STATEMENT OF WORK

PHASE II Analytical Assessment of Field Data for Sealed Attics in Florida Climate Zones 1 and 2

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For the

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1. BACKGROUND

During the 2015-2016 fiscal year and with financial support of $90k from the Florida Building Commission (FBC) and $11k from the Florida Roofing and Sheet Metal Contractors Association (FRSA[1]), the University of Florida (UF) and the Oak Ridge National Laboratory (ORNL) completed Phase I of a study that setup four residential home demonstrations in Florida climate zones CZ-1A and CZ-2A. A Phase II continuance of the study is proposed to analytically evaluate the hygrothermal (heat and moisture flow) performance and durability of sealed attic construction where expanded foam insulation is applied directly to the underside of the roof deck.

The four homes are instrumented for measuring temperature and relative humidity of the indoor living space, the outdoor air and the attic air. In addition, the temperature, relative humidity and moisture content of the roof sheathing are being monitored and recorded by remotely-accessible data acquisition equipment. Air leakage tests on the whole house, on the sealed attic and in the HVAC ducts were conducted on all four homes; results are listed in Table 1. Digital and infrared images were captured to document the thermal performance of the sealed attics. Field tests commenced June 1, 2016. Data acquisition will continue for one full year to document heat and moisture flows, which, in turn will serve to benchmark an analytical tool kit for predicting the heat and moisture flows in Florida's hot and humid climate.

Table 1: Florida Home Descriptive and Leakage Results

Characteristic	House 1	House 2	House 3	House 4
Location	West Palm Beach	Venice	Orlando	Gainesville
Attic	Sealed ocSPF	Sealed ocSPF	Sealed ocSPF	Sealed ocSPF
Type of roof	Standing seam metal	Concrete barrel tile	Asphalt shingle	Asphalt shingle
Conditioned Area	2,043 sq. ft.	3,592 sq. ft.	2,348 sq. ft.	3,055 sq. ft.
Conditioned Volume	29,670 cubic ft.	42,183 cubic ft.	22,115 cubic ft.	29,022 cubic ft.
Attic Volume	6,800 cubic ft.	7,692 cubic ft.	5,106 cubic ft.	14,002 cubic ft.
Total ACH at 50Pa	6.7	2.2	8.6	5.2
Leakage Breakdown Attic / Conditioned Space	58% / 42%	36% / 64%	12% / 87%	5% / 95%
Total Duct Leakage	0.11 CFM / sq. ft.	0.16 CFM / sq. ft.	0.26 CFM / sq. ft.	0.21 CFM / sq. ft.
HVAC System	AC with Elec Furnace Air-Handler in attic Ducts in attic	Heat Pump Air-Handler in closet Ducts in attic	Heat Pump HVAC outside No Duct in tested attic	Heat Pump Air-Handler in closet Supply Ducts in attic
Dehumidifier	NA	UltraAir	NA	Master Bath
Roof deck insulation ($h\cdot ft^2\cdot {}^\circ F/Btu$)	R-15: 4" ocSPF	R-21: 5.5" ocSPF	R-15: 4" ocSPF	R-27: 7" ocSPF
Code minimum R-value/ Active FECC*	R-19: 2010 FECC	R-19: 2010 FECC	R-19: 2002 FECC	R-19: FECC 2007
*FECC code in effect during application of spray foam to seal attic by prescription requirement.				

[1] The FRSA is an alliance of companies actively engaged in the roofing contracting business in the State of Florida.

The Building Technology Research Integration Center (BTRIC) at ORNL has factual data on long-term performance of sealed attic construction that were collected at two separate field demonstrations (Natural Exposure Test Facility[2] in Charleston, SC and the Campbell Creek Home demonstration[3] in Knoxville, TN). The studies helped formulate and benchmark a risk assessment methodology for predicting potential water buildup and subsequent damage to wood roof sheathing. The methodology also predicts the deviance of the conditioned space below sealed attics, from the ASHRAE Standard 55 comfort conditions. BTRIC has developed an exclusive capability to model and simulate the hygrothermal dynamics of sealed, semi-conditioned attics. The toolkit[4] is composed of EnergyPlus and WUFI1D. EnergyPlus computes the heat transfer exchanges (convection and radiation) prevalent in a sealed attic as well as the thermal performance of the complete building envelope and inner environment. Computations from EnergyPlus are relayed to WUFI1D as boundary conditions for predicting the hygrothermal performance (moisture flows) in the roof construction. Combined the two codes can predict the risk of abnormally high relative humidity in the conditioned space and the risk for long-term moisture accumulation in the roof structure.

