DRAFT

Draft Final Report for Project Entitled:

Impact of Spray Foam Insulation on Durability of Plywood and OSB Roof Decks

Performance Period: 1/6/2014 – 6/15/2014

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Presented to the

Florida Building Commission
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by

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1 EXECUTIVE SUMMARY

This is a draft final report. The final version will be submitted prior to the end of the project performance period after the Roofing Technical Advisory Committee (TAC) provides feedback.

The project goal is to prepare a state-of the art review of the literature on wood roof decks insulated with spray-applied foam, experimentally evaluate the relative drying characteristics of wood roof deck configurations and to inspect existing Florida homes with installed spray-foam insulated roof decks.

The March 20, 2015 interim report presented a comprehensive review of literature pertaining to spray foam installation and moisture issues comprising over 85 peer-reviewed papers and reports (http://bit.ly/1Skdele). The formation of the Advisory Panel and draft Experimental Research Plans (ERPs) were presented to the Roofing Technical Advisory Committee. As of June 15, Experimental Research Plans (ERP) 1, 2, and 3a have been completed, and ERP 3b and ERP 4 are scheduled to be complete by June 25th and results will be presented to the TAC at that time. This report presents the results and analysis of all ERPs. This report will be appended as ERP 3B and 4 are completed.

In the scope of work in ERP 2, the research team surveyed the roofs of two Orlando, FL homes that have closed cell spray foam installed. Measurements revealed both roof decks had low moisture content values of less than 6%. The attic temperatures were approximately 30 degrees cooler, and asphalt shingle temperature 21 degrees warmer than in another house that did not have spray foam insulation. The team noted unlike the roofs brought to our attention experienced water leaks and sheathing damage, these roofs were geometrically simple shapes, without roof dormers, penetrations or other irregularities.

From ERP 3 experimental testing results showed that roofing samples made with closed cell foam insulation dried more slowly than samples having open cell foam insulation or no insulation. There was little difference between drying rate of the open cell foam insulation samples and samples with no insulation installed. Among the choices of roofing underlayment samples with self-adhered membrane underlayment exhibited the slowest drying rate. There was no significant difference in sample drying rates for samples having 1-ply versus 2-ply 30# asphaltic felt underlayments.

One surprising observation in our ERP 3b (Point-source water leakage tests), was that oriented strand board (OSB) sheathing retained much higher moisture levels than did the plywood sheathing. Additionally, the self-adhered membrane underlayment was not as effective at restricting the spread of moisture travel throughout the sheathing specimens.

Major Recommendations and Future Work

- The drying rates of plywood and OSB deserve further study particularly in relation to values used in hygrothermal analyses (WUFI 5.0 etc.). Generally numerical analysis software use similar draying rates for OSB and plywood roof sheathing. However our experimental testing shows that plywood tends to have lower moisture contents over prolonged exposures to a leak. Further research is needed to determine whether recommendations for specific sheathing types are warranted in the Florida Building Code.

- Despite efforts of the research team and its Advisory Panel members only three examples of water related deterioration in SPF insulated roofs were found, and none of these cases were provided in form of engineering (forensic) reports with through investigative procedures. As such, the research team lacks sufficient evidence of widespread and systemic failures of spray foam insulated wood roof decks to conclude that premature deterioration of wood roof decks insulated with spray foam insulation is a problem in Florida. Continued efforts are needed to identify other cases of moisture deterioration in SPF roofs and perform forensic analysis to ascertain the primary causes of the deterioration. The findings of this research would guide the Florida Building Commission in deciding whether to address moisture issues with SPF roofs in more detail in the building code.
- In two of the three homes where water was discovered at the interface between wood roof decks and spray insulation, the severely deteriorated sheathing was adjacent to roof dormers with window and wall flashing details, which may have failed and provided a passage for water to enter the roof system. The extensive deterioration suggests, high volume of water leakage occurred for extended periods. The research team recommends that non-destructive test procedures be developed to detect water leakage in roofing having spray foam insulation. It is obvious that owners should be made aware of the risks of long-term, undetected water leaks and effective methods to mitigate this risk through regular maintenance. The effectiveness of non-destructive leak detection methods would be critical in determining the extent to which the Florida Building Commission addresses leakage in unvented attics. If the methods are effective, then recommendations could be made for homeowners to incorporate such methods as part of their regular maintenance of SPF-insulated roofs.

Proposed research for the 2015-2016 fiscal year

The following proposed topics submitted for consideration will advance the project goals and answer additional questions that were raised during the completion of the 2014-1015 fiscal year project.

- Survey the construction industry to poll their experience with spray foam insulated roof decks. Perform a thorough survey among roof contractors, foam installers and manufacturers to estimate of the number of unvented attics using spray foam insulation within the State of Florida and conduct inspections on a limited sample of these installations. Such a survey would provide a baseline to evaluate the potential severity/extent of water-related wood deck deterioration problem. The root causes of any failures observed would need to be established to determine the magnitude of the issue.

- A natural extension of the work initiated in ERP 3a and 3b would be to repeat the drying rate test sequences but instead of maintaining constant high temperature and constant relative humidity, subject roofing to normal diurnal changes in temperature and humidity. In this case, the underside conditions would be held constant to simulate typical “attic” temperature/humidity fluctuations, as recorded by the data loggers installed in the Orlando homes (ERP 2).

- A further extension of ERP 3a and 3b would be to consider multiple cycles of wetting and drying. As discussed in the literature review, the permeance of wood sheathing materials, particularly OSB, changes with repeated wetting and drying cycles, but this effect is not considered in the current numerical studies of moisture effects on unvented wood roofs. This research would settle whether OSB or plywood is a preferred sheathing option for SPF roofs.
- Develop and evaluate non-destructive methods of moisture detection of wood roof decks insulated with spray foam insulation, including techniques such as infrared thermal imaging, and water leak detector paper.
- Evaluate the effect of dual thermal insulation barriers at the ceiling and roof deck levels on moisture and air quality in the living and attic spaces. When SPF insulations are installed as retrofit options, ceiling insulation may be left in place. Few studies in the literature have presented analysis of this condition, whether the attic space is a conditioned, semi-conditioned or unconditioned space. The airflow exchange between attic and living space may be lower than found in unvented roofs, exacerbating the moisture or air quality concerns. This configuration needs further research so that homeowners and contractors can be guided as to the best approach.

DISCLAIMER

This report presents the findings of research performed by the University of Florida. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors, partners and contributors. The Energy Technical Advisory Committee of the Florida Building Commission will provide a final disposition on the implications for the Florida Building Code.

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- R806.4 – Florida Building Code – Residential Buildings
- 611.7.1.2 – Florida Building Code – Existing Building
- 606.3 – Florida Building Code – Existing Building
- TAS 110 Testing Application Standard – Florida Building Code
- ICC-ES AC 377 – Acceptance Criteria for Spray Polyurethane Foam
- ASTM C1029 - Specification for Spray-Applied Rigid Cellular Polyurethane Thermal Insulation

3 Statement of Work

- Form a Working Advisory Panel that consists of all stakeholders; Spray foam manufacturers, wood product manufacturers, roofing and general contractors, installers and consulting engineers (structural and mechanical) and homeowners. Advisory Panel will review and approve Experimental Research Plans before implementation.
- Solicit from the Advisory Panel and from the public domain all available literature and conduct a state-of-the-art review on the properties and field performance of spray applied foam insulations (open cell and closed cell foams), and related causes of water leakage and deterioration of wood roof decks.
- Develop experimental research plans for the a) inspection of existing houses and b) experimental testing of wood roof deck configurations to determine relative drying characteristics of the systems.
    - Design and fabricate a device to measure the comparative evaporation rates through roof cross-sections. Conduct testing to evaluate and compare the drying rates of traditional roofs, against roofs insulated with spray-applied foam insulation of various permeabilities. This first phase proof of concept (controlled temperature and humidity) is advisable before more extensive comparison.
    - Survey the roof constructions having installed SPF insulations to evaluate the relative moisture content in the wood sheathing and SPF layers. Conduct interviews with the homeowner/occupant as to the comfort and thermal efficiency and risk perception of the installations. Install temperature and humidity data loggers in the roof attics to provide long-term record of temperature fluctuations adjacent to the installed SPF insulation in the roof.
    - Conduct numerical hygrothermal model of two representative wood roof systems with installed SPF insulation to compare with physical data from the test homes.
- Interpret results, and determine if any Code changes are warranted.
- Recommend follow-up testing if necessary to evaluate the impact of moisture from within the attic space and/or conditioned space within the house.
- Produce a report that explains the results and implications for the Code. It is the intention that this report will also serve the dual-purpose of a draft manuscript to be prepared for peer-review and possible publication by an appropriate engineering journal (e.g. Building and Environment), to enable wider review and comment by the industry.

4 Deliverables

- An interim report will be provided by February 15, 2015 that details the current status and progress toward completing the work described above. In addition, the Interim report will be presented to the Commission's Energy Technical Advisory Committee at a time agreed to by the Contractor and Department's Project Manager.

- A final report providing a state of the art literature review and conclusions, including technical information on the problem background, results of tests and analysis and implications to the FL Building Code will be submitted to the Program Manager by June 15, 2015. In addition, the final report will be presented to the Commission’s Energy Technical Advisory Committee at a time agreed to by the Contractor and Department’s Project Manager.
- Recommendation(s) that may require revision to future edition of the FBC will be analyzed using the criteria outlined in the currently adopted code modification form.

5 Introduction

5.1 Motivation

The practice of spraying foam to the underside of a roof deck has a 20-30 year history with no recorded widespread systemic failures issues. However, there have been cases reported in the media of water damage and deterioration of wood roof decks that have been insulated with spray-applied foam insulation. As a result, construction industry professionals have expressed concern that an unidentified problem exists. Spray foam prevents thorough inspection of the underside of the roof deck and it may also slow or prevent the evaporation of water that leaks into the roof deck. Despite those limited concerns, spray foam insulations have been used with increasing frequency in Florida residential constructions in both new and existing residential buildings, as thermal insulation, as well as a structural adhesive and secondary water barrier. Some known facts of the performance of spray-foam insulated wood decks are given below:

- Premature deterioration of wood roof decks (plywood and oriented strand board sheathing) occurs as a consequence of long-term, high moisture load in the wood. Impermeable layers may contribute to this drying potential issue in the roof system.

- Moisture as liquid or moisture vapor may enter the wood either from above (through defects in the roof cover or flashing) of from the underside (by diffusion of moisture vapor from the air in the attic or occupied space).

- Spray foam insulations can create a barrier that reduces the drying rates of wood roof decks, which may result in an unfavorable buildup of moisture in the wood. Different insulation formulations may have differing effects on wood drying rates and moisture retention.

Damage investigations of spray foam-insulated wood roof decks in Florida have found instances where deterioration of a wood deck has occurred due to water intrusion. The role that spray foam insulation may have played is subject of conjecture and some studies in the general literature; http://bit.ly/1tqMi9y; Holladay (2014) “Open Cell Spray Foam and Damp Roof Sheathing” and http://bit.ly/1tqJN7f; Bailes (2014) “Will Open-Cell Spray Foam Insulation Really Rot Your Roof?” These documents referred to hygrothermal studies conducted by Oakridge National Laboratories showing moisture-safe unvented roofs can be constructed within every US climate zone. Further, studies concluded there is negligible risk of developing mold within the attic space, assuming an airtight roofing system. The Oakridge studies were conducted assuming a controlled leakage rate up to a maximum 1% of the annual rainfall volume.

Test reports and studies have documented several beneficial properties of using SPF insulation in the hot humid Florida climate. In addition to thermal insulation, some spray foam insulations are used a secondary water barriers and as a structural retrofit. Closed-cell spray foam insulation can substantially improve wind uplift resistance to wood roofs, Prevatt et al. (2010) http://bit.ly/1qasUsl. The UF testing did identify under abnormally high water leakage that water was retained by the wood sheathing that had closed cell spray foam onto it. The wind uplift resistance was not significantly affected Prevatt et al. (2014) http://bit.ly/1pwoj21.

- The FBC 2013 Product Approvals include spray-applied foams for use below wood roof decks from five manufacturers. The products are approved as a secondary water barrier, thermal insulation and/or as structural adhesives for wind uplift retrofits in residential construction.

5.2 Scope of Work

The original scope of work is listed below:

1) An interim report will be provided by February 15, 2015 that details the current status and progress toward completing the work described above. In addition, the Interim report will be presented to the Commission's Energy Technical Advisory Committee at a time agreed to by the Contractor and Department's Project Manager.
2) A report providing a state of the art literature review and conclusions, including technical information on the problem background, results of tests and analysis and implications to the FL Building Code will be submitted to the Program Manager by June 1, 2015. In addition, the final report will be presented to the Commission's Energy Technical Advisory Committee at a time agreed to by the Contractor and Department's Project Manager
3) Recommendation(s) that may require revision to future edition of the FBC will be analyzed using the criteria outlined in the currently adopted code modification form.
4) A breakdown of the number of hours or partial hours, in increments of fifteen (15) minutes, of work performed and a brief description of the work performed. The Contractor agrees to provide any additional documentation requested by the Department to satisfy audit requirements.

5.3 Definitions

To avoid confusion, it is important to clearly define some specific terms related to the classification of roof assemblies.

<u>Conditioned Space</u> – The part of the building that is designed to be thermally conditioned (heated or cooled), either for the comfort of occupants or for other reasons such as preserving temperature-sensitive goods.

<u>Unconditioned Space</u> – A space that is neither directly nor indirectly conditioned space, which can be isolated from conditioned space by partitions and/or closeable doors.

<u>Unvented Cathedralized Attic</u> – A structure that provides the same flat attic floor that is characteristic of a conventional attic, however, the underside of the roof deck and the inside of the gables are insulated and the attic space is never vented. Sometimes this configuration is simply referred to by the more broad term of "unvented attic".

<u>Unvented Cathedralized Ceiling</u> – A ceiling configuration in which the underside of the roof deck is insulated and also forms the ceiling of the conditioned space. In this configuration there is no attic space and no venting.

<u>Vented Attic</u> – An attic designed to allow airflow in and through the attic space. In vented attics, typically the air, vapor and thermal controls are installed at the ceiling level. Vents at the eaves, ridge and even along the slope of the roof deck provide the means of air infiltration and exfiltration.

These attic configurations are illustrated in Figure 1.

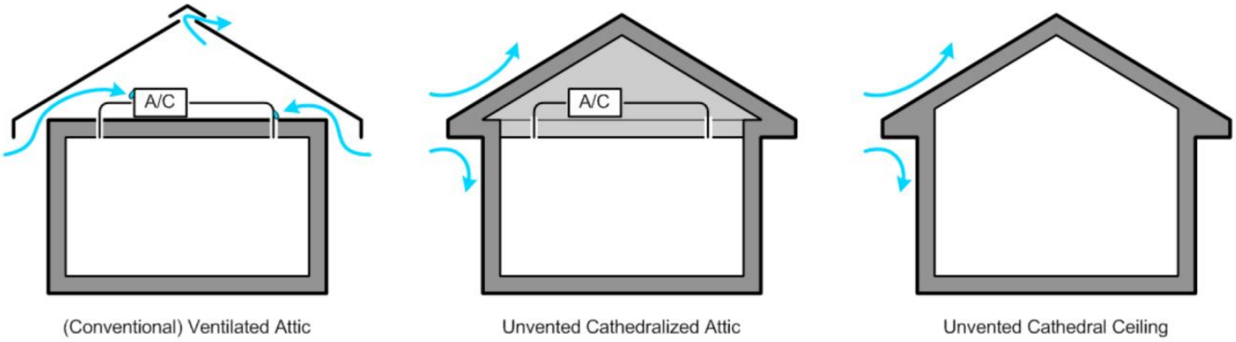


Figure 1: Illustration of common attic assemblies with different venting configurations. Illustration from Schumaker (2007).

6 Experimental Research Plan 1: Forming of Advisory Panel

An Advisory Panel of experts, researchers and construction professionals was convened to advise the Research Team and to help identify information for the Literature Review. Panel members came from Trade Associations representing roofing installers, engineering wood materials, and manufacturers of roofing underlayment and of spray-applied foam insulation products, in additional to contractors and consulting engineers (structural and mechanical). Invitations were extended to researchers in Florida and elsewhere who have worked on unvented attics and spray foam insulation issues in the past.

The input of the Advisory Panel was invaluable to present the latest information from their respective organizations, as well as to vet the experimental research plans developed by the Research Team. The compositions of the Advisory Panel is listed as follows:

NAME	Company	Representing
David Brandon	Brandon Construction	custom building, general contractor
John Broniek	Icynene	spray foam manufacturer
Paul Coats	American Wood Council	wood products representative
Bill Coulbourne	Applied Technology Council	engineering resources publisher
Rick Duncan, PhD	SFPA	spray polyurethane foam alliance
Mike Ennis	SPRI	single ply roofing institute
Mike Fischer	Dir. Codes & Regulatory Affairs, Kellen	asphalt roofing manufacturers
Jaime Gascon	Miami/Dade Building Office	building code official
Jason Hoerter	NCFI	spray foam manufacturer
Yuh Chin T. Huang, MD, MHS	Pulmonary Medicine Specialist	Duke University Medical Center
Scott Kriner	Metal Construction Association	Metal roofing association
Joseph Lstiburek, PhD	Building Science Corporation	building envelope consultant
Mo Mandani	Florida Building Commission	
Sean O’Brien	Simpson Gumpertz & Heger Inc.	building envelope consultants
Rick Olson	Tile Roofing Institute	producers clay & concrete tile roofing
Marcin Pazera, PhD	Owens Corning	Asphalt shingle roofing
Mike Petty	Icynene	spray foam manufacturer
Tim Reinhold, PhD	IBHS	insurance association
David Roodvoets,	Building Envelope Consultant	
Arlene Stewart	Consultant	Florida Homebuilders Association
Todd Wishneski	BASF	spray foam manufacturer
BJ Yeh, PhD	Engineered Wood Association/APA	Engineered wood industry
Mark Zehnal	Florida Roofing & Sheet Metal Contractors	Roofing professionals association

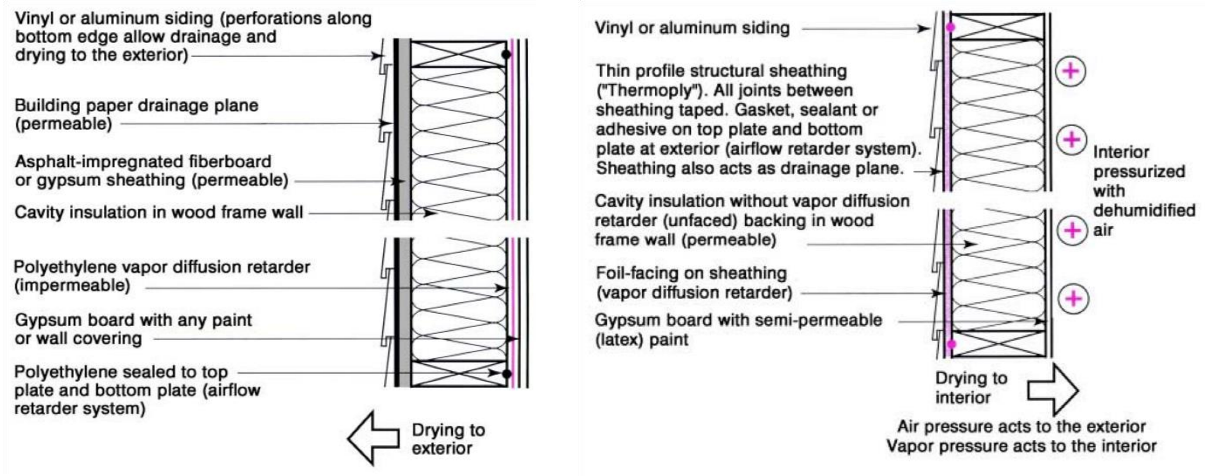
The Advisory Panel met twice during the project, once in Orlando, FL for the first in-person meeting in 21/22 January 2015 and again by teleconference on 12 February 2015. The minutes are attached in the Appendix B.

7 Literature Review

The primary purpose of the building envelope is to protect the occupants of the building from adverse elements. This includes providing a comfortable interior environment in which conditioned air is kept inside, and moisture and ambient air is prevented from entering, all while maintaining high air quality. Achieving this requires a thorough understanding of moisture and air transport between the interior and exterior spaces, which occurs through the various building materials we typically use to construct our buildings. While there is no single, exclusive methodology for the design and construction of a proper building envelope, there are some general rules for ensuring proper building envelope performance, which are summarized below from Trechsel et al (2001) and illustrated further in Figure 2:

- Install a vapor retarder on the inside of the insulation in cold climates,
- Install a vapor retarder on the outside of the insulation in warm climates,
- Prevent or reduce air infiltration,
- Prevent or reduce rainwater leakage, and
- Pressurize or depressurize the building so as to prevent warm, moist air from entering the building envelope.

While these general rules provide basic guidelines that are appropriate for most circumstances, they do not address all of the complexities associated with building envelope design. One particular design choice that has generated a significant amount of research and discussion is the choice of a vented or unvented attic space. Traditional wood-framed pitched roofs have been constructed with fibrous batt insulation at the ceiling plane, with a large volume above this insulation, typically referred to as the attic, well ventilated to the exterior air. However in a move towards more energy efficient building envelope designs, there is a growing trend towards insulating the sloped roof plane rather than the ceiling plane. This design results in the entire building volume being insulated, which can increase the energy efficiency of the building envelope by allowing the attic to contain HVAC systems, duct distribution, and also add conditioned living or storage space. However the lack of ventilation in these roof assemblies limits the capability of the roof system to transport infiltrating moisture, whether from interior or exterior sources, away from components of the roof that are susceptible to decay, rot or fungus growth with prolonged exposure to elevated moisture levels.



- Vapor diffusion retarder to the interior
- Airflow retarder to the interior
- Permeable exterior sheathing and permeable building paper drainage plane
- Ventilation provides air change (dilution) and also limits the interior moisture levels.

- Vapor diffusion retarder to the exterior
- Airflow retarder to the exterior
- Pressurization of conditioned space
- Impermeable exterior sheathing also acts as drainage plane
- Permeable interior wall finish
- Interior conditioned space is maintained at a slight positive air pressure with respect to the exterior to limit infiltration of exterior, hot, humid air
- Air conditioning also provides dehumidification (moisture removal) from interior

Figure 2: Classic wall assemblies for cold climates (left) and hot-humid climates (right) from Lstiburek (2002). The same principles mostly apply for roof assemblies.

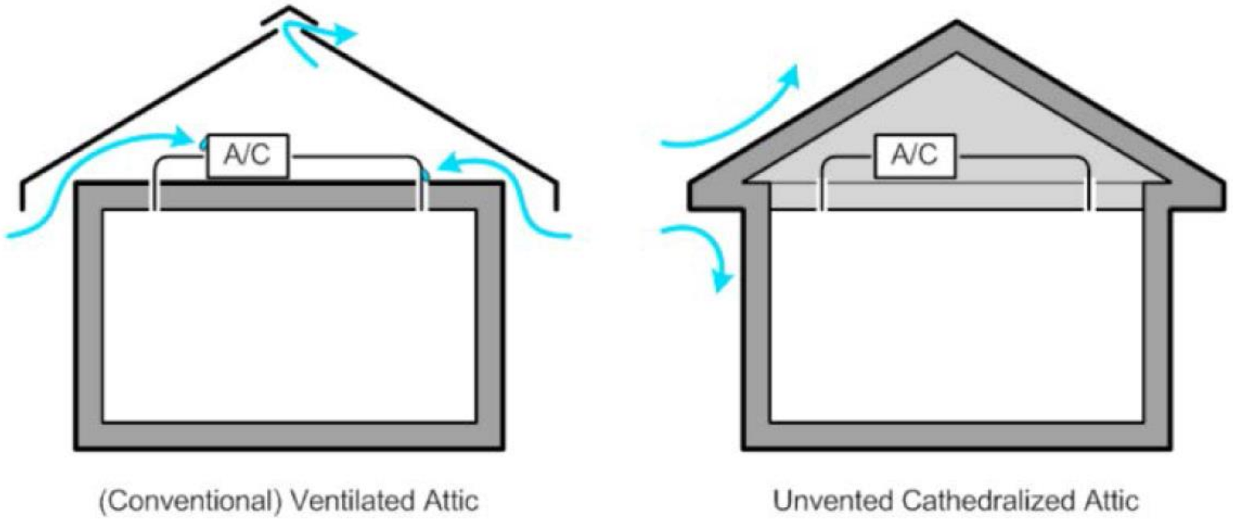
This chapter summarizes the current knowledge on unvented and vented attics, specifically related to moisture transport or lack thereof in roof systems with spray-applied polyurethane foams. Section 1 briefly summarizes vented and unvented roof assemblies. Section 2 describes spray-applied polyurethane foams and their use in unvented attics. Section 3 summarizes the implications of moisture in wood materials. Section 4 describes and contextualizes recent research into moisture issues in vented and unvented attics. Section 5 summarizes additional research relevant to vented or unvented attics, spray foams or moisture transport in wood and wood composite materials.

7.1 Vented and Unvented Attics

A vented attic is one in which there are means for consistent air flow through the attic space, typically by allowing air to flow in through the soffits and exit through ridge or gable vents. In vented attics, air, vapor and thermal barriers are installed at the ceiling level.

An unvented attics is one where the air, vapor and thermal barriers are installed at the roof deck, causing the attic to become a conditioned space. No interior-to-exterior air flow is typically allowed through the attic space.

The two types of attics are illustrated in Figure 3. When the ceiling is installed directly to the roof slope framing, whether vented or unvented, the roof is further classified as a cathedral ceiling.



(Conventional) Ventilated Attic

Unvented Cathedralized Attic

Figure 3: Illustration of vented (conventional) and unvented or cathedral attics, from Grin et al (2010).

Hendron et al (2002) summarized the advantages and disadvantages of unvented attics, as reproduced here in Table 1. While there are distinct advantages to an unvented attic, these can be outweighed by the disadvantages if a systemic approach to the design of the complete building envelope is not utilized. For example, in an unvented attic any moisture in the roof plane has significantly less air volume to disperse into, which limits the capability of the wood framing and decking to dry. Therefore specific care must be taken to handle any moisture accumulation in the wood roof components.

Table 1: Potential advantages and disadvantages for unvented attics (Hendron et al. 2002)

Potential Advantages	Potential Disadvantages
• Milder environment for air ducts • Eliminates cost of installing vents • Semiconditioned storage area • Smaller latent load on air conditioner (humid climates only)	• Larger area for air leakage and heat gain/loss • Additional cost for insulation • More difficult to install insulation at roof plane compared to ceiling plane • Higher roof sheathing temperature • Higher shingle/tile temperature • Gas appliances (e.g., furnace, water heater) located in attic must be closed-combustion or be moved to garage.

7.2 Spray-applied Polyurethane Foams in Unvented Attics

Polyurethanes were originally developed in the late 1930s, and began to be used in a variety of applications, including spray applications, in the post-World War II 1950s. Polyurethane spray foams consists of two components, an A-side and a B-side, which must be mixed on site before being sprayed onto the desired surface. The A-side is typically a mixture of approximately 50% methylene diphenyl diisocyanate (MDI) and 50% polymeric methylene diphenyl diisocyanate (pMDI), two chemicals which are very reactive and therefore sensitive to improper mixing with water or other compounds. The B-side is a blowing agent, primarily low-conductivity gases or water, which boil from the heat of the exothermic reaction between it and the A-side chemicals. This causes bubbles to form, and the curing of such bubbles determines the density of the foam. Water-blown foams are typically low density, open cell foams. They are permeable to vapor transmission and are non-structural, but have high resistance to air flow. Foams with low-conductivity gasses as blowing agents, known as closed-cell foams, are typically much denser than open cell foams. Wu et al investigated structure-property correlations in polyurethane rigid foams based on effects of crosslink density, aromaticity, plasticizer and index. Specific focus was given to the effect of the glass transition temperature, which typically defines the limits of the service temperature, mechanical strength, stability and long term aging behavior. The study demonstrated the importance of proper mixing and processing on the properties of SPFs.

Due to their high resistance to airflow and high R-values, spray-applied polyurethane foams (SPFs) are commonly used in unvented attic applications. Closed cell spray-applied polyurethane foams (ccSPF) have further uses as structural components, Datin et al (2010), and secondary water barriers, Nelson and Der Ananian (2009), due to their denser composition and strong bond to most structural substrates. However questions have arisen as to whether the presence of SPFs on the underside of the roof decking will lead to elevated moisture contents and eventual rot and decay of the roof structure. This is particularly a concern for ccSPF, which indeed can be considered a secondary water barrier, Nelson and Der Ananian (2009). The value of a secondary water barrier is apparent during a severe weather event, where the presence of a secondary water barrier can prevent thousands of dollars in losses from moisture damage to interior contents. Over the lifetime of a structure however, the same properties that make ccSPF a suitable secondary water barrier can exacerbate moisture problems in wood roofs by limiting the drying potential of roof assemblies that have had moisture enter the wood roof system.

There is a large body of existing research on various aspects of ocSPF and ccSPF in wood attics. Moisture-related research is the focus of Section 4 of this chapter. Thermal and structural performance of SPFs is not the focus of this project, but it is useful to summarize a few such studies to demonstrate the potential benefits of SPFs.

Shreyans (2011) monitored the thermal performance of closed cell spray foam insulation (ccSPF) installed in the roof deck of a vented, 1970s home in Gainesville FL. It was shown that a 1 in. layer of ccSPF was sufficient to reduce mean temperatures in a ventilated attic from 124°F to 105°F. This attic temperature reduction also had positive benefits to energy consumption required for the cooling load in the home, with daily energy consumption being reduced by 26% after ccSPF was installed in the attic. No significant differences were noted in RH in the attic before and after the ccSPF installation, but this is somewhat expected since the attic remained ventilated even after the ccSPF installation. The results were able to be matched by simulations of the thermal performance using the WUFI Pro 4.2 hygrothermal model.

Datin et al (2010) evaluated the wind-uplift capacity of ccSPF-retrofitted wood roof structures and compared the results to standard construction methods using nails only. ccSPF was installed ether as fillets between the truss framing and roof sheathing or in continuous layers across the entire cavity between the top chord of the roof trusses and the roof sheathing. The results demonstrated that ccSPF retrofits increased the wind resistance of pre-1994, Florida code-minimum roof panels by as much as 300%. The findings suggest ccSPF is a strong retrofit choice for the more than 60% of existing residential inventory that may be susceptible to wind-uplift failures. Prevatt et al (2014) followed up on this study by investigating the wind-uplift capacity of ccSPF-retrofitted wood sheathing panels that been exposed to an extreme leakage scenario. Despite the accumulation of significant amounts of moisture (moisture contents over 70%, sheathing visibly saturated in some locations), no significant effects on the wind-uplift capacity of the panels was observed.

7.3 Moisture Impacts on Wood Roofs

Moisture in wood roof systems typically arises from two main sources (Lstiburek 2002): (1) liquid flow, e.g., rainwater, and (2) air transport and vapor diffusion. Each of these mechanisms is capable of causing moisture-related building problems. Moisture arising from liquid flow requires a physical breach in the building envelope, either due to a design flaw, physical damage or an unusual loading scenario (e.g., wind-driven rain from a hurricane). Vapor diffusion is more subtle, and varies by climate. In warm, humid climates, known as cooling climates, the warm air at the exterior of the building envelope is driven towards the cooler, drier air of the conditioned interior. In cold climates, known as heating climates, the warm, moist air is typically within the interior of the building envelope and is driven towards the cold, dry air outside the building envelope. As a result, in cooling climates, condensation tends to form on the exterior surface of the insulation, which is at the sheathing/insulation interface in an unvented attic. The opposite is true for heating climates, with condensation tending to form on the underside of the insulation. In intermediate climates, or during seasonal changes, the direction of the vapor diffusion can be more difficult to ascertain. The importance of the climate zones on building envelope strategy is well-recognized in the existing literature. The United States has been divided into 7 different climate zones, as shown in Figure 4from the US Department of Energy.

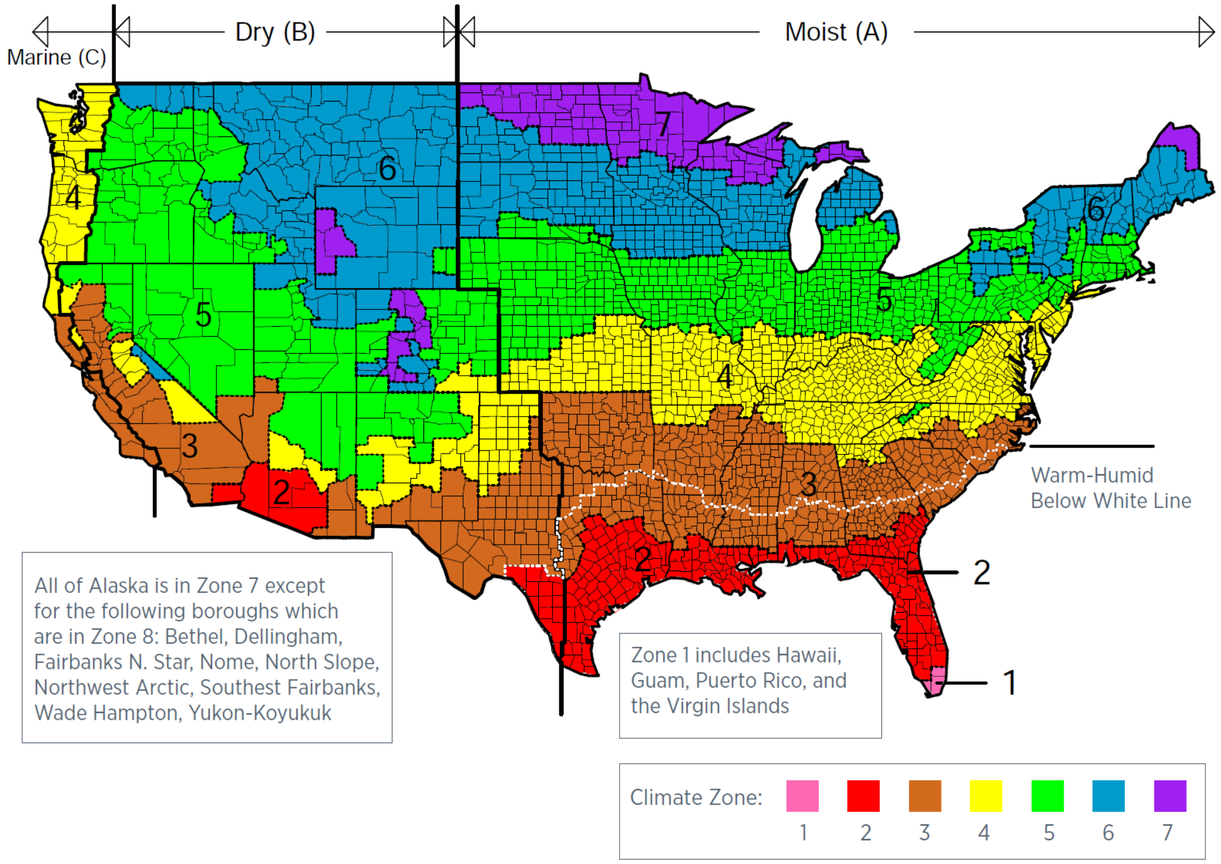


Figure 4: International Energy Conservation Code (IECC) Climate Regions (DOE, 2013).

