Final Report:

Field Evaluation of Thermal Performance and Energy Efficiency of ccSPF Retrofitted Vented Residential Attic

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FOREWORD

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SUMMARY

This report documents the findings of an experimental investigation on field evaluation of thermal performance and energy efficiency of closed-cell spray-applied polyurethane foam (ccSPF) sponsored by the Department of Community Affairs, Florida. The work was conducted at University of Florida, Gainesville (UF) under the direction of Principal Investigator, Dr. David O. Prevatt. Field evaluation was performed on a test house located at in Northwest Gainesville, Florida. As a due-diligence measure the roof deck and roofing was inspected by a professional roofing contractor before installation of the insulation.

Temperature, relative humidity, weather data, electricity and gas consumption data in the house were continuously monitored before and after ccSPF installation in vented attic of the test house. Temperature and relative humidity sensors were installed at eight locations in the house and attic data is being continuously recorded. A weather station was also installed to monitor ambient conditions, including wind speed, solar radiation, temperature and relative humidity. The installed energy monitors collected data at the appliance level as well as for the house as a whole. After ccSPF was installed in the attic, five temperature and relative humidity sensors were placed to monitor surface temperatures on the underside of foam and OSB sheathing.

One aspect of the research was to assess qualitatively, the effect of the additional insulation on the thermal comfort within the conditioned space in the house. To address the scientific basis for these a thermal scan was performed to determine the ceiling temperatures before and after installation. In addition, air tightness testing was carried out on the building envelope and a duct leakage (duct blaster test) done prior to insulation installation. The building engineer's recommendations for improving the air tightness of an existing Florida home are included in the appendices.

It was found that the foam insulation resulted in a decrease of about 20^0F in peak attic temperatures during summer after ccSPF installation. A preliminary analysis the energy data showed that there was/was not a noticeable decrease in energy usage for the home. The results are corroborated by data from the local utility company on the consumption of electricity and gas during the month after the ccSPF was installed.

A summary of previous testing done at UF to determine the uplift capacity of wood roof panels retrofitted with ccSPF is also presented here. This report also includes a summary of three field visits of ccSPF installations in Florida. Existing guidelines for ccSPF installation are reviewed and some suggestions to improve the installation process are discussed.

KEYWORDS: Vented attic, ccSPF, Field evaluation, Energy efficiency, Thermal performance.

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1. INTRODUCTION

1.1 Motivation

The benefits of closed-cell spray-applied polyurethane foam (ccSPF) for thermal insulation of wood roof attics are well known. Research at the University of Florida has shown that a ccSPF fillet applied along the joint between wood truss/rafter to roof sheathing increases the wind uplift capacity of a traditional roof by a factor of 2.0 to 2.5. Furthermore, ccSPF is impermeable to water and so it acts as a secondary water barrier that reduces water leakage in the event the roof covering is compromised during hurricanes. Finally, ccSPF is an excellent thermal insulator (~R6 per in.) which provides beneficial energy savings for heating and cooling.

However, the widespread use of ccSPF retrofit in existing homes has been limited due to the scarce body of knowledge regarding the durability of ccSPF, its effect on rate of wood degradation and quantifiable data on thermal performance of installed roofs. Information is needed by the homeowners to consider the options for retrofit, as well as by the Florida Building Commission and code officials in order to develop policy for implementation and guidance.

The research addresses a complex problem that has confounded building professionals working in the hot humid climates of southeastern states. This research project evaluates and compares the (before and after) thermal performance and energy consumption in an existing residential home attributable to the installation of ccSPF insulation to the underside of a wood roof deck in a vented attic configuration.

1.2 Background

During the 2004 hurricanes, (McCarty, 2005) found that almost half of a survey population of nearly 12,000 Florida residents had to evacuate at least once prior to a hurricane, despite almost all respondents living beyond surge-prone coastal regions. The wind-induced damage occurred to nearly one-third of the study-areas homes, which sustained major damage and median losses of $11,000 (2004 dollars). These losses are occurring to the roof structures due to inadequate structural systems, improper design and poor construction. The structural retrofit is the one approach that can significantly reduce future losses to Florida homes from hurricanes and reduce energy consumption. Many post-storm surveys and reports, (FEMA, 2006, Gurley, 2006, Graettinger, 2006) have documented the failures of wood framed roofing in recent hurricanes. The damage affects the older structures with disproportionately high levels of damage due in part to the fragility of these structures as is discussed below.