This proposed second phase of work will benchmark the toolkit to the field data for all homes. The benchmarked toolkit will be used to perform sensitivity analyses to document which parametric changes in key sealed attic parameters have the biggest impacts on performance and moisture accumulation in wood roof structures. These results will lead to development of sealed attic design guidelines applicable to the future construction of sealed attics throughout the state of Florida. Ultimately, such a guideline will be submitted to the FBC for adoption into and strengthening of the Florida Energy Conservation Code (FECC).

2. INTRODUCTION

Conventional attic design ventilates the attic using soffit and ridge vents to circulate outdoor air through the attic and remove moisture emanating primarily from occupant activity within the adjacent conditioned space. A new design was introduced to Florida and approved by the FBC in 2007 where the attic is sealed to the outdoor ambient. Moisture damage in vented and sealed attics is often the result of poor design and/or poor workmanship allowing the intrusion of bulk water into the structure. Some of the modes of moisture entry are:

- An inadequate or failed roof flashing, that creates paths for water leakage allowing liquid water (from exterior events - rain and snow) to flow into the interior attic. Such leakage over time will elevate the moisture contents of the wood structural members in the roof, (sheathing, rafters and wood truss) resulting in deterioration and failure. In roofs without sprayed-on insulation, leaking water will likely drip into the attic, and leave stains on the underside of the roof sheathing, making it relatively easy to detect leaks. However, the detection of water leaks is hindered in roofs having ccSPF insulation because water will not readily drip through the ccSPF layer.

- Passage of water vapor due to leakage of unwanted outdoor air through inadequately-sealed exterior walls can lead to a risk of water condensation within "nominally" sealed attics[5].

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[2] Miller, W., Railkar, S., Shiao, M. and Desjarlais, A. 2017."Sealed Attics Exposed to Two Years of Weathering in a Hot and Humid Climate," THERM XIII, ASHRAE Transactions, 2016, to be published Jan. 2017.
[3] Boudreaux, P., S. Palin, and R. Jackson. 2013. Moisture Performance of Sealed Attics in the Mixed-Humid Climate, ORNL/TM-2013/525, Oak Ridge National Laboratory.
[4] Pallin, S., Kehrer, M., and Miller, W. 2013." A Hygrothermal Risk Analysis Applied to Residential Unvented Attics," THERM XII, ASHRAE Transactions,2013.
[5] Parsons, G. and Drzyzga, M., "Insulating and Air Sealing Low-Pitch Residential Attic Spaces: Cost-Effectiveness Evaluation" Thermal Performance of the Exterior Envelopes of Buildings, XII, proceedings of ASHRAE THERM XII, Clearwater, FL., Dec. 2013.

- Passage of water vapor from the interior conditioned space through gaps and joints and directly through the ceiling dry wall and interior wall outlets etc. can increase the moisture loads in attic spaces. The extent of this moisture load increase is a direct function of the moisture generated by occupants.

In Phase I work the selected 4 homes were the residence of a builder or homeowners affiliated with the building industry. The selection criteria helped minimize and hopefully eliminate the confounding issue of poor workmanship.

3. OBJECTIVE/PURPOSE

An unvented and sealed attic is one approach to bringing the HVAC ducts into the conditioned space that can reduce space conditioning energy by 10%. This practice shows good hygrothermal performance in hot-dry climates, but utilizing this approach in humid and mixed-humid climates requires careful design and consideration to ensure the moisture durability of this energy efficient measure. Boudreaux, Pallin and Jackson[6] recommend that sealed attics be conditioned to mitigate the moisture buildup issue as do Roppel, Norris and Lawton[7].

The goal of this project is to provide guidance for building moisture durable sealed attics in Florida. To accomplish this, the ORNL probabilistic risk assessment toolkit (PRAT) will be benchmarked against measured field data in Florida from homes with sealed attics utilizing open-cell and closed-cell spray polyurethane foam. Once the toolkit is benchmarked, a series of probabilistic runs will be made to determine what variables are most important to the success of the sealed attic approach and guidelines identified for moisture durable ranges of these key variables.