Lstiburek (2002) identified three strategies for controlling moisture in buildings:

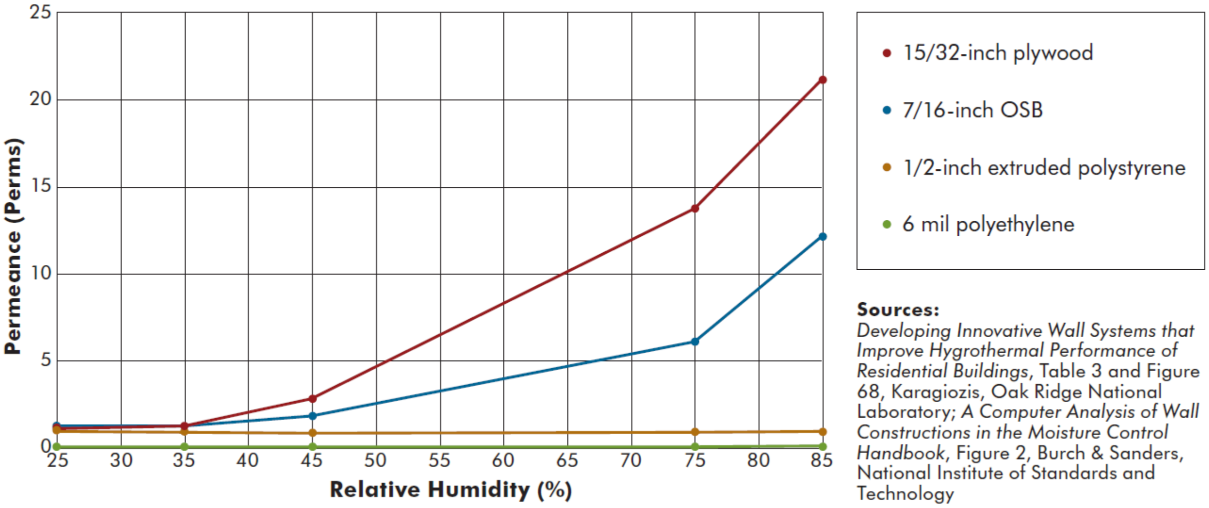
5) Control of moisture entry;
6) Control of moisture accumulation;
7) Removal of moisture.

Vented attics employ the third strategy as the airflow through the attic space is efficient at transporting incumbent moisture out of the roof system if designed properly. Unvented attics often utilize the first strategy, using moisture and/or vapor retarders to prevent moisture from entering the system. However, roof systems that are the most effective at keeping moisture out are also conversely the least effective at controlling moisture accumulation if moisture does enter the system (Pallin et al. 2013; Lstiburek, 2002).

Rose (1998) recommended an air chute which would provide an air gap between the sheathing and the top of the insulation in unvented attics, allowing ventilation to carry the moisture out of the roof system. Prevatt et al (2013) demonstrated potential with this approach in a full-scale experiment as described in Section 3.4. However, more recent research has included recommendations for sealing wood components at both the interior and exterior boundaries, with the objective of preventing any moisture intrusion at all (Rudd 2005); Pallin et al. 2013).

While the ultimate objective is to prevent moisture infiltration entirely, wood does provide a hygric buffer (i.e., moisture storage) capacity of 40-50 gallons in a typical home (Lstiburek, 2002). However if wood is exposed to elevated moisture contents for prolonged periods of time, it becomes susceptible to decay, rot and the growth of mold. Viitanen (1997) found that the brown rot decay fungus requires a moisture content (MC) of 25-28% for growth. At these MCs, growth could be activated at a temperature as low as 5°C after several months of exposure, with more rapid growth as temperatures increase. These MCs can be achieved from equilibrium with air at relative humidity of 94-96%. The threshold for safe relative humidity to which wood can be exposed is typically taken as 80%, which gives an equilibrium moisture content in the wood of 16% (Carll and Wiedenhoeft 2009; Lstiburek 2002; Saber et al. 2010). The general rule for wood protection in construction is to keep moisture contents below 20%, as no fungi can grow below 20% moisture content. Between 20% and 30% (generally taken as fiber saturation point), fungi growth is possible in locally saturated fiber. Above fiber saturation, and with temperatures between 10 and 40°C, conditions are well suited for fungi growth (Derome and Fazio 2000; Griffin 1977).

Of particular importance to this project is the moisture performance of plywood and OSB sheathing, which account for the vast majority of all structural wood panels in the US. Figure 5e shows the vapor permeance (a measure of a material’s ability to permit moisture transport through the material) for plywood and OSB as compared to two common vapor retarders. While the water vapor permeance for both plywood and OSB increase with relative humidity, the permeance of plywood is higher than OSB, particularly at higher relative humidities. This would suggest that plywood is able to dry more quickly than OSB, a finding also noted by other studies (Ojanen and Ahonen 2005; Wu et al. 2008)). With respect to surface moisture absorption, plywood tends to absorb more moisture than OSB under equivalent circumstances. Ojanen and Ahonen (2001) found that plywood products absorbed water faster than OSB during the first four days of exposure, but slowed after this initial period. Water absorption into OSB started slow but increased significantly after 1-2 weeks, and moisture levels in OSB exceeded those of plywood after 2-3 weeks. The likely cause of these results is the differences in water repellence of the two materials. OSB typically has water-repellant surface coatings that limit the absorption and drying efficiency initially. Timusk (2008) found that cyclic wetting/drying had a large effect on permeability of OSB, with permeability doubling after just one cycle. This was also noted by (Nofal and Kumaran 2003). Wu and Ren (2000) however, noted that under long-term RH cycles (12 month initial cycle followed by two 6 month cycles), the actual equilibrium moisture content did not change significantly from one cycle to another.



Sources:
Developing Innovative Wall Systems that Improve Hygrothermal Performance of Residential Buildings, Table 3 and Figure 68, Karagiozis, Oak Ridge National Laboratory; *A Computer Analysis of Wall Constructions in the Moisture Control Handbook*, Figure 2, Burch & Sanders, National Institute of Standards and Technology

Figure 5: Water vapor permeance for building materials as a function of relative humidity (APA, 2009).

In summary, while plywood and OSB are both common structural sheathing options, they do have different hygric properties that may make one option more suitable for certain applications. Therefore, different results can be anticipated for moisture related studies using both plywood and OSB.

7.4 Impacts of Moisture in Vented and Unvented Attics

Derome et al (2010) used a large-scale environmental chamber to evaluate the risk of moisture accumulation in single cavity, flat roof models fully insulated with cellulose fiber. The roof structure consisted of 45 mm by 150 mm wood joists, covered by 19 mm by 150 mm wood planks overlaid with a self-adhesive modified bituminous membrane. Moisture load was simulated through varying the exterior relative humidity. The test sought to establish the implications of moisture diffusion only (little or no air leakage) and air exfiltration together with moisture diffusion on the wood roof assemblies. Moisture contents in the wood roof assemblies were monitored using a combination of resistance-based moisture sensors and gravimetric samples. With little or no air-leakage, moisture contents remained below 16% throughout the year-long test period. With air leakage and moisture diffusion effects, moisture contents steadily rose during the 90 day wetting period (RH between 65% and 71%), reaching as high as 35%, before slowly falling during the 100 day drying period to around 10%. Ultimately, while moisture contents rose and fell during the wetting and drying periods, there was no carryover of moisture from one cycle to another, limiting the potential for wood rot and decay.

Prevatt et al (2014) exposed five full-scale wood roof specimens to 90 days of simulated and natural rainfall in a Florida climate to evaluate moisture accumulation in closed cell spray-applied polyurethane roofs. Test specimens consisted of 9.1 m (30 ft) by 3 m (10 ft) gable roof “attics” with a roof slope of 26° (6 in 12), oriented north-south. All specimens were constructed using wood trusses and 11.1 mm (7/16 inch) thick OSB decking. The roof system consisted of 30# felt and asphalt shingles, as shown in Table 2. Moisture contents in the wood trusses, temperature and relative humidity were monitored throughout the duration of the exposure period using sensors and proprietary software from SMT Research. Details of the complete test setup and scope are available in McBride (2011).

Table 2: Test matrix for full-scale roof specimens in Prevatt et al (2014).

Roof 1	Roof 2	Roof 3	Roof 4	Roof 5
No ccSPF	25 mm continuous layer ccSPF + 75 mm fillet	25 mm continuous layer ccSPF + 75 mm fillet	75 mm continuous layer ccSPF	75 mm continuous layer ccSPF
(104) 13-mm leak gaps	(104) 13-mm leak gaps	No Leaks	(104) 13-mm leak gaps	No Leaks

After the exposure period, the roofing system was removed, revealing significant moisture buildup in the roof specimens with leaks and ccSPF, primarily on the south facing roof slope. No moisture buildup was observed in the specimen without ccSPF or those without leaks. Moisture contents in the framing of the specimens with ccSPF and leaks reached as high as 70%. The presence of the moisture did not significantly affect wind uplift capacities of the sheathing panels. The tests demonstrated that for a worst-case leakage scenario, ccSPF inhibited the ability of the roof system to dry. Without ccSPF, a roof under the same worst-case leakage scenario was able to dry, preventing any moisture accumulation.

A subsequent study by Prevatt et al (2013), built on the results from the Prevatt et al (2014) study to evaluate potential differences between OSB and plywood on moisture accumulation and retention in ccSPF-retrofitted wood roofs. The study also evaluated the performance of two moisture mitigation methods – (1) the use of a self-adhered membrane on the top surface of the sheathing, taking the moisture control approach laid out by Lstiburek (2002); and (2) the presence of an air gap between the ccSPF and the sheathing for 2/3rds of the capacity width, leaving the full fillet to retain the structural benefits. This approach follows the recommendation of Rose (1996). Four full-scale monoslope attic specimens were constructed and oriented so that the slope faced south, based on the findings from Prevatt et al (2014) that moisture accumulation was significantly higher on the south slope. Specimens were exposed to natural and simulated rainfall for approximately 9 months, and leaks were deliberately cut into the roof covering to allow moisture intrusion into the roof sheathing. Results demonstrated that self-adhered underlayment on the top surface of the roof sheathing was effective at limiting moisture accumulation in both OSB and plywood panels, with moisture contents greater than 20% only observed locally at the locations of leak gaps. The air gap allowed the sheathing to dry approximately twice as fast as sheathing without the air gap. The authors also noted that moisture was absorbed more readily into the plywood panels, in agreement with previous research (Ojanen and Ahonen, 2005; Wu et al, 2008).

Prevatt et al (2013) also used bench top testing to quantify drying rates of plywood and OSB samples both with and without ccSPF in a conditioned environment. Samples measuring 6 inch by 6 inch by ½-inch thick were exposed to a continuous drip of water at a nominal rate of 1 mL/min over a 24-hr period, and then allowed to dry in the conditioned environment. The edges of the wood samples were sealed with a water sealant to restrict moisture transport through the samples to 1-dimension. Results showed that for a 2:12 roof slope, plywood and OSB samples with ccSPF dried 61% and 40% slower respectively than samples without ccSPF. For samples elevated to match a 6:12 roof slope, plywood and OSB with ccSPF dried 51% and 65% slower respectively. The half-life, based upon the exponential fit to the drying data, for each sample type is given in Table 3.

Table 3: Drying rates (half-life in hours) for OSB and plywood samples with and without ccSPF from Prevatt et al (2013)

	OSB w/ ccSPF	**OSB w/o ccSPF**	**Plywood w/ ccSPF**	**Plywood w/o ccSPF**
2:12 Roof Slope	72.7	51.5	61.5	38.1
6:12 Roof Slope	91.2	55.3	72.0	47.8

Shreyans (2010) used a 1D WUFI Pro 4.2 hygrothermal model to simulate the drying times of twelve different roof configurations. The evaluated parameters included the use of plywood versus OSB, vented versus unvented attic space, and no spray foam, 1 inch ccSPF, and 3 inch ccSPF. Roof performance was modeled over a ten year period, with an incidental leakage event simulated in the summer of the third year. The simulated leakage had a leakage rate of 0.038 in/hr for a duration of eight hours. Exterior climate conditions were taken from recorded climate data in Gainesville, FL (Climate Zone 2). Interior conditions were set at a temperature of 70°F with a relative humidity of 35% +/- 15%. The results demonstrated that after the leakage was event, moisture contents in the twelve roof configurations varied between 15% (unvented OSB without ccSPF) and 63% (vented plywood with 3 inch ccSPF). Drying times were quantified as the amount of time necessary for the roof system to return below 80% RH after the introduction of the leak. Drying times varied from as little as 3 months to as much as 7 years. The shortest drying time was found in the unvented OSB roof without ccSPF, followed closely by the plywood roof of the same configuration, whether vented or unvented. The longest drying time was found in the unvented OSB roof with 3 inch ccSPF, followed closely by the plywood roof of the same configuration.

Saber et al (2010) exposed four full-scale wood wall assemblies to high sheathing moisture contents and continuously monitored the drying rate over time. The 2.44 m by 2.44 m (8 ft by 8 ft) wood wall assemblies consisted of wood stud framing with glass fiber insulation filling the stud cavities, 11.5 mm (7/16 inch) OSB sheathing, 6-mil polyethelene vapor barrier on the interior of the wall assembly. A polyolefin sheathing membrane was installed on the outer surface of the OSB in one wall assembly, while two other assemblies had asphalt impregnated building paper installed on the exterior OSB surface, with one also having gypsum installed on the interior of the assembly. The last wall assembly did not have a sheathing membrane installed. Sheathing moisture contents for all wall assemblies were above 35% at the start of the drying period, and the assemblies were continuously weighed to monitor the loss of moisture with time. The physical drying rates were compared with a hygrothermal model, known as hygIRC-C, which solved the coupled 2D and 3D Heat, Air and Moisture transport equations in porous median and non-porous media.

Without any sheathing membrane, the moisture in the wall assembly had a half-life of 480 hours. With the polyolefin sheathing membrane, the drying rate was significantly slower, with moisture contents only reducing from 51% to 35% during 384 hours of drying. The wall assembly with asphalt impregnated sheathing membrane but no gypsum had an initial moisture content of 70%, which was reduced by half in 385 hours. The wall assembly with gypsum installed had an initial moisture content of 37%, but dried very slowly, reducing to 28% MC in 576 hours. The results demonstrated that drying rates in OSB sheathing are significantly affected by the components of the wall assembly, particularly the use of vapor barriers. The physical and numerical results agreed well for all wall assemblies, with errors remaining within +/- 5%.

Salonvaara et al. (2013) investigated the moisture performance of sealed (i.e., unvented) attics compared to vented attics in order to understand the risks of high moisture content in the roof sheathing and high humidity in the attic. Open-cell spray foams were simulated in the unvented attic. To compare effects of vapor permeability, spray foam permeances of 23 perm-in (33.58 ng/smPa) and 54 perm-in (78.84 ng/smPa) were used. The vented attic was simulated with blown fiberglass insulation on the ceiling deck. The simulation was conducted in four different cities in four different climate zones - Miami, FL; New Orleans, LA; Atlanta, GA; and Baltimore, MD. The moisture performance of the attic was simulated in two ways: first the roof sheathing moisture content was analyzed with a building enclosure simulation model, and second the attic humidity was investigated using a whole house simulation model. Moisture loads were developed to represent two cases – (1) vapor pressure resulting from interior moisture load of 4 g/m^3 (0.00025 lb/ft^3), based upon assumed moisture production and ventilation rates, and (2) same conditions as (1) plus rain intrusion into the wood roof sheathing amounting to 1% of local rainfall totals. The models used for the moisture analysis were WUFI-Pro and WUFI-Plus. The models were calibrated against measured attic humidity and temperature data in a Tennessee home from Oak Ridge Lab. Results of the study demonstrated that the vented attic performed well with moisture contents remaining below 15% in the roof sheathing with or without the rain intrusion. Even with 1% water intrusion, the moisture content of the OSB stayed below 15% by weight at all times in all the four climate zones. The moisture content levels in the unvented attic were generally higher than in the vented attic. Without rain intrusion, moisture contents remained below 20%. With 1% rain intrusion, moisture contents in all but Climate Zone 1 (Miami, FL) were above 20%, with Climate Zone 4 (Baltimore, MD) having the highest moisture contents (30%) and the most prolonged exposure to moisture contents above 20%. Moisture contents increased with increasing permeance of the spray foam for all but Climate Zone 1 (Miami, FL).

Pallin et al. (2013) performed a hygrothermal risk analysis for unvented residential attics hosting an HVAC system to determine the critical parameters in the development of wood rot and mold. The hygrothermal model included two main components:

1) A WUFI 1D model, which predicts moisture transport through a single axis. Two models were used to simulate the north and south faces.
2) A custom MATLAB model to model the radiative heat exchange in intermediate air spaces or surfaces, and is not capable of calculating indoor boundary conditions.

Key input parameters to the hygrothermal models included indoor heat and moisture production, hygrothermal material properties, air leakage, outdoor climate, orientation and location of the building and roof slopes, features of the HVAC system, and user behavior, i.e., HVAC setpoint temperatures, maintenance, etc. In the study, 224 different compositions were simulated for an unvented attic, with the varied parameters consisting of the thermostat setpoint, outdoor climate, vapor permeance of the spray foam, air leakage rates of the ventilation, airtightness of the ceiling floor, and the indoor moisture production. Outcomes for each composition consisted of three different performance indicators: (1) the maximum moisture content of the OSB sheathing, (2) the HVAC system energy demand, and (3) the mold growth index of the wood-based materials in the attic space. The simulated roof was assumed to have OSB sheathing (no thickness specified), asphalt shingles, and spray-applied polyurethane foam (SPF), both closed-cell and open-cell. Seven different climates (locations) were simulated. Moisture contents were simulated over a 1 year period.

Moisture contents started at 16% and varied between 13% and 55% between all of the models over the simulated year. The models with the highest ending moisture contents for all 7 climate locations were north-facing open-cell models, with moisture contents between 37% and 54%. The lowest ending moisture contents were observed in closed-cell, south-facing roofs, with moisture contents never exceeding 14%. The most important parameters to the OSB moisture content identified in the model were the vapor permeance of the SPF (higher was better), the climate conditions (although no trends are stated related to climate and moisture), and the indoor moisture production (higher moisture production increased risk). The climate with the highest moisture ending moisture contents was Baltimore, MD.

Nelson and Der Ananian (2009) used the WUFI hygrothermal software to compare moisture drying rates of vented and unvented roof assemblies. The models varied by insulation type (glass-fiber batt, open-cell SPF, closed-cell SPF), sheathing type (plywood or OSB) and weather-resistant barrier type (felt or self-adhered rubberized asphalt membrane [SRAM]). They conducted 1D moisture movement studies and predicted the moisture build-up that would in occur in wood following introduction of a leak and subsequent years of thermal cycling. Their study simulated conditions in Miami, FL and Boston, MA over a ten year period. A single leak was introduced, simulating a wind-driven rain storm, with a leakage rate of 976.5 g water/m^{2}h (0.20 lb water/ft^{2}hr) for eight hours in the third summer of each simulation. Moisture was quantified by %RH in the wood sheathing and gypsum, with 80% RH taken as the threshold for initiation of decay. Results showed that unvented roof assemblies with ccSPF (perm rate = 0.17 perms) had the slowest drying potential, requiring a minimum of 7 months for sheathing to dry with felt underlayment and a minimum of 12 months with SRAM. Open-cell SPF and glass-fiber batt insulation roof assemblies, whether vented or unvented, performed significantly better with drying times of 2 months or less. In the Boston, MA climate, unvented ccSPF roof assemblies were again the slowest to dry, requiring 14 months to dry with felt and at least 26 months with SRAM. Vented ccSPF roof assemblies were able to dry in 2 months, similarly too all other roof assemblies considered. In both the hot and cold climates, drying times for OSB and plywood in all roof assemblies differed by a month or less.

Grin et al (2013) conducted hygrothermal modeling using WUFI 5 software on roof assemblies located in hot, rainy climates (Miami), cold climates (Minneapolis) and a rainy, marine climate (Seattle). Roof assemblies were modeled on the north orientation only with parameters as given in Table 4 from exterior to interior. Leakage rates were based on ASHRAE 160 (ASHRAE 2008) recommendations for wall design leakage rates, given as 1% of the water reaching the surface. A 4 ft^2 area near the ridge of a 6/12 pitch roof was chosen for the leakage calculations, which, based on US Climate Normals data, gives 1% of annual rainfall as 1 gallon/4

ft^2 (2.6 L/4 ft^2), 2 gallon/4 ft^2 (7.9 L/4 ft^2), and 1 gallon/4 ft^2 (4.2 L/4 ft^2) for Minneapolis, Miami and Seattle respectively.

Table 4: Basic Modeled Roof Assemblies in Grin et al (2013)

Minneapolis Roof A	**Minneapolis Roof B**	**Miami and Seattle Roof A**	**Miami and Seattle Roof B**
Exterior air	Exterior air	Exterior air	Exterior air
Asphalt shingles	Asphalt shingles	Asphalt shingles	Asphalt shingles
½-in plywood or OSB structural roof sheathing	½-in plywood or OSB structural roof sheathing	½-in OSB structural roof sheathing	½-in OSB structural roof sheathing
R-25 ccSPF	R-25 ocSPF + 5 perm	R-12 ccSPF	R-30 ocSPF
R-24 fibrous air and vapor permeable insulation	R-24 fibrous air and vapor permeable insulation	R-19 fibrous air and vapor permeable insulation	
Interior air	Interior air	Interior air	Interior air

The modeling results demonstrated that all of the roof assemblies modeled exhibited drying capacity to handle minor rainwater leakage. The authors state that “the 2012 IRC-compliant roofing system in Minneapolis using ccSPF on plywood sheathing with cellulose insulation on the interior has the capability according to the modeling to safely dry 53 oz (1.6 L) of water through a 4-ft2 area of plywood per year. MCs > 20% were seen during the modeling, but the systems were typically able to dry during the summer and return to < 8% MC. Within the Seattle analysis the ccSPF insulated OSB-sheathed roofs were able to handle up to 1% rainwater leakage, while the ocSPF roof experienced elevated MC when more than 0.6% rainwater leakage was introduced into the system. This is due to both rainwater leakage and outward vapor drives during the heating season. The ocSPF roofs dried out much more readily than the ccSPF roofs. The Miami analysis showed that that both ccSPF and ocSPF roofs dried, even up to 1.5% rainwater leakage, although both experienced more short-term fluctuation than similar roofs in the Seattle climate”. In general, the ocSPF dried more readily than ccSPF. Orientation and sheathing materials had relatively small impacts on drying capabilities in comparison to the type of SPF and vapor permeance coatings used.

Prahl et al (2014) used computational fluid dynamics and a 2D hygrothermal model to evaluate the moisture risk in unvented attics with ccSPF insulation due to air leakage paths from the unvented attic space to the exterior. The analysis was particularly focused on airflow paths from plumbing penetrations, spray foam delamination, framing intersections, and ridge vent sealing. The modeled roof system was based upon an actual 2,000 ft^2 home in Minneapolis, MN, which had an unvented attics with OSB sheathing, ccSPF (depth or permeance not given) and shingles and other roofing materials, although only the OSB and ccSPF were modeled in this study. Results showed that low airflow rates (less than 2.5 CFM at 4 Pa) resulted in moisture contents above 20% in the surrounding sheathing, localized to an area 5 inches from the crack, for most of the winter and spring in cold climates. However in all cases the accumulated moisture was able to dry during the full annual cycle.

Straube et al (2010) used the WUFI Pro 4.0 hygrothermal model to evaluate the moisture performance of unvented, cathedralized-attic wood roofs. The influences of roofing materials, interior environments and climate zones were the primary considerations of this study. Several different insulation products, including fibrous and foam insulations, were included in the study. The modeled roofs had 3:12 roof slopes and were oriented to the north, considered the worst-case scenario for colder climates. Local weather data for each location was used for the exterior conditions of the model. Interior conditions were varied from medium to high interior moisture levels, based on EuroNorm Standard 15026 (Euronorm 2007). The study identified the most important factor as the control of airflow through the insulation itself. The worst moisture performances were typically linked to poor airflow control. Full-depth ccSPF resulted in moisture contents below 16% all year for all 7 US climate zones. Full-depth ocSPF performed well in warm or mild climate zones, but resulted in prolonged exposure to moisture contents above 16% in cooler climate zones.

Alturkistani et al. (2008) developed a standardized test method for evaluating building envelope drying capacity and demonstrated it using thirty-one wall assemblies. The different configurations were obtained by varying the interior finish (two different gypsum types), sheathing type (OSB, fiberboard or plywood) and cladding system (wood siding on furring and Tyvek, and cement stucco on metallic lath). The insulated core in all configurations was glass fiber insulation. The moisture loading was provided using evaporation of water from containers placed within the stud cavity of the walls at the bottom plate. The containers were not refilled during the course of the experiment. The amount of evaporated moisture was measured continuously using load cells under the water containers. Moisture contents in the wood wall components (2x6 studs and sheathing) were monitored weekly using gravimetric samples that were removed, weighed and reinstalled. The drying capacity of different building envelopes was quantified using the Drying by Evaporation Index (DEI), which was used as a measure of the rate of moisture movement out of the stud cavity. The wall configurations with fiberboard sheathing demonstrated the highest drying capacity (maximum of 99%), followed by plywood (maximum of 89%) and then OSB (maximum of 82%).

As can be seen with the number of reviews above, there is a significant body of work assessing the thermal and moisture performance of vented and unvented attics with SPF for a variety of climates. Table 5 summarizes the “best” and “worst” roof configurations from the various studies, with the assessments based upon the ability of the roof configuration to remain below 16%, the typically assumed threshold for acceptable moisture levels in wood members.

In general, the multiple studies available in the published literature demonstrate good agreement, so long as the assumptions and limitations of each study are taken into account. Studies which investigated moisture loads from interior or exterior humidity sources only generally were in agreement that ccSPF was effective at preventing any moisture accumulation to unsafe levels. However, studies which incorporate leakage generally found that ccSPF was the least effective at controlling moisture contents, while vented roof assemblies or ocSPF generally performed better. Warm climates generally provided a better drying environment than cold climates. No significant differences between plywood and OSB were observed in most numerical models, although the physical experiments did tend to demonstrate differences in performance by sheathing type (Prevatt et al, 2013; Alturkistani et al, 2008). This is an important reminder that many of the existing research conclusions are based upon numerical models which are only as good as the inputs and assumptions that are provided to them. As these models continue to improve and include more complexity, it is possible that some conclusions may change. The importance of comparisons of the models to physical experimental results or field studies cannot be overstated.

The body of literature available today on this subject matter demonstrates the fact that there is no one-size-fits-all building envelope solution for all configurations and all climates. There are design choices that can be made that will allow nearly any configuration (e.g., vented or unvented, ccSPF or ocSPF or fibrous insulation, etc) to perform adequately, so long as the design of the system is approached holistically with a thorough understanding of building envelope science.

Table 5: Summary of reviewed literature regarding moisture performance of various roof assemblies

Reference	**Test Type**	**Climate Zone(s)[1]**	**Configurations**	**Moisture Source**	**Best Performance**	**Worst Performance**
Prevatt (2014)	Full Scale	2	OSB sheathing with and without ccSPF	Natural and simulated rainfall, roof leaks	OSB w/o ccSPF	OSB w/ ccSPF
Prevatt (2013)	Full Scale	2	OSB, Plywood sheathing, ccSPF, air gap, felt underlayment, self-adhered membrane	Natural and simulated rainfall, roof leaks	OSB/Ply w/ Self-adhered membrane	N/A
Prevatt (2013)	Bench top	Conditioned	OSB, Plywood, ccSPF, self-adhered membrane	Point drip	Plywood w/o ccSPF	OSB w/ ccSPF and self-adhered membrane
Shreyans (2010)	Numerical (1D WUFI Pro 4.2)	2	Vented and unvented attics, plywood and OSB, ccSPF and no ccSPF	Simulated leak	Unvented OSB without ccSPF	Vented plywood with ccSPF
Saber (2010)	Full Scale and Numerical (hygIRC-C)	Unspecified	OSB, glass fiber insulation, gypsum, sheathing membranes	Initial Saturation	OSB w/ asphalt impregnated membrane	OSB w/ asphalt impregnated membrane and gypsum
Salonvaara et al. (2013)	Numerical (1D WUFI-Pro and WUFI-Plus)	1, 2, 3, 4	OSB, vented and unvented, ocSPF and blown fiberglass	Interior RH and rain intrusion (1% of climate normals)	Vented (blown fiberglass)	Unvented with high permeance ocSPF
Pallin et al. (2013)	Numerical (1D WUFI)	1 – 7	224 different configurations, all with OSB and SPF. Parameters include spray foam permeance (ocSPF and ccSPF), various air leakage rates, airtightness.	Interior RH	ocSPF with low air leakage rate	ccSPF with high leakage rate
Nelson and Ananian (2009)	Numerical (1D WUFI 4.1)	1 and 5	Insulation type (glass-fiber batt, ocSPF, ccSPF); sheathing type (plywood, OSB); weather-resistant barrier (felt or self-adhered membrane)	Simulated leak (1% of climate normals)	ocSPF and glass-fiber batt with plywood or OSB	ccSPF with plywood or OSB
Grin et al (2013	Numerical (1D WUFI 5.0)	1, 4 and 7	Insulation type (cellulose in combination with ccSPF or ocSPF); sheathing type (plywood or OSB)	Simulated leak (1% of climate normals)	ocSPF with plywood or OSB	ccSPF with plywood or OSB
Prahl et al. (2014)	Numerical (2D WUFI 5.0)	6, 7	OSB sheathing, ccSPF insulation, various air leakage flow rates	Interior RH	ccSPF with low airflow rates (<2.5 CFM at 4 Pa)	ccSPF with high airflow rates (≥2.5 CFM at 4 Pa)
Straube et al. (2010	Numerical (1D WUFI Pro 4.0)	1 – 7	Insulation type (ocSPF, ccSPF, fibrous); various air tightness levels; roofing materials (varied by solar absorption)	Interior RH (medium to high)	ccSPF (all climate zones)	ocSPF (particularly in cooler climate zones)

[1] Climate zones refer to the US Department of Energy Climate Zones as given in Figure 4.

7.5 Field Performance Reports for Spray Foam Insulated Roofs

In addition to the numerous numerical and physical research experiments regarding moisture in unvented attics, it is paramount to also summarize any field investigations that are available. These provide “real-world” performance of these roof systems and can serve to validate the existing body of experimental work. There are a few such studies, which are summarized below. Anecdotal evidence of moisture issues in SPF attic systems from various web sources and personal communications is also included.

Rudd (2004) performed field investigations of six cold climate homes (located in Minnesota, Wisconsin and Massachusetts) and five hot, humid climate homes (located in Texas and Florida) to quantify the performance of unvented, cathedral attics. Four of the cold climate homes had ocSPF with thicknesses varying between 3 and 9 inches, while one home had ccSPF of 3 inch thickness. Roof sheathing consisted of plywood, OSB or wood planks, and all homes had asphalt shingles. House and attic relative humidity was measured, along with attic temperatures. Moisture contents of the sheathing and framing were measured using resistance-based moisture meters. Attic relative humidity in the six homes were as low as 30% in some homes and more than 85% in others. Sheathing moisture contents were between 6 and 7% in the home with ocSPF, but were greater than 20% in all but one of the homes with ocSPF. In all homes, the highest sheathing moisture contents were on nominally north-facing slopes. Framing moisture contents ranged from 6% to 12% in all six homes. In the hot, humid climate homes, moisture contents were only measured in two homes, both of which had open-cell, low density foam insulation under plywood roof sheathing, creating a sealed (non-vented) attic. The roof covering consisted of 15# building felt and asphalt shingles. Sheathing moisture contents ranged between 7 and 16% with a median of 10%. Framing moisture contents ranged from 7 to 12% with a median of 9%. There were no signs of moisture condensation, mold, or delamination.

Boudreaux et al (2013) studied eight homes in a mixed-humid climate to investigate the moisture performance of sealed attics. Four of the homes were unvented attics, the remaining four were vented attics. Two of the unvented attics and one of the vented attics were unoccupied. All homes had OSB roof sheathing with 15# felt paper and asphalt shingles. All had been retrofitted in the months preceding the start of the monitoring period. Moisture levels were quantified as the partial pressure of water vapor (Pa) over a 9 month period between January 2012 and September 2012. On average, the sealed attic homes had approximately 20-30% higher attic and interior moisture levels as compared to the vented attic homes. Despite the higher attic and interior moisture in the sealed attic, there was no indication of mold or material degradation.

Colon (2011) investigated the thermal and moisture performance of a home in Rockledge, FL which was constructed in March 2010. The home featured a sealed attic with open cell spray foam insulation, as shown in Figure 6. Temperature and relative humidity were monitored in the conditioned space, attic and outdoors for a full year, between April 2010 and April 2011, at 15 minute intervals. The home was not occupied during the testing period, but the air conditioner did operate. It was noted that the new home started an interior RH near 60%, which slowly decreased towards the target of 50% over the course of 5 months. The author indicated that high humidity content is common in new construction for the first year or two of use due to moisture in building materials. In the sealed attic, relative humidity, measured 6 inches below the sprayed roof deck, reached as high as 83% in May 2010 and 78.3% in April 2011, but were as low as 45% during the winter months.

Figure 6: (Left) Front view of home showing conventional hip roof and shingles; and (right) View of the open-cell spray foam insulation in the attic (Colon 2011)

Schumaker (2008) performed field investigations of multiple roofs to assess the hygrothermal performance of insulated, sloped, wood-framed roof assemblies. The homes or test facilities were located in Vancouver, BC, Ottawa, ON, and Coquitlam, BC in Canada and in Atlanta, GA in the United States. The test hut in Coquitlam, BC contained two roof assemblies with OSB sheathing, asphalt shingles and ocSPF insulation creating an unvented attic. Moisture contents in the sheathing remained below 19% over the course of a year of monitoring. The Vancouver, BC test house also utilized ocSPF to create an unvented attic. The home was constructed just prior to the beginning of the monitoring period. Interior relative humidity remained below 60% throughout a 27 month monitoring period. Moisture contents in the sheathing during the initial months after monitoring began reached 25%, but in subsequent years, moisture contents for the same month of the year were steadily lower, remaining less than 18% in the last year. The high initial moisture contents appeared to be due to the moisture stored within the construction materials.

7.6 Information Received on Moisture Damage to Roofs

The Advisory Panel was asked to provide any evidence of roof deterioration in spray foam insulated roofs. We received the following photographic descriptions:

7.6.1 House 1

Mark Zehnal provided evidence of a damaged roof system in Palm Beach County that had closed cell spray foam insulation installed. We were told that the home was built in 2005 and was repaired in 2014. This series of photographs documents the extent of damage to the roof deck and wood framing adjacent to a large dormer. The photos show a rotted deck adjacent to a dormer . The photos did not identify the source of the water (although experience suggests failed flashing below the window sill and or failed base flashing along the dormer wall are potential sources).

Figure 7: Moisture damage in an unvented attic with ccSPF. Moisture was particularly event around the visible dormer (Courtesy of Mark Zehnal).

7.6.2 House 2

The roof system of a Palm Beach Gardens, FL house with spray applied insulation showed signs of water intrusion damage. As seen in the photo the sheathing and wood framing both began to rot and is speculated to be caused by the elevated moisture content of the sheathing due to a leak caused by roof defection. As was seen in the first case this damage occurred next to a window which suggests the moisture could have entered the system due to failed flashing at the window sill and been trapped between the spray foam and the sheathing. A forensic study was not conducted on this home so these photos are considered anecdotal and just an example of a home with spray foam and moisture damage.

Figure 8: Moisture damage around a gable dormer to an unvented attic with ccSPF.