Closed-cell spray-applied polyurethane foam (ccSPF) is an innovative building thermal insulation system, and its presence in Florida's residential construction industry is growing. ccSPF has high thermal insulating properties (R6 per inch thickness) and it is a durable (water tolerable) building product. Typical ccSPF formulations 2 inches thick have a permeability of 1 perm or less (i.e. practically impermeable to water), and they also act as a vapor barrier. ccSPF is the only FEMA-approved insulator for use in their Flood Insurance program in below-grade locations. The thermal properties of spray foam insulation have tremendous potential to reduce heat gain, heat loss and energy use in homes yet questions remain as to appropriate fire retardation approaches suited to residential homes.

Recent testing by the University of Florida (Prevatt, 2007, Prevatt, 2007) have quantified the relatively high adhesive strength of one ccSPF formulation installed to retrofit wood panels. The retrofitted panels have approximately 2.0 to 2.5 times the uplift strength of original wood panels connected using 2 in. long nails. Thus, ccSPF is also suitable as a structural retrofit system to mitigate hurricane damage to existing structures. The structural benefits of ccSPF retrofit are realized even if all original fasteners are missing or ineffective.

While the current ccSPF insulation market focuses primarily on new construction of non-vented attics (and to lesser extent exterior wall insulation), a vast potential market exists for ccSPF in retrofit applications of existing residential structures. As shown in Figure 1.1, approximately 80% of the existing housing stock was built before 1994, when more stringent wind resistant provisions were first introduced to building codes in Florida (Census, 2003).

The construction of wood roofs using plywood sheathing was particularly vulnerable because the sheathing was attached either with smooth shank 6d common (2 in. long) nails or metal staples that had very low wind uplift resistance.

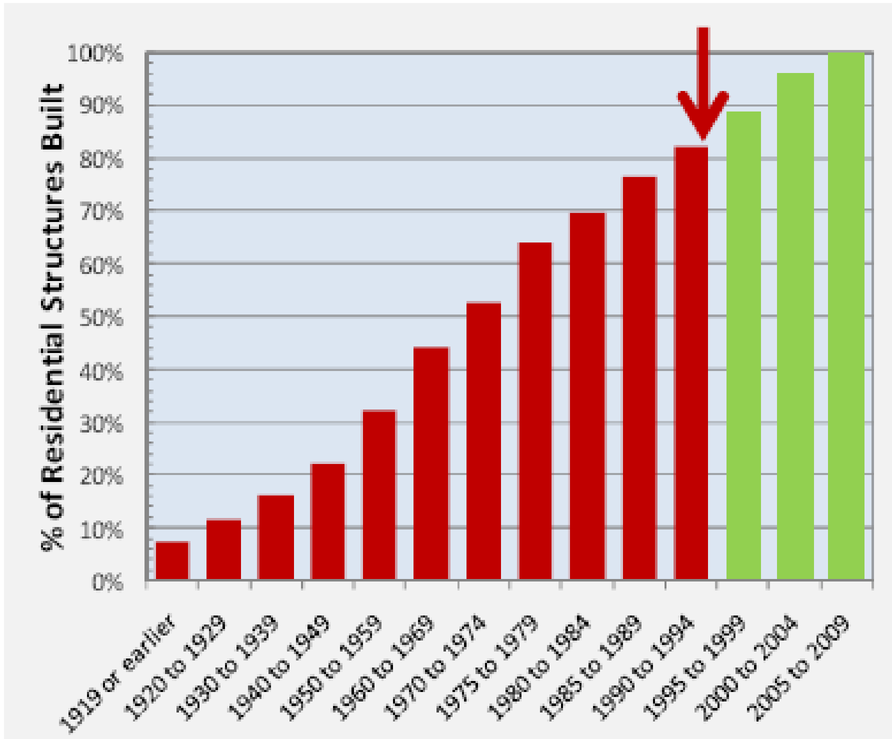


Figure 1.1: Percentage of existing residential structures by year built (US Census)

The loss of roof sheathing, particularly from roof corners in residential construction is prevalent particularly in older homes due in large part to the inadequacies in connection detailing prevalent in pre-1994 building codes. Tests at UF showed the structural inadequacy of using 2 in. long smooth shank nails in hurricane-prone regions. Although minimum code requirements have since been strengthened since 1994, the vast majority of homes today still contain the inadequate connections. In addition, field studies show that there is high possibility that fasteners installed (nailed blind) through the roof deck will many times miss the wood member, resulting in poorly installed and vulnerable roof panels.

The vulnerabilities of a large proportion of older homes within the current inventory of residential housing underscore the need to develop reliable retrofit strategies to improve the wind resistance of these roofs. The costs associated with the poor design of roofs and poor construction have contributed to the significant annual losses sustained by Florida in hurricanes. The damage results in billions of dollars in losses as well as significant disruptions to the lives of hundreds of thousands of Florida residents in our coastal communities.

