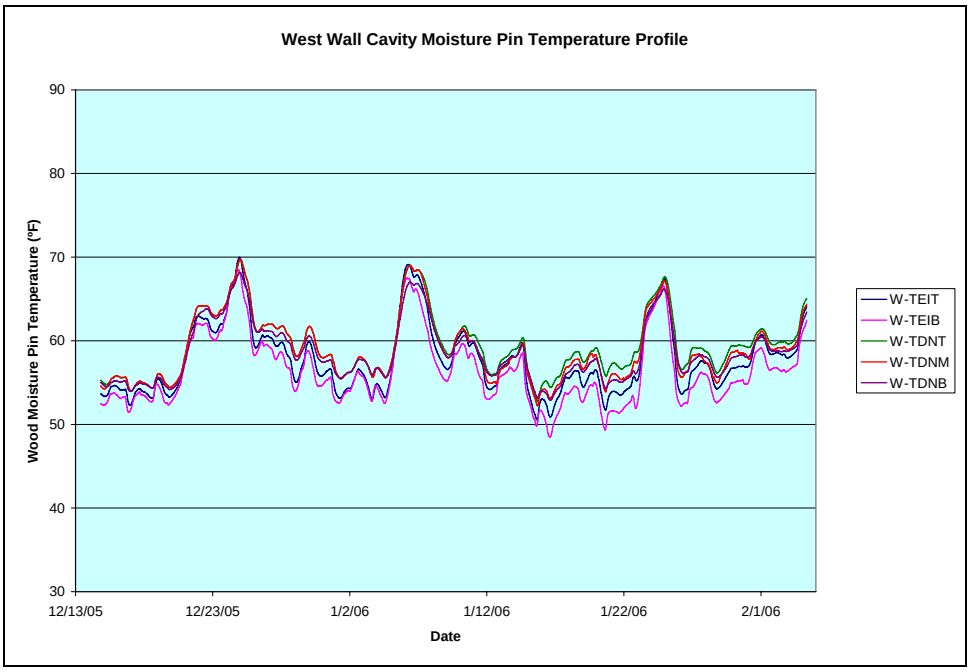


Figure 77 West Wall Cavity Moisture Pin Temperature Profile

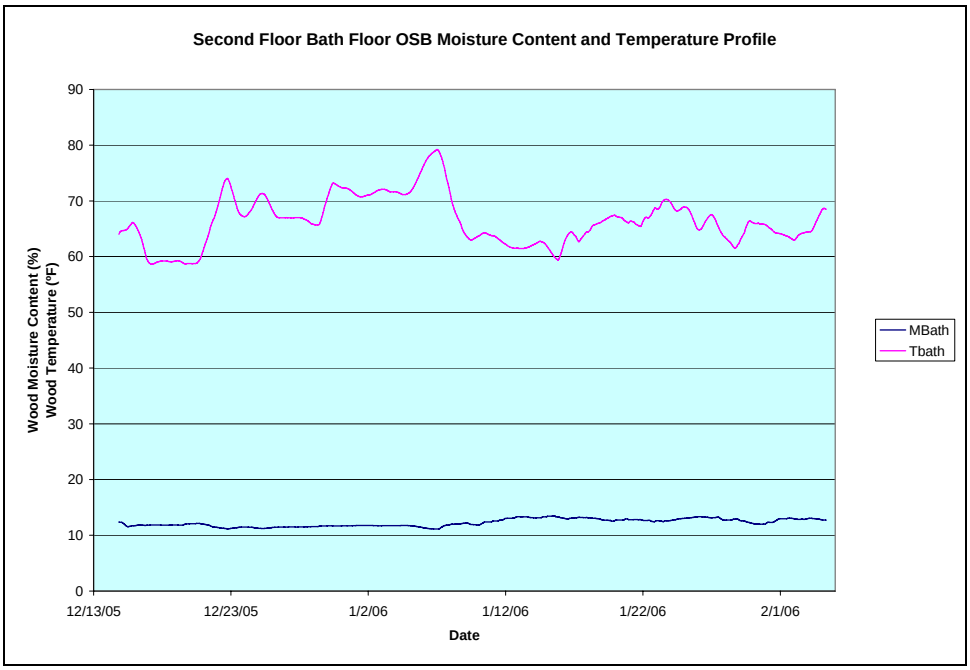


Figure 78 Bathroom Floor OSB Moisture Content and Temperature Profile

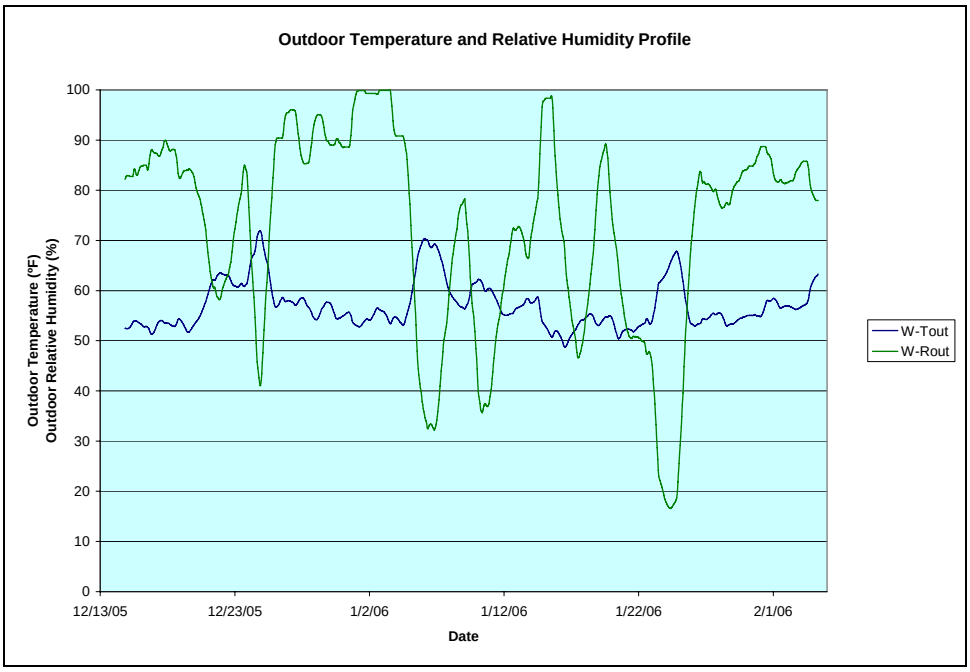


Figure 79 Outdoor Temperature and Relative Humidity Profile

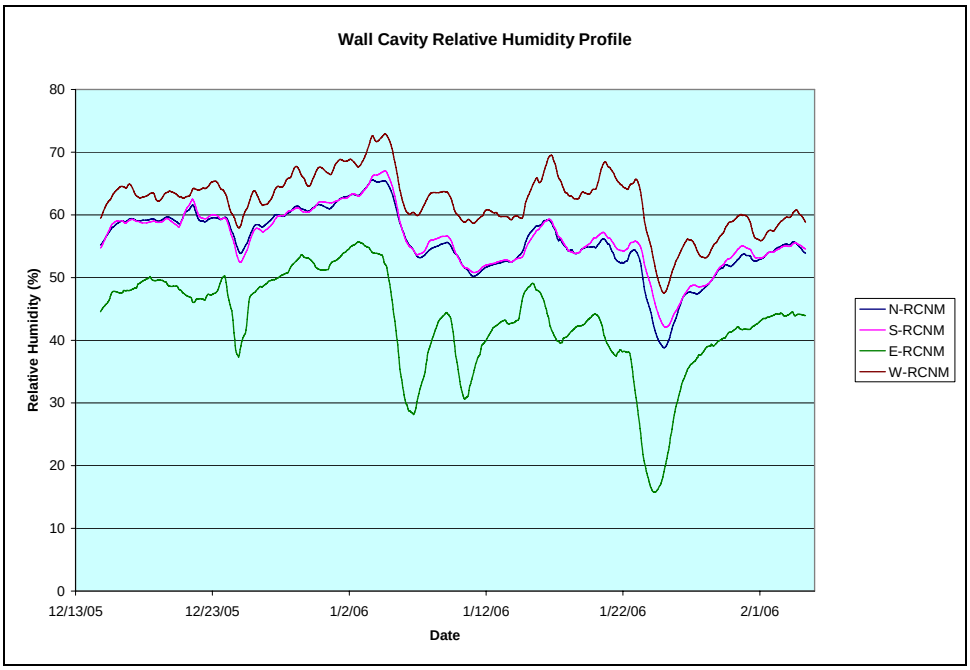


Figure 80 Wall Cavity Relative Humidity Profile

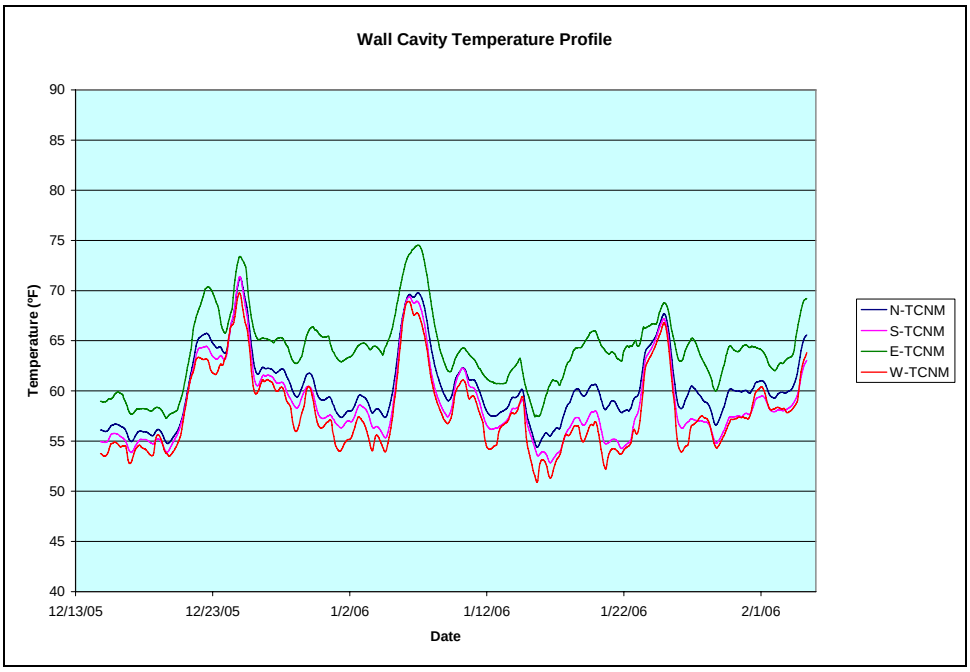


Figure 81 Wall Cavity Temperature Profile

4.0 Clarum Homes Demonstration Home

4.1 Goal

The goal of this task was to support construction of the Clarum Homes Demonstration Home in Northern California.

4.2 Scope

The scope of this task was to work with Clarum Homes and participating manufacturers during the construction period to ensure that construction of the demonstration home proceeded according to plan. Clarum Homes used the design information provided by the project team and participating manufacturers and consultants to build the home containing recommended assemblies and construction practices. The project team also documented costs and recorded construction using videotapes and photographs as appropriate.