7.6.3 House 3

An additional home installed with ccSPF installed on the underside of the wooden roof sheathing was identified in which the foam had to be removed from the home as a result to a homeowner allergy to the spray foam insulation. As the foam was being stripped, a buildup of moisture was detected on the wood framing and underside of the wood sheathing. A forensic study of the home was then conducted in which a chemical ratio test of the spray foam was performed as this is the typical diagnosis of a moisture related spray foam issue. The ratio of the spray foam was confirmed to be correct and was identified as completely reacted (solid) and thus concluded this was not the cause of the moisture buildup, It is the motivation of this study to determine the effects of moisture buildup in wood sheathing in homes such as this to gain insight on how to prevent problems due to a building envelope moisture intrusion.

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Figure 9: Evidence of moisture buildup in home installed with ccSPF. Note the moisture on both the sheathing and wood framing

7.7 Moisture in Foam Insulated Roofs and Health Effects

Mark Zehnal told the research team by email that one of his FRSA member contractors was asked by the homeowner to remove the closed cell spray foam insulation that was installed during the construction of an addition. The homeowner experienced allergic reactions after the foam insulation was installed. The homeowner explained the occupants had no symptoms before the foam was installed but they continued to experience allergy / illness after installation (no length of time specified). The Contractor had foam samples tested, which indicated all chemicals were mixed at “proper” ratios and they had completely reacted (in a solid form). Photographs of the removal of the spray foam were presented earlier in Section 3.6.3. The Contractor reported to Mark Zehnal as follows:

1. On examination, moisture was observed on the deck side of the foam insulation and along the top chord of the wood trusses.
2. Foam samples showed signs of heat stress and moisture in direct contact with the 19/32” CDX plywood, and the foam had a darker color near the wood deck as compared with the underside (attic side) of the installation.

By way of explanation, the Contractor wrote that vapor transmission (moisture) occurs at the hottest time of day driving moisture into areas of lower vapor pressure (i.e. inside the attic). This vapor transmission may be associated with moisture trapped in the roof sheathing and being driven through the foam insulation into the attic (internal air flow). The Contractor hypothesized that sealed attic systems have (unanticipated) air exchanges between attic and interior (occupied) spaces, which may help maintain dehumidified conditions in the attic. However such air exchange may also simultaneously draw off-gasses from newly installed foam insulation into the occupied spaces, thus adversely affecting air quality.

The Contractor also described to Zehnal of a similar situation that was witnessed by his (the Contractor's) colleague. In that case a homeowner reported experiencing allergic reactions following the installation of foam insulation (no type specified). The homeowner stated the allergic reaction was highest during the hottest part of the day (midday and into afternoon). This would coincide with the vapor transmission of the moisture from the roof side & deck being driven into the attic cavity.

7.7.1 Health Effects Studies

While occupant health was not included in the original scope of this project, the above information was brought to the attention of the research team and we shared this with the Advisory Panel. Volatile organic compounds (VOCs) occur in many areas of the construction industry and they are known to cause allergic reactions. The influence of VOCs on indoor air quality is discussed by the Environmental Protection Agency (EPA 2012). Spray foam insulation is one of dozens of construction materials that can produce VOCs. In addition, a fully sealed attic may also create a tighter sealed building and indoor air quality can be diminished over time if insufficient make-up air is provided. The literature reviewed below documented some instances where occupants experienced adverse reactions following the installation of spray foam insulation.

A recent EPA initiative has focused attention on identifying potentially harmful chemicals in spray foam insulations (EPA 2015). This effort is conducted with the involvement of the major spray foam insulation trade associations and some companies. The result has been a strengthened protocol for safe handling, evacuation and re-occupation of premises before and after the spray foam installation.

Spray foam insulations are comprised of two components; A-side and B-side that are mixed together. The A-side consists of isocyanates, which the EPA website states can cause skin, eye and lung irritation, and have been identified as the leading attributable chemical cause of work-related asthma. The B-side of SPFs is usually a blend of chemicals, many of which are toxic. The primary risk for exposure to these chemicals is during installation and curing, while the chemical reaction is underway.

After SPF is applied and cured, it is typically considered relatively inert, meaning the harmful chemicals do not continue to be released over time (EPA 2015). However, if occupants are allowed re-entry into a building after SPF installation too soon, while the curing process is still ongoing, or during demolition or disassembly, they can be exposed to toxic emissions from the chemicals. The EPA recommends 24-hours after installation before re-entry without personal protection equipment, but they mention that curing times are highly variable and that more research is needed. To address long-term concerns for exposure potential the EPA website includes the following:

- Maintenance workers, including plumbers and electricians, should not heat or grind spray foam. Spray foam can potentially generate toxic emissions under these circumstances.
- Building renovations, demolition, or building disassembly done years later can disturb spray foam insulation. Performing hot work on or near polyurethane foam may lead to potential exposures to isocyanates and other toxic emissions.

Tsuang and Huang (2012) documented the case of a 36-year old man and 38-year old woman with no prior significant health history, who displayed signs of asthma after returning to their home 4 hours after SPF was installed. Attempts were made to remediate the issue through ventilation and ultimately, removal of the SPF after three months. The symptoms remained however and the occupants decided to vacate the home.

Huang and Tsuang (2014) studied the adverse health effects of spray polyurethane foam on 13 adults from 10 households (ages 33 to 82) where there was faulty application of SPF in the homes; i.e.

- Occupants not being asked to leave premises during the spray
- Occupants told to return too early after spray
- Lack of ventilation of home during spraying
- Improper spray technique (faulty mixing ratio)

The author's determined volatile organic compounds (VOCs) present in air samples within the homes and by taking samples of the foam itself to isolate chemical signatures. The results indicate that installed foam insulation can cause health problems as it can become a "reservoir" or off-gassing source for VOC's long after installation was completed. The authors concluded in order for someone to be adversely affected by SPF they had to be exposed to the spray as it was being installed. The research supports EPA website's contention that fully cured spray foam insulation is considered inert and safe, but curing rates are affected by type of product, applicator technique, foam thickness, and temperature and humidity conditions.

The fact that there are thousands of homes in the United States with SPF installed and only a handful of reported cases have shown adverse health effects should not be overlooked, but the few cases of adverse health effects should also not be ignored. The available evidence indicates that for the most part SPF insulation is a safe building construction material when mixed and installed properly and allowed adequate time to cure. The risk of adverse health effects can be magnified however if installers do not ensure the homeowners fully understand the proper procedures for installation and re-entry, and the potential risks associated with ignoring these procedures. The risks can also be magnified for occupants who have pre-existing health conditions or are sensitive to the chemical compounds in SPFs. We believe that health effects of SPF should continue to be an area of further research, as the number of reported cases may not be representative of the actual number of cases, some of which may be misdiagnosed due to a lack of available information. Furthermore, the industry should be proactive in assessing the curing and re-entry times that are being recommended by installation contractors to the occupants to ensure that safe timelines are being followed.

8 ERP 2: Inspection of Existing Homes installed with spray foam insulation to determine relative drying characteristics of system

In combination with the experimental tasks of this project, it is beneficial to investigate the performance of existing homes that have had spray foam insulation installed. This provides insight into the actual performance of such homes in a hot, humid Florida environment, as well as an opportunity to discuss aspects of the spray foam insulations with the homeowners who chose to have it installed.

8.1 Objective

The objective of Task 2 is to evaluate the moisture performance of existing single-family residential structures in Florida with wood roof decks insulated with spray foam insulation. Specifically, temperature and relative humidity are measured in the attic, the exterior and interior of houses to compare the moisture environments of full-scale, occupied homes with SPF. Homeowner’s perceptions of cost, risk and benefits of SPF are ascertained through in-person interviews and questionnaires.

8.2 Approach

It was proposed that homes currently having SPF installed on the underside of roof sheathing would have temperature and relative humidity sensors installed for comparative full-scale testing. The original plan was to use wireless sensors and data acquisition hardware to capture data without disturbing residents. However it was more reliable and cost-effective to use LogTag HAXO-8 Temperature and Humidity Recorders, which have been used successfully in previous projects by the PI. The original scope of the project was to investigate five homes, but this was dependent upon being able to identify suitable homes with homeowners willing to work with us on the project. Due to limited response, the original scope was reduced to three homes. Two of the homes have spray foam insulation in unvented attics, while the other is an unvented attic with blow-in insulation which will serve as a control. The complete descriptions of each home are provided in the following section.

The investigative team performed all three assessments on June 4, 2015. For each home, photographs of the exterior, roof, and interior attic space were taken. The roof was visually inspected for any abnormalities and the locations of chimneys, vents and potential leak sources, if any, were identified. Shingle surface temperatures were taken using a Raytech MiniTemp IR. Following visual inspection of the exterior and roof, the team entered the attic space and visually inspected the SPF insulation (if present) for any evidence of delamination or degradation. Temperature, SPF thickness and moisture contents of the wood sheathing were then taken in the unvented attic spaces if possible. Temperature and moisture contents only were taken in the vented attic space. LogTags were placed in the attic space and the exterior of the home to monitor temperature and relative humidity. Moisture contents were obtained using a Delmhorst BD-2100 handheld moisture meter with a 21-E electrode attachment to accommodate the 3.25 inch insulated contact pins necessary to penetrate the foam insulation layer.

Figure 11 provides a photograph of a moisture content about to be taken. The homeowners of the homes with SPF were interviewed by a member of the investigative team to collect information on the cost, performance, risk perceptions, and any known issues with the SPF insulation. The full questionnaires are provided in Appendix A. The questions concerning the performance of the SPF insulation included:

Question 1) Did the homeowner choose the SPF or was it installed prior to owning the house?
Question 2) What was the cost of the SPF insulation?
Question 3) What is the homeowner's perception of the impact of SPF on the comfort level of the home?
Question 4) What is the homeowner's perception of the impact of SPF on the energy costs of the home?
Question 5) How concerned is the homeowner about potential damage from moisture leaks in the roof?
Question 6) Is the homeowner aware of any past problems with the roof?

8.3 Results of the Investigation

Characteristics of the three homes are given in Table 6. The results of the investigation are summarized below for each of the three homes that were investigated.

Table 6: Summary of the three homes investigated for moisture performance

Home Identification	Location	Year Built	Insulation Type	Installation Year
Home 1	Orlando, FL	1975	ccSPF	2010
Home 2	Altamonte Springs, FL	1974	Blown-in insulation	N/A
Home 3	Altamonte Springs, FL	1969	ocSPF	2010

8.3.1 Home 1

Home 1 is a wood-frame structure built in 1975 in Orlando, FL. It has a somewhat complex roof, with two distinct parallel ridges and multiple roof step-downs, gable dormers and chimneys and a 5 in 12 roof slope. The dominant ridge-lines are oriented East-West. A large oak tree just north of the home provides shade for approximately half of the roof during the summer months. The roof structure consisted of wood trusses, plywood sheathing, felt underlayment and architectural asphalt shingles. The home was re-roofed in 2010, the same year ccSPF was installed in the roof and walls of the home. The HVAC system is located outside the home. Visual inspections of the roof and ccSPF did not reveal any abnormalities. The roof materials, including the foam insulation, all appeared to be in good working condition with no obvious defects. Moisture content, foam thickness and temperature of the foam surface were taken at eighteen points within the attic space. The locations within the footprint of the home and the data for each location are provided in Appendix A. Shingle surface temperatures were taken at 2:37 PM. A weather station located at the Orland Executive Airport, approximately 1.5 miles away from Home 1, reported an ambient temperature of 89.8°F and relative humidity of 52% at that time. A summary of the data measured at Home 1 is given in

Table 7. Three LogTag temperature/humidity data loggers were installed in the attic space and one was placed outside to record ambient conditions. Locations of the installed LogTags are also provided in Appendix A.

Table 7: Summary of attic temperatures, shingle temperatures, ccSPF thickness and sheathing moisture contents for Home 1

	ccSPF Surface Temperature (°F)	**Shingle Surface Temperature (°F)**	**ccSPF Thickness (inches)**	**Sheathing Moisture Content (%)**
Median	87	136	2.5	6.2
Minimum	81	101	2	6.0
Maximum	91	145	3.25	7.3

The homeowner was a roofing contractor and was interviewed to evaluate their perceptions of spray foam insulations and the risks that may be associated with it. The homeowner chose to install ccSPF because of the anticipated energy benefits. The cost of the installation in both the walls and roofs was approximately $10,000. The homeowner believed the ccSPF had a significant impact on the comfort of the home, but was unsure of the impact on energy costs because the home had been renovated, including installation of the ccSPF, immediately after they had bought the home and therefore there were no “before” costs to compare to. The homeowner was not aware of any problems with the roofing, but did have significant concerns over the potential for moisture damage from undetected leaks.

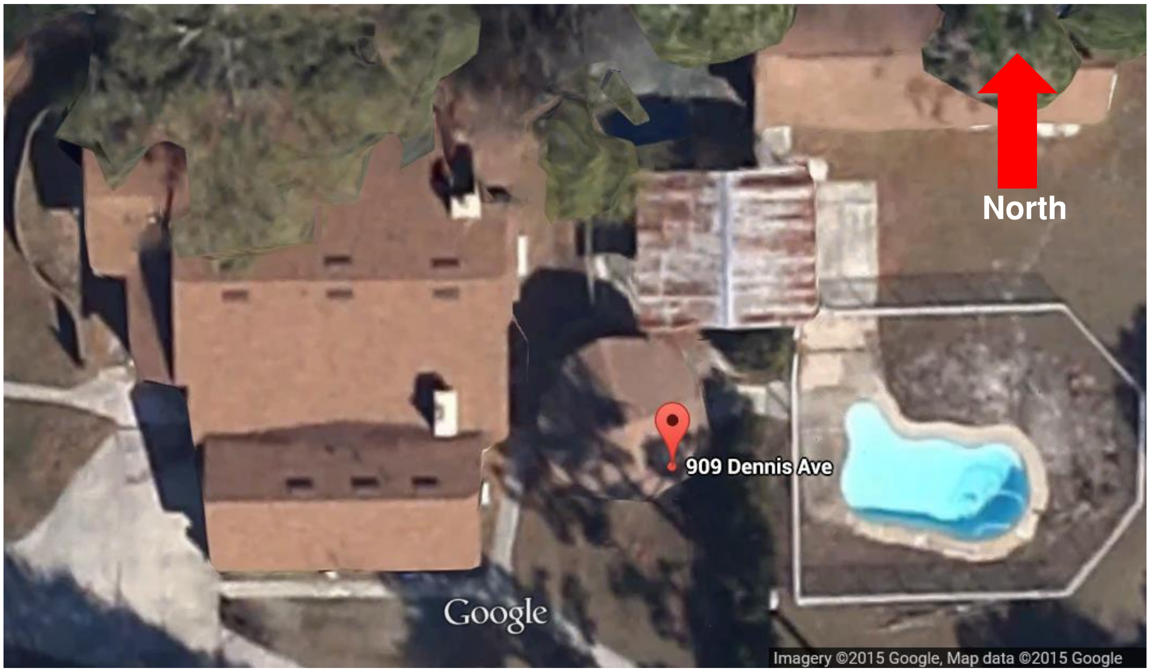


Figure 10: Aerial view of Home 1 showing the layout of the roof structure.

Figure 11: (Left) View of the front of the house from ground. (Right) View from inside the attic showing the ccSPF and a moisture content measurement being taken.

8.3.2 Home 2

Home 2 is a concrete-block home built in 1969 located in Altamonte Springs, FL. The home has an L-shaped hip roof with a 3 in 12 roof slope and wood plank roof deck. The shingles are at the end of their useful life and the homeowner has plans to replace the roof in the coming weeks. The homeowner is aware of several small leaks in the roof, near the fireplace and near a skylight in the kitchen, that have been present for several months. The homeowner had ocSPF installed in 2010 to help reduce energy costs and better seal the building envelope. Originally it had been installed throughout the attic, even over the garage. But earlier in 2015, the homeowner removed the ocSPF from the garage and plans to install an air barrier between the garage and rest of the attic space. The homeowner is concerned that carbon monoxide from the car when in the garage will become trapped in the attic space and become dangerous for the occupants. The HVAC system is located outside the home.

Figure 12: (Left) Aerial view of Home 2. The red dot indicates the approximate location of the photo to the right. (Right) ocSPF installed in the attic space. The truss shown is directly over the garage wall. SPF to the right of the truss, over the garage, has been removed by the homeowner.

Moisture contents, ocSPF surface temperatures and ocSPF thickness were measured at multiple locations in the attic. The data is summarized in Table 8. The full data is available in Appendix A. Shingle surface temperatures were not taken because it was 6:30 PM when the home was inspected and the sun was already obscured by neighboring trees. No evidence of elevated moisture contents were observed in the wood decking, but we were unable to access the areas with known leaks due to their locations near the eave of the attic. When the homeowner replaces the roof in a few weeks however, it would be beneficial to observe the moisture contents and condition of the roof deck when the shingles are removed.

Table 8: Summary of ocSPF surface temperatures, thickness and roof deck moisture contents in Home 2

	ocSPF Surface Temperature (°F)	**Shingle Surface Temperature (°F)**	**ocSPF Thickness (inches)**	**Sheathing Moisture Content (%)**
Median	94	No Data	5.4	6.0
Minimum	93		3.5	6.0
Maximum	95		7.5	6.1

The homeowner installed the ocSPF in January 2010 after many hours of personal research into the benefits and potential problems. The cost of the installation was $4,500. The homeowner perceives some benefit to it, noticing that the AC runs less throughout the day. This has resulted in slightly lower energy costs. But the homeowner is unsure of whether he wants to keep the foam or not, and is considering taking it out before replacing the roof. The homeowner is somewhat concerned about moisture problems with the foam, but is mostly concerned about air quality. An air test was performed several years installation of the ocSPF and the results indicated elevated levels of CO2 in comparison to typical levels in homes. The homeowner is concerned that the installation of the ocSPF without consideration of the entire building envelope may lead to air quality and moisture problems in the future. The homeowner was particularly interested in learning the relative humidity levels in the attic once the data becomes available.

8.3.3 Home 3

Home 3 is a concrete block home located also located in Altamonte Springs, FL. The home has a T-shaped floor plan (shown in Figure 13) with a gable roof at a 4 in 12 roof slope. The roof structure consists of wood trusses with plywood sheathing, which is overlaid with an unknown underlayment and asphalt shingles. The attic is insulated at the ceiling level with blown-in insulation. Attic vents are present at the gable ends. Moisture contents and interior attic temperatures were taken at a few points within the attic, and shingle surface temperatures were measured at 5:00 pm. The observed data is summarized in Table 9. A weather station 3.5 miles away recorded an ambient temperature of 92°F and relative humidity of 43%. The sky was partly cloudy. During inspection of the roof sheathing, discoloration of the plywood was noted (Figure 13) in several locations, and the wood seemed brittle as the moisture meter pins were stuck in the wood. The areas were dry to the touch however and the moisture meter did not measure elevated moisture contents. It appears there may have been roof leaks there in the past that had subsequently dried out. The homeowner was not aware of any roof leaks. One LogTag was installed inside the attic, near the center of the roof, and another was placed outside to capture ambient conditions.

Figure 13: (Left) Aerial view of Home 3; (Right) Apparent water damage in the plywood sheathing. No moisture was present at the time of inspection, and no evidence of past moisture was evident in the insulation below.

Table 9: Interior attic temperatures, shingle temperatures and sheathing moisture contents in Home 3

	Interior Sheathing Temperatures (°F)	Shingle Surface Temperatures (°F)	SPF Thickness (inches)	Roof Sheathing Moisture Content (%)
Median	126	115	None	< 7%
Minimum	94	90		
Maximum	147	132		

8.3.4 Summary of Field Investigations

Three homes were inspected to evaluate the effects of SPF insulation on wood sheathing. Two of the homes had SPF insulation installed – one with ccSPF and the other with ocSPF – and the third house did not have SPF insulation and served as a control. In all three homes, no evidence of elevated moisture contents were observed, with moisture contents at every location measured being less than 8%. Home 2 did have a couple of known leaks in the roof, but the areas with the leaks were inaccessible from the attic. The homeowner is planning to replace the roof shingles in the coming weeks and it would be beneficial to observe the condition of the roof decking when it is replaced. Interior attic temperatures were lowest in the ccSPF roof (Home 1) despite the inspection being performed in the house near the hottest time of the day. Temperatures in the ocSPF roof (Home 2) were 4°F higher on average, despite being measured near the end of the day. Temperatures in the vented attic (Home 3) were the highest of all with median temperatures nearly 40°F higher than those in the unvented attics. Median shingle surface temperatures were 21°F higher in the unvented attic than in the vented attic for approximately equal ambient temperatures. The temperatures of the shingles above the vented attic were taken later in the day (5:00 PM versus 2:30 PM), which may have contributed to the differences.

Table 10: Summary of Field Observations for ERP 2

	Inspection Time	Roof Deck Insulation Type	Interior Temperature (°F)	Shingle Surface Temperature (°F)	Moisture Content (%)
Home 1	2:37 PM	ccSPF/3 in.	87	136	6.2
Home 2	6:30 PM	ocSPF/5 in.	94	Not Measured	6.0
Home 3	5:00 PM	None	126	115	< 7.0

9 Experimental Research Plan 3A: Comparative Tests: Drying Rates of Insulated Uniformly Wetted Wood Roof Decks

9.1 Objective

The objective of this study is to evaluate the relative drying rates of wood roof deck configurations with various foam insulation characteristics. The approach is to simulate a 1D moisture movement out of a wood roof deck saturated at the start and subjected to a differential temperature (exterior –interior) conditions.

9.2 Motivation

Small-scale proof of concept experiment is needed to confirm an approach for monitoring roof deck drying rates. Experiment will be used as precursor to more elaborate testing, if this is justified by results.

9.3 Approach

Fabricate 36, 12” x 12”, flat roof specimens and measure the 1-D comparative drying rates through wood roof cross-sections having a) traditional (no insulation), b) open-cell and c) closed-cell spray foam insulation. Measure interior and exterior climate for 1 month. Interior conditions will be representative of a conditioned space. Exterior conditions will artificially simulate a hot/humid climate via heat lamps and moisture released from samples. This will create a vapor drive with hygrothermal properties typical of Climate zone 1. Roof sheathing will be water-soaked at start of experiment up to a moisture content exceeding threshold for decay of 30%. Moisture content will be monitored via gravimetric weighing per ASTM D4442 of removable roof specimens. Relative humidity and temperature of interior and exterior space monitored with Log Tag sensors.

Figure 14: Isometric view of Insulated Thermal Chamber

9.3.1 Insulated Chamber

The Insulated Thermal Chamber is 11 ft by 5 ft by 6.5 ft tall (interior dimensions) (Figure 15). The insulation consists of R19 Batten Insulation and 2 in. thick Perma "R" polystyrene rigid insulation board. The chamber consists of a thermally controlled portion housed above the roof specimens and an ambient condition of the lab below subjected the specimens to an approximate 70F thermal variance (Figure 16). Thermal control is provided by two Radiant Electric Heat 1445CL surface mounted heaters that produce 5150 BTU of energy each. Each heater measures 46 in. by 15 in. by 1-1/8 in. and it is centered on the 1/3 points on the roof deck. The roof deck temperature is thermostat controlled by two Johnson Control A419 thermostats to a set temperature of 150F. Log Tag data loggers have been placed in 4 locations inside the "Top" of the thermal chamber and 1 in the bottom ambient condition to capture the relative humidity and temperature at various points in the structure. The roof deck supports the 36 specimens that are approximately 22 in. below the heaters (Figure 16). The interior condition below the roof deck is open to the laboratory – a semi-controlled space with average temperature 65.7 ^{o}F and relative humidity of 48%.

Figure 15: Insulated Thermal Chamber

Figure 16: Thermally controlled top portion (Left) lower interior chamber open to ambient Temperature (Right).

9.3.2 Specimen Fabrication

The roof specimens are 12 in. by 12 in. cross-sections of a typical roof system. Each specimen (Plywood or OSB) has asphalt shingles and roofing underlayment (30# or Ice & Water

Shield) installed (Figure 19). Table 11 provides the system matrix of the number of samples with or without spray foam insulation (closed cell (ccSPF) or open cell (ocSPF)). Wood roof sheathing was purchased from traditional hardware stores. Sheathing acclimated in the lab for approximately 14 days. Moisture content was measured using a handheld DelmHorst Instrument point moisture meter – Model BD-2100. Average moisture values for the sheathing were 7.24% and 6.94% for plywood and OSB sheathing, respectively. All of the roof specimen constructed can be seen in Table 11.

Figure 17: Chamber Test Deck

Table 11: System Matrix for Comparative Drying Rates

	1-layer 30# Building paper (1P)			**2-layer 30# Building paper (2P)**			**Ice & Water Shield (SA)**		
	Control (no foam)	Open cell foam	Closed cell foam	Control (no foam)	Open cell foam	Closed cell foam	Control (no foam)	Open cell foam	Closed cell foam
Plywood	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X
OSB	X	X	X	X	X	X	X	X	X
	X	X	X	X	X	X	X	X	X

Spray foam insulation was installed by Gale Insulation in Alachua, FL on 03/27/15 beginning at 8:30am. A grid system pre-fastened to the sheathing provided a 12 in. x 12 in x 3 in. opening for insulation. A single-pass foam was used for the open cell spray foam application (ocSPF) (Figure 2), and two passes used for the closed cell spray foam (ccSPF) application. For the ocSPF the foam expansion was quite large, exceeding the depth of the samples. These samples will maintain the "as sprayed" surface and form a "skin" which is representative of spray foam insulation in practice.

Figure 18: Installation of open-celled SPF insulation

Samples were allowed to cure for 48 hours before the samples were separated from the wood framing. The edges of the wood sheathing and spray foam insulation were coated with two waterproofing coats using Gaco Roof to minimize chance of lateral moisture transfer and ensure 1 dimensional drying. Each sample was weighed using an Ohaus Ranger 7000 digital scale and placed in a plastic covered bin.

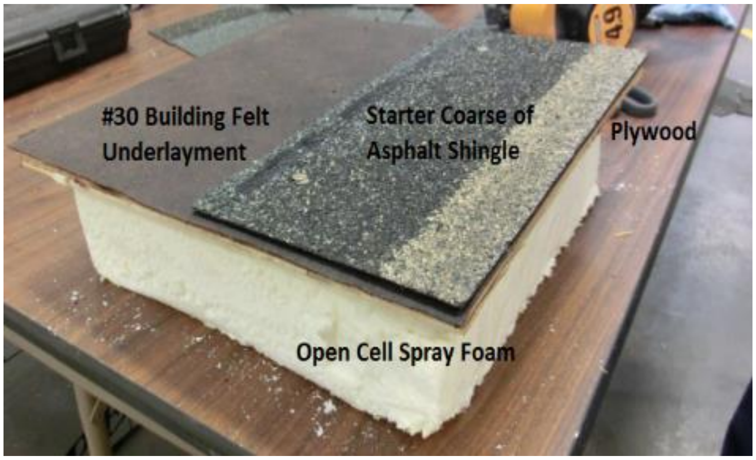


Figure 19: Cross Section of Roof Specimen

9.3.3 Wetting procedure

The initial moisture content of the wood sheathing for each sample was determined using a Delmhorst BD-2100 hand-held moisture meter. The sample was then weighed in order to determine the amount of water absorption necessary to reach the equilibrium wood saturation of 30% as seen in the calculation below.

Sample calculation:

$$MC_{Initial} = 7.4\%$$

$$MC_{Desired} = 30\%$$

$$\begin{aligned} \Delta MC &= MC_{Desired} - MC_{Initial} \\ &= 30\% - 7.4\% = 22.6\% \end{aligned}$$

$$TotalWt = 2.60\ lb$$

$$\begin{aligned} FoamWt &= Vol_{SPF} \cdot \rho_{SPF} \\ &= (0.292 ft^3) \cdot (2 lb / ft^3) = 0.58\ lb \end{aligned}$$

$$\begin{aligned} WoodWt_{Initial} &= TotalWt\ -\ FoamWt \\ &= 2.60\ lb - 0.58\ lb = 2.02\ lb \end{aligned}$$

$$\begin{aligned} WaterWt_{Initial} &= WoodWt_{Initial} \times MC_{Initial} \\ &= 2.02\ lb \times 7.4\% = 0.15\ lb \end{aligned}$$

$$\begin{aligned} WoodWt_{Dry} &= WoodWt_{Initial} - WaterWt_{Initial} \\ &= 2.02\ lb - 0.15\ lb = 1.87\ lb \end{aligned}$$

$$1 + \Delta MC = \frac{WoodWt_{Dry} + WaterWt_{Additional}}{WoodWt_{Dry}}$$

Thus,

$$\begin{aligned} WaterWt_{Additional} &= WoodWt_{Dry} \times \Delta MC \\ &= 1.87\ lb \times 22.6\% = 0.42\ lb = 6.77\ oz \end{aligned}$$

$$\begin{aligned} WaterVol_{Additional} &= \frac{WaterWt_{Additional}}{\rho_{Water}} \\ &= \frac{0.42\ lb}{62.4\ lb / ft^3} = 0.0068\ ft^3 = 6.51\ oz = 192.55\ ml \end{aligned}$$

Each sample of wood sheathing (and insulation, if any) was placed into plastic bags (double wrapped) and the measured volume of water (calculated above) was added to the bag (Figure 20). The weight of water was standardized to 180 grams per sample in order to expedite process based on preliminary testing of water absorption. The samples were weighed over a 48 hour period – (at 24, 36 and 48 hour) until saturated equilibrium weight was achieved. Once the saturated weight was achieved in all 36 samples, they were weighed to obtain the initial saturated weight. The samples were then installed with the appropriate roofing material (pre-cut) which consisted of 3-tab asphalt shingle and underlayment (#30 building felt and Self Adhering roof membrane), cut to just fit the individual roofing sample. These roofing coverings are fastened to the roof deck using roofing nails tacked along the perimeter of each sample at 6 in. o.c. To minimize systematic (epistemic) measurement errors, the roofing sample locations within the roof grid were randomized and sample were weighed in random order. The change in weight in each sample will be monitored throughout the testing period using an Ohaus Ranger 7000 scale (Figure 21). The weight change will be monitored regularly, (twice daily in initial weeks and recorded).

Figure 20: Wrapped sample being saturated

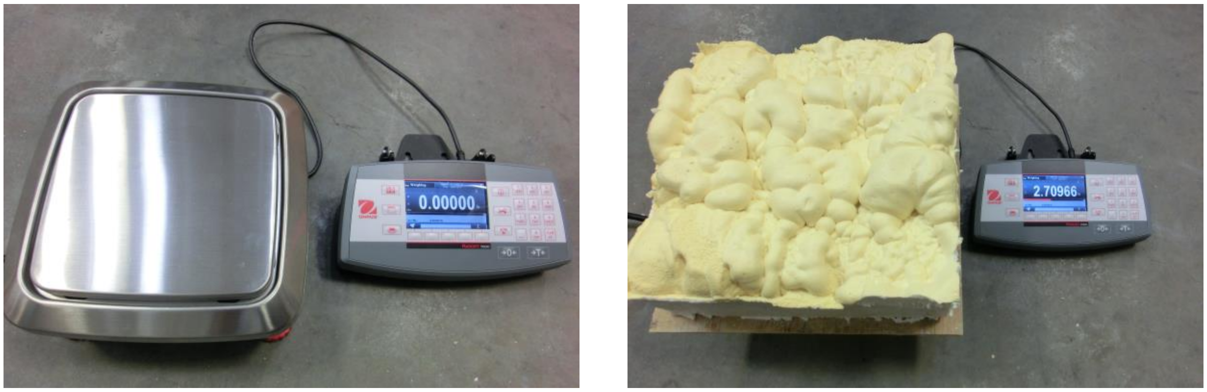


Figure 21: Weighing procedure for installed roof deck samples

9.3.4 Temperature and RH control

The temperature and relative humidity within the "attic" area below the samples are maintained at climate conditions of the laboratory. The 18-ton HVAC system in this 7,000 sf high-bay laboratory space can maintain a nominally constant temperature and remove moisture to maintain relatively low relative humidity conditions. While moisture gain to the top side may occur we are not planning to control for this moisture buildup, as the hot side of the chamber represents “outside” conditions. Average relative humidity in Florida is generally high – i.e. 77% yearly average for Gainesville, FL. The roof deck temperature is controlled by two Johnson Control A419 thermostats to a set temperature of 150F. The thermostat will be placed at the roof deck level, and connected to an on/off switch in series with ceramic heater circuit. The Advisory Panel advised at the 21/22 January 2015 meeting to limit the thermal loading to constant temperature difference and to evaluate moisture movement in a horizontal roof deck. This test setup is not intended to simulate IR heat thermal load or actual moisture flow in sloped real roof assemblies subjected to daily temperature fluctuations. Temperature and RH conditions were monitored above and below the samples using LogTag data loggers at the four corners of the structure, and the changes in moisture (i.e. sample weight) monitored over the test period. Results from this experiment plan to be justified using a WUFI 1-D numerical simulation in the future to be used for comparison to the experimental moisture changes. Figure 22 and Figure 23 show temperatures and relative humidity for three locations within the "attic" area and one location in the conditioned space at the entrance to the thermal chamber.