There are over 20 million homes with wood-framed roof structures located in hurricane-prone areas. Most of these structures are inadequately built to resist hurricane force winds. Despite forty years of research (from Hurricane Camille through Hurricane Ike), and incremental design modifications, changes to roof designs have had limited impact on reducing the damage caused by hurricanes.

Residential buildings consume more than one-fifth of the energy used in the United States today [Energy Information Administration], and 50% of this energy is used for heating and cooling rooms. A significant reduction in energy use can only be made if the thermal insulating performance of unvented attics is substantially improved for a large proportion of existing residential roofs.

ccSPF has several additional beneficial qualities that make it suitable to this use. It is claimed (by ccSPF installers and homeowners) that ccSPF installed in a typical vented attic of a residential home will reduce the ambient attic temperature by 20 to 40 degrees Fahrenheit on hot summer days. In hot humid climates, such as the state of Florida, reducing attic temperatures from 140 degrees to 95 degrees creates a more efficient (semi-conditioned) space for the heating and cooling system to operate. Independent verification of these claims is needed and will go a long way to encourage homeowners to retrofit their older homes, which in the long-term is the most efficient way of reducing the extensive damage that is annually sustained by Florida housing inventory. (Lstiburek, 2006) provides comprehensive reviews of the attic ventilation issues, pertaining to vented versus non-vented attic configurations.

Thus as a retrofit application, ccSPF in wood roof structures provides three very important benefits; 1) significant improvement of the wind uplift (structural) resistance of the roof, 2) significant reduction in energy consumption for heating and cooling of the home and 3) a durable secondary water barrier to limit water penetration through the roof structure during hurricanes. However, test data are needed to compare the energy performance of the vented and unvented roof configurations.

Studies have established the energy efficient performance of non-vented attics that are thermally isolated from the exterior (make-up airflow is provided by the mechanical air system). The cost to convert the majority of existing residential roofs to unvented systems may be beyond the level of homeowners. By enclosing the HVAC units and air ducts the thermal load and moisture loads are significantly reduced which increases its energy efficiency and longevity. The research to develop these systems is based on (Parker, 2005) at the Florida Solar Energy Center. They confirmed that energy consumption for heating and cooling of buildings can be reduced by 20% to 40% through using non-vented attics. Specifically, this study will test the hypothesis that vented attic installations of ccSPF can lower energy bills by 40% and improve indoor air quality in residential homes.

1.3 Scope of Work

Task 1: Conduct thorough engineering survey of the existing roof structure and condition of the roof coverings, particularly to evaluate the existing risk for water leakage and failure of asphalt shingles.

Document the existing construction conditions within the roof attic in engineering sketches and detailed photographs. Document and carry out roofing repair necessary to minimize likelihood of water leakage to the ccSPF/sheathing interface. Record interior conditions of attic air handling equipment.

Task 2: Develop and install instrumentation to monitor temperature and humidity in attic and conditioned spaces, energy usage, and ambient weather conditions.

Continuously monitor physical changes in hygrothermal parameters and energy consumption to establish baseline performance of the existing residential roof structure before ccSPF is installed. The instrumentation and data acquisition will continue to provide the post-retrofitted conditions through end of the project.

Task 3: Review and Develop Installation Specifications for ccSPF retrofit

Compile current industry knowledge and consumer expectations, building code provisions, contractor challenges and specifications for retrofitting attics using ccSPF. Prepare contract specifications suitable for installing ccSPF in vented attic configurations.

Task 4: ccSPF Insulation Installation and Documentation

ccSPF insulation will be installed in a test house by a certified ccSPF installer in accordance with the specifications developed in Task 3. The installation methods will be fully documented and presented in a “layman’s” technical guideline for ccSPF installation. Monitoring of roof conditions continues through project close as described in Task 2.

Task 5: Comparative Study on Energy Usage Report and Details of ccSPF installs.

Prepare final report that includes the comparison of before and after hygrothermal conditions and energy usage in test house. The written and illustrated final report will document the research methodology, the findings and conclusions. The report will include draft specification and Layman’s Technical Guide to ccSPF installation in vented attics.