Specifically, Phase II work will investigate the effect of envelope leakage, duct leakage, and internal heat generation on the moisture content of the roof sheathing. Based on the analytical results safe operating leakage thresholds will be recommended.

Task 0. – Research Contract between the ORNL and the UF
The ORNL will work under subcontract to the UF. The contract will be considered new work because the FBC will close-out the Phase I contract and issue new funds upon approval of the FBC. Therefore UF will subcontract work to the ORNL, but will include funds to manage the project and for the support and mentoring of a Masters level civil engineering graduate student to conduct research, leading to a Master thesis at UF. A contract will be approved by ORNL and UF for collaborating on the project for the FBC.

Deliverable:

- **Report:** Approved Research Contract between UF and the ORNL.

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[6] Boudreaux, P., Pallin, S. and Jackson, R. 2016. "Investigation of the proposed solar driven moisture phenomenon in asphalt shingle roofs," in Thermal Performance of the Exterior Envelopes of Buildings, XIII, proceedings of ASHRAE THERM XII, Clearwater, FL., Dec. 2016.

[7] Roppel, P., Norris, N. and Lawton, M. 2013. "Highly Insulated, Ventilated, Wood-Framed Attics in Cool Marine Climates. ASHRAE Thermal Performance of the Exterior Envelopes of Whole Building XI International Conference.

Task 1 – Benchmarks of Probabilistic Risk Assessment Toolkit (PRAT) against Field Data
The PRAT enables a sensitivity analysis of the moisture content of the roof sheathing to key input variables. These key input variables are the probability distributions of envelope leakage areas, duct leakage rates, thermostat set point, and indoor heat and moisture generation rates. This probabilistic moisture content distribution output from the toolkit will be benchmarked against the measured data. The toolkit uses EnergyPlus energy simulation software and WUFI heat and moisture transport software in series to first determine the attic side boundary conditions (EnergyPlus) then the hygrothermal performance of the attic roof assembly (WUFI). A graduate student from UF will work with ORNL personnel to reduce field data for the demonstration sites and will in parallel to ORNL run simulations to benchmark the toolkit. The task will serve in part for the completion of requirements of a Master's thesis for the student.

Milestone: Ceiling Joists

- Field-measured roof sheathing moisture content will be compared to probabilistic moisture content distribution from toolkit.
- PRAT will be exercised with fixed details measured from the field sites (leakage areas, etc. less probabilistic – more deterministic) and field results will be compared to this narrower distribution.

Deliverable:

- Report: Letter report by UF describing the results of the benchmarks.

Task 2 – Sealed attic Sensitivity Analysis and Recommendations
After the PRAT is benchmarked it will be used to investigate the indoor comfort and durability of homes with unvented attics in the hot, humid climate of Florida. The independent variables to be studied include the leakage areas of 1) the attic to the outside, 2) the living space to the outside, and 3) the living space to the attic space, as well as 4) the attic duct leakage 5) the interior moisture generation rate, 6) the thermostat set points, and 7) interior heat generation. These key input variables and others that may be identified in Task 2, will be investigated and recommendations will be made for establishing moisture-safe ranges. Other variables that will be investigated, although not probabilistically, are details of the roof construction (i.e. ocSPF, ccSPF, depth of foam, and depth of permeable insulation under roof sheathing).

Milestone:

- Modify EnergyPlus input files and WUFI input files to reflect appropriate attic designs for Fl.
- Run PRAT.
- Complete sensitivity analysis to see which probabilistic variables most affect each attic design.

Deliverable:

- Recommendations Letter Report: Document summarizing the results of the sensitivity analysis and any recommendations that follow for moisture durable sealed attics in FL climate.

4. SUMMARY OF MILESTONES/DELIVERABLES

The milestones and deliverables pertinent to ORNL and UF are provided in Table 2 and 3.