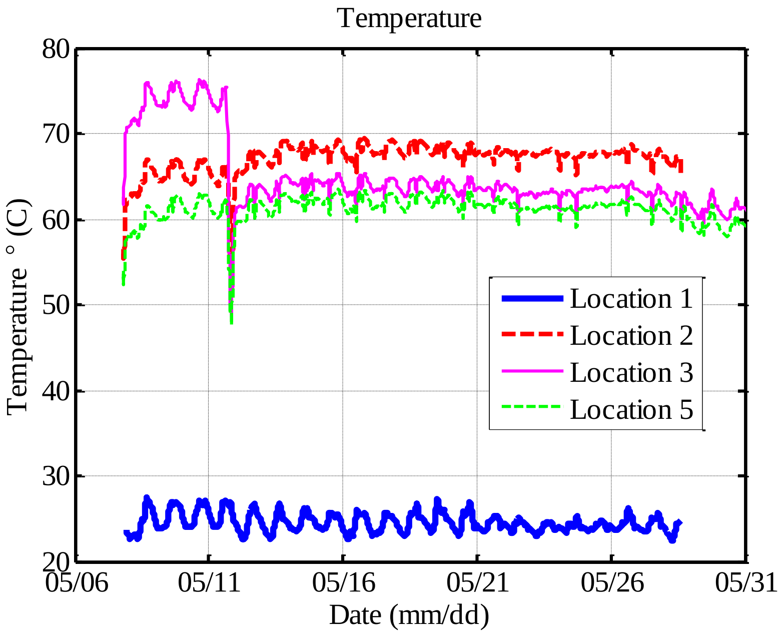


Figure 22: Log Tag Temperature Data

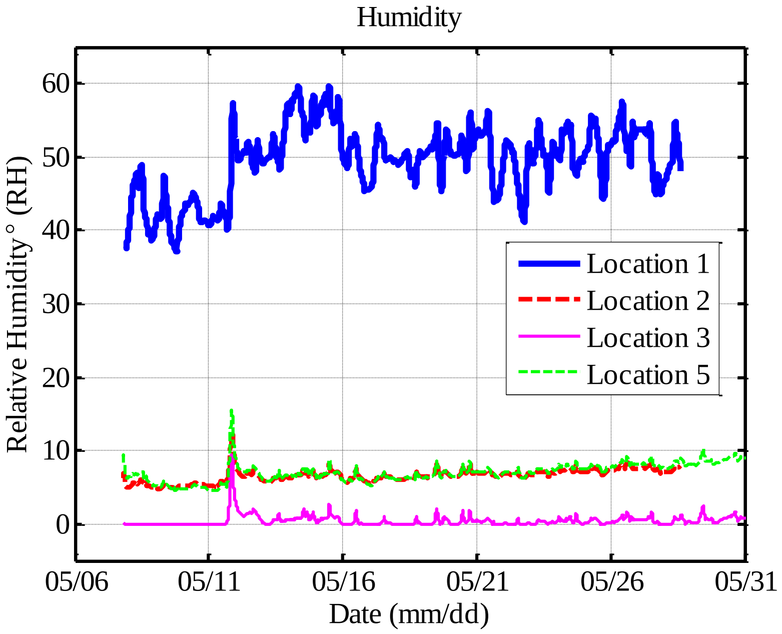


Figure 23: Log Tag Humidity Data

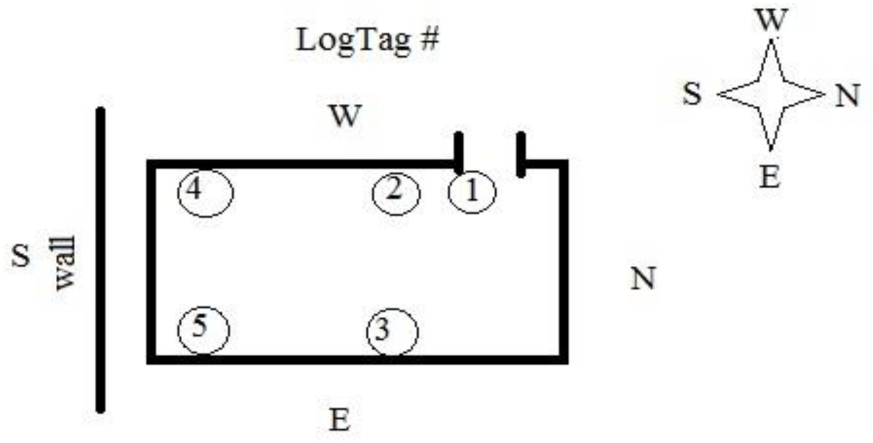
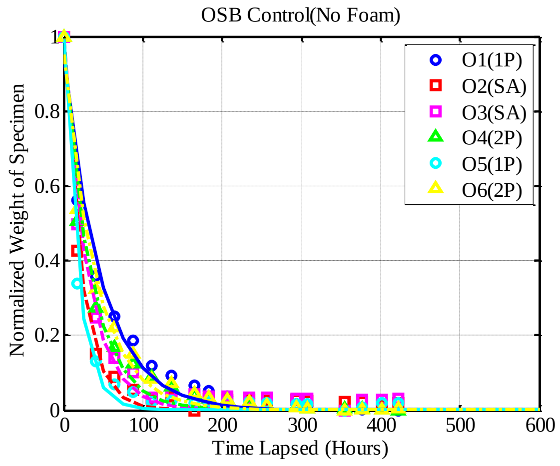
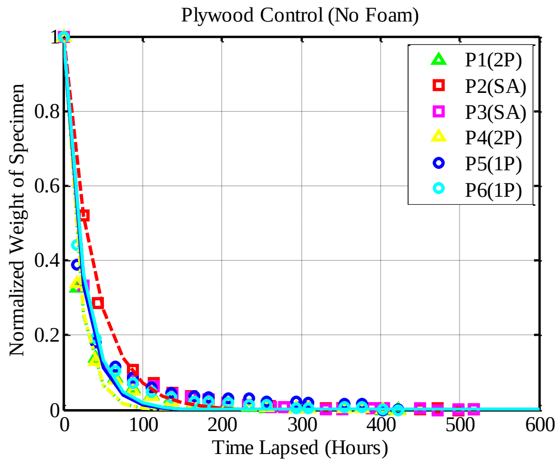


Figure 24: Map Location of Log Tag Placement (Note: Log Tag 1 is in lower level and 2-5 are in the temperature controlled attic space.)

9.4 Results

The weights of the specimen were recorded daily. The time elapsed between each weighing was taken by subtracting the date and time the sample was put in the thermal chamber from the time it was weighed. The weight of each specimen against the time lapsed in hours was plotted. This provides a general curve of the amount of water lost by the sample over time. Because each sample had a different starting weight a normalized plot was made for each sheathing and insulation type. The normalized results were obtained by taking the all the sample weights and dividing them by the initial weight. These graphs show the deviation of the drying rate trends of each sample.





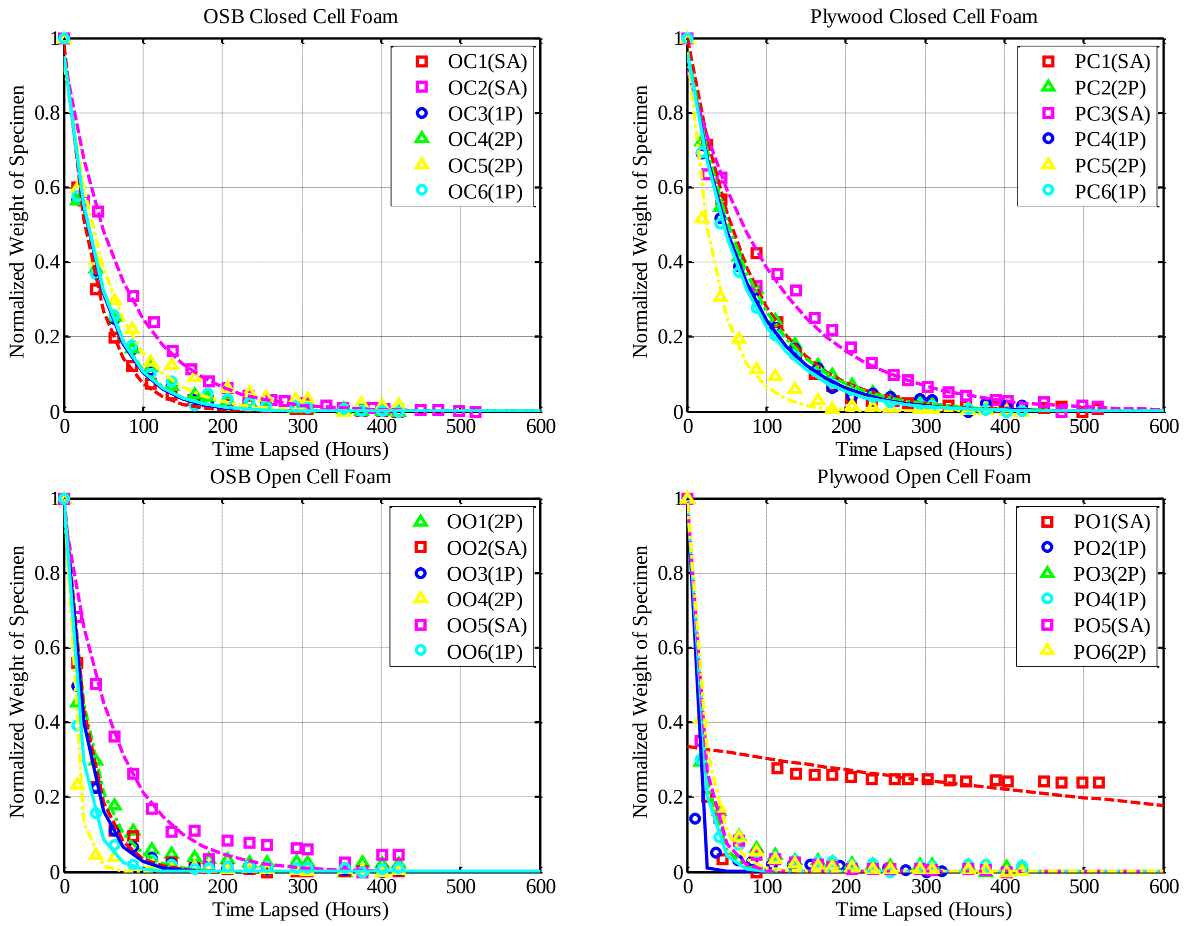
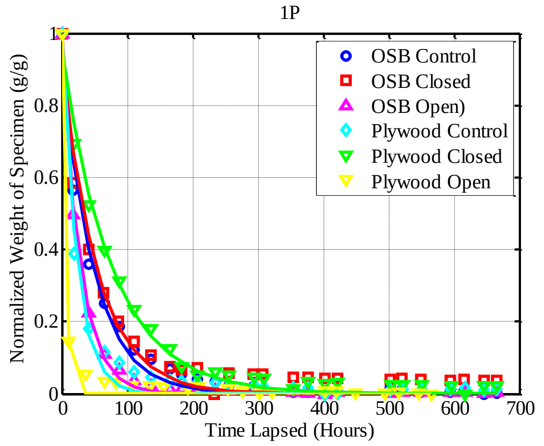
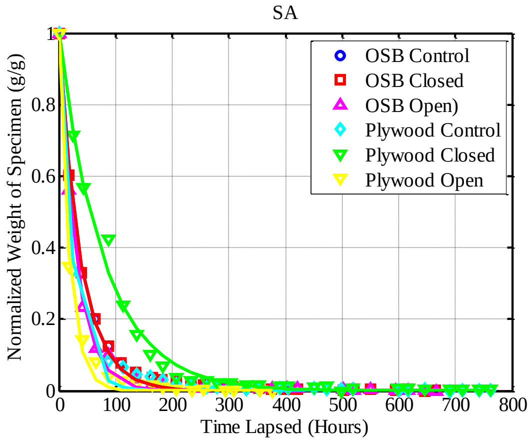


Figure 25: Normalized Drying Rate Data





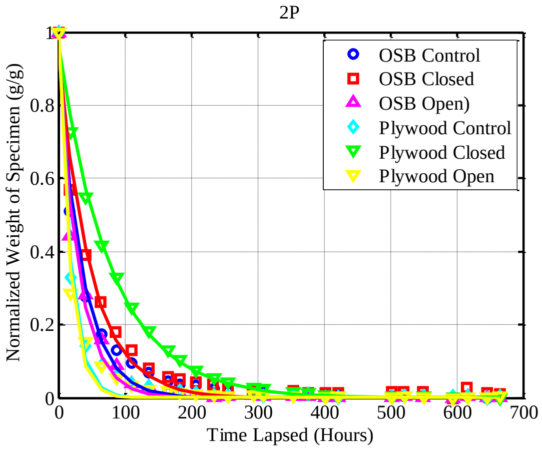


Figure 26: Normalized Data

In this study, half-life was used to evaluate the drying rates of all the specimen from the thermal chamber testing. It is representative of the amount of time required for the amount of water weight to fall to half its initial value. The term is used more generally for discussing any type of exponential decay. It has been well established that the exponential decay function is adequate to fit the curves of the weight change of all this specimen from this study, as illustrated in Figure 25 and Figure 26. We obtained the half-life of 36 samples by interpolating their individual weight variation curves. Figure 27 presents the 36 half-life times, along with the mean and standard deviation of each group of data. Results showed that the mean of the half-life for the plywood specimen with ccSPF installed is the highest among six groups. As compared with the plywood specimen with ccSPF, the ccSPF OSB roof panels have a shorter half-life time, but still superior to others. As a whole, the installation of ccSPF slows down the drying process of roof panels, regardless of the types of underlayment and roof panel materials.

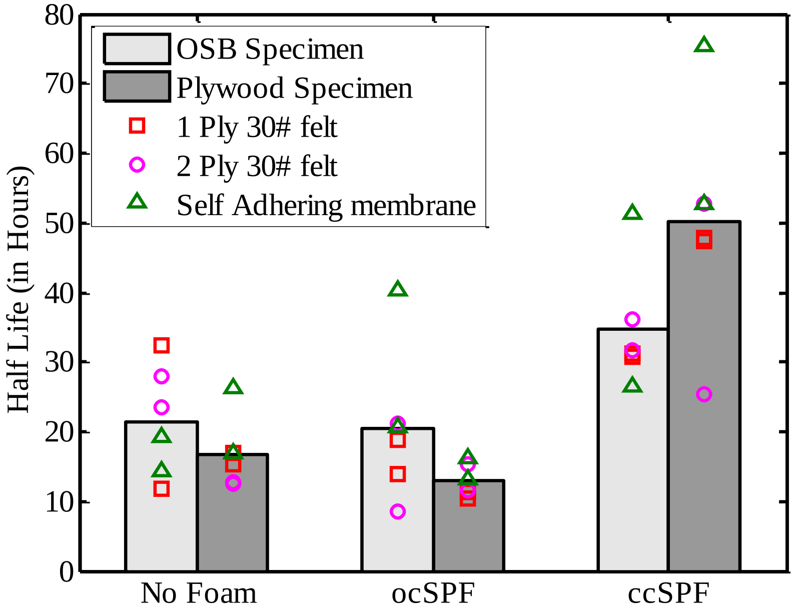


Figure 27: Half-life for all specimen

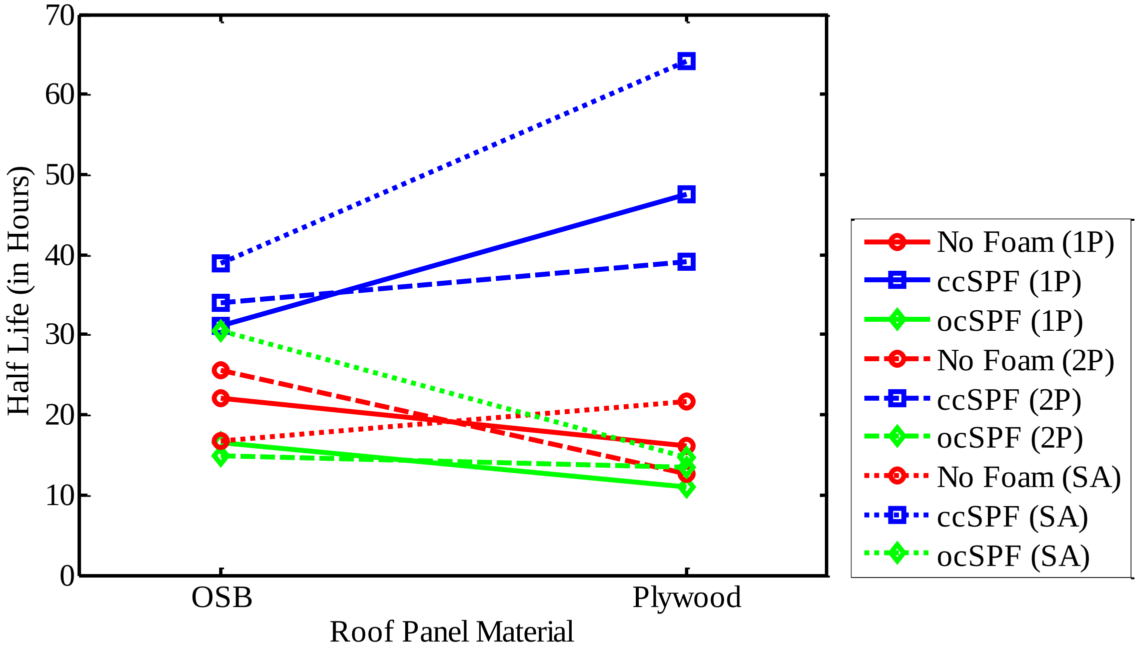


Figure 28: Interaction plot for different roof panel materials

As mentioned earlier, two random samples were measured in this study for each roof panel material, each type of underlayment and each foam installation. We took the average of the two repetitions and plotted them in Figure 28. It was observed that OSB samples have a larger half time than plywood samples, except in the case of specimen with ccSPF installed. It indicates that there is an interaction between the foam installation and roof panel materials.

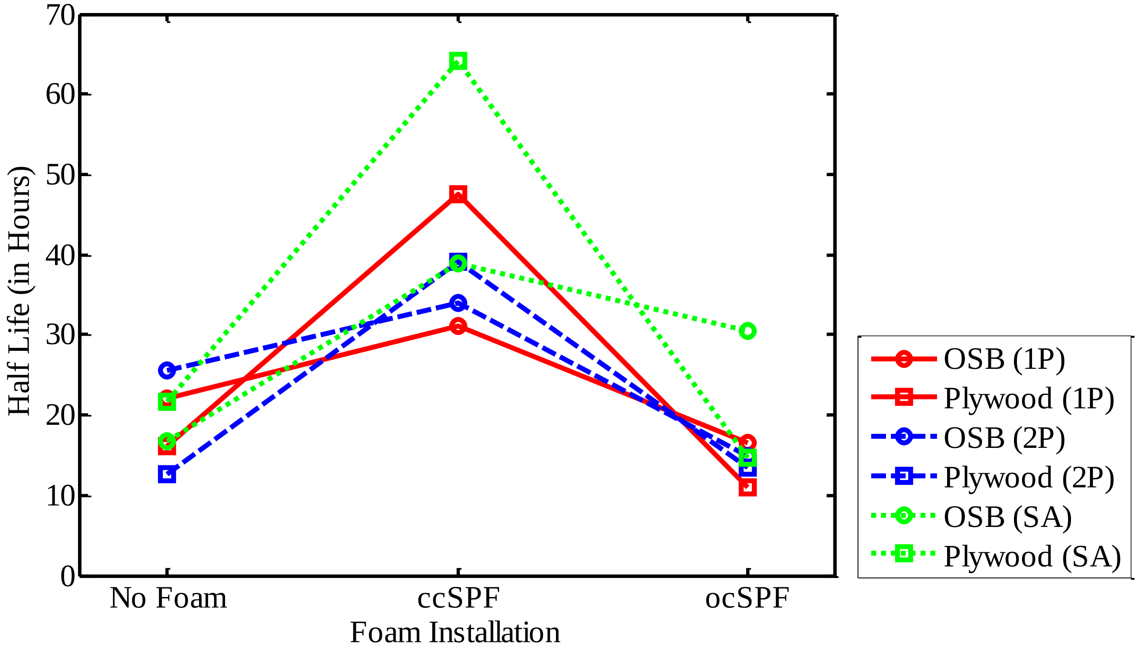


Figure 29: Interaction plot for different foam installations

Figure 29 presents the interaction plot of the samples with various foam installations. The half-life of ccSPF samples is the highest, whereas ocSPF samples have the lowest half-life, except for plywood sample with self-adhering underlayment.

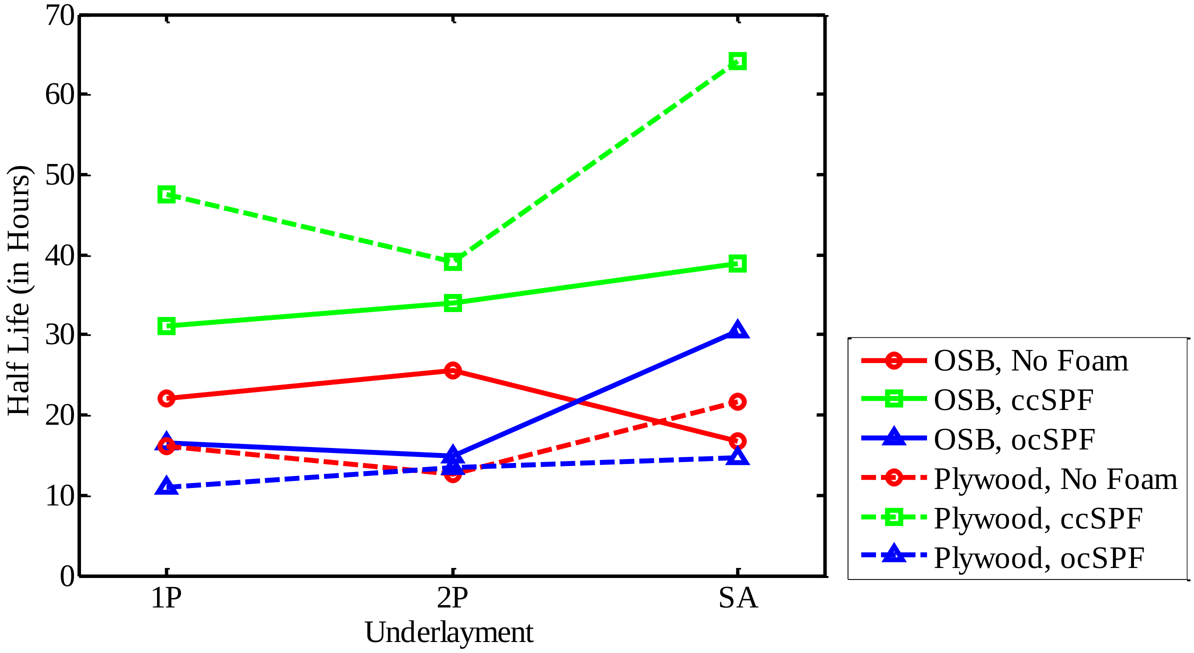


Figure 30: Interaction plot for different types of underlayment

Figure 30 presents the interaction plot of samples with different types of underlayment. Generally, the samples with self-adhering underlayment have a higher half-life than the other two types of underlayment. It means that the installation of self-adhering underlayment slows drying process of wood member.

9.5 Conclusions

Findings from ERP 3a are summarized below.

- The average drying rates for all underlayment types, from fastest to slowest are ranked as follows:
    1) Plywood ocSPF
    2) Plywood Control
    3) OSB ocSPF
    4) OSB Control
    5) OSB ccSPF
    6) Plywood ccSPF
- Multiple underlayment plys did not affect drying rates.
- Self-adhered membrane slowed the drying rate compared to 30# felt underlayments in five of the six specimens.

10 Experimental Research Plan 3B: Point Source Water Leakage

10.1 Objective

The objectives of this research are to determine: (i) the rate of moisture spread in plywood and OSB roof decking from a point leak source; (ii) if a non-destructive method of detecting moisture due to a roof leak is feasible (using Infra-red photography). The study will advance our understanding of the moisture movement along and within a wood roof deck having a moisture impermeable layer applied to its underside.

10.2 Motivation

To determine the moisture spreading effect over time that spray foam and roof sheathing have when subjected to a typical roof failure and leakage scenario. The purpose is to perform comparative testing to existing homes with roof damage and spray foam.

10.3 Approach

Fabricate 64, 2’x4’, test samples with 2 in 12 mono-sloped south-facing roof pitch installed with spray foam insulation to determine the spread of moisture from a point source leak. The south orientation yields the highest moisture contents (Prevatt et al. 2014) and the constant roof slope is typical of one side of a roof assembly. Specimens were exposed to a continuous drip of water between 1-3 mL/min for up to 8 weeks. The methodology for the point source leakage is from (Prevatt et al. 2014) in which a series of drip emitters will provide continuous wetting. The moisture accumulation over time will be monitored via gravimetric sampling of 4” x 4” roof samples per ASTM D4442. These moisture contents will be plotted versus time to develop contour plots to show the spread of moisture throughout sheathing. This will answer: (A) Does Peel and Stick limit absorption of moisture into wood? and (B) Does having 2 vapor retarders (top-underlayment, bottom- SPF) limit drying of moisture? The full test matrix is provided in Table 12.

Table 12: Test Matrix for ERP 3b

Exposure Period	OSB				Plywood			
	#30 Felt - 1 layer		Peel and Stick		#30 Felt - 1 layer		Peel and Stick	
	No Foam	ccSPF	No Foam	ccSPF	No Foam	ccSPF	No Foam	ccSPF
Start	X	X	X	X	X	X	X	X
1 week	X	X	X	X	X	X	X	X
2 week	X	X	X	X	X	X	X	X
2 week - No Leak	X	X	X	X	X	X	X	X
4 week	X	X	X	X	X	X	X	X
6 week	X	X	X	X	X	X	X	X
8 week	X	X	X	X	X	X	X	X
8 week - No Leak	X	X	X	X	X	X	X	X

10.3.1 Specimen Fabrication

64 wood deck test samples (each sample measures 4 ft long x 2 ft wide) were fabricated with 3-tab asphalt shingle roofing and one of two underlayment materials (#30 felt or grace ice and water shield). Additional membrane flashing was installed along top and sloping edges to minimize potential for incidental water entry from sources other than the leak point source (Figure 31). All samples were installed on a 3 ft tall frame (low side) with a 2 in 12 roof slope (minimum permitted roof slope for steep-sloped roofing per FL Building Code (1507.2 - Asphalt shingles)) (Figure 32). The specimen were faced due south to maximize the solar exposure to the samples.

Figure 31: Membrane installed on all edges to prevent uncontrolled moisture travel

Figure 32: Asphalt Shingle Installation (Left) and Sample Placement (Right)

10.3.2 Wetting Procedure

An in-line non pressure actuating drip emitters attached to ¼ inch tubing at a slope of ¼ inch per foot point was installed at the center of each sample 4 inches from the high side (Figure 33). A calibrated, consistent rate of water of 1-3 mL/min will pass directly to the roof deck through a 5/8” diameter hole in the roofing and underlayment. A 4 inch pressure head is maintained by supply reservoirs which have intake and outflow valves to keep the pressure head constant (Figure 34). The experiment was constructed outside of the Powell Lab and exposed to existing Gainesville weather, including natural thermal cycling, in addition to the point-source water leak during the 8-week exposure period. Temperature and relative humidity readings will be recorded from the local airport weather station that is 1.65 miles from the test site.

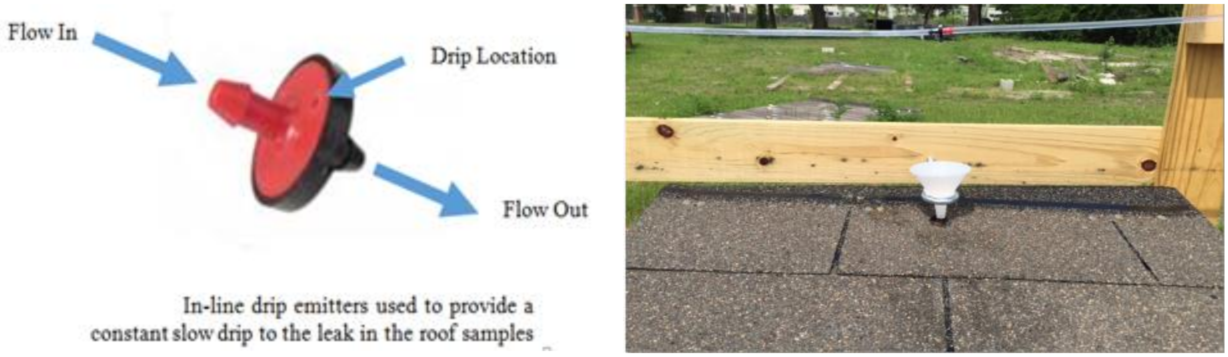


Figure 33: Drip Emitter Diagram (Left) Drip Emitter Test Setup (Right)

Figure 34: Complete Test Configuration

10.3.3 Data Acquisition

At the end of Weeks 1, 2, 3, 4, 6 and 8, one set of samples was harvested. For each sample, (25) 4 in. by 4 in. gravimetric specimens was extracted from a sample (Figure 36) and the spray foam was carefully cut from the sheathing specimen without damaging the sheathing. The samples are wrapped in cellophane to seal moisture before weighing within 24 hours with an OHAUS Ranger 7000 scale. The moisture contents of each specimen were determined per ASTM D 4442.

It should be noted that, as can be seen in Figure 35, mineral deposits from the water formed over time on the drippers and slowed the dripping rate below the desired 1-3 mL/min. This was unexpected and the differences in drip rate were not obvious until week 6. All of the drippers over the week 8 samples were replaced at week 6 and checked to ensure a consistent flow rate, but it is probable that Week 6 samples, and possibly even some Week 4 samples, experienced slower dripper flow rates than Week 1 and 2 samples.

Figure 35: Old dripper with mineral deposits indicated by white ellipse

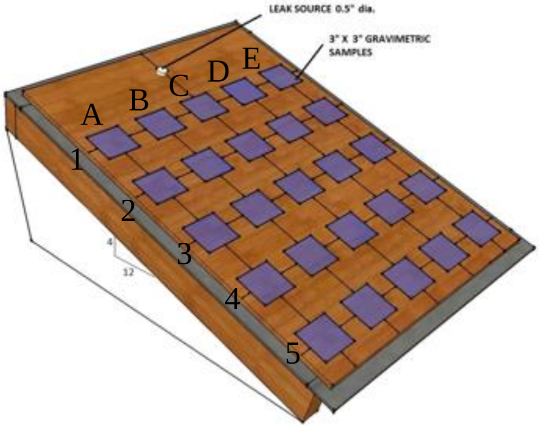


Figure 36: Specimen numbering scheme

At the end of week 8, the spread of moisture in the samples will be quantified using an FLIR Thermacam PM 695 infrared camera.

10.4 Results

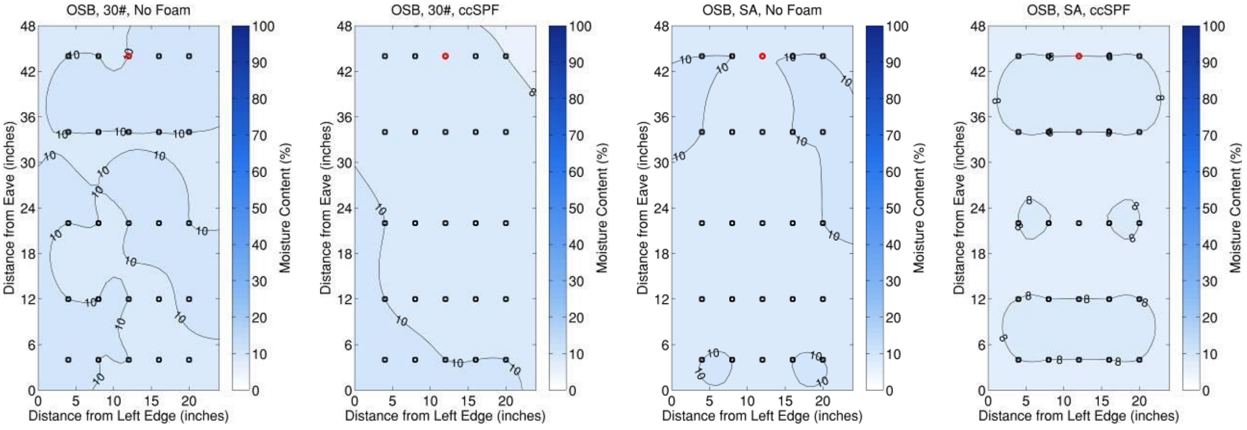
The weight of moisture in grams for each gravimetric sample was summed for each specimen to obtain a total moisture weight. This provides a measure of the total moisture absorbed into the specimen after the end of the exposure period, giving a quantitative comparison of the moisture retention in the various specimens. Table 2 gives the preliminary moisture results for each specimen.

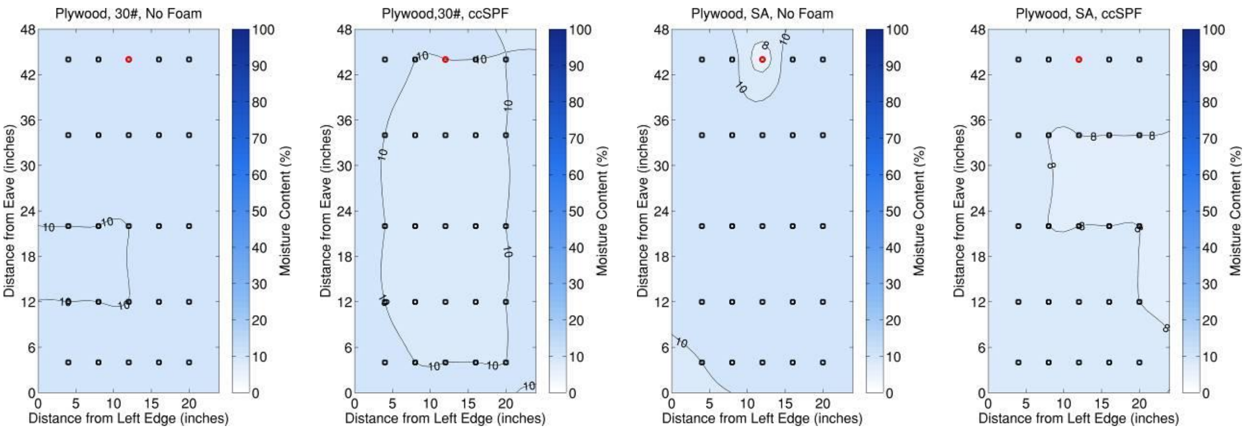
Table 13: Total Moisture (g) in the 25 gravimetric samples for each specimen in the test matrix

	OSB				Plywood			
	#30 Felt - 1 layer		Peel and Stick		#30 Felt - 1 layer		Peel and Stick	
	No Foam	ccSPF	No Foam	ccSPF	No Foam	ccSPF	No Foam	ccSPF
Start	200.5	163.7	159.3	134.1	172.7	165.2	192.8	135.1
1 week	627.0	1692.2	838.9	882.1	937.9	316.3	164.4	174.4
2 week	843.1	2011.1	528.9	1748.0	985.2	1034.7	36.6	415.2
2 week – No Drip	125.6	109.6	114.4	118.6	147.7	132.7	144.9	90.9
4 week	978.0	1788.9	602.7	1825.2	152.5	826.2	195.5	264.4
6 week[1]	143.2	1231.1	237.5	1060.1	362.8	632.6	130.9	204.0
8 week	X	X	X	X	X	X	X	X
8 week - No Leak	X	X	X	X	X	X	X	X

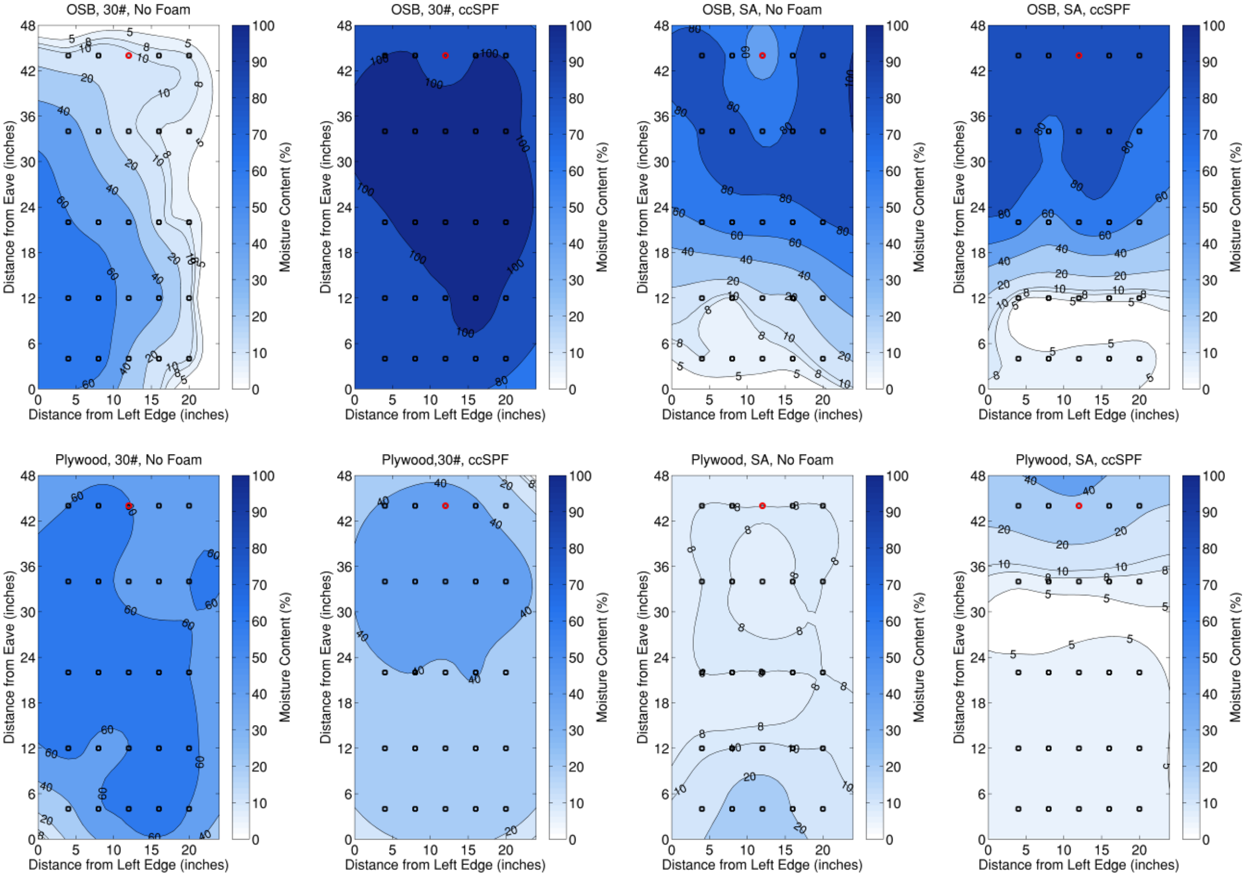
The spread of moisture within the samples over time is visualized using contour plots, interpolating the moisture contents based on the moisture data from the 25 gravimetric samples within each specimen. The contours are presented below by week, with labels at the top of each plot identifying the specimen type. The plots are oriented such that the specimens sloped from top to bottom. The location of the point leak source is identified by the red circle. Black rectangles indicate the center point of the 4 inch by 4 inch gravimetric samples.