4.3 Approach

One demonstration home, Lot No. 24 (Figures 82 and 83), was built as a part of the Clarum Homes Pajaro Vista development in Watsonville, California. The home is predominantly open frame construction except at shear walls, which have OSB sheathing (Figure 84). Wall cladding is one-coat stucco with exterior insulation and additional wall cavity insulation (Figure 85). Participating manufacturers provided technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. Data acquisition system specifications for the demonstration home were developed by the project team in conjunction with project advisors and Commission staff.

4.4 Materials and Installation Practices

Table 4 provides information on the materials and installation practices for the Clarum Homes Demonstration Home. Housewrap selected for the demonstration home was DuPont Tyvek® StuccoWrap™ (5 foot roll) and DrainWrap™ (9 foot roll). This allowed comparison of installation experience with the other demonstration homes in Southern California, as well as with Clarum's standard construction materials and practices. Window flashing was Dupont™ FlexWrap™ and StraightFlash™. Window installation followed ASTM E 2112-01R Method A1. Caulking with backer rods was planned for installation around all windows, but was not installed due to builder preference. Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals.

USG HUMITEK™ mold-resistant gypsum panels were installed in the utility room and bathrooms. USG Fiberock® gypsum panels were installed in bath and shower areas.

Broan-Nutone LLC Model QTXE080FL continuous duty low sone fan/light controlled by Tamarack Humitrak™ AS dehumidistat were installed in both bathrooms and the laundry room. This strategy automatically operates the exhaust fan whenever humidity conditions exceed the setpoint. The incremental cost of this technology was evaluated and homeowner acceptance will be evaluated by the participating builder.