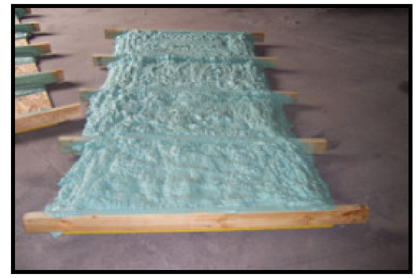
2. WIND UPLIFT (STRUCTURAL) RESISTANCE OF SPRAY FOAM INSULATION

In 2007, the PI conducted an experimental investigation sponsored jointly by Honeywell Specialty Materials (Honeywell) and Huntsman to identify the structural benefits of spray-applied polyurethane foam (SPF) in wood roof construction. The research evaluated the wind uplift capacity of ½ in. thick by 4 ft. by 8 ft. oriented strand board (OSB) panels that were nailed to 2 in. by 4 in. southern yellow pine (SYP) framing members spaced 2 ft. apart.

The retrofits consisted of a 3 in. triangular fillet along the wood-framing to sheathing panel joint, or a continuous 3 in. thick ccSPF layer applied to the underside of the roof sheathing. The wind uplift capacity of these panels was assessed by an air pressure test method following the modified ASTM E330, Method B test protocol. When the results were compared with similar tests on unretrofitted roof systems, it was found the resistance of the ccSPF-retrofitted panels increased to between 2 to 3 times greater than the resistance of the unretrofitted ones.

(a) Unretrofitted

(b) Foam Fillet



(c) 3” Foam Layer

Figure 2.1: Unretrofitted and retrofitted test panels

Figure 2.2 shows the results of the wind uplift tests on the panels. The mean failure pressure for the unretrofitted panels was 77 psf and the 3 in. ccSPF layer increased the uplift capacity by almost 3 times. Foam fillet configuration exhibited an increase of about 2 times in the uplift strength.

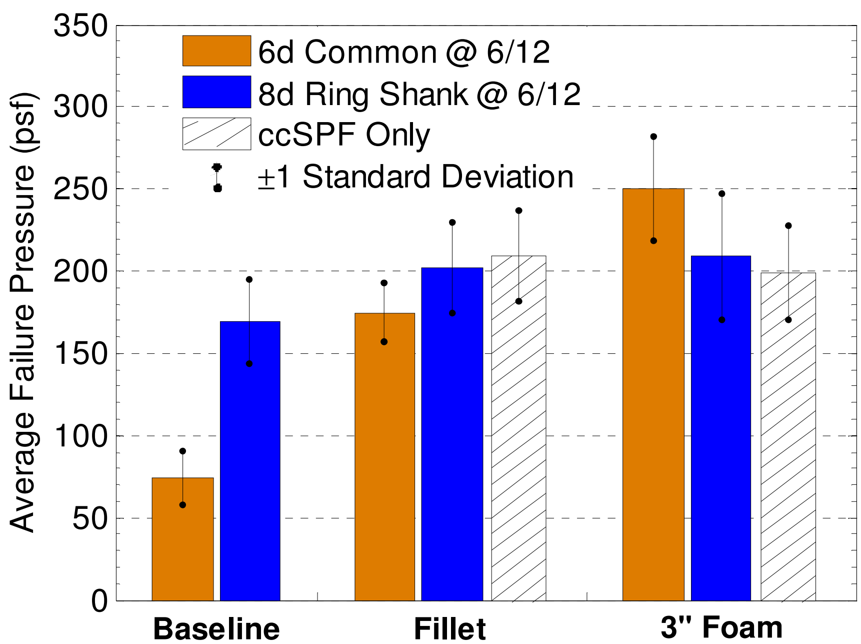


Figure 2.2: Results of wind uplift tests on roofing panels

The research did not evaluate the potential damaging effects of water trapped between ccSPF and underside of the sheathing panel. It is known that high moisture content in wood can lead to deterioration of wood strength. This present study aims to address some of these issues through long term monitoring in a field installation of ccSPF.

3. CLOSED-CELL SPRAY FOAM INSTALLATIONS IN EXISTING FLORIDA HOMES

Three residential houses and one office building was investigated for the Spray-applied Polyurethane Foam (SPF) installations in Florida. One house was located in Pinellas Park, FL and the other two houses and office building were located in Tampa, FL.

3.1 Pinellas Park

On 19 November 2010, the research team inspected a house located in Pinellas Park, FL, during the installation of ccSPF to the attic. The single-storey house had a gable roof (approximately 4 in 12 slope) with a vented attic. Ventilation is provided by ridge and soffit (eave) vents and the roof had gable end vents. There was approximately 6 in. thick layer of blown insulation in the roof. ccSPF foam was installed a 1 in. thick layer with 3 in. fillets along the wood framing members, Figure 3.2.

The installers covered the soffit vents prior to spraying to prevent excess spray from escaping and damaging the walls or exterior vegetation. The installers used an exhaust fan to remove attic fumes from the spray process during the work. On a typical sized house (say 1800 sf) the foam installation job usually takes about 3-4 hours to complete.