Week 0

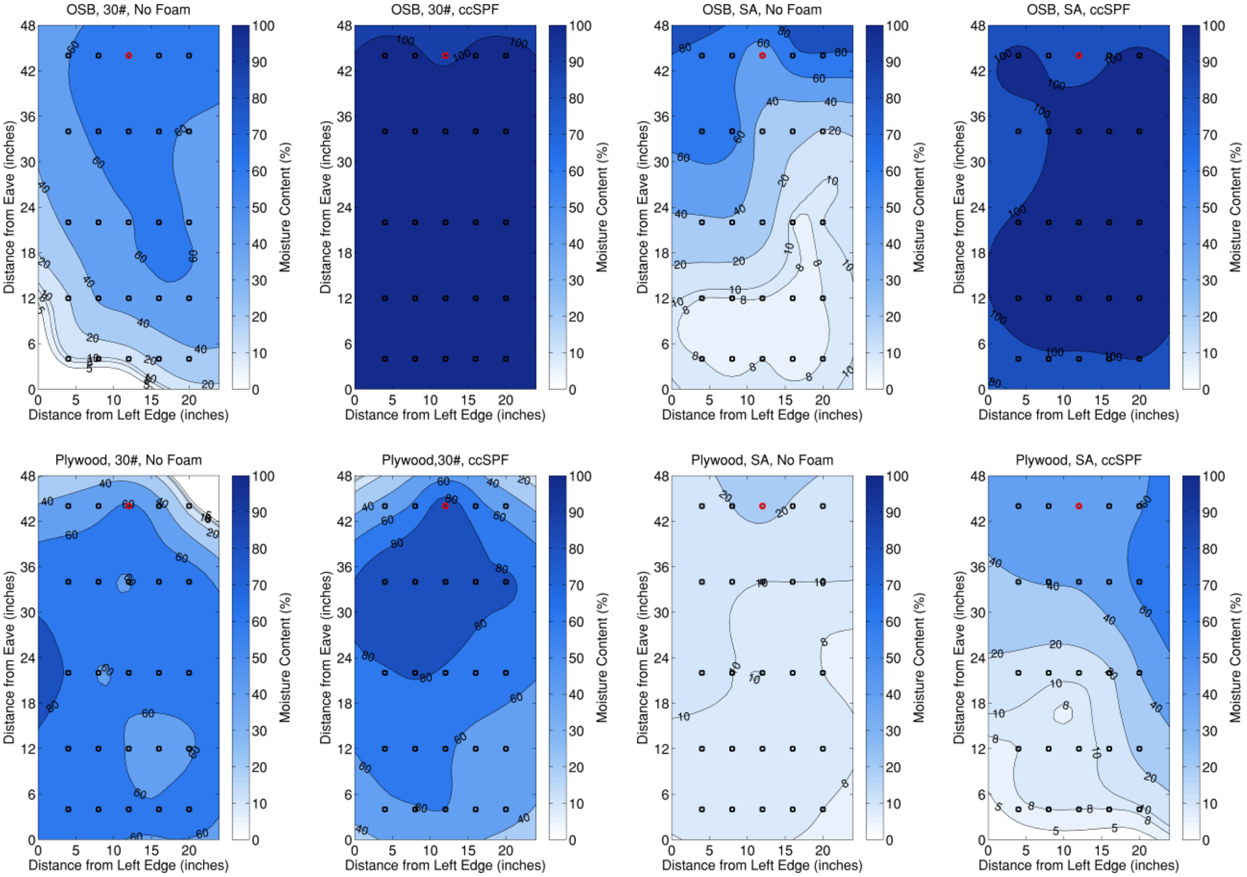



Plywood, 30#, No Foam
Plywood,30#, ccSPF
Plywood, SA, No Foam
Plywood, SA, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)
0
6
12
18
24
30
36
42
48
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100

Week 1


OSB, 30#, No Foam
OSB, 30#, ccSPF
OSB, SA, No Foam
OSB, SA, ccSPF
Plywood, 30#, No Foam
Plywood,30#, ccSPF
Plywood, SA, No Foam
Plywood, SA, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)
0
6
12
18
24
30
36
42
48
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100

Week 2



OSB, 30#, No Foam

OSB, 30#, ccSPF

OSB, SA, No Foam

OSB, SA, ccSPF

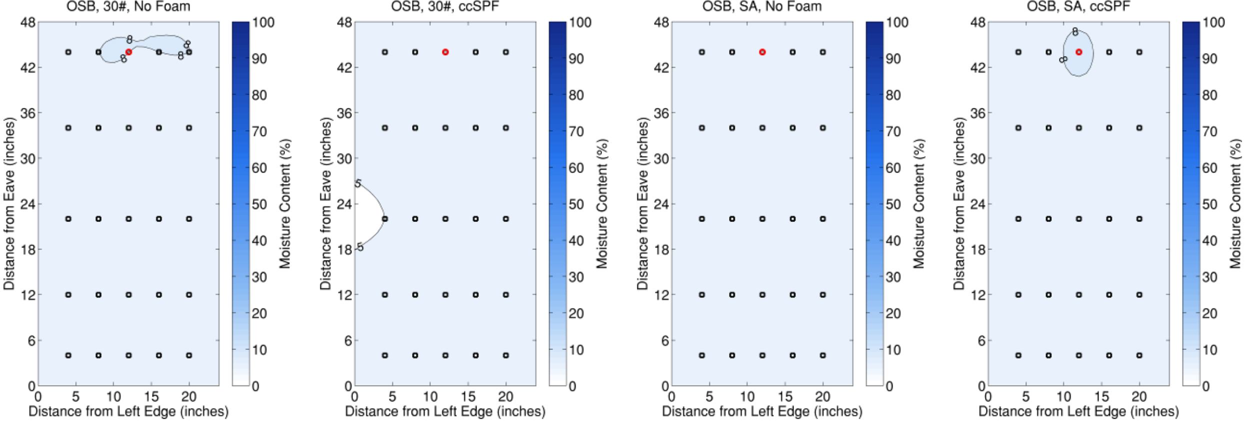
Plywood, 30#, No Foam

Plywood,30#, ccSPF

Plywood, SA, No Foam

Plywood, SA, ccSPF

Week 2 (No Drip)

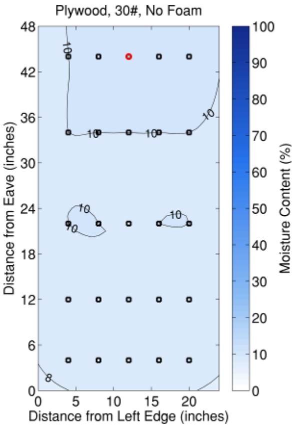


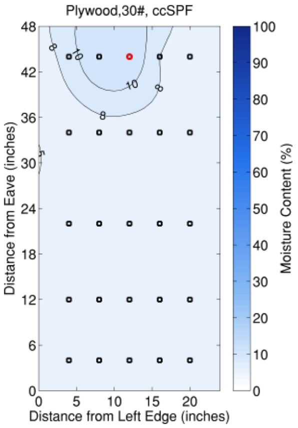
OSB, 30#, No Foam

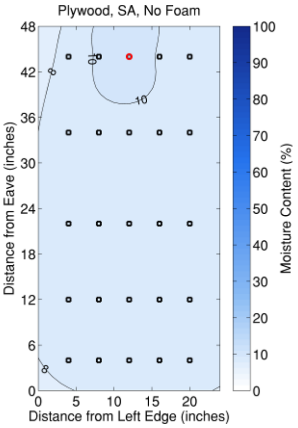
OSB, 30#, ccSPF

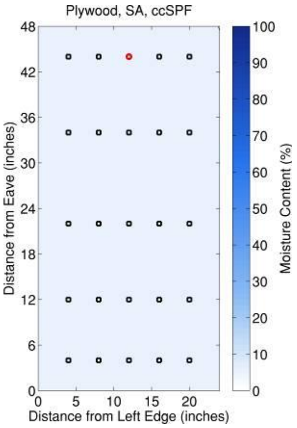
OSB, SA, No Foam

OSB, SA, ccSPF

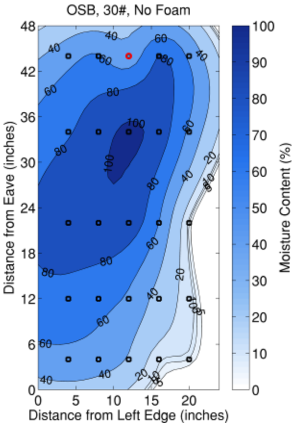

Plywood, 30#, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

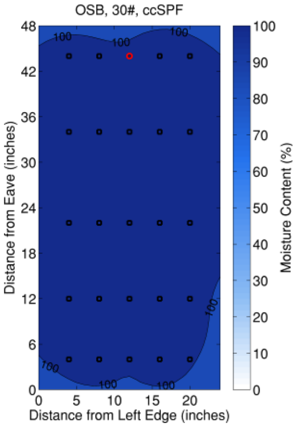

Plywood,30#, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

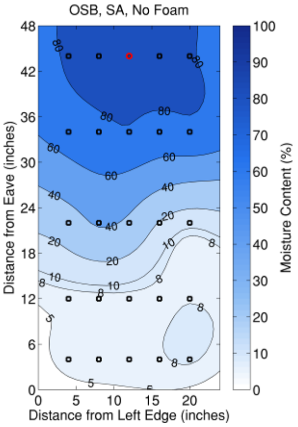

Plywood, SA, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

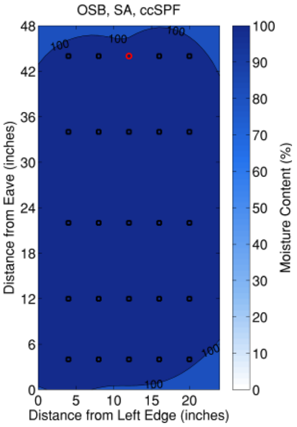

Plywood, SA, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

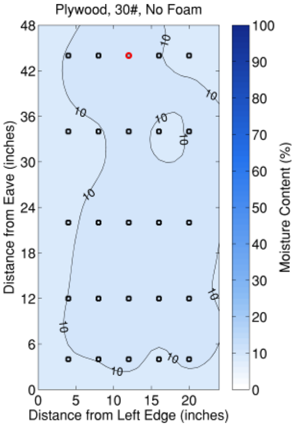
Week 4

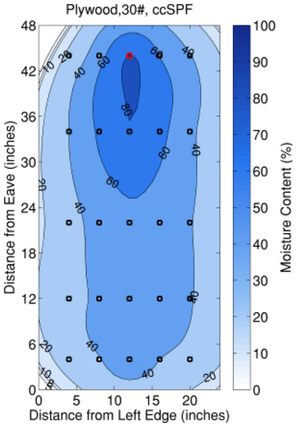

OSB, 30#, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

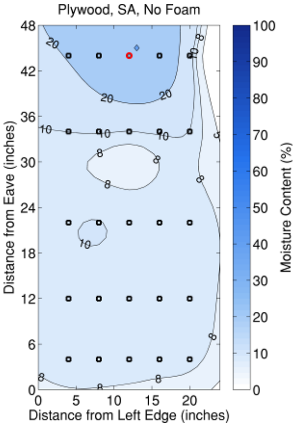

OSB, 30#, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

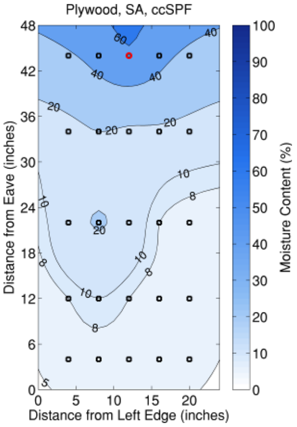

OSB, SA, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)


OSB, SA, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

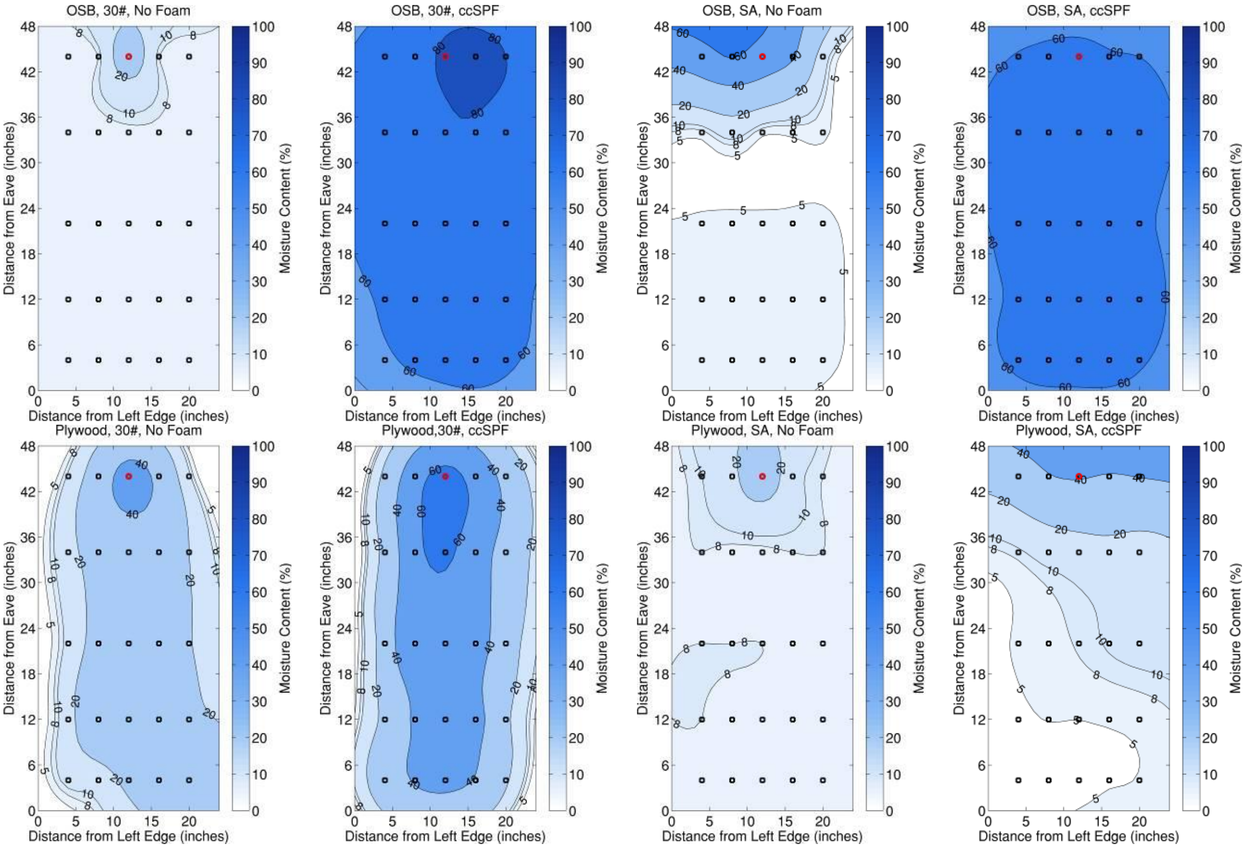

Plywood, 30#, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)


Plywood,30#, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)


Plywood, SA, No Foam
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)


Plywood, SA, ccSPF
Distance from Eave (inches)
Distance from Left Edge (inches)
Moisture Content (%)

Week 6



Week 8
[Data to be added]

Week 8 (No Drip)
[Data to be added]

10.5 Conclusions

The point leak source is clearly visible in many of the specimens through the high moisture contents centered around the location of the leak source. The moisture tends to emanate away from this point towards the sides and bottom of the specimen over time. The moisture travel down the slope of the roof (from top to bottom) is evident by comparing Week 1 samples to the ensuing weeks. By Week 2, the OSB samples with ccSPF are saturated (moisture contents near 100%), and this trend continues for most samples in Week 4. In Week 6, the effect of the slower drip rates is obvious with the total moisture significantly less than in preceding weeks. Overall the spread of moisture is relatively uniform, i.e., there are no significant irregularities or discontinuities in the contours themselves, which could be an indication of poor quality data.

Observations:

- In samples with drip leaks, 15 of the 16 samples with ccSPF had higher total moisture than the equivalent specimen without ccSPF.
- In samples without leaks, total moisture remained low throughout, although plywood specimens had more moisture than OSB specimens.
- Peel and stick was more effective at limiting moisture accumulation in plywood samples than in OSB samples.
- The highest total moisture, 2011 grams, was observed in the OSB specimen with 30# felt and ccSPF after two week exposure. The third and fifth highest moisture totals were also observed in this specimen type, for one week and four week exposures.
- In general for specimens with ccSPF, OSB specimens had higher moisture totals than plywood specimens.

11 Experimental Research Plan 4: Numerical hygrothermal model of wood roof deck samples with SPF insulation

11.1 Objective

Develop 1-D hygrothermal models of wood roof deck systems with installed spray foam insulation. Originally, this ERP sought to develop a numerical model of moisture movement in the roofs of the existing roofs in ERP 2 – Field Studies. However, during Advisory Panel Meeting it was decided that given the number of unknown factors in the existing construction this would not provide useful information, within timeframe of the project. As a result, the Advisory panel suggested modifying ERP 4 to simulate replicating the moisture movement in experimental samples conducted by the University of Florida research team, described in Experimental Research Plan 3a (ERP 3a).

The motivation for this work is that the simulated hygrothermal movement is predicated through numerical simulation is well established for one-directional moisture movement related to temperature fluctuations. The experimental samples were kept within a limited temperature range.

11.2 Test Set Up

Engineering Consultants Simpson Gumpertz & Heger Inc. (SGH) is performing hygrothermal (combined heat + moisture migration) simulations of the various asphalt shingle roof systems evaluated as part of this project. They are using the WUFI 5.3 computer program, developed by the Fraunhofer Institute for Building Physics, to simulate drying rates for a variety of insulated and uninsulated roof systems, in effect simulating the same insulation/underlayment/roof sheathing configurations that were included in the physical test samples of ERP 3a, described in Section 5, above. WUFI is a finite element simulator that calculates heat and moisture flows based on defined material properties, surface transfer coefficients, and time varying interior and exterior environmental conditions.

We re-created the laboratory tests using WUFI, matching the material geometries and initial wetting of the sheathing per the laboratory procedures. We will compare the model results to those obtained in the lab to better understand how closely the model represents the physical phenomena related to drying in these roof assemblies. Once the correlation between the model and the physical testing has been established, we will perform an additional series of analyses to evaluate drying potential at different insulation thicknesses than those reviewed in the laboratory.

Our final analysis will include a comparison of our WUFI analysis with the laboratory results, based on both relative drying rates and “half life” for the initial wetting as described in the report.

This analysis is currently underway by SGH and their results will be presented during the Roofing TAC meeting.

12 References

Alturkistani, A., Fazio, P., Rao, J., and Mao, Q. (2008). "A new test method to determine the relative drying capacity of building envelope panels of various configurations." *Building and Environment*, 43(12), 2203-2215.

Carll, C., and Wiedenhoeft, A. C. (2009). "Moisture-related properties of wood and the effects of moisture on wood and wood products." *Moisture control in buildings: the key factor in mold prevention, 2nd ed. West Conshohocken, PA: ASTM International*, 54-79.

Derome, D., and Fazio, P. (2000). "Large-scale testing of two flat roof assemblies insulated with cellulose." *Journal of architectural engineering*, 6(1), 12-23.

EPA (2012). "An Introduction to Indoor Air Quality: Volatile Organic Carbons (VOCs)." <http://www.epa.gov/iaq/voc.html>.

EPA (2015). "Spray Polyurethane Foam (SPF) Home." <http://www.epa.gov/oppt/spf/spray_polyurethane_foam.html>. (6/14, 2015).

Griffin, D. M. (1977). "Water potential and wood-decay fungi." *Annual Review of Phytopathology*, 15(1), 319-329.

Grin, A., Smegal, J., and Lstiburek, J. (2013). "Application of Spray Foam Insulation Under Plywood and OSB Roof Sheathing." *Building America Report–1312*.

Hendron, R., Anderson, R., Reeves, P., and Hancock, E. (2002). *Thermal performance of unvented attics in hot-dry climates*, National Renewable Energy Laboratory.

Huang, Y.-C. T., and Tsuang, W. (2014). "Health effects associated with faulty application of spray polyurethane foam in residential homes." *Environmental Research*, 134(0), 295-300.

Lstiburek, J. (2002). "Moisture control for buildings." *ASHRAE journal*, 44(2), 36-41.

Nelson, P. E., and Der Ananian, J. S. (2009). "Compact asphalt shingle roof systems: Should they be vented?" *Journal of ASTM International*, 6(4).

Nofal, M., and Kumaran, K. (2003). "Behavior of engineered wood materials under the effect of wetting and drying cycles." Citeseer.

Ojanen, T., and Ahonen, J. (2005). "Moisture performance properties of exterior sheathing products made of spruce plywood or OSB." VTT Working Papers 1459 7683 (http://www. vtt. fi/inf/pdf/) 2005.

Ojanen, T. T. (2001). "Thermal and Moisture Performance of a Sealed Cold-Roof System with a Vapor-Permeable Underlay." *Thermal Performance of the Exterior Envelopes of Buildings VIII*.

Pallin, S., Kehrer, M., and Miller, W. A. (2013). "A Hygrothermal Risk Analysis Applied to Residential Unvented Attics." Oak Ridge National Laboratory (ORNL).

Prevatt, D., McBride, K., Roueche, D., and Masters, F. (2014). "Wind Uplift Capacity of Foam-Retrofitted Roof Sheathing Panels Subjected to Rainwater Intrusion." *Journal of Architectural Engineering*, B4014001.

Prevatt, D. O. (2010). "Field evaluation of thermal performance and energy efficiency of ccSPF retrofitted vented residential attic." *Rep. No. UF01-10, Univ. of Florida, Gainesville, FL*.

Prevatt, D. O. (2013). "Spray-foam Retrofit of Wood Residential Roofs Interim Report."Sea Grant.

Prevatt, D. O. "Wind Uplift Capacity of Foam Retrofitted Roof Sheathing Subjected to Water Leaks." *Proc., Residential Building Design Conference*.

Rose, J. D., and American Plywood, A. (1998). "Preliminary testing of wood structural panel shear walls under cyclic (reversed) loading." American Plywood Association.

Rudd, A. (2005). "Field Performance of Unvented Cathedralized (UC) attics in the USA." *Journal of Building Physics*, 29(2), 145-169.

Saber, H. H., Lacasse, M. A., Swinton, M. C., and Kumaran, M. K. (2010). "Benchmarking of hygrothermal model against measurements of drying of full-scale wall assemblies."

Salonvaara, M., Karagiozis, A., and Desjarlais, A. "Moisture Performance of Sealed Attics in Climate Zones 1 to 4." *Proc., Thermal Performance of the Exterior Envelope of Whole Buildings XII International Conference*.

Schumaker, C. (2007). "BSD-149: Unvented Roof Assemblies for All Climates — Building Science Information." Building Science Corporation.

Shreyans, S. (2011). "Thermal performance of foam retrofitted vented residential attic."

Straube, J., Smegal, J., and Smith, J. (2010). "Moisture-Safe Unvented Wood Roof Systems." *Buildingscience. com*.

Timusk, P. C. (2008). *An investigation of the moisture sorption and permeability properties of mill-fabricated oriented strandboard*.

Trechsel, H. R. (2001). *Moisture Analysis and Condensation Control in Building Envelopes*, ASTM.

Tsuang, W., and Huang, Y.-C. T. (2012). "Asthma Induced by Exposure to Spray Polyurethane Foam Insulation in a Residential Home." *Journal of Occupational and Environmental Medicine*, 54(3).

Viitanen, H. A. (1997). "Modelling the time factor in the development of mould fungi-The effect of critical humidity and temperature conditions on pine and spruce sapwood." *Holzforschung-International Journal of the Biology, Chemistry, Physics and Technology of Wood*, 51(1), 6-14.

Wu, Q., and Ren, Y. (2000). "Characterization of sorption behavior of oriented strandboard under long-term cyclic humidity exposure condition." *Wood and fiber science*, 32(4), 404-418.

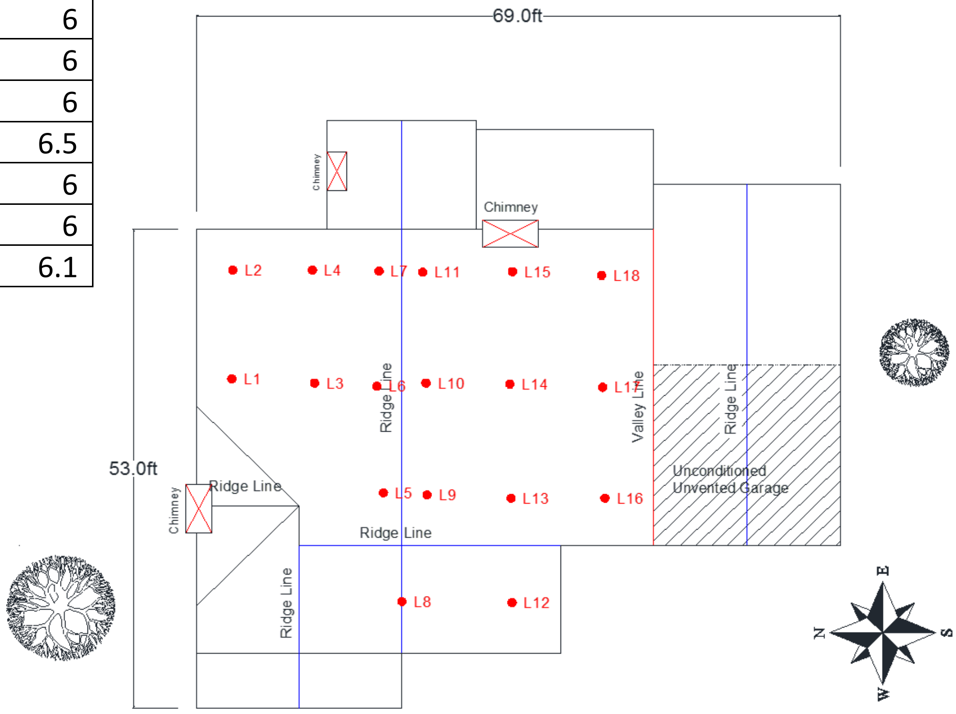
Wu, Y., Fazio, P., and Kumaran, M. (2008). "Moisture buffering capacities of five North American building materials." *Journal of Testing and Evaluation*, 36(1), 489.

13 Appendix

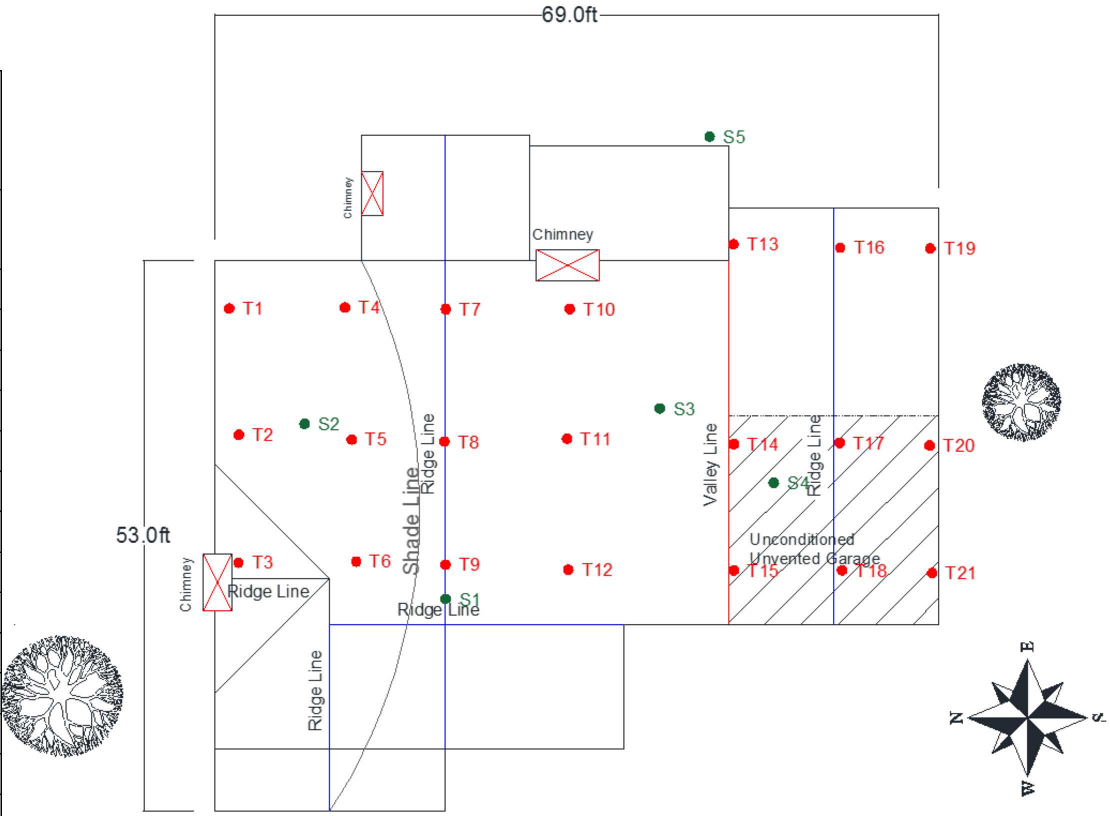
A. ERP 2 House Inspection Data

a. House 1

Attic			
Location	Temp (°C)	Thickness (in)	MC (%)
L1	27.2	3	7.3
L2	28	2 7/8	6.7
L3	28.4	3	6
L4	28.8	3 1/4	6.2
L5	28.6	2 3/8	6.3
L6	32.4	2 1/4	6.6
L7	31.6	2 1/2	7
L8	28.6	2 7/8	6
L9	30.6	2 1/2	6
L10	32.4	2 3/4	6.2
L11	31.4	2 1/4	6.3
L12	28.4	2 1/2	6
L13	33	2	6
L14	31	2 1/2	6
L15	31.8	2 5/8	6.5
L16	31.5	2 1/4	6
L17	30.2	2 1/4	6
L18	31.2	2 1/2	6.1

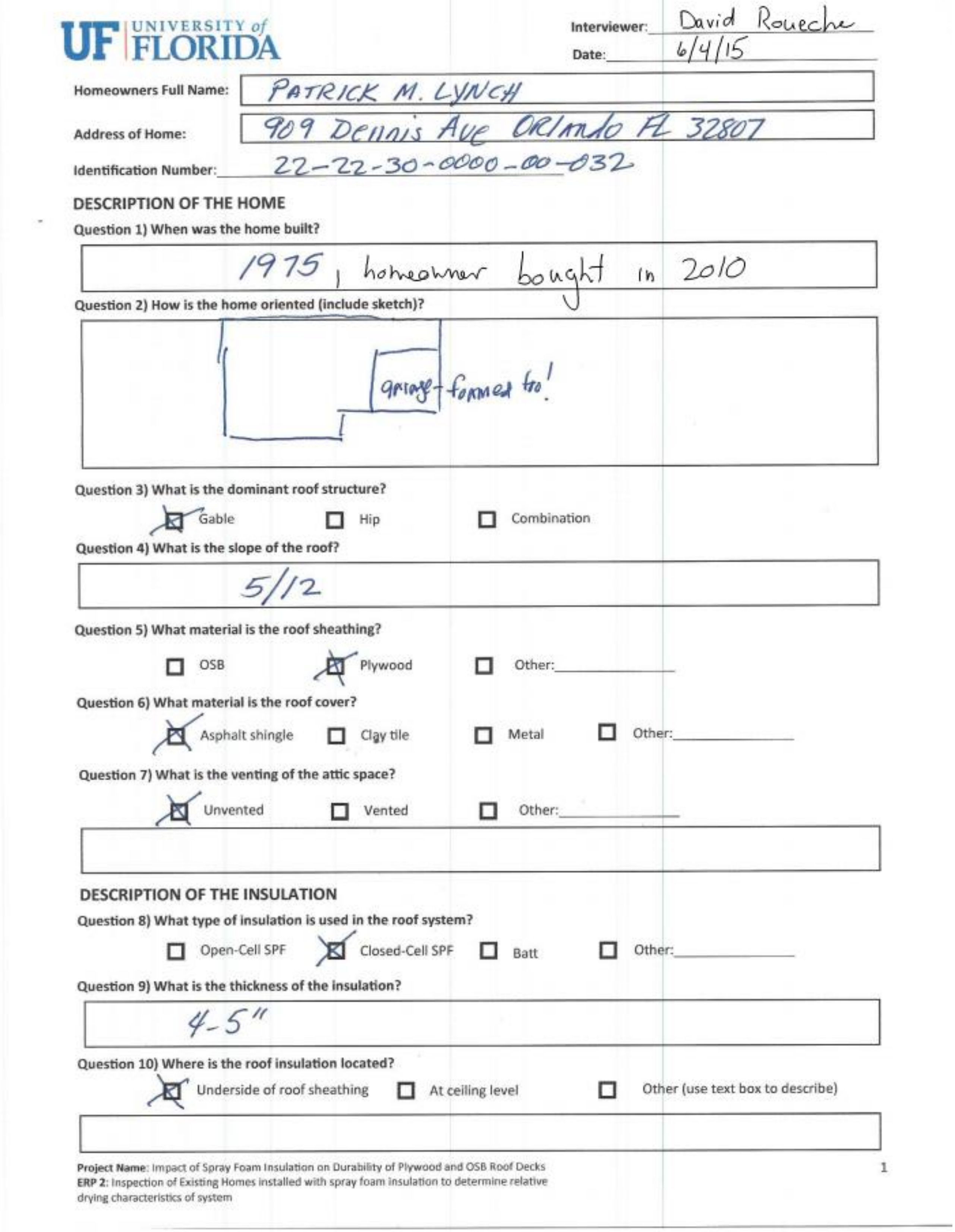


Shingle Surface Temperature Readings	
Location	Temp (°C)
T1	34.6
T2	34.2
T3	35.0
T4	47.4
T5	42.8
T6	38.2
T7	56.8
T8	56.6
T9	54.4
T10	54.2
T11	61.4
T12	61.6
T13	54.8
T14	60.4
T15	59.8
T16	58.6
T17	60.4
T18	63.8
T19	58.4
T20	38.8
T21	59.0



Logtags	
Logtag	Serial#
S1	1310012680
S2	1310012684
S3	1310012678
S4	1310012679
S5	1310012682

b. House 1 Questionaire



UF UNIVERSITY of FLORIDA

Interviewer: David Roueche
Date: 6/4/15

Homeowners Full Name: PATRICK M. LYNCH

Address of Home: 909 Dennis Ave Orlando FL 32807

Identification Number: 22-22-30-0000-00-032

DESCRIPTION OF THE HOME

Question 1) When was the home built?