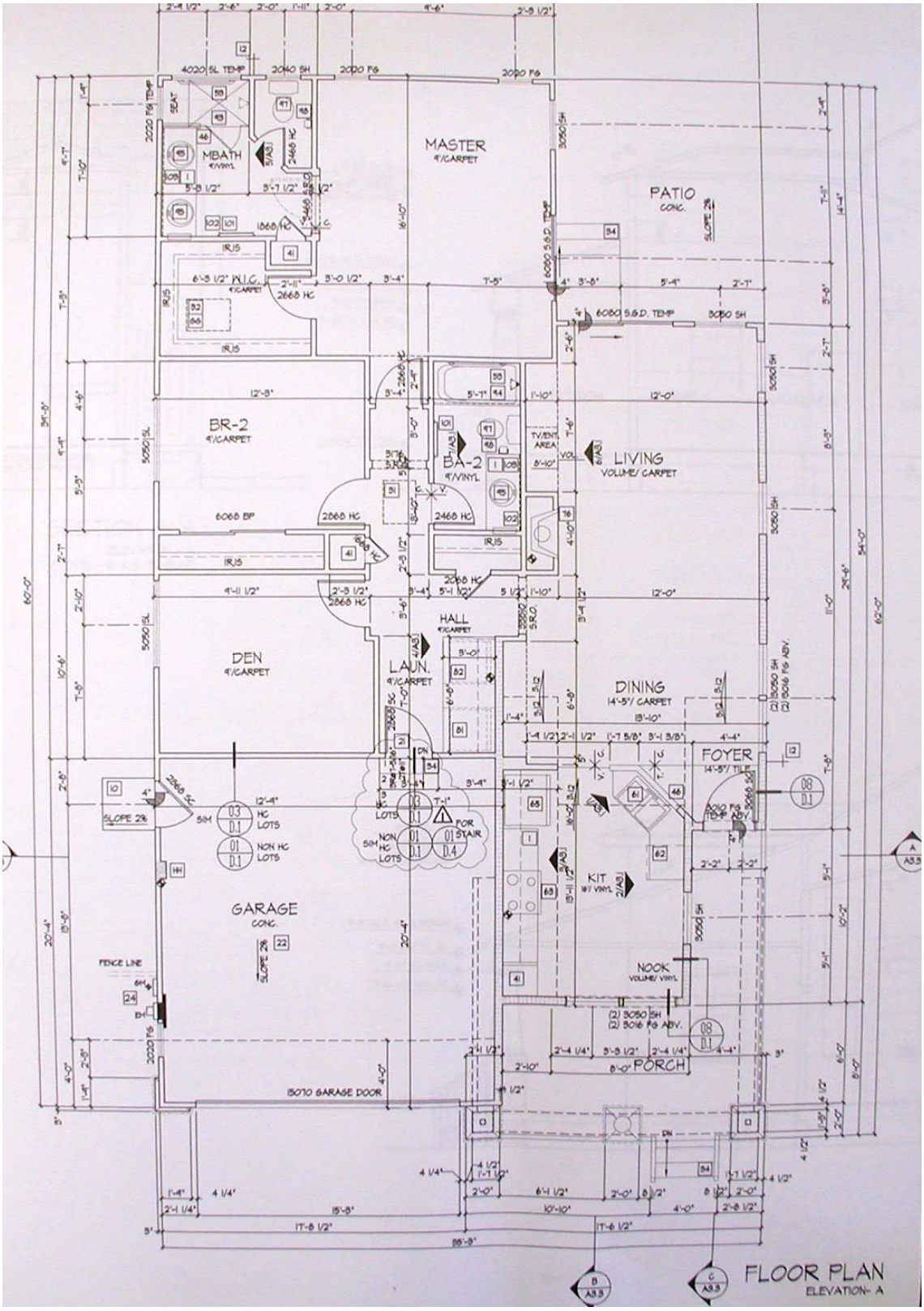


Figure 82 Clarum Demonstration Home Floor Plan

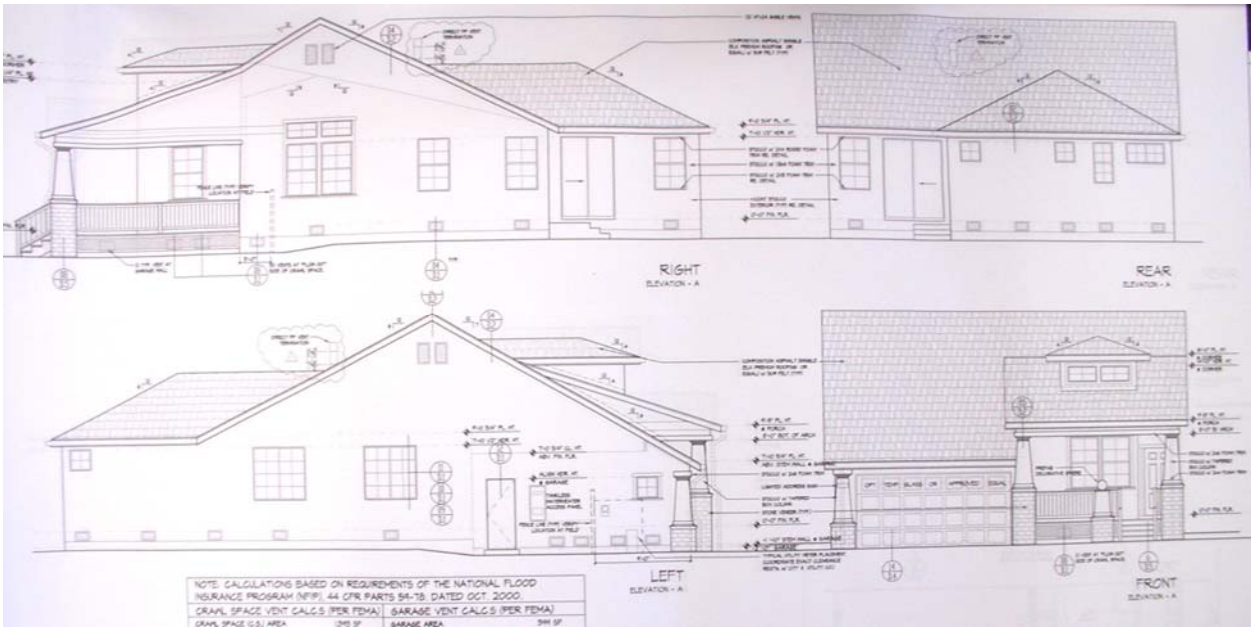


Figure 83 Clarum Demonstration Home Elevations

Figure 84 Clarum Demonstration Home Open Frame Construction

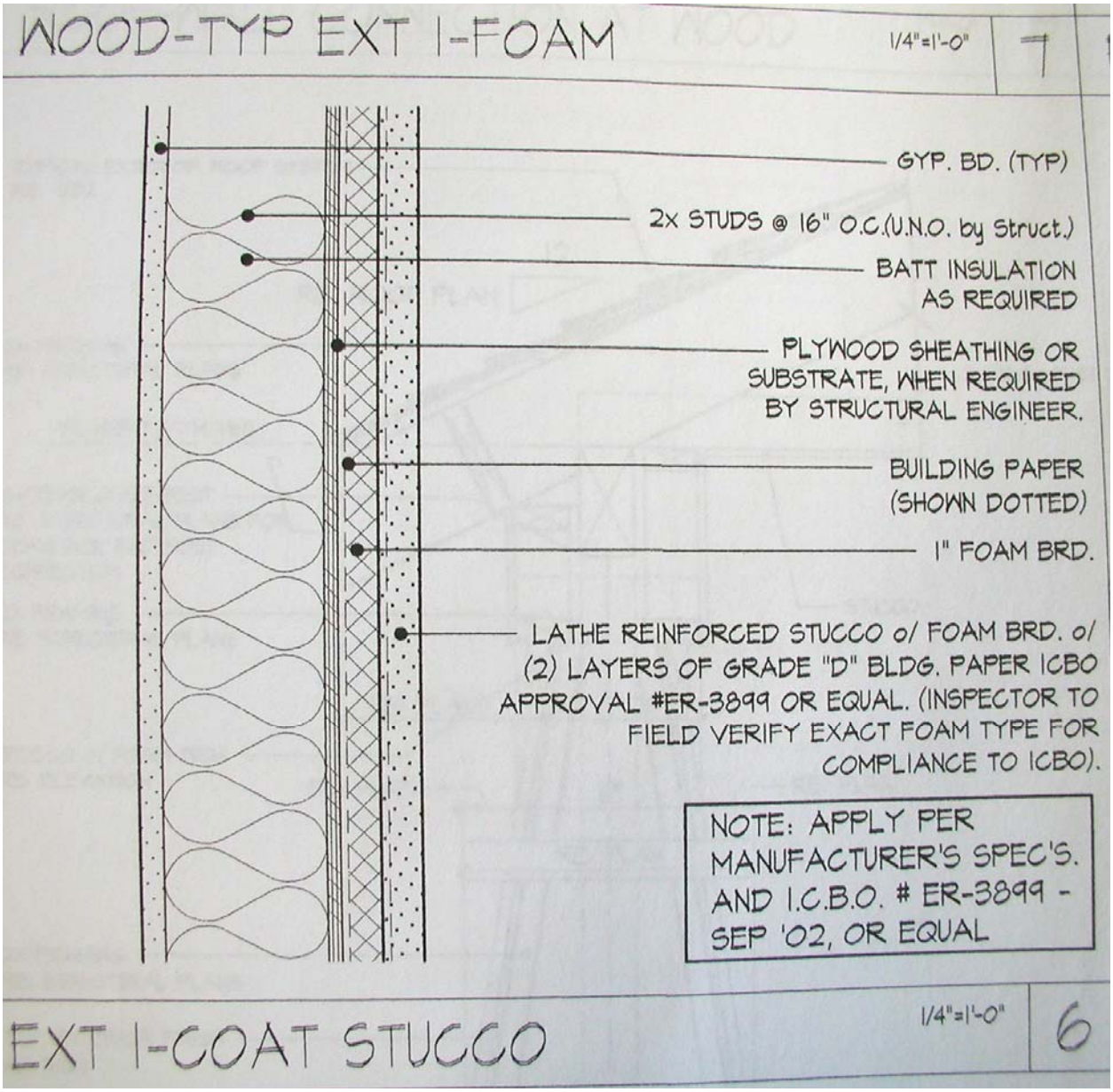


Figure 85 Insulated One-Coat Stucco Wall Detail

Table 4 Clarum Demonstration Home Materials and Contacts

Supplier	Product/Service	Contacts
Broan-Nutone LLC	Continuous Duty Bath Fan/Lights	Terry Pond, Kevin Morris
Dow Chemical	Foam Sealant	Bob Braun
DuPont Nonwovens	Housewrap, Tape, Flashing	Marc Silveira
Tamarack Technologies, Inc.	Ventilation Fan Controllers	Paul Raymer
USG	Mold-Resistant Gypsum Panels	Paul Shipp

4.5 Installation

Housewrap and self-adhering window flashing were installed on October 11-12, 2005. Fan/lights and mold-resistant gypsum panels were installed during December 2005.

4.5.1 Water-Resistive Barrier Construction Sequence