Figure 3.1: Front view of the house

Figure 3.2: ccSPF sprayed to seal openings where hose/pipes pass through the roof deck

3.2 Tampa, FL

Two graduate students visited two Tampa, FL residential homes built by a residential contractor, Mr. Jeff Wolf. One of the homes had open cell-spray foam polyurethane insulation installed in the attic, while the second was insulated using ccSPF. These residences were custom construction and they had unvented roof attic configurations. A 3 in. foam layer was used in both homes. Figure 3.3 shows the surfacial differences between the denser (more compact) ccSPF and the spongy open cell foam installation. In this case, there were no soffit, ridge or gable end vents so the foam installations extended continuously down to the ceiling.


Figure 3.3: House 1 with ocSPF installed in the attic

The contractor also installed a 3 in. thick layer of open cell spray foam insulation in his office. Figure 3.5 shows a photograph of the installation with water-stained ceiling tiles below the roof structure, confirming the water-permeability of open cell spray foam insulation.

Figure 3.4: Office roof with ocSPF installed

4. REVIEW OF ARCHITECTURAL SPECIFICATIONS AND INSTALLATION INSTRUCTIONS FOR WIND-UPLIFT RESISTANCE

This section summarizes the architectural specifications and general installation instructions for ccSPF that were reviewed for this project (NCFI Polyurethanes, 2009, FL DCA Product Approval FL#13001, FL DCA Product Approval FL#9975).

General Requirements:

- Foam should be separated from occupied spaces with an approved 15-minute fire rated thermal barrier and covered by an approved ignition barrier in attic and crawl spaces where entry is made only for service of utilities.

Material Properties:

- The nominal density of ccSPF used is approximately 2.0 lb/ft^3.

Specifications:

- Surfaces to be sprayed must be clean and dry. Metal surfaces need to be devoid of grease, oil and other debris primer coatings should be used if necessary.
- Masking off of areas to be protected with tape and plastic sheeting is mandatory as ccSPF forms a tenacious bond with most surfaces.
- A nominal ½ in. thick first layer of ccSPF should be installed to ensure strength properties are obtained. One manufacturer recommends application using a box frame pattern, Figure 4.1.

- The clean up procedure consists of removing any masking materials or overspray. Excess insulation is to be shaved off to the desired thickness.

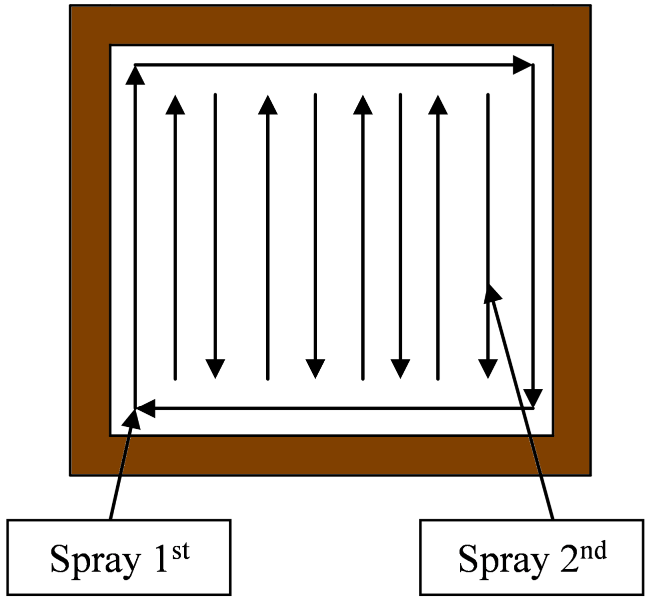
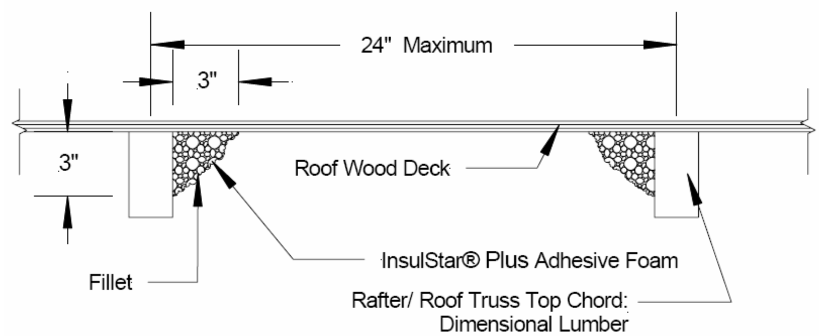