1975, homeowner bought in 2010

Question 2) How is the home oriented (include sketch)?

garage - foamed too!

Question 3) What is the dominant roof structure?

☒ Gable ☐ Hip ☐ Combination

Question 4) What is the slope of the roof?

5/12

Question 5) What material is the roof sheathing?

☐ OSB ☒ Plywood ☐ Other:

Question 6) What material is the roof cover?

☒ Asphalt shingle ☐ Clay tile ☐ Metal ☐ Other:

Question 7) What is the venting of the attic space?

☒ Unvented ☐ Vented ☐ Other:

DESCRIPTION OF THE INSULATION

Question 8) What type of insulation is used in the roof system?

☐ Open-Cell SPF ☒ Closed-Cell SPF ☐ Batt ☐ Other:

Question 9) What is the thickness of the insulation?

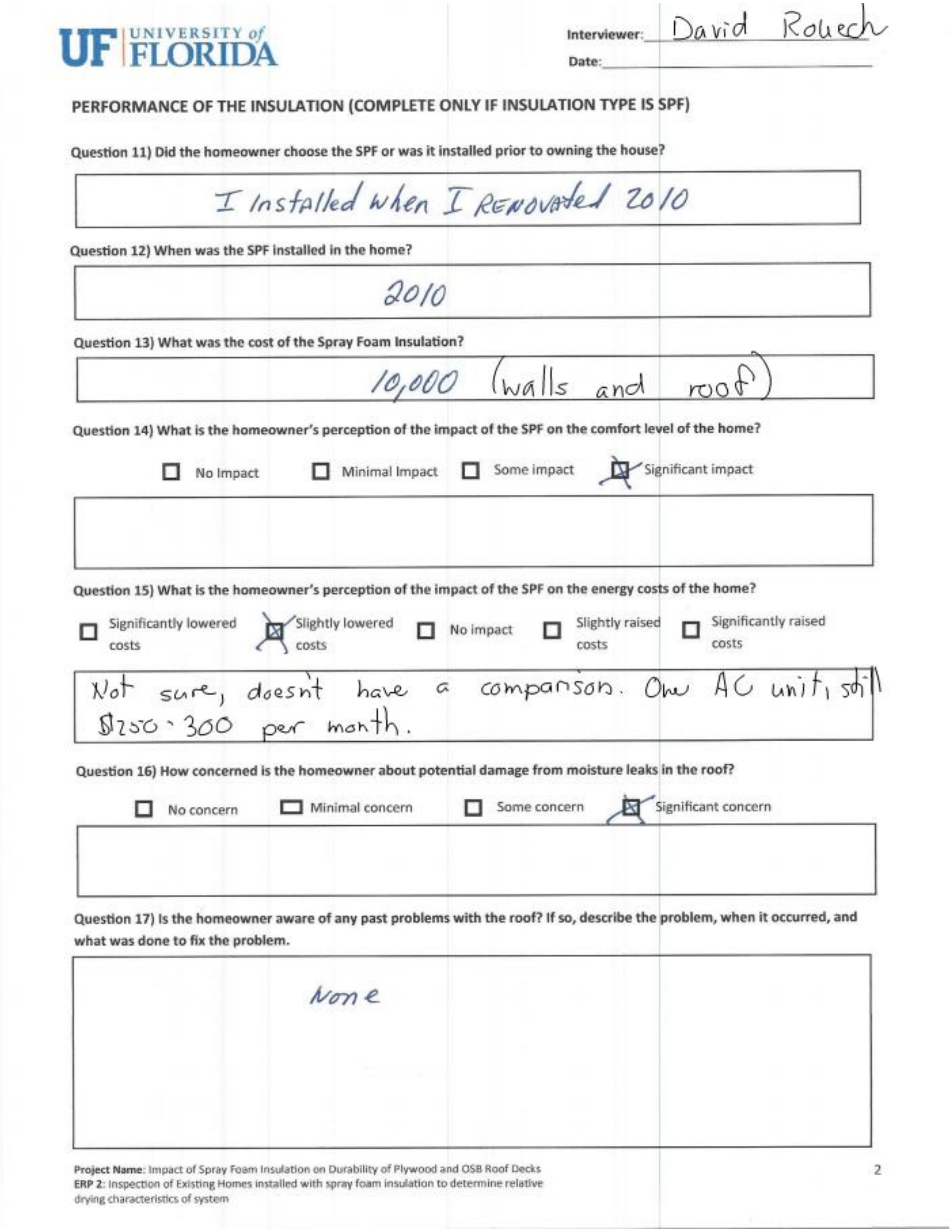
4-5"

Question 10) Where is the roof insulation located?

☒ Underside of roof sheathing ☐ At ceiling level ☐ Other (use text box to describe)

Project Name: Impact of Spray Foam Insulation on Durability of Plywood and OSB Roof Decks
ERP 2: Inspection of Existing Homes installed with spray foam insulation to determine relative drying characteristics of system

1



UF UNIVERSITY of FLORIDA

Interviewer: David Rouech

Date:

PERFORMANCE OF THE INSULATION (COMPLETE ONLY IF INSULATION TYPE IS SPF)

Question 11) Did the homeowner choose the SPF or was it installed prior to owning the house?

I Installed when I Renovated 2010

Question 12) When was the SPF installed in the home?

2010

Question 13) What was the cost of the Spray Foam Insulation?

10,000 (walls and roof)

Question 14) What is the homeowner's perception of the impact of the SPF on the comfort level of the home?

☐ No Impact ☐ Minimal Impact ☐ Some impact ☒ Significant impact

Question 15) What is the homeowner's perception of the impact of the SPF on the energy costs of the home?

☐ Significantly lowered costs ☒ Slightly lowered costs ☐ No impact ☐ Slightly raised costs ☐ Significantly raised costs

Not sure, doesn't have a comparison. One AC unit, still $250-300 per month.

Question 16) How concerned is the homeowner about potential damage from moisture leaks in the roof?

☐ No concern ☐ Minimal concern ☐ Some concern ☒ Significant concern

Question 17) Is the homeowner aware of any past problems with the roof? If so, describe the problem, when it occurred, and what was done to fix the problem.

None

Project Name: Impact of Spray Foam Insulation on Durability of Plywood and OSB Roof Decks
ERP 2: Inspection of Existing Homes installed with spray foam insulation to determine relative drying characteristics of system

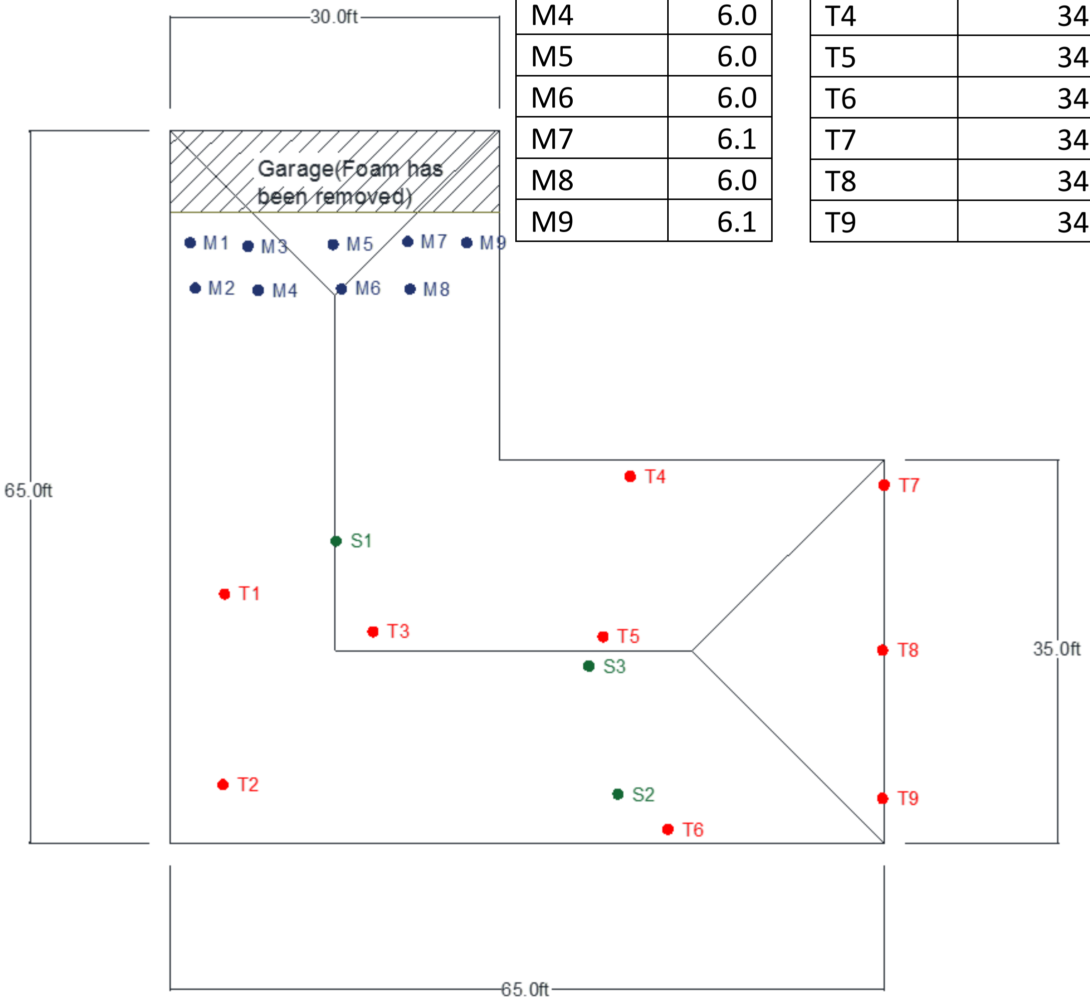
2

c. House 2

Logtags	
Logtag	Serial#
S1	1310012681
S2	1310012683
S3	1310012686

Moisture Content	
Location	MC %
M1	6.0
M2	6.1
M3	6.0
M4	6.0
M5	6.0
M6	6.0
M7	6.1
M8	6.0
M9	6.1

Attic Temperature Readings	
Location	Temp (°C)
T1	34.6
T2	33.8
T3	34.2
T4	34.8
T5	34.8
T6	34.8
T7	34.4
T8	34.6
T9	34.8



d. House 3

Asphalt Shingles Temperature			
Location	Temp (°C)	Location	Temp (°C)
T1	46.4	T21	48.2
T2	41.8	T22	36.2
T3	36.2	T23	35.6
T4	44.2	T24	55.4
T5	34	T25	54.2
T6	34	T26	55
T7	44	T27	54.6
T8	35.8	T28	55.8
T9	38	T29	55.6
T10	37.4	T30	55.6
T11	32.8	T31	53.8
T12	48.6	T32	55.8
T13	47.2	T33	54.8
T14	40.8	T34	54.2
T15	35.2	T35	54.2
T16	32.4	T36	52.8
T17	52.8	T37	54.4
T18	32.4	T38	54.4
T19	33.6	T39	54
T20	49	T40	53.6

Logtags	
Logtag	Serial#
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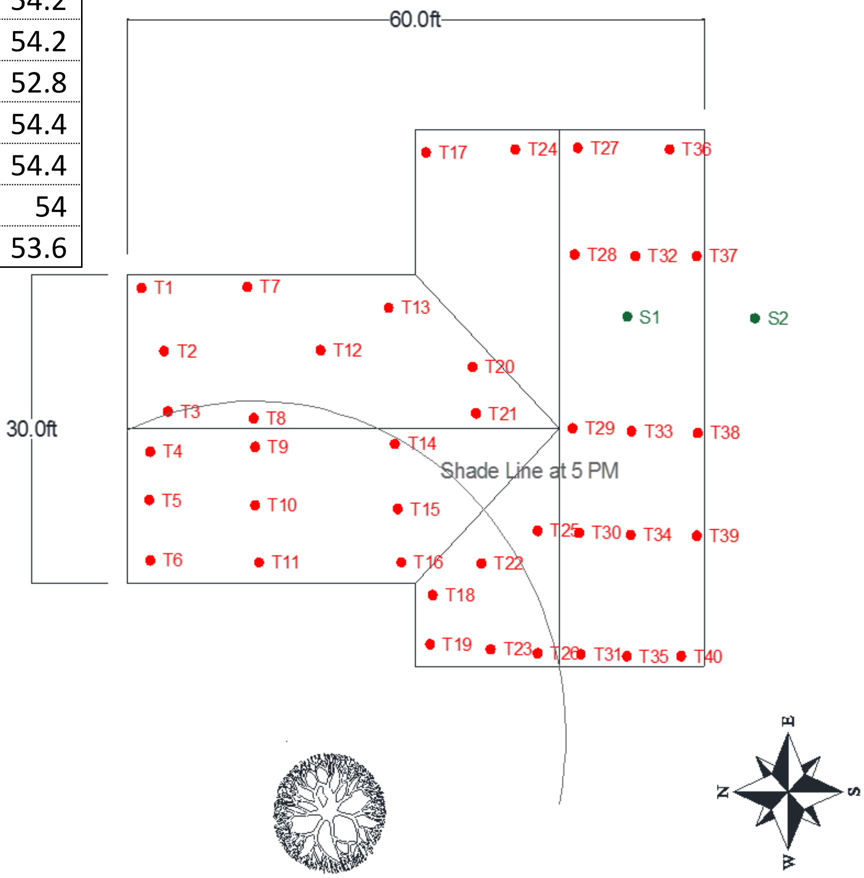
S2	1310012676



Attic Temperature Readings	
Location	Temp (°C)
T1	34.6
T2	34.2
T3	35.0
T4	47.4
T5	42.8
T6	38.2
T7	56.8
T8	56.6
T9	54.4
T10	54.2
T11	61.4
T12	61.6
T13	54.8
T14	60.4
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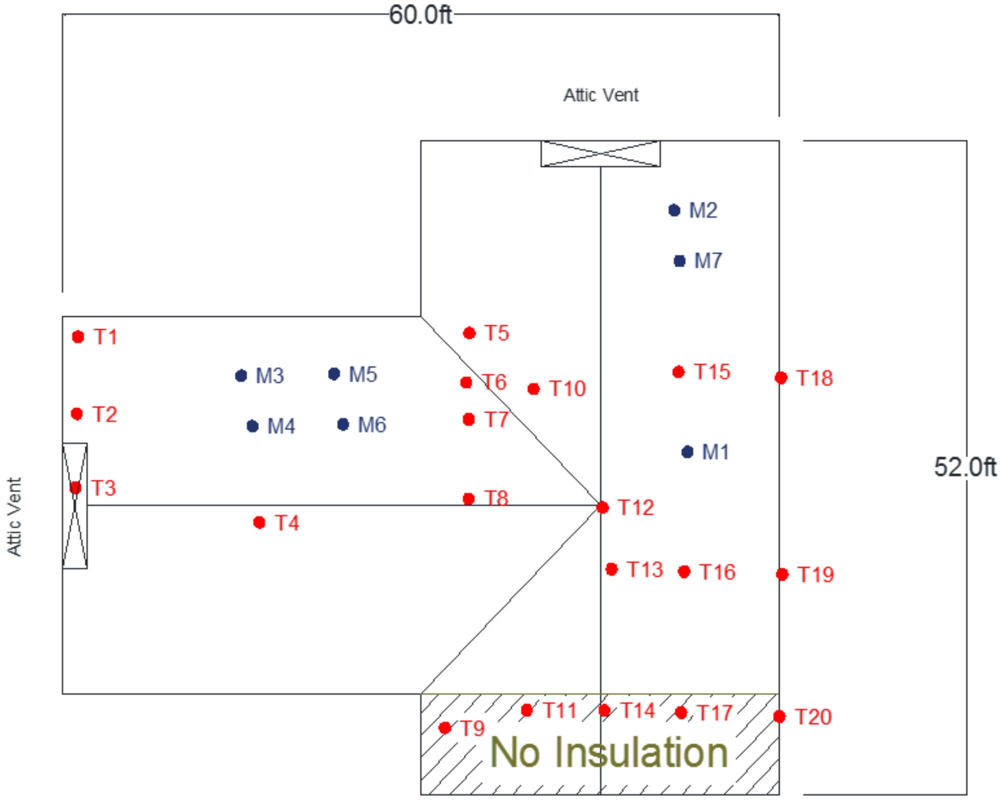
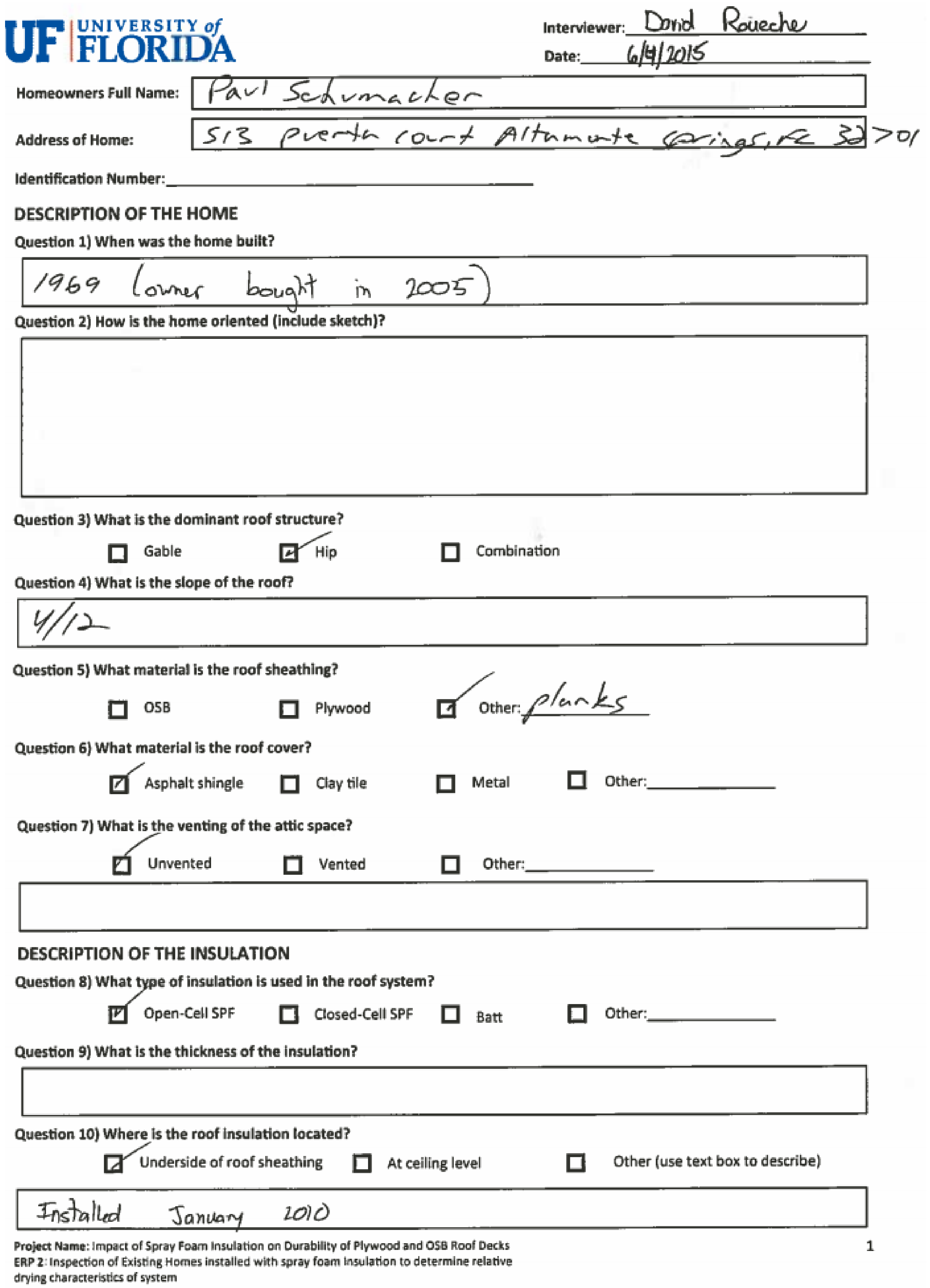
T16	58.6
T17	60.4
T18	63.8
T19	58.4
T20	38.8
T21	59.0



Moisture Content	
Location	MC %
M1	6.1
M2	< 7 .0
M3	
M4	
M5	
M6	
M7	

e. House 3 Questionaire



UF UNIVERSITY of FLORIDA

Interviewer: David Roueche

Date: 6/4/2015

Homeowners Full Name: Paul Schumacher

Address of Home: 513 Puerta Court Altamonte Springs, FL 32701

Identification Number: ____________________

DESCRIPTION OF THE HOME

Question 1) When was the home built?

1969 (owner bought in 2005)

Question 2) How is the home oriented (include sketch)?

Question 3) What is the dominant roof structure?

☐ Gable ☑ Hip ☐ Combination

Question 4) What is the slope of the roof?

4/12

Question 5) What material is the roof sheathing?

☐ OSB ☐ Plywood ☑ Other: planks

Question 6) What material is the roof cover?

☑ Asphalt shingle ☐ Clay tile ☐ Metal ☐ Other:__________

Question 7) What is the venting of the attic space?

☑ Unvented ☐ Vented ☐ Other:__________

DESCRIPTION OF THE INSULATION

Question 8) What type of insulation is used in the roof system?

☑ Open-Cell SPF ☐ Closed-Cell SPF ☐ Batt ☐ Other:__________

Question 9) What is the thickness of the insulation?

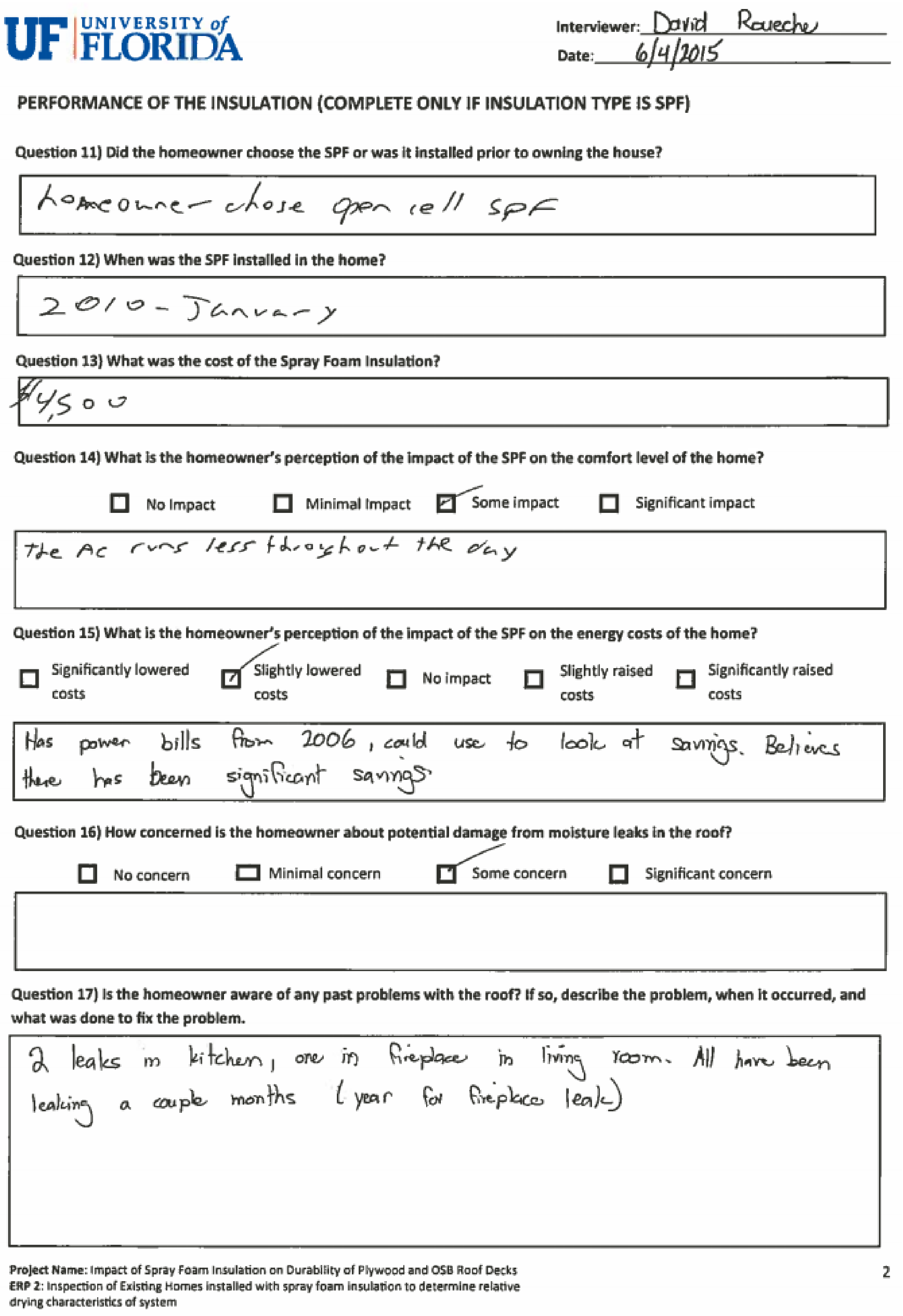
Question 10) Where is the roof insulation located?

☑ Underside of roof sheathing ☐ At ceiling level ☐ Other (use text box to describe)

Installed January 2010

Project Name: Impact of Spray Foam Insulation on Durability of Plywood and OSB Roof Decks
ERP 2: Inspection of Existing Homes installed with spray foam insulation to determine relative drying characteristics of system

1



UF UNIVERSITY of FLORIDA

Interviewer: David Roueche
Date: 6/4/2015

PERFORMANCE OF THE INSULATION (COMPLETE ONLY IF INSULATION TYPE IS SPF)

Question 11) Did the homeowner choose the SPF or was it installed prior to owning the house?

homeowner chose open cell SPF

Question 12) When was the SPF installed in the home?

2010 - January

Question 13) What was the cost of the Spray Foam Insulation?

$4,500

Question 14) What is the homeowner's perception of the impact of the SPF on the comfort level of the home?

☐ No Impact ☐ Minimal Impact ☑ Some impact ☐ Significant impact

The AC runs less throughout the day

Question 15) What is the homeowner's perception of the impact of the SPF on the energy costs of the home?

☐ Significantly lowered costs ☑ Slightly lowered costs ☐ No impact ☐ Slightly raised costs ☐ Significantly raised costs

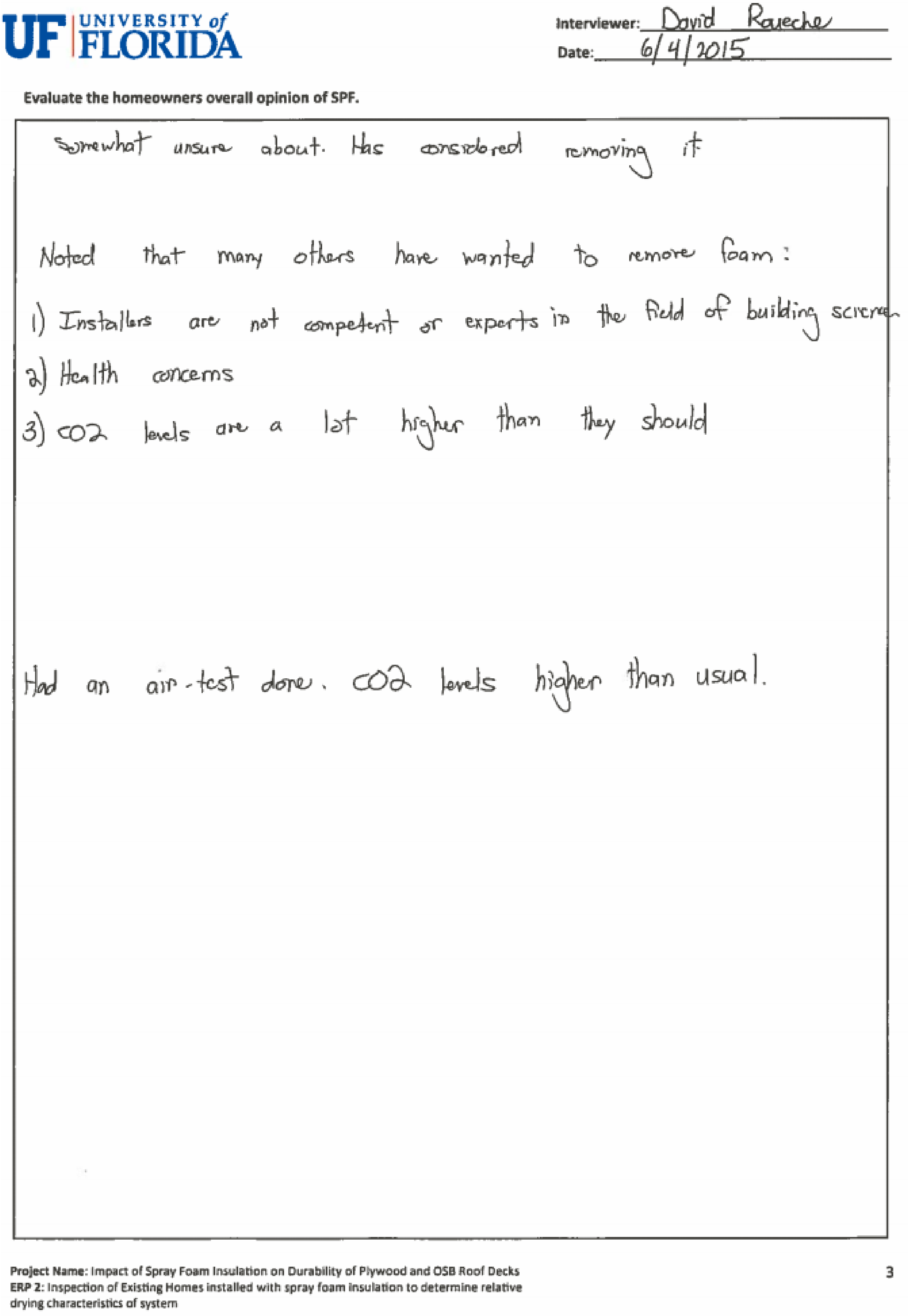
Has power bills from 2006, could use to look at savings. Believes there has been significant savings.

Question 16) How concerned is the homeowner about potential damage from moisture leaks in the roof?

☐ No concern ☐ Minimal concern ☑ Some concern ☐ Significant concern

Question 17) Is the homeowner aware of any past problems with the roof? If so, describe the problem, when it occurred, and what was done to fix the problem.

2 leaks in kitchen, one in fireplace in living room. All have been leaking a couple months (1 year for fireplace leak)



UNIVERSITY of FLORIDA

Interviewer: David Raueche
Date: 6/4/2015

Evaluate the homeowners overall opinion of SPF.

Somewhat unsure about. Has considered removing it

Noted that many others have wanted to remove foam:

1) Installers are not competent or experts in the field of building science
2) Health concerns
3) CO2 levels are a lot higher than they should

Had an air-test done. CO2 levels higher than usual.

B. Advisory Panel Meeting Minutes

a. 1-30-15 Advisory Panel Meeting Minutes

Impact of spray foam on the durability of plywood and OSB wood roof decks

Prepared by:

David O Prevatt and Trent Vogelgesang
University of Florida, Gainesville, FL

30 January 2015

NOTES OF Advisory Panel Meeting
Held on 21-22 January 2015, Hyatt Regency - Orlando, FL International Airport

Attendees:

Table 14: 1-30-15 Meeting Attendees

In Person	Webinar
Scott Kriner day1/day 2	Jaime Gascon, day1/day 2
Jason Hoerter, day1/day 2	Rick Olson, day 1
Mark Zehnal, day1/day 2 by webinar	Sean O'Brien, day 1
Todd Wishneski, day1/day 2	David Brandon, day 1
Mike Fischer, day1/day 2	Yuh Chin T. Huang, day1/day 2
Mike Ennis, day1/day 2	Bill Coulbourne, day 1
Marcin Pazera, day1/day 2	Arlene Stewart, day1/day 2
John Broniek, day1/day 2	Tim Reinhold, day1/day 2
David Roodvoets, day1/day 2	Mo Mandani, day1/day 2
Tim Smail, day1/day 2	Rick Duncan, day 2
Eric Vaughn, day1/day 2	
David Prevatt, day1/day 2	
Trent Vogelgesang, day1/day 2	
Mark Lisek, day 2	

1. Day *1 – Literature Review and Data Collection – Prevatt – University of Florida*
   - Literature review: Research team requested Advisory Panel to provide additional reports and peer-reviewed papers to add to literature review. In particular only two examples of roofing performance issues were found. Broniek stated SPFA estimates that nationwide, there are around 100,000 installed wood deck spray foam roofs. Question outstanding is how widespread are the issues of moisture build-up?
     - **ACTION ITEM:** UF will develop literature and circulate to Advisory Panel for review. DATE? Sections will include structural performance, hygrothermal modeling, health-related issues, experimental tests, field performance of wood/spray foam composite roof decks.

    - Include history of Florida Building Code changes referring to SPF on wood roof decks. Mike Fischer provided a summary for UF to review.
- Data Collection:
    - **ACTION ITEM**: Request from SPFA to provide updated figures on volume and number of wood/spray foam roof decks installed in Florida
        - Identify new construction versus retrofit.
    - UF seeking timeline of foam installs related to changes in building code

2. *Use of* Spray Foam *in Roofing: Broniek – Icynene*

- Importance of fire retardants not addressed in UF literature review. May need to be considered in testing with spray foam and code provisions related to include as a parameter in testing.

ACTION ITEM: UF to consider including fire-retardant treatment issues within literature review.

3. *Field* observations *of damaged foam insulated roofs: Zehnal – FRSA*

- Presented two homes that suffered problems – a) water related (via roof leaks) and b) due to health-related issues of occupants. More quantifiable, fact-based information is needed to justify the seriousness or extent of the problems.
    - **ACTION ITEM**: Zehnal will request of FRSA members for additional documentation on cases of problems related to wood/spray roof decks.

4. *Contemporary Attic Construction in Residences: Brandon –Brandon Construction Company*

- Brandon Construction Company is a GC company and they have used open cell spray foam in roof deck construction for the past eight years with no issues. Their market is in high-end custom homes. Brandon takes precaution such as evacuating the home for 48 hours and venting the home, providing supply and return ducts in the attic and avoiding cold spots. Brandon uses mechanical engineers to size the ventilation system
- Recommendations:
    - Evacuate building for 2 days after install – leave home open to vent.
    - Condition all attics with supply and return ducts to cycle air.
    - Ensure no "cold spots" by providing ventilation to all spaces of attic.
- **ACTION ITEM:** UF to include documentation for procedure and training needs to be developed & followed for inspectors to ensure quality and safe installation. Should installers be certified?