The stucco contractor installed housewrap using a three-person crew (Figure 86). After installing weep screeds, nine foot high DrainWrap™ rolls were wrapped around the perimeter of the house, including over window openings (Figure 87). Trim pieces were applied to posts, eaves, and other envelope features (Figure 88). The stucco contractor used staples rather than capped nails to fasten the housewraps to reduce labor content and cost. All seams were overlapped at least 9" and taped (Figure 89).

4.5.2 Window Installation Method

The window installation contractor installed all window flashing and windows. ASTM E 2112-01R Method A1 protocols (Figure 90)were followed (windows installed after housewrap), using Dupont™ FlexWrap™ flexible self-adhering sill flashing (Figure 91), with ¼" flanged vinyl backer rod beneath the length of flashing on the sill at the interior side of the window frame to create a backdam (Figure 92). The vinyl was flexible enough to compress when the windows were installed. The interior sides of window head and jamb flanges were fully caulked (Figure 93). Window sill flanges were not caulked. This design was intended to allow any water collected by the sill flashing to drain back outdoors. Exterior sides of window flanges were not caulked. Instead, jamb and head flashing was Dupont™ StraightFlash™ self-adhering flashing (Figure 94). Prior to application of interior window treatments, Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals as an air barrier. The goal was to reduce air pressure differential across the window and minimize the risk of leaks due to wind-driven rain.

4.5.3 Mold-Resistant Gypsum Panels

USG HUMITEK™ mold-resistant gypsum panels were installed in all walls with plumbing chases in the utility room and bathrooms. USG Fiberock® gypsum panels were installed behind bathtubs and showers instead of greenboard. Incremental cost of these products was about $20 per bathroom. No incremental labor content was required for either material.