Figure 4.1: Box spray application technique for applying ccSPF to a surface

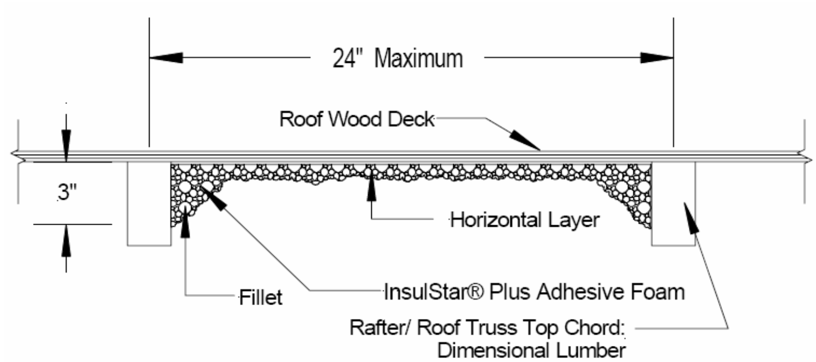
Technical Drawings and Details:

- Typically there are three protection levels approved in the Florida Building Product Approvals, diagrammatically represented in Figure 4.2.
    - Level 1, consists of fillet only at the sheathing seams and along wood framing joints.
    - Level 2, consists of the Fillet at wood joints and a minimum ½ in. thick layer covering protrusions.
    - Level 3, protection consists of fillet at wood joints plus a 3 in. thick fill.

Level 1



Level 2



Level 3

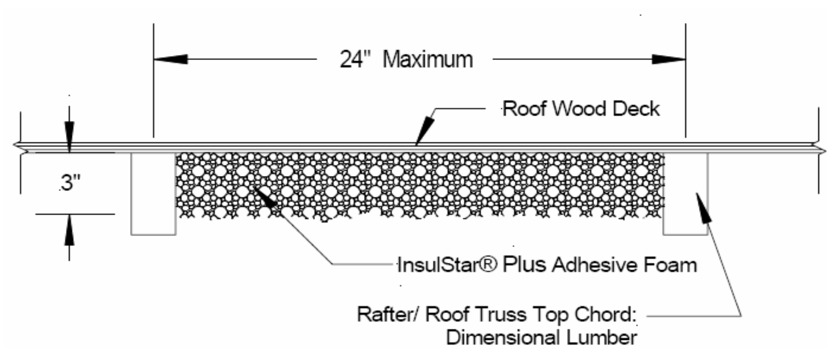


Figure 4.2: Sketch showing the Three Protection Levels of ccSPF Structural Retrofit of Wood Roof Sheathing Panel Roof

5. TEST HOUSE DESCRIPTION

5.1 General Layout

The test house is a single family detached structured with a total floor area of about 2400 square feet, located in a suburban neighborhood of Gainesville, FL. The house was constructed in 1972 and most of the houses in the neighborhood are of similar construction and vintage. The front of the house faces to the west and the main roof ridge is oriented in a north-south direction. The house is amply shaded by large live oak trees with extensive canopies located on the east and west sides, Figure 5.1. Figure 5.2 illustrates the general plan and layout of the test house on the site.

Figure 5.1: A photograph of the test house.

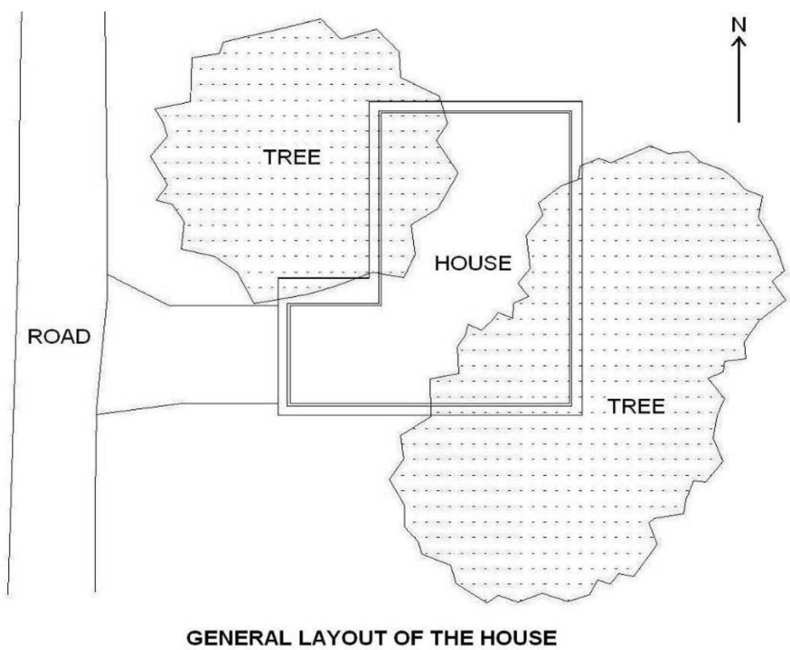


Figure 5.2: Layout and orientation of the test house.