5. *Health Related Issues to Spray foam insulation – Huang – Duke University*

- Dr. Huang presented environmental medicine research related to health related issues to inhabitants exposed to air contaminates suspected to be from spray foam insulation. His research showed evidence that occupants developed asthma after installation of spray foam. Several issues addressed in his presentation will be included in the literature review.

6. *ccSPF, Water and Wind resistance of roofs – Prevatt – University of Florida*

- Prevatt presented a summary of UF research on use of spray foam as a structural retrofit. An approach using a below deck roof vent was found to reduce moisture content of wood deck. The width of the vent was smaller than span of the roof trusses – which could hamper drying potential at those (along-top chord) locations.
- Prevatt showed counter-intuitive photographs of higher moisture content in south-facing roofs versus north-facing ones from UF previous testing – no consensus on reason.

7. *Open Discussion*

- Jason Hoerter (NCFI), closed cell is interchangeable with open cell foam if used <u>according to the manufacturer's specifications.</u> IMPORTANT to note this requirement.
- Open-celled foam has two opinions in Florida. Despite its high vapor permeance rating, Zehnal stated that open-cell foam may form a water impermeable barrier under certain conditions (shown via a small sample test).
- There was some discussion on terminology: Sealed, unsealed, conditioned, unconditioned attics and spaces. **ACTION ITEM:** UF will include a definition of these spaces. ADVISORY PANEL: Is there an industry-accepted interpretation?
    - Sealed, "Unvented" – No ventilation to exterior exists.
    - Unsealed, "Vented" – Ventilation to exterior exists.
    - Conditioned – Supply and return duct in attic, also sealed to the exterior.
    - Unconditioned- No supply and return duct in attic, could be sealed or unsealed.
- A potential concern in Florida: Will moisture accumulate in attic of SPF roof system when HVAC not functioning (i.e. during electrical outage after hurricane)?

8. *Small group activity – Develop questions that would help shed light on discussions. Based on discussion, UF will develop questionnaire for advisory panel members*

a. *How to quantify extent of water-related issues with due spray foam/wood deck roofs?*

- Develop a survey for research of site problems. Send to organizations in 1.8.2
    - Describe failure mechanism?
    - How should we define failure modes of wood/spray foam system?
    - Types of SPF?
    - Survey – quantify numbers new construction versus retrofit?
    - Is spray foam work permitted by building inspectors?
    - Describe ventilation system used?
    - Physical properties of roof system, roofing, underlayment, roof deck, insulation
    - Provide descriptions of source and consequences of leakage and high internal humidity?
    - Date of the installation
    - What was the governing building code at the time?

b. *Locate reliable, factual data on problems related to wood/spray foam roof decks*

- **ACTION ITEMS:** Request Advisory Panel support to reach out to their members.
    - Mark Zehnal : FRSA and RCI – Send email to 800 members of FRSA

  - Arlene Stewart: FHBA and BOAF
  - Mike Fischer will distribute survey to Asphalt Roofing Manufacturers Association.
  - Rick Olson may be able to distribute as well to the Tile Roofing Institute.
  - IBHS? Ask Tim Reinhold

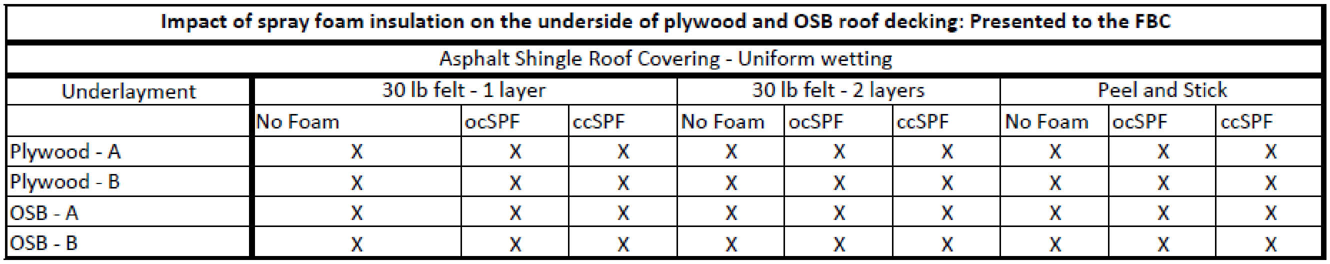
c. *How do we effectively use data obtained from study to provide input for the experimental research plan?*

- Determine what patterns/characteristics of performance exist & frequency of failures
- Any claims data? Searched Office of Insurance Regulation Guidelines and no claims for spray foam insulation arose.
- **ACTION ITEM**: UF needs to find source for claims data.

9. *Experimental* RESEARCH PLAN – LABORATORY TESTING

(1) Objective to compare drying rates of roof/spray foam decks. Due to short period of research a preliminary study will be conducted. Approach: used wood decks with pre-soaked water content and set within test setup having a temperature difference from topside to underside.

a. *Laboratory Testing - Comparative drying rates for 6 laboratory specimens*



Impact of spray foam insulation on the underside of plywood and OSB roof decking: Presented to the FBC

Asphalt Shingle Roof Covering - Uniform wetting

Underlayment	30 lb felt - 1 layer			30 lb felt - 2 layers			Peel and Stick		
	No Foam	ocSPF	ccSPF	No Foam	ocSPF	ccSPF	No Foam	ocSPF	ccSPF
Plywood - A	X	X	X	X	X	X	X	X	X
Plywood - B	X	X	X	X	X	X	X	X	X
OSB - A	X	X	X	X	X	X	X	X	X
OSB - B	X	X	X	X	X	X	X	X	X

- The laboratory testing will consist of 36 flat roof test set-ups. The variables for testing are the type of underlayment, foam type (None, Open Cell or Closed Cell) and plywood or OSB sheathing. All sheathing will be uniformly pre-soaked to a moisture content greater than 20 percent after foam insulation is installed to determine drying characteristics of various assemblies.

- **Procedure** of point leakage and spread of moisture (separate from above) –
  - Use similar roofing cross-sections but dry wood deck only. Introduce water leak and monitor the spread of water away from spot location.
    - Soak sheathing in a volume of water until optimal MC reached.
  - **ACTION ITEM:** investigate feasibility of thermal cameras to detect water leaks if possible.
  - **ACTION ITEM:** Review papers on experimental testing published by Building Science Corporation. Research team needs Advisory Panel help to locate appropriate ones.

- **Test set-up**: A gravimetric testing approach was agreed on to determine moisture content and compare drying rates among different roof assemblies. Samples will be isolated to replicate one-dimensional drying and moisture vapor movement. Exterior roof surface heated to create temperature differential within the laboratory. Three underlayment materials will be compared. Asphalt shingle roof
    - Single-layer 30# building felt paper
    - Dual-layer 30# building felt paper
    - SRAM – Self Adhering Rubberized Asphalt Membrane

- **ACTION ITEMS**: UF will prepare experimental research plan and share with Advisory Panel.

10. FIELD TESTING SCOPE

- UF Team seeks help to identify 6-8 houses with spray foam/wood roof decks for monitoring. Opportunities are available through FSEC and the Building America Homes. Spray foam manufacturers and Brandon Construction may be willing to assist.
    - **ACTION ITEMS**: Request Mo Mandani to contact FSEC on UF's behalf to solicit help. Dave Roodvoets will contact Bill Miller about availability of Building America homes.

11. WUFI ANALYSIS

- Advisory Panel recommended that WUFI analysis be used to compare results from laboratory testing rather than houses – as it was not clear what benefit the latter result would yield. This comparison could establish the validity of WUFI's capability to model such structures and used to determine the best and worst case scenarios.
- **ACTION ITEMS:** Discuss change of scope with Mo Mandani and with SGH.

12. GOAL OF RESEARCH AND TIMELINE

- Through testing and literature review the project will determine whether rational concerns exist about use of spray foam on the underside of wood roof decks. Final report is due on June 1, 2015. A proposal may be forthcoming as to more extensive testing to address the issues.

b. 2-12-15 Advisory Panel Meeting Minutes

Impact of spray foam on the durability of plywood and OSB wood roof decks

Prepared by:

David O Prevatt and Trent Vogelgesang
University of Florida, Gainesville, FL

NOTES OF Advisory Panel Meeting
Held on 12 February 2015 via Webinar

Attendees:

Table 15: 2-12-15 Meeting Attendees

Scott Kriner, MCA
Mo Mandani, FBC
BJ Yeh, Engineered Wood Association
Todd Wishneski, BASF
Mike Petty, Icynene
Jason Hoerter, NCFI
Mike Ennis, SPRI
Marcin Pazera, Owens Corning
Tim Smail, FLASH
David Prevatt, UF
Trent Vogelgesang, UF

1. INTRODUCTION
   - The purpose of the webinar was to discuss the status of the upcoming Interim Report that was due on 15 February 2015
2. Research GOALS
   - State of the Art Literature Review on Wood/Foam Roof Decks
     - Evidence-based papers and reports
     - Assign causes and consequences of water intrusion
     - Weigh the risks and benefits of spray foam insulation use
   - Experimental Research
     - Laboratory Model (simulate drying times in roofs)
     - Field Survey of foam-insulated Roofs (performance feedback)
     - Hygrothermal Modeling (Small-scale Validation Experiments)
   - Recommendations for the Florida Building Commission
     - Changes to Building Code

  - Recommended further research
  - Need for survey of industry on extent of issues and concerns

3. Summary of ADVISORY Panel Meeting on January 21/22
   - The meeting minutes of the 21/22 January Advisory Panel meeting were distributed beforehand and no vocal comments were stated.
   - Interim report discussion followed focusing on a summary of action items and the status of those items
   - Need input from advisory panel for field surveys and an existing number of homes that can be documented for damage due to spray foam insulation
   - Goal to define, sealed versus unsealed attics, conditioned versus unconditioned attics and vented versus unvented attics.
4. *ERP 1:* State *of the art literature review*
   - Discussed ensued on identifying additional peer reviewed papers on the subject of moisture related problems with spray applied foam insulation applied to the underside of wooden roof sheathing
   - Photos of damaged roofs were shown but were anecdotal evidence and a desire expressed find sufficient information of damaged roofing with SPF issues.
   - A draft of the literature review was then sent to advisory panel for review and comments
5. *ERP 2:* Inspection *of existing homes with spray applied foam insulation*
   - Change in scope from initial plan by reducing number of homes to be studied from 5 to 2 homes based on availability.
   - From this section an additional home was identified by advisory panel members and a final total of 3 homes were selected to be analyzed.
6. *ERP 3a:* Comparative *drying rates of uniformly wetted roof specimens*
   - The ERP was explained in detail and was reviewed and approved by the panel
   - Desire expressed to find local Gainesville spray foam manufacturer to spray samples with both open celled spray foam insulation and closed cell spray foam insulation as soon as possible.
7. *ERP 3b: Point source moisture spreading*
   - Based upon the Advisory Panel meeting on 21/22 January this section was added to determine how spray foam insulation affects the spread of moisture from a point source.
   - Discussion of test setup and using a sprinkler system to continuously soak the roof specimens.
   - The thickness of the closed cell spray foam to be used on the roofing specimens was determined to be 3 inches based on the experts in the spray foam manufacturer industry.
8. *Schedule*
   - Complete ERP 1: State of the art literature review and add papers that the advisory panel members can find.

- ERP 2: Formally change scope of research plan from 5 homes to 3 based on availabity.
- ERP 3a: Finish construction of test setup on 02/16 and finalize options for heating of roof elements to create a thermal difference. Begin testing by March.
- ERP 3b: Begin construction of test setup, beginning with a modification of the water-drip devices. Testing to begin in March.

9. *Advisory Panel Action Items*

- Survey professionals for cases of damaged roofing due to spray appied foam insulation.
- UF to develop questionnaire to be distributed to associations involved with the Advisory Panel in order to encourage response.
- Solicit the number of spray foam installations in Florida from SFPA.
- Determine fire retardants commonly used in the installation of spray applied foam insulation.

10. *Discussion and Comments*

- Jason Hoerter: Discussion of ERP 3b and how the roof specimens would be gravimetrically weighed to determine the moisture content spread over time. Desire expressed to determine issues with existing homes and compare to experimental testing.
- BJ Yeh: Concern for the generic permeance rate of the wood and desire expressed to run ASTM testing to determine the actual permeance of the plywood and OSB wood sheathing.
- All documents sent to Advisory Panel for review after meeting.

C. Reviewed Literature

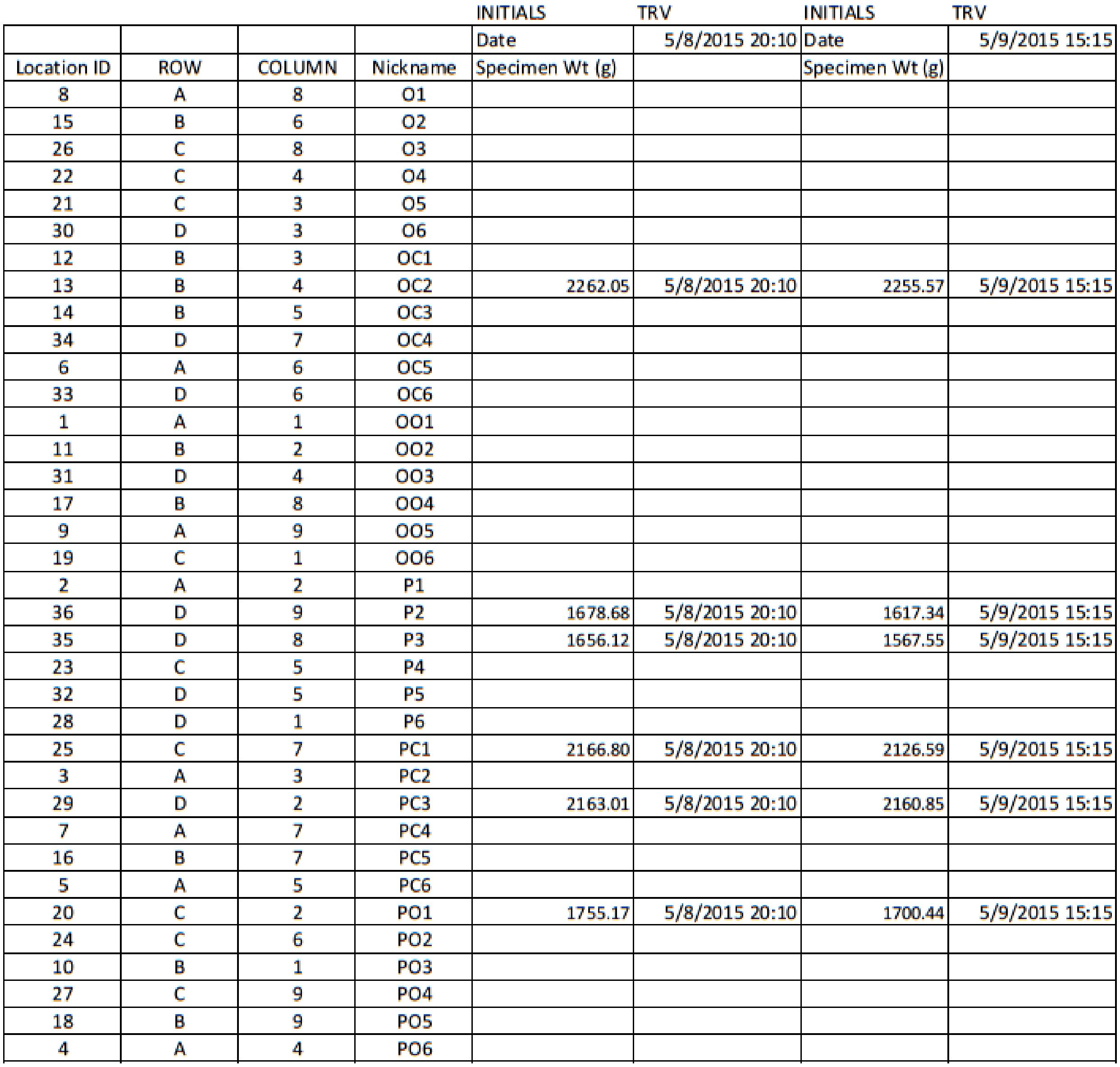
A full list of the literature reviewed as part of the State of the Art Literature Review can be seen below. A pdf copy of each paper can be accessed here https://www.dropbox.com/sh/7r66p2m7fslfrgf/AAD4E-felyk2kO11_tAhcHjTa?dl=0.

Index	**First Author**	**Year**	**Title**
1	Saber	2010	3d thermal model for predicting thermal resistance of SPF wall assemblies
2	Bomberg-Lstiburek	1998	Spray Polyurethane foam in external envelopes of buildings
3	Booth	2002	Foam insulation in low sloped roofing systems
4	Carll	2009	Moisture related properties of wood
5	Datin	2011	Wind uplift capacity of residential wood
6	Derome	2000	Large scale testing of two flat roof assemblies insulated with cellulose
7	Hendron	2002	Thermal performance of unvented attics in hot dry climates
8	Huang	2014	Health effects associated with faulty application of spray polyurethane foam in residential homes
9	Jerman	2012	Effect of Moisture content on heat and moisture
10	Lstiburek	2008	Moisture control for buildings
11	Lstiburek	1993	Humidity Control in the humid south
12	Parker	2005	Literature review of the impact and need for attic ventilation in Florida homes
13	Prevatt	2014	Wind uplift capacity of foam retrofitted roof sheathing panels subjected to rainwater intrusion
14	Rudd	2008	Lstiburek
15	Smits	1994	Effect of cellsize reduction on polyurethane foam physical properties
16	Timusk	2008	An investigation of the moisture sorption and permeability properties of mill fabricated OSB
17	Trechsel	1985	Moisture in buildings-An Overview
18	Wu	2012	Rheology Study in Polyurethane rigid foams
19	Zabel-Morrell	1992	Wood Microbiology-decay and its prevention
20	Salonvaara	2013	Moisture Performance of sealed attics in climate zones 1 to 4
21	Gates	2013	Analysis and initial results of cold climate wood framed home retrofit
22	Dickson	2013	Guide to closing and conditioning ventilated crawlspaces
23	Lukachko	2013	Hybrid wall construction and quality control issues in Wyandotte Michigan
24	Zoeller	2013	Retrofitting the southeast the Cool Energy House
25	Pallin	2013	A hygrothermal risk analysis applied to residential unvented attics
26	Mayer	2014	Finite Element thermal modeling and correlation of various building wall assembly systems
27	Puttagunta	2013	Performance House A Cold Climate Challenge Home
28	Walker	2013	An Assessment of envelope measures in mild climate deep energy retrofits
29	Morse-Fortier	2012	Potential Problems Arising from composite foam panels
30	Dixon	2012	Investigation of the Wind Resistance of Asphalt Shingles
31	Badiu	2013	Researches regarding the causes of degradation of roof systems
32	Ojanen	2000	Sealed cold roof and energy

33	Straube	2010	EE12-4 Moisture-Safe Unvented Wood Roof Systems
34	Grin	2012	Moisture and structural analysis for high performance hybrid wall assemblies
35	Alturkistani	2008	A new test method to determine relative drying capacity...
36	Grin	2013	Application of Spray Foam Insulation Under Plywood and OSB roof sheathing
37	Oustad	2005	Calculation of Moisture and Heat Transfer in Compact Roofs and Comparison with Experimental data
38	Lstiburek	2014	Cool Hand Luke Meets Attics
39	Prevatt	2010	Field evaluation of thermal performance and energy efficiency of ccSPF retrofitted vented residential attic
40	Sorahan	1993	Mortality and cancer morbidity of production works in the UK flexible polyurethane foam industry
41	Lesage	2007	Airborne (MDI) Concentrations associated with the application of SPF in residential construction
42	Mcbride	2011	UF-thesis WIND UPLIFT PERFORMANCE OF CCSPF-RETROFITTED ROOF SHEATHING SUBJECTED TO WATER LEAKAGE
43	Shreyans	2011	UF-thesis THERMAL PERFORMANCE OF FOAM RETROFITTED VENTED RESIDENTIAL ATTIC
44	DOE	2012	Application of Spray foam insulation under plywood and OSB sheathing
45	Nelson	2009	Compact Asphalt Shingle Roof systems - Should they be vented?
46	Honeywell	N/A	Energy Performance and Closed-Cell Spray Foam A Better Building Technology
47	Owens-Corning	N/A	Insulate with Integrity
48	Yuan et al	2010	Hygrothermal performance of wood-framed wall systems using spray polyurethane foam
49	Parker	2002	Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida
50	Straube	2010	Building America Special Research Project - High R-Value Enclosures for High Performance Residential Buildings in all climate zones
51	EPA	2012	Vacate and Safe Re-Entry Time
52	Shafer	2013	Spray Foam Basics for the Fire Service
53	Smegal	2013	Hygric Redistribution in insulated assemblies- retrofitting residential envelopes without creating moisture issues
54	DIPS	2013	Sealed Attic System
55	Centex	N/A	What happens with a roof leak and spray foam
56	BASF	2011	Guidelines Reoccupancy Guidelines
57	Holladay	2014	Open-Cell Spray Foam and Damp Roof Sheathing
58	Bailes	2014	Does open cell spray foam really rot roofs
59	APA	2009	Water vaper permeance of wood structural panels
60	APA	2011	Wood moisture content and the importance of drying in wood building systems
61	Schumacher	2008	Hygrothermal Performance of Insulated Sloped Wood-framed Roof Assemblies
62	CASMA	2015	Technical Bulletin HOT ROOF DESIGNS
63	Santos	N/A	Solving the Air Barrier Riddle - Permeable or impermeable
64	Hubbs	2003	Building Envelope Performance Monitoring
65	Icynene	N/A	Open Cell Spray Foam
66	Building	2008	Unvented Roofs Hot Humid Climates and Asphalt Roofing Shingles

	Science Corporation		
67	Datin	2007	Wind-Uplift capacity of residential wood roof sheathing panels retrofitted with insulation
68	Morrison	2007	THESIS
69	ASTM	2007	Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
70	Desjarlais	2012	Energy and Moisture Performance of Attic Assemblies.docx
71	APA	2009	Moisture Vapor and Perms J450
72	Boudreaux	2013	Moisture performance of sealed attics in mixed-humid climate
73	Schumacher	2008	Hygrothermal Performance of Insulated Sloped Wood-framed Roofs
74	Desjarlais	2012	Energy and Moisture Performance of Attic Assemblies
75	DOE	2009	Building Science-Based Climate Maps
76	FSEC	2011	New Construction Builders Challenge
77	Griffin	1977	Water potential and wood-decay fungi
78	Grin	2013	Application of spray foam insulation under plywood and oriented strand board roof sheathing
79	Maref	2002	Executive summary of research contributions related to moisture management
80	Maref	2010	Drying response of wood-frame construction
81	Nofal	1999	Behavior of engineered wood materials under the effect of wetting and drying cycles
82	Ojanen	2012	Moisture performance properties of exterior sheathing products
83	Roueche	2013	Wind Uplift Capacity of ccSPF Roofs Subjected to Water Leaks
84	Prahl	2014	Moisture risk in unvented attics due to air leakage paths
85	Rudd	2004	Field performance of unvented cathedralized attics
86	Saber	2010	Benchmarking of hygrothermal model against measurements of drying of full-scale wall assemblies
87	Straube	2010	Moisture safe unvented wood roof systems
88	Wu et al	2008	Moisture buffer capacity

D. ERP 3A Data



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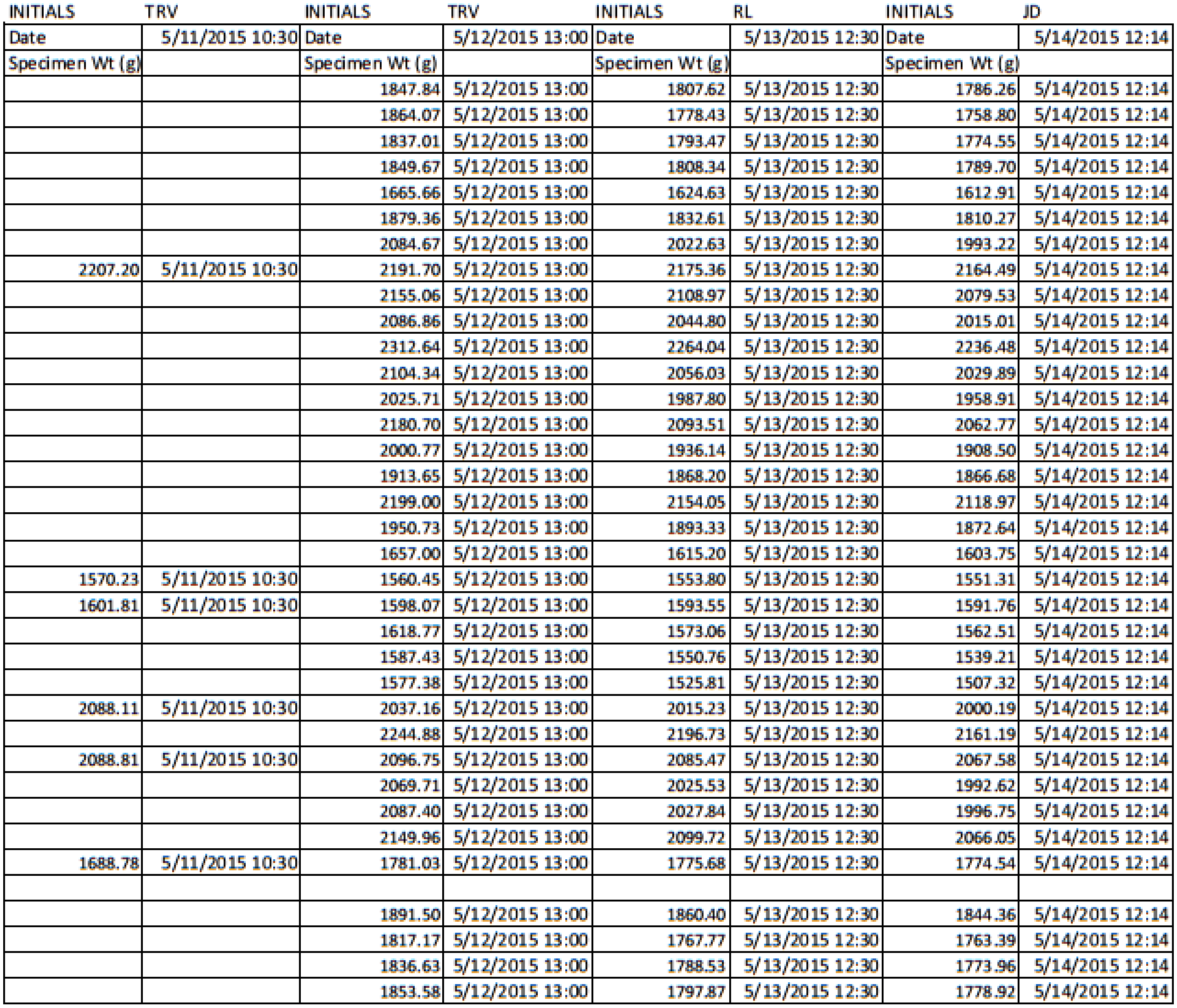

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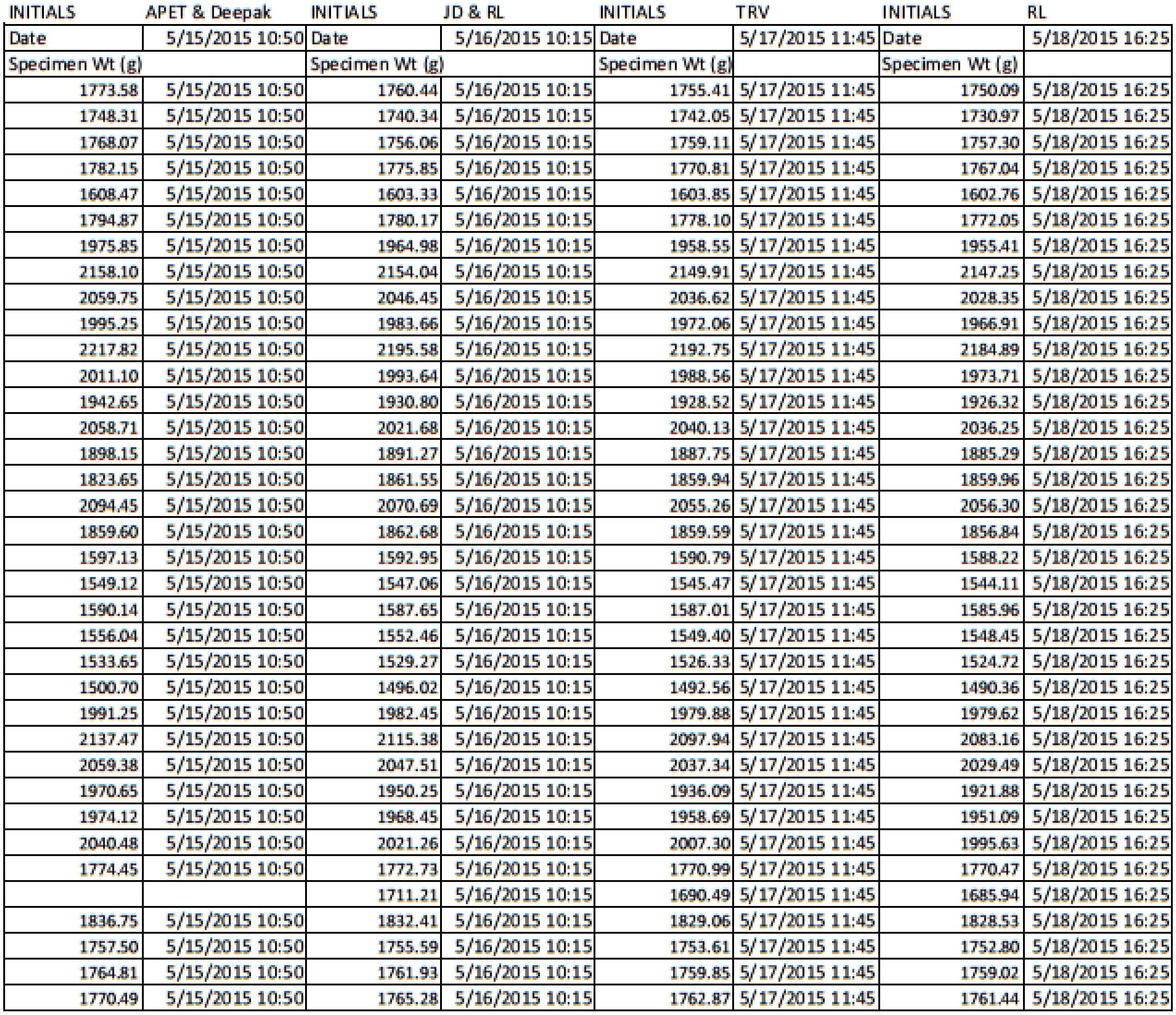