4.5.4 Bath Fan and Controls

Broan-Nutone LLC QTXE080FL continuous duty low sone fan/lights controlled by a Tamarack Humitrak™ AS dehumidistat were installed in in both bathrooms and the laundry room. The list price of the QTXE080FL fan/light is $278. The Humitrak™ AS dehumidistat costs about $140. Incremental labor content for the controllers in a normal installation would be minimal, as the controllers would replace the conventional on-off switch. However, in these homes, the controllers were installed in parallel with the on-off switch to enable the homeowner to manually operate the fan/light independent of the controller.

Figure 86 Housewrap Application with 3-Person Crew

Figure 87 Housewrap Continuous Sheet Rolled over Windows

Figure 88 Housewrap Trim Pieces Applied to Garage Wall

Figure 89 All Housewrap Seams Taped

Figure 90 Window Installation, ASTM E 2112-01R Method A1

Figure 91 Self-Adhering Flexible Sill Flashing Installation

Figure 92 ¼" Flanged Vinyl Backdam Stapled to Sill

Figure 93 Window Head and Jamb Flanges Caulked

Figure 94 Jamb and Head Flashing

4.6 Observations

4.6.1 Water-Resistive Barrier Construction Sequence

Experience with housewrap in this demonstration home was similar to that at the John Laing Inland Division homes. Open frame construction posed additional challenges for tape seals with textured housewrap (Figure 95). While taped seals are not considered critical elements of the WRB at seams or shingle-lapped penetrations, there may be some impact on air retarder performance. The only locations that require tape to seal fully for WRB functionality are at the v-cut joint extending beyond the head flashing (Figure 96). The risk of leaks through this cut should be minimal, but are worth consideration. Additional protection at this cut can be provided by shingle-lapping a second piece of tape along the seam.

Clarum remains open to discussions about housewraps based on the potential for further energy efficiency and durability, but at this time they intend to continue using double ply building paper for future developments with insulated one-coat stucco cladding.

4.6.2 Window Installation Method

Experience with window flashing in this demonstration home was similar to that at the John Laing Inland Division homes with identical flashing. An improved flanged vinyl backdam (versus backer rod) for this installation facilitated stapling to the sill. Reveals were adequate to accommodate the backdam, but reduced clearances for the foam sealant (Figure 97). The flashing material was able to withstand the leveling tool used by the window installer without damage (Figure 98). For sill pan installations, the contractor would have to use a different leveling method to avoid interference with the sill pan backdam.

Clarum is currently evaluating these flashing and installation approaches as a part of their quality and risk management strategy and may consider them in future developments.

4.6.3 Mold-Resistant Gypsum Panels

Installation of mold-resistant gypsum panels went smoothly and did not impact the production schedule. The incremental cost of the materials was the only significant difference. Clarum remains interested in pursuing this technology option for appropriate situations, and will evaluate both materials as a part of their risk management strategy for future developments.

4.6.4 Bath Fan and Controls

Installation of bath fan/lights and controls went smoothly and did not impact the production schedule. Clarum perceives the relative humidity controller to be a solution to a laundry area humidity control issue, and plans to provide future feedback on the value they attach to this feature.

Figure 95 Poor Tape Adhesion in Open Frame Construction

Figure 96 Tape Seal at V-Cut above Head Flashing

Figure 97 Reduced Sill Reveal with Backdam

Figure 98 Good Compatibility Between Flexible Sill Flashing Backdam and Leveling Tool

4.7 Long Term Data Acquisition

The automated DAS is a Campbell Scientific CR10X datalogger with 64 channel MUX, punchdown blocks, power supply, and wireless modem. Sensors include temperature, relative humidity, moisture content, and wood temperature under one window on each side of the home (Figures 99 through 101). Outdoor air temperature and relative humidity are also being monitored.

The DAS wiring was installed on October 12-13, 2005. Final DAS hookup is contingent on electricity connection and is scheduled for the second week of March 2006. Long term monitoring for this home is planned throughout 2006.