Table 2. Milestones for FBC Project

Task	***Milestone***	*Completion Date*
Task 1. – Benchmarks of Probabilistic Risk Assessment Toolkit		
	Roof sheathing moisture content compared to probabilistic moisture content distribution from toolkit	February, 2017
	Simulations using fixed details from field sites for comparing moisture content in field to simulation result	March, 2017
Task 2. – Design Guidelines for FBC		
	Sensitivity analysis to see what probabilistic variables most affect each attic design	April, 2017
	Recommendations for designing moisture durable sealed attics based on sensitivity analysis	May, 2017

Table 3. Deliverables for FBC Project

Task	***Deliverables***	*Completion Date*
Task 0. – Contract Approved by ORNL and UF For Collaborative Work		
	Signed Research Contract submitted by DOE ORO to FBC	November, 2016
Task 1. – Benchmarks of Probabilistic Risk Assessment Toolkit		
	Interim Report showing the comparison of field data to PRAT simulations	April, 2017
Task 2. – Sealed Attic Design Guidelines for the FBC		
	Final Report Guidance document providing best practices for designing moisture durable sealed attics in Florida.	May, 2017

5. ESTIMATED BUDGET

The Engineering School for Sustainable Infrastructure and Environment is working with the ORNL in Tasks 1, 2 and 3 of the study. It is recommended that the award from the FBC be funded to UF and that UF subcontract work to ORNL because of the existing contract agreements between the FBC and the various universities in the state of Florida. The DOE waives ORNL advanced payment requirement because of Florida state-statutes pertaining to UF being a land-grant institution. The work is a non-federally funded project. The Budget is provided in two scenarios, one is for the complete request, the other by Task and by home.

ORNL Budget by Category

Category	**FY2017**
Labor	$40,450
Materials & Supplies	$0
Travel	$3,420
Subcontract	$0
Overhead	$50,255
Subtotal	$94,125
FAC	$0
Grand Total	$94,125

UF Budget Breakdown

UF Civil & Coastal Eng. Budget	**FY2017**
Faculty salary & fringe	$14,712
(1) Student*-Salary	$20,500
Lab Tech	$
Admin Assistant	$7,964
Materials & Supplies	$1,000
Travel	$3,000
Subcontract ORNL	$94,125
Sub Total	$141,301
F&A	$14,130
UF Total Contract	$155,431

ORNL Budget Breakdown by Task

Task	Breakdown per Home	Budget Scenarios for Homes Simulated in Tasks 1 and 2			
		One Home	Two Homes	Three Homes	All Homes
Task 1 and 2					
1 Home (40%)	$36,282	$36,282			
2 Homes (30%)	$27,212		$63,494.5		
3 Homes (15%)	$13,605			$77,099.25	
4 Homes (15%)	$13,605				$90,705
Materials & Supplies		$0	$0	$0	$0
Travel		$3,420	$3,420	$3,420	$3,420
Total		$39,702	$66,913.5	$80,519.25	$94,125

Detail breakdown for travel follows.

ORNL Travel (3 people, 2 Day Trip)

Category	Occurrence	Each
Airfare	3	$1,000
M & IE	3	$40
Accommodations	3	$100
Rental Van	0	$0
Subtotal		$3,420

UF Travel

UF Civil & Coastal Eng. Budget	FY2016
Travel	$
Accommodation & per diem	$
Subtotal	$

ORNL Budget Breakdown by Labor Hours

UT-Battelle, LLC manages and operates the ORNL for the Department of Energy (DOE). ORNL is DOE's largest multi-program laboratory facility performing applied and basic research for the private sector, other federal agencies, and states. All work is performed on the basis of full-cost recovery, as mandated by law. For ORNL full cost includes all direct costs incurred in performing research work, all allocable costs incurred by DOE or UT-Battelle, and a Federal Administrative Charge (FAC) of 3% of these costs. Generally, rates charged by UT-Battelle ae based on a standard rate methodology. Under the process, rates for labor, organization burden, space pool, general and administration, etc. are set at the beginning of the year. The accounting system conforms to DOE Orders and is periodically reviewed by the DOE.

Person	Hours	Hourly Rate*	FY2017
W.A. Miller	40	$238.91	$9,556.25
J.A. Atchley	0	$167.28	$0
T. Gehl	0	$208.09	$0
S. Pallin	200	$202.87	$40,574.38
P. Boudreaux	200	$202.87	$40,574.38
Grand Total			$90,705
• Hourly rate includes overhead = $50.3k			

UF Budget Breakdown by Labor Hours

Person	Hours	Hourly Rate	Fringe	Tuition	IDC	Total
D. Prevatt	113.38	$65.97	$16.95	$0.00	$8.29	$
Admin Assistant	94.12	$27.37	$11.74	$0.00	$3.91	$
Student		$14.18	$0.08	$0.00	$1.43	$