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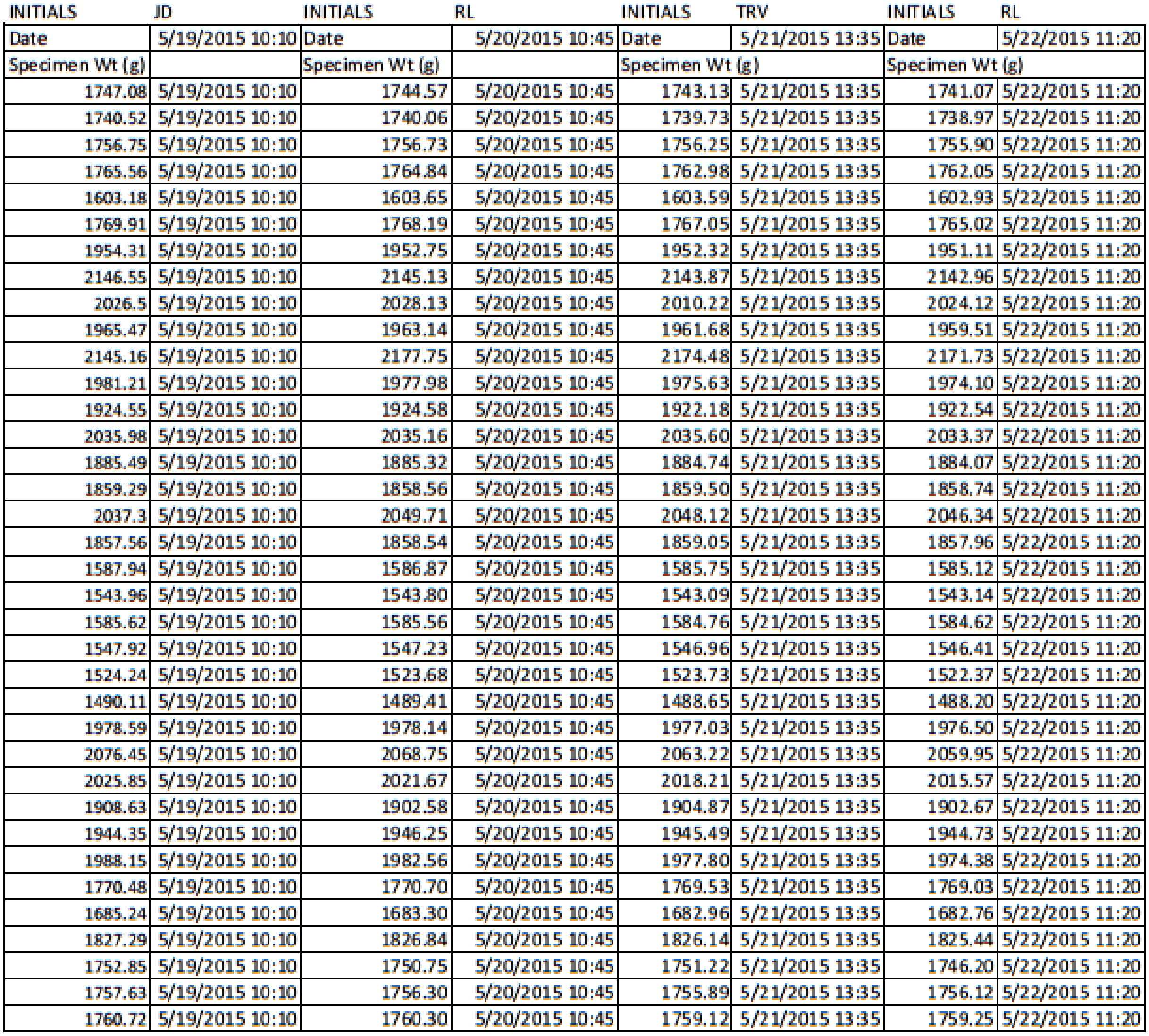
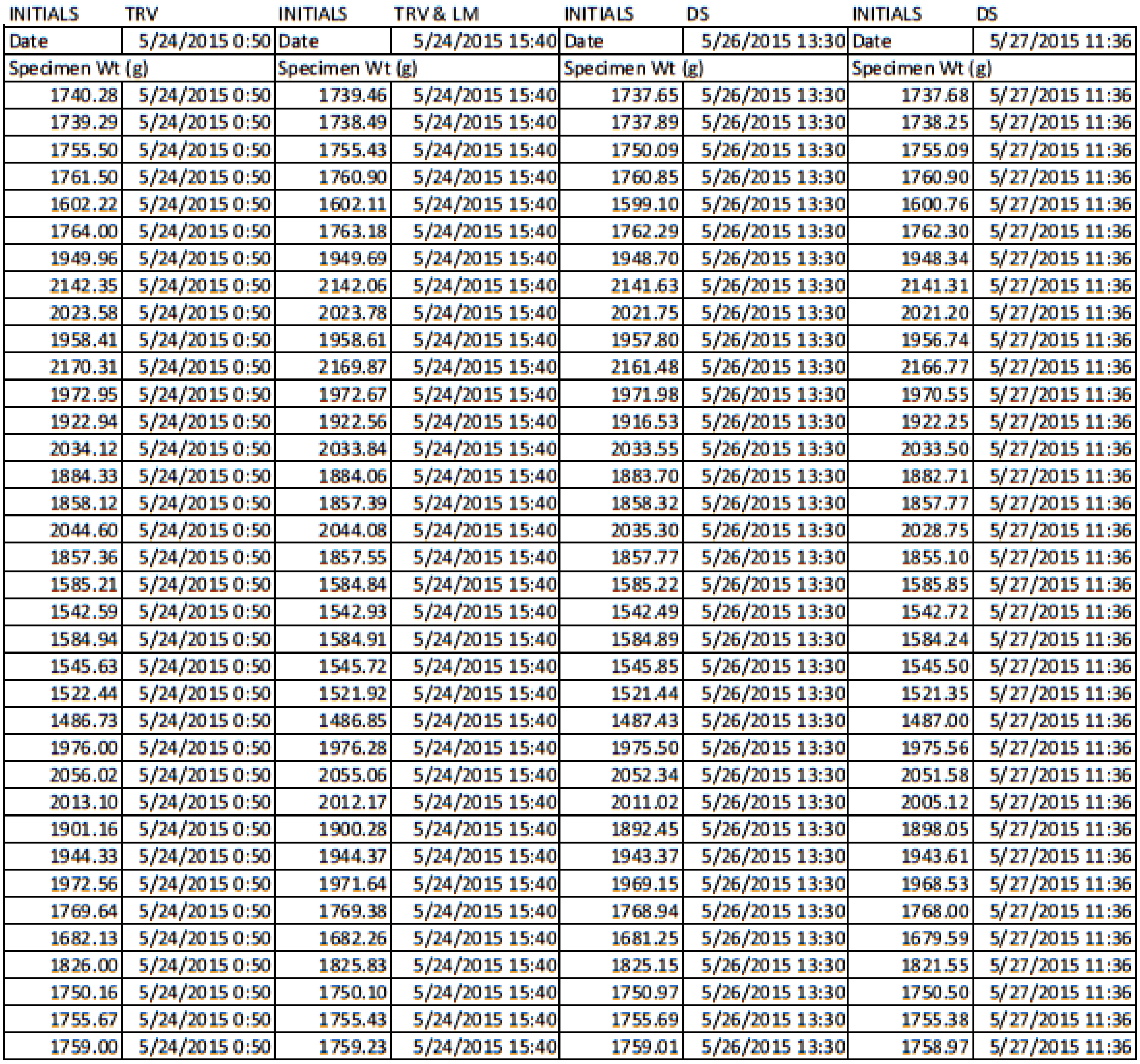
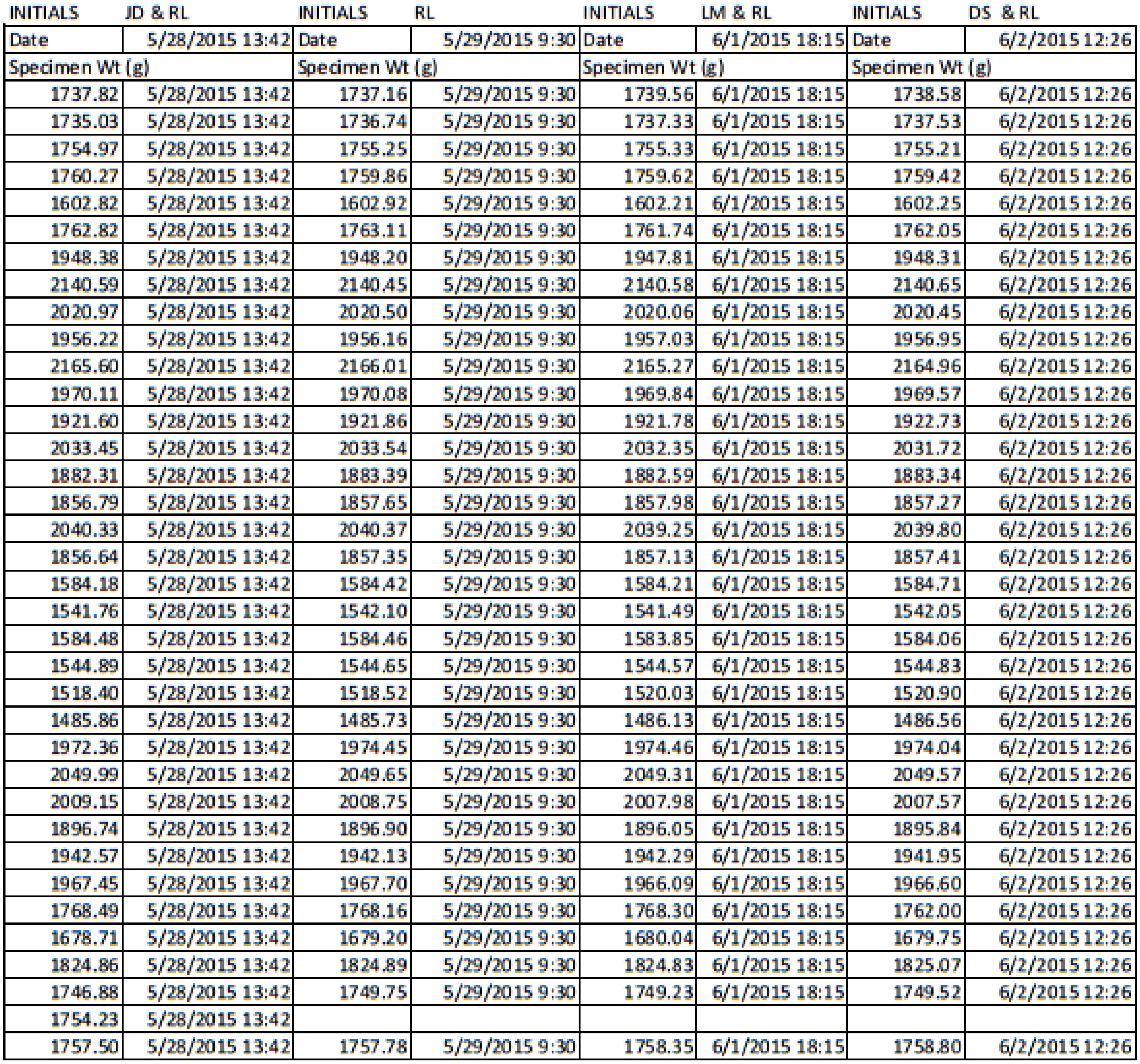
1608.47	5/15/2015 10:50	1603.33	5/16/2015 10:15	1603.85	5/17/2015 11:45	1602.76	5/18/2015 16:25
1794.87	5/15/2015 10:50	1780.17	5/16/2015 10:15	1778.10	5/17/2015 11:45	1772.05	5/18/2015 16:25
1975.85	5/15/2015 10:50	1964.98	5/16/2015 10:15	1958.55	5/17/2015 11:45	1955.41	5/18/2015 16:25
2158.10	5/15/2015 10:50	2154.04	5/16/2015 10:15	2149.91	5/17/2015 11:45	2147.25	5/18/2015 16:25
2059.75	5/15/2015 10:50	2046.45	5/16/2015 10:15	2036.62	5/17/2015 11:45	2028.35	5/18/2015 16:25
1995.25	5/15/2015 10:50	1983.66	5/16/2015 10:15	1972.06	5/17/2015 11:45	1966.91	5/18/2015 16:25
2217.82	5/15/2015 10:50	2195.58	5/16/2015 10:15	2192.75	5/17/2015 11:45	2184.89	5/18/2015 16:25
2011.10	5/15/2015 10:50	1993.64	5/16/2015 10:15	1988.56	5/17/2015 11:45	1973.71	5/18/2015 16:25
1942.65	5/15/2015 10:50	1930.80	5/16/2015 10:15	1928.52	5/17/2015 11:45	1926.32	5/18/2015 16:25
2058.71	5/15/2015 10:50	2021.68	5/16/2015 10:15	2040.13	5/17/2015 11:45	2036.25	5/18/2015 16:25
1898.15	5/15/2015 10:50	1891.27	5/16/2015 10:15	1887.75	5/17/2015 11:45	1885.29	5/18/2015 16:25
1823.65	5/15/2015 10:50	1861.55	5/16/2015 10:15	1859.94	5/17/2015 11:45	1859.96	5/18/2015 16:25
2094.45	5/15/2015 10:50	2070.69	5/16/2015 10:15	2055.26	5/17/2015 11:45	2056.30	5/18/2015 16:25
1859.60	5/15/2015 10:50	1862.68	5/16/2015 10:15	1859.59	5/17/2015 11:45	1856.84	5/18/2015 16:25
1597.13	5/15/2015 10:50	1592.95	5/16/2015 10:15	1590.79	5/17/2015 11:45	1588.22	5/18/2015 16:25
1549.12	5/15/2015 10:50	1547.06	5/16/2015 10:15	1545.47	5/17/2015 11:45	1544.11	5/18/2015 16:25
1590.14	5/15/2015 10:50	1587.65	5/16/2015 10:15	1587.01	5/17/2015 11:45	1585.96	5/18/2015 16:25
1556.04	5/15/2015 10:50	1552.46	5/16/2015 10:15	1549.40	5/17/2015 11:45	1548.45	5/18/2015 16:25
1533.65	5/15/2015 10:50	1529.27	5/16/2015 10:15	1526.33	5/17/2015 11:45	1524.72	5/18/2015 16:25
1500.70	5/15/2015 10:50	1496.02	5/16/2015 10:15	1492.56	5/17/2015 11:45	1490.36	5/18/2015 16:25
1991.25	5/15/2015 10:50	1982.45	5/16/2015 10:15	1979.88	5/17/2015 11:45	1979.62	5/18/2015 16:25
2137.47	5/15/2015 10:50	2115.38	5/16/2015 10:15	2097.94	5/17/2015 11:45	2083.16	5/18/2015 16:25
2059.38	5/15/2015 10:50	2047.51	5/16/2015 10:15	2037.34	5/17/2015 11:45	2029.49	5/18/2015 16:25
1970.65	5/15/2015 10:50	1950.25	5/16/2015 10:15	1936.09	5/17/2015 11:45	1921.88	5/18/2015 16:25
1974.12	5/15/2015 10:50	1968.45	5/16/2015 10:15	1958.69	5/17/2015 11:45	1951.09	5/18/2015 16:25
2040.48	5/15/2015 10:50	2021.26	5/16/2015 10:15	2007.30	5/17/2015 11:45	1995.63	5/18/2015 16:25
1774.45	5/15/2015 10:50	1772.73	5/16/2015 10:15	1770.99	5/17/2015 11:45	1770.47	5/18/2015 16:25
		1711.21	5/16/2015 10:15	1690.49	5/17/2015 11:45	1685.94	5/18/2015 16:25
1836.75	5/15/2015 10:50	1832.41	5/16/2015 10:15	1829.06	5/17/2015 11:45	1828.53	5/18/2015 16:25
1757.50	5/15/2015 10:50	1755.59	5/16/2015 10:15	1753.61	5/17/2015 11:45	1752.80	5/18/2015 16:25
1764.81	5/15/2015 10:50	1761.93	5/16/2015 10:15	1759.85	5/17/2015 11:45	1759.02	5/18/2015 16:25
1770.49	5/15/2015 10:50	1765.28	5/16/2015 10:15	1762.87	5/17/2015 11:45	1761.44	5/18/2015 16:25



INITIALS	JD	INITIALS	RL	INITIALS	TRV	INITIALS	RL
Date	5/19/2015 10:10	Date	5/20/2015 10:45	Date	5/21/2015 13:35	Date	5/22/2015 11:20
Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)	
1747.08	5/19/2015 10:10	1744.57	5/20/2015 10:45	1743.13	5/21/2015 13:35	1741.07	5/22/2015 11:20
1740.52	5/19/2015 10:10	1740.06	5/20/2015 10:45	1739.73	5/21/2015 13:35	1738.97	5/22/2015 11:20
1756.75	5/19/2015 10:10	1756.73	5/20/2015 10:45	1756.25	5/21/2015 13:35	1755.90	5/22/2015 11:20
1765.56	5/19/2015 10:10	1764.84	5/20/2015 10:45	1762.98	5/21/2015 13:35	1762.05	5/22/2015 11:20
1603.18	5/19/2015 10:10	1603.65	5/20/2015 10:45	1603.59	5/21/2015 13:35	1602.93	5/22/2015 11:20
1769.91	5/19/2015 10:10	1768.19	5/20/2015 10:45	1767.05	5/21/2015 13:35	1765.02	5/22/2015 11:20
1954.31	5/19/2015 10:10	1952.75	5/20/2015 10:45	1952.32	5/21/2015 13:35	1951.11	5/22/2015 11:20
2146.55	5/19/2015 10:10	2145.13	5/20/2015 10:45	2143.87	5/21/2015 13:35	2142.96	5/22/2015 11:20
2026.5	5/19/2015 10:10	2028.13	5/20/2015 10:45	2010.22	5/21/2015 13:35	2024.12	5/22/2015 11:20
1965.47	5/19/2015 10:10	1963.14	5/20/2015 10:45	1961.68	5/21/2015 13:35	1959.51	5/22/2015 11:20
2145.16	5/19/2015 10:10	2177.75	5/20/2015 10:45	2174.48	5/21/2015 13:35	2171.73	5/22/2015 11:20
1981.21	5/19/2015 10:10	1977.98	5/20/2015 10:45	1975.63	5/21/2015 13:35	1974.10	5/22/2015 11:20
1924.55	5/19/2015 10:10	1924.58	5/20/2015 10:45	1922.18	5/21/2015 13:35	1922.54	5/22/2015 11:20
2035.98	5/19/2015 10:10	2035.16	5/20/2015 10:45	2035.60	5/21/2015 13:35	2033.37	5/22/2015 11:20
1885.49	5/19/2015 10:10	1885.32	5/20/2015 10:45	1884.74	5/21/2015 13:35	1884.07	5/22/2015 11:20
1859.29	5/19/2015 10:10	1858.56	5/20/2015 10:45	1859.50	5/21/2015 13:35	1858.74	5/22/2015 11:20
2037.3	5/19/2015 10:10	2049.71	5/20/2015 10:45	2048.12	5/21/2015 13:35	2046.34	5/22/2015 11:20
1857.56	5/19/2015 10:10	1858.54	5/20/2015 10:45	1859.05	5/21/2015 13:35	1857.96	5/22/2015 11:20
1587.94	5/19/2015 10:10	1586.87	5/20/2015 10:45	1585.75	5/21/2015 13:35	1585.12	5/22/2015 11:20
1543.96	5/19/2015 10:10	1543.80	5/20/2015 10:45	1543.09	5/21/2015 13:35	1543.14	5/22/2015 11:20
1585.62	5/19/2015 10:10	1585.56	5/20/2015 10:45	1584.76	5/21/2015 13:35	1584.62	5/22/2015 11:20
1547.92	5/19/2015 10:10	1547.23	5/20/2015 10:45	1546.96	5/21/2015 13:35	1546.41	5/22/2015 11:20
1524.24	5/19/2015 10:10	1523.68	5/20/2015 10:45	1523.73	5/21/2015 13:35	1522.37	5/22/2015 11:20
1490.11	5/19/2015 10:10	1489.41	5/20/2015 10:45	1488.65	5/21/2015 13:35	1488.20	5/22/2015 11:20
1978.59	5/19/2015 10:10	1978.14	5/20/2015 10:45	1977.03	5/21/2015 13:35	1976.50	5/22/2015 11:20
2076.45	5/19/2015 10:10	2068.75	5/20/2015 10:45	2063.22	5/21/2015 13:35	2059.95	5/22/2015 11:20
2025.85	5/19/2015 10:10	2021.67	5/20/2015 10:45	2018.21	5/21/2015 13:35	2015.57	5/22/2015 11:20
1908.63	5/19/2015 10:10	1902.58	5/20/2015 10:45	1904.87	5/21/2015 13:35	1902.67	5/22/2015 11:20
1944.35	5/19/2015 10:10	1946.25	5/20/2015 10:45	1945.49	5/21/2015 13:35	1944.73	5/22/2015 11:20
1988.15	5/19/2015 10:10	1982.56	5/20/2015 10:45	1977.80	5/21/2015 13:35	1974.38	5/22/2015 11:20
1770.48	5/19/2015 10:10	1770.70	5/20/2015 10:45	1769.53	5/21/2015 13:35	1769.03	5/22/2015 11:20
1685.24	5/19/2015 10:10	1683.30	5/20/2015 10:45	1682.96	5/21/2015 13:35	1682.76	5/22/2015 11:20
1827.29	5/19/2015 10:10	1826.84	5/20/2015 10:45	1826.14	5/21/2015 13:35	1825.44	5/22/2015 11:20
1752.85	5/19/2015 10:10	1750.75	5/20/2015 10:45	1751.22	5/21/2015 13:35	1746.20	5/22/2015 11:20
1757.63	5/19/2015 10:10	1756.30	5/20/2015 10:45	1755.89	5/21/2015 13:35	1756.12	5/22/2015 11:20
1760.72	5/19/2015 10:10	1760.30	5/20/2015 10:45	1759.12	5/21/2015 13:35	1759.25	5/22/2015 11:20



INITIALS	TRV	INITIALS	TRV & LM	INITIALS	DS	INITIALS	DS
Date	5/24/2015 0:50	Date	5/24/2015 15:40	Date	5/26/2015 13:30	Date	5/27/2015 11:36
Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)	
1740.28	5/24/2015 0:50	1739.46	5/24/2015 15:40	1737.65	5/26/2015 13:30	1737.68	5/27/2015 11:36
1739.29	5/24/2015 0:50	1738.49	5/24/2015 15:40	1737.89	5/26/2015 13:30	1738.25	5/27/2015 11:36
1755.50	5/24/2015 0:50	1755.43	5/24/2015 15:40	1750.09	5/26/2015 13:30	1755.09	5/27/2015 11:36
1761.50	5/24/2015 0:50	1760.90	5/24/2015 15:40	1760.85	5/26/2015 13:30	1760.90	5/27/2015 11:36
1602.22	5/24/2015 0:50	1602.11	5/24/2015 15:40	1599.10	5/26/2015 13:30	1600.76	5/27/2015 11:36
1764.00	5/24/2015 0:50	1763.18	5/24/2015 15:40	1762.29	5/26/2015 13:30	1762.30	5/27/2015 11:36
1949.96	5/24/2015 0:50	1949.69	5/24/2015 15:40	1948.70	5/26/2015 13:30	1948.34	5/27/2015 11:36
2142.35	5/24/2015 0:50	2142.06	5/24/2015 15:40	2141.63	5/26/2015 13:30	2141.31	5/27/2015 11:36
2023.58	5/24/2015 0:50	2023.78	5/24/2015 15:40	2021.75	5/26/2015 13:30	2021.20	5/27/2015 11:36
1958.41	5/24/2015 0:50	1958.61	5/24/2015 15:40	1957.80	5/26/2015 13:30	1956.74	5/27/2015 11:36
2170.31	5/24/2015 0:50	2169.87	5/24/2015 15:40	2161.48	5/26/2015 13:30	2166.77	5/27/2015 11:36
1972.95	5/24/2015 0:50	1972.67	5/24/2015 15:40	1971.98	5/26/2015 13:30	1970.55	5/27/2015 11:36
1922.94	5/24/2015 0:50	1922.56	5/24/2015 15:40	1916.53	5/26/2015 13:30	1922.25	5/27/2015 11:36
2034.12	5/24/2015 0:50	2033.84	5/24/2015 15:40	2033.55	5/26/2015 13:30	2033.50	5/27/2015 11:36
1884.33	5/24/2015 0:50	1884.06	5/24/2015 15:40	1883.70	5/26/2015 13:30	1882.71	5/27/2015 11:36
1858.12	5/24/2015 0:50	1857.39	5/24/2015 15:40	1858.32	5/26/2015 13:30	1857.77	5/27/2015 11:36
2044.60	5/24/2015 0:50	2044.08	5/24/2015 15:40	2035.30	5/26/2015 13:30	2028.75	5/27/2015 11:36
1857.36	5/24/2015 0:50	1857.55	5/24/2015 15:40	1857.77	5/26/2015 13:30	1855.10	5/27/2015 11:36
1585.21	5/24/2015 0:50	1584.84	5/24/2015 15:40	1585.22	5/26/2015 13:30	1585.85	5/27/2015 11:36
1542.59	5/24/2015 0:50	1542.93	5/24/2015 15:40	1542.49	5/26/2015 13:30	1542.72	5/27/2015 11:36
1584.94	5/24/2015 0:50	1584.91	5/24/2015 15:40	1584.89	5/26/2015 13:30	1584.24	5/27/2015 11:36
1545.63	5/24/2015 0:50	1545.72	5/24/2015 15:40	1545.85	5/26/2015 13:30	1545.50	5/27/2015 11:36
1522.44	5/24/2015 0:50	1521.92	5/24/2015 15:40	1521.44	5/26/2015 13:30	1521.35	5/27/2015 11:36
1486.73	5/24/2015 0:50	1486.85	5/24/2015 15:40	1487.43	5/26/2015 13:30	1487.00	5/27/2015 11:36
1976.00	5/24/2015 0:50	1976.28	5/24/2015 15:40	1975.50	5/26/2015 13:30	1975.56	5/27/2015 11:36
2056.02	5/24/2015 0:50	2055.06	5/24/2015 15:40	2052.34	5/26/2015 13:30	2051.58	5/27/2015 11:36
2013.10	5/24/2015 0:50	2012.17	5/24/2015 15:40	2011.02	5/26/2015 13:30	2005.12	5/27/2015 11:36
1901.16	5/24/2015 0:50	1900.28	5/24/2015 15:40	1892.45	5/26/2015 13:30	1898.05	5/27/2015 11:36
1944.33	5/24/2015 0:50	1944.37	5/24/2015 15:40	1943.37	5/26/2015 13:30	1943.61	5/27/2015 11:36
1972.56	5/24/2015 0:50	1971.64	5/24/2015 15:40	1969.15	5/26/2015 13:30	1968.53	5/27/2015 11:36
1769.64	5/24/2015 0:50	1769.38	5/24/2015 15:40	1768.94	5/26/2015 13:30	1768.00	5/27/2015 11:36
1682.13	5/24/2015 0:50	1682.26	5/24/2015 15:40	1681.25	5/26/2015 13:30	1679.59	5/27/2015 11:36
1826.00	5/24/2015 0:50	1825.83	5/24/2015 15:40	1825.15	5/26/2015 13:30	1821.55	5/27/2015 11:36
1750.16	5/24/2015 0:50	1750.10	5/24/2015 15:40	1750.97	5/26/2015 13:30	1750.50	5/27/2015 11:36
1755.67	5/24/2015 0:50	1755.43	5/24/2015 15:40	1755.69	5/26/2015 13:30	1755.38	5/27/2015 11:36
1759.00	5/24/2015 0:50	1759.23	5/24/2015 15:40	1759.01	5/26/2015 13:30	1758.97	5/27/2015 11:36



INITIALS	JD & RL	INITIALS	RL	INITIALS	LM & RL	INITIALS	DS & RL
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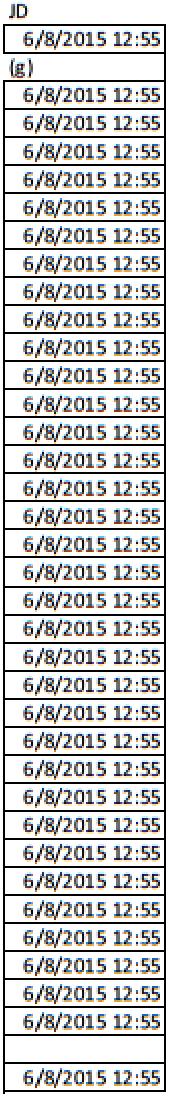
Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)	
1737.82	5/28/2015 13:42	1737.16	5/29/2015 9:30	1739.56	6/1/2015 18:15	1738.58	6/2/2015 12:26
1735.03	5/28/2015 13:42	1736.74	5/29/2015 9:30	1737.33	6/1/2015 18:15	1737.53	6/2/2015 12:26
1754.97	5/28/2015 13:42	1755.25	5/29/2015 9:30	1755.33	6/1/2015 18:15	1755.21	6/2/2015 12:26
1760.27	5/28/2015 13:42	1759.86	5/29/2015 9:30	1759.62	6/1/2015 18:15	1759.42	6/2/2015 12:26
1602.82	5/28/2015 13:42	1602.92	5/29/2015 9:30	1602.21	6/1/2015 18:15	1602.25	6/2/2015 12:26
1762.82	5/28/2015 13:42	1763.11	5/29/2015 9:30	1761.74	6/1/2015 18:15	1762.05	6/2/2015 12:26
1948.38	5/28/2015 13:42	1948.20	5/29/2015 9:30	1947.81	6/1/2015 18:15	1948.31	6/2/2015 12:26
2140.59	5/28/2015 13:42	2140.45	5/29/2015 9:30	2140.58	6/1/2015 18:15	2140.65	6/2/2015 12:26
2020.97	5/28/2015 13:42	2020.50	5/29/2015 9:30	2020.06	6/1/2015 18:15	2020.45	6/2/2015 12:26
1956.22	5/28/2015 13:42	1956.16	5/29/2015 9:30	1957.03	6/1/2015 18:15	1956.95	6/2/2015 12:26
2165.60	5/28/2015 13:42	2166.01	5/29/2015 9:30	2165.27	6/1/2015 18:15	2164.96	6/2/2015 12:26
1970.11	5/28/2015 13:42	1970.08	5/29/2015 9:30	1969.84	6/1/2015 18:15	1969.57	6/2/2015 12:26
1921.60	5/28/2015 13:42	1921.86	5/29/2015 9:30	1921.78	6/1/2015 18:15	1922.73	6/2/2015 12:26
2033.45	5/28/2015 13:42	2033.54	5/29/2015 9:30	2032.35	6/1/2015 18:15	2031.72	6/2/2015 12:26
1882.31	5/28/2015 13:42	1883.39	5/29/2015 9:30	1882.59	6/1/2015 18:15	1883.34	6/2/2015 12:26
1856.79	5/28/2015 13:42	1857.65	5/29/2015 9:30	1857.98	6/1/2015 18:15	1857.27	6/2/2015 12:26
2040.33	5/28/2015 13:42	2040.37	5/29/2015 9:30	2039.25	6/1/2015 18:15	2039.80	6/2/2015 12:26
1856.64	5/28/2015 13:42	1857.35	5/29/2015 9:30	1857.13	6/1/2015 18:15	1857.41	6/2/2015 12:26
1584.18	5/28/2015 13:42	1584.42	5/29/2015 9:30	1584.21	6/1/2015 18:15	1584.71	6/2/2015 12:26
1541.76	5/28/2015 13:42	1542.10	5/29/2015 9:30	1541.49	6/1/2015 18:15	1542.05	6/2/2015 12:26
1584.48	5/28/2015 13:42	1584.46	5/29/2015 9:30	1583.85	6/1/2015 18:15	1584.06	6/2/2015 12:26
1544.89	5/28/2015 13:42	1544.65	5/29/2015 9:30	1544.57	6/1/2015 18:15	1544.83	6/2/2015 12:26
1518.40	5/28/2015 13:42	1518.52	5/29/2015 9:30	1520.03	6/1/2015 18:15	1520.90	6/2/2015 12:26
1485.86	5/28/2015 13:42	1485.73	5/29/2015 9:30	1486.13	6/1/2015 18:15	1486.56	6/2/2015 12:26
1972.36	5/28/2015 13:42	1974.45	5/29/2015 9:30	1974.46	6/1/2015 18:15	1974.04	6/2/2015 12:26
2049.99	5/28/2015 13:42	2049.65	5/29/2015 9:30	2049.31	6/1/2015 18:15	2049.57	6/2/2015 12:26
2009.15	5/28/2015 13:42	2008.75	5/29/2015 9:30	2007.98	6/1/2015 18:15	2007.57	6/2/2015 12:26
1896.74	5/28/2015 13:42	1896.90	5/29/2015 9:30	1896.05	6/1/2015 18:15	1895.84	6/2/2015 12:26
1942.57	5/28/2015 13:42	1942.13	5/29/2015 9:30	1942.29	6/1/2015 18:15	1941.95	6/2/2015 12:26
1967.45	5/28/2015 13:42	1967.70	5/29/2015 9:30	1966.09	6/1/2015 18:15	1966.60	6/2/2015 12:26
1768.49	5/28/2015 13:42	1768.16	5/29/2015 9:30	1768.30	6/1/2015 18:15	1762.00	6/2/2015 12:26
1678.71	5/28/2015 13:42	1679.20	5/29/2015 9:30	1680.04	6/1/2015 18:15	1679.75	6/2/2015 12:26
1824.86	5/28/2015 13:42	1824.89	5/29/2015 9:30	1824.83	6/1/2015 18:15	1825.07	6/2/2015 12:26
1746.88	5/28/2015 13:42	1749.75	5/29/2015 9:30	1749.23	6/1/2015 18:15	1749.52	6/2/2015 12:26
1754.23	5/28/2015 13:42						
1757.50	5/28/2015 13:42	1757.78	5/29/2015 9:30	1758.35	6/1/2015 18:15	1758.80	6/2/2015 12:26

INITIALS	RL & AT	INITIALS	RL	INITIALS	JD & RL	INITIALS	JD & RL	INITIALS
Date	6/3/2015 17:25	Date	6/5/2015 14:15	Date	6/6/2015 11:35	Date	6/7/2015 17:25	Date
Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)		Specimen Wt (g)		Specimen Wt
1737.65	6/3/2015 17:25	1737.19	6/5/2015 14:15	1737.76	6/6/2015 11:35	1736.58	6/7/2015 17:25	1736.62
1737.47	6/3/2015 17:25	1736.12	6/5/2015 14:15	1736.94	6/6/2015 11:35	1736.13	6/7/2015 17:25	1736.44
1756.00	6/3/2015 17:25	1755.03	6/5/2015 14:15	1755.27	6/6/2015 11:35	1754.70	6/7/2015 17:25	1754.40
1759.50	6/3/2015 17:25	1758.99	6/5/2015 14:15	1759.76	6/6/2015 11:35	1758.80	6/7/2015 17:25	1759.04
1602.50	6/3/2015 17:25	1601.29	6/5/2015 14:15	1601.73	6/6/2015 11:35	1600.80	6/7/2015 17:25	1601.37
1762.00	6/3/2015 17:25	1760.80	6/5/2015 14:15	1760.88	6/6/2015 11:35	1760.28	6/7/2015 17:25	1761.15
1948.16	6/3/2015 17:25	1947.41	6/5/2015 14:15	1948.09	6/6/2015 11:35	1947.16	6/7/2015 17:25	1947.41
2140.10	6/3/2015 17:25	2139.72	6/5/2015 14:15	2140.24	6/6/2015 11:35	2139.68	6/7/2015 17:25	2139.45
2020.32	6/3/2015 17:25	2019.59	6/5/2015 14:15	2019.90	6/6/2015 11:35	2019.48	6/7/2015 17:25	2019.54
1956.91	6/3/2015 17:25	1953.38	6/5/2015 14:15	1959.86	6/6/2015 11:35	1956.52	6/7/2015 17:25	1956.02
2164.97	6/3/2015 17:25	2164.46	6/5/2015 14:15	2164.47	6/6/2015 11:35	2164.07	6/7/2015 17:25	2164.10
1969.05	6/3/2015 17:25	1969.18	6/5/2015 14:15	1969.51	6/6/2015 11:35	1968.72	6/7/2015 17:25	1969.14
1922.21	6/3/2015 17:25	1921.56	6/5/2015 14:15	1922.33	6/6/2015 11:35	1922.07	6/7/2015 17:25	1922.19
2032.45	6/3/2015 17:25	2032.03	6/5/2015 14:15	2031.99	6/6/2015 11:35	2031.85	6/7/2015 17:25	2031.42
1883.05	6/3/2015 17:25	1883.17	6/5/2015 14:15	1883.49	6/6/2015 11:35	1882.35	6/7/2015 17:25	1883.46
1856.56	6/3/2015 17:25	1857.07	6/5/2015 14:15	1857.08	6/6/2015 11:35	1856.11	6/7/2015 17:25	1856.55
2040.05	6/3/2015 17:25	2039.57	6/5/2015 14:15	2039.77	6/6/2015 11:35	2039.38	6/7/2015 17:25	2039.49
1857.03	6/3/2015 17:25	1858.14	6/5/2015 14:15	1858.11	6/6/2015 11:35	1857.72	6/7/2015 17:25	1857.86
1584.95	6/3/2015 17:25	1584.72	6/5/2015 14:15	1584.89	6/6/2015 11:35	1583.89	6/7/2015 17:25	1584.57
4542.25	6/3/2015 17:25	1541.08	6/5/2015 14:15	1541.62	6/6/2015 11:35	1542.00	6/7/2015 17:25	1541.98
1584.75	6/3/2015 17:25	1583.49	6/5/2015 14:15	1583.56	6/6/2015 11:35	1583.56	6/7/2015 17:25	1583.50
1544.85	6/3/2015 17:25	1544.69	6/5/2015 14:15	1545.13	6/6/2015 11:35	1544.58	6/7/2015 17:25	1544.44
1520.57	6/3/2015 17:25	1520.74	6/5/2015 14:15	1521.15	6/6/2015 11:35	1519.98	6/7/2015 17:25	1520.63
1486.12	6/3/2015 17:25	1487.19	6/5/2015 14:15	1486.97	6/6/2015 11:35	1486.65	6/7/2015 17:25	1487.15
1973.75	6/3/2015 17:25	1973.58	6/5/2015 14:15	1973.81	6/6/2015 11:35	1973.25	6/7/2015 17:25	1973.60
2049.72	6/3/2015 17:25	2048.78	6/5/2015 14:15	2048.79	6/6/2015 11:35	2048.27	6/7/2015 17:25	2048.19
2007.03	6/3/2015 17:25	2007.03	6/5/2015 14:15	2007.04	6/6/2015 11:35	2006.42	6/7/2015 17:25	2006.37
1895.93	6/3/2015 17:25	1895.11	6/5/2015 14:15	1889.26	6/6/2015 11:35	1894.88	6/7/2015 17:25	1894.80
1941.81	6/3/2015 17:25	1941.39	6/5/2015 14:15	1941.70	6/6/2015 11:35	1940.80	6/7/2015 17:25	1941.00
1966.46	6/3/2015 17:25	1965.98	6/5/2015 14:15	1966.52	6/6/2015 11:35	1966.20	6/7/2015 17:25	1965.65
1767.66	6/3/2015 17:25	1767.91	6/5/2015 14:15	1767.72	6/6/2015 11:35	1767.14	6/7/2015 17:25	1767.03
1678.78	6/3/2015 17:25	1678.53	6/5/2015 14:15	1679.21	6/6/2015 11:35	1678.28	6/7/2015 17:25	1678.15
1824.85	6/3/2015 17:25	1824.18	6/5/2015 14:15	1824.67	6/6/2015 11:35	1824.65	6/7/2015 17:25	1824.87
1749.38	6/3/2015 17:25	1748.98	6/5/2015 14:15	1749.48	6/6/2015 11:35	1748.99	6/7/2015 17:25	1748.74
1758.47	6/3/2015 17:25	1757.48	6/5/2015 14:15	1758.22	6/6/2015 11:35	1757.94	6/7/2015 17:25	1757.85



JD
6/8/2015 12:55
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