Figure 99 Moisture Sensors in North and West Wall Cavities Below Windows

Figure 100 Moisture Sensors in West Bedroom Wall Cavity

Figure 101 Moisture Sensors in South Wall Cavity

5.0 Conclusions and Research Recommendations

5.1 Conclusions

The demonstration home planning, construction, and monitoring tasks met all project goals and successfully implemented nearly all recommended assemblies and construction practices. Implemented items included WRB's, window installation methods, mold-resistant sealer and gypsum panels, exhaust ventilation control strategies, and moisture-resistant concrete slab installation methods and materials. Recommendations not implemented included caulk and backer rod around penetrations (builder choice), plastic sill pans (compatibility with windows), and recessed concrete slab seats in door sills (schedule and coordination with concrete contractor). Construction drying service demonstration was delayed due to the unusually dry winter in Southern California.

Voluntary builder and manufacturer commitment, cooperation, and input were critical to the success of the demonstration homes tasks. Unwaivering support from the participating builders' executives throughout this project provided necessary authority and legitimacy when interacting with purchasing staff, field superintendents, contractors, designers, building science consultants, participating manufacturers, and customer service representatives.

Participating manufacturer involvement and support provided by product experts in each company enhanced the project credibility with the participating builders and provided the opportunity for real-time feedback and resolution as the inevitable design and field installation issues arose. Key manufacturer support (all non-contractual and fully funded by the manufacturers) included materials and installation procedures, building science expertise and networking contacts, installation supervision, and project feedback. All participants viewed this project as important to their stakeholder interests.

Builder and manufacturer feedback to date indicates mutually beneficial value from their participation. Acknowledged benefits from participation included:

- Education about theoretical benefits and real-world application of techniques and materials that are intended to reduce the risk of mold formation and growth.
- Reinforcement of market value of current high quality practices.
- Increased awareness of key building science issues and impacts on mold risk.
- Implementation of recommendations in future developments based on demonstrated results.
    - ASTM E 2112-01R window installation design details
    - Self-adhering flashing
    - Low noise energy efficient fan/lights coupled with RH sensors
    - Class A vapor retarder under slabs
    - New slab designs to avoid interior grade beams
    - Recessed concrete seats in door sills
    - Consideration of mold-resistant treatments and materials
    - Consideration of construction drying services
    - Increased attention to wall assembly installation quality, especially at all penetrations
- Identification of issues with WRB installation procedures and sequence for stucco cladding when striving for theoretically optimal performance.

Based on project results, builders and participating manufacturers have expressed willingness to participate in future demonstrations.

5.2 Research Recommendations

Task 4 demonstration home results corroborated research needs identified during the Task 2 situation analysis and Task 3 laboratory evaluations. Research recommendations based on cumulative project results focus on three major initiatives:

1. Expand field demonstration and monitoring of materials and methods with acknowledged energy efficiency, risk reduction, and performance benefits selected for full-scale implementation or further evaluation by builders under this project;
2. Develop and evaluate laboratory and field performance test methods for wall penetrations integrated with cladding and wall assemblies; and
3. Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for window/wall interfaces.

Recommended field demonstration and monitoring efforts include:

- Continue long term slab and moisture data acquisition initiated under this project.
- Expand field demonstration and monitoring of ACI 302.1-04R concrete slab installation methods and materials throughout California.
    - Alternative interior grade beam designs
    - Exterior footing vapor retarder and waterproofing application solutions
    - Optimized concrete mix strategies
    - Additional climatic conditions
    - Additional soil conditions
- Collect comprehensive field data on window flashing and WRB performance and energy impact with stucco cladding throughout California.
    - Alternative WRB options and installation sequences
    - Sill pan flashing designs integrated with window installation methods and two-ply and two-layer WRB design options
        - window and stool compatibility
        - backdam designs
        - foam sealant air barrier effect
        - interior reveal designs to integrate air barrier with WRB
- Evaluate mold-resistant sealer and gypsum panel cost and efficacy over time as a part of a comprehensive mold risk reduction strategy.

The ASTM E 2112 standard committee recently formed a working group to explore options on fenestration installation performance test methods. Public and private stakeholder involvement in this process is strongly encouraged. Collaborative research efforts to evaluate candidate methods in laboratories and in the field are recommended.

The root cause field data collection and analysis program comprises a data collection effort involving laboratory experiments, laboratory house data collection and analysis, and targeted new homes representing a full cross section of California construction and climate zones. The overall goal is to link moisture parameters with appropriate home construction parameters to enable authoritative root cause analysis of moisture and mold problems.