The axial length of the house is parallel to the street. As viewed from the street, the garage is located on the right (southern end) and connects perpendicularly to the main house. On the left side of the garage is a covered walkway leading to the front entrance.

The test house is 38' wide by 63' long. The exterior walls are 8'-6" tall and there is a 24 in. wide eave extending beyond the walls. The roof ridge is 14'-9" above grade for the main roof and about 12'-4" above grade over the garage. The garage which is located at the south-west corner, measures 21'-10" wide and 18' long in plan.

5.2 Type of Construction

The house has cinderblock exterior walls with a stucco finish. All gable end walls are clad with a painted wood siding material (T-111) (Figure 6.1).

The roof consists of asphalt shingles placed over felt underlayment on 7/16" OSB sheathing with a slope of 4:12. Metal plate roof trusses span between the exterior wall, and are fastened to them with galvanized metal straps.

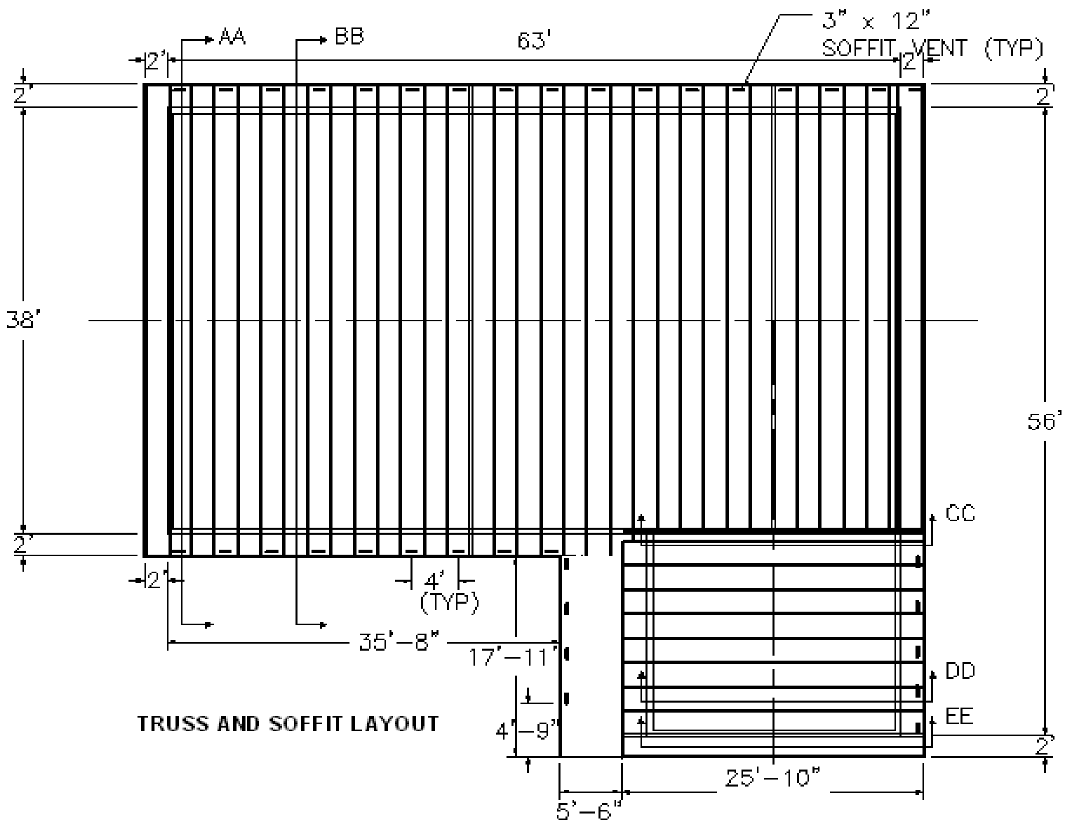


Figure 5.3: Truss and Soffit Details

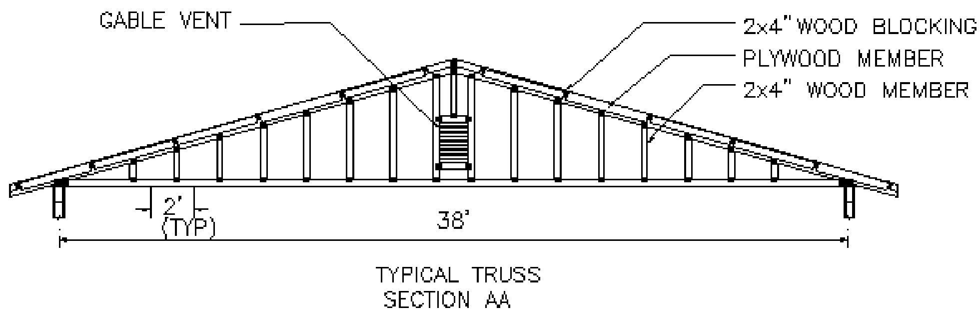


Figure 5.4: Main gable end truss

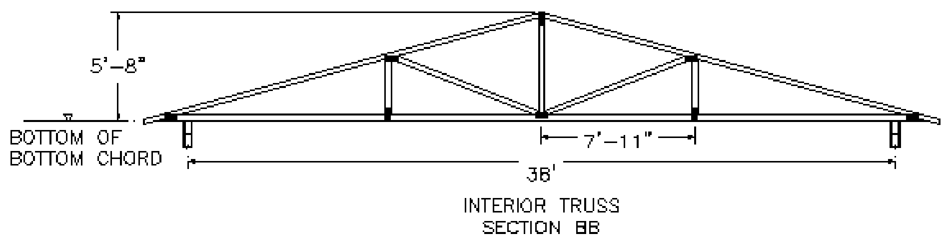


Figure 5.5: Interior trusses

The gable trusses (Figure 5.4) are built using two 2x4" SYP members stacked vertically on top of each other for the top member. The top 2x4" is connected to the main truss by 8" long, 2x4" wood blocking. There are five blocks spaced 4' on center of each side of the truss. Figure 5.5 shows all other interior truss design.

The following figures show the truss design at different sections in the garage.

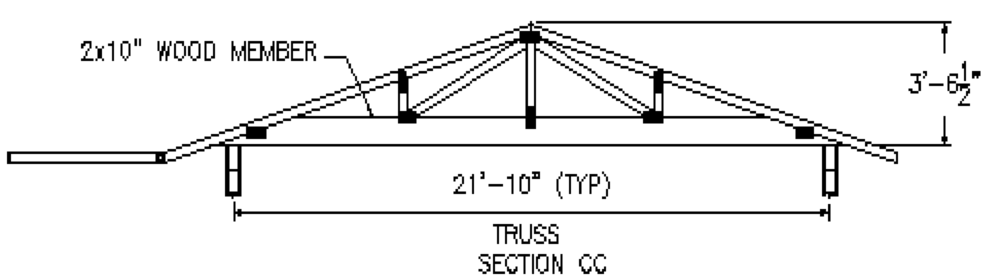


Figure 5.6: Truss at section CC (intersection of garage and house attic)

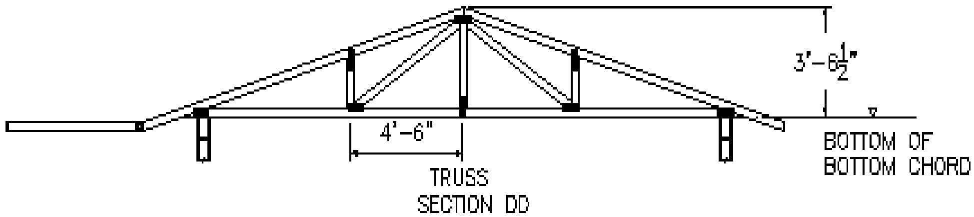


Figure 5.7: Interior trusses in the garage

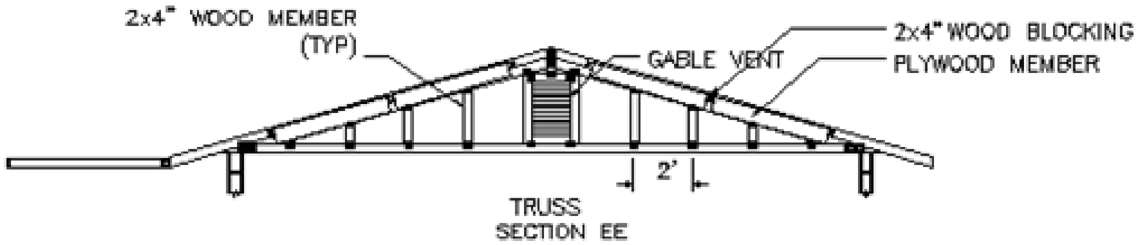


Figure 5.8: Gable end truss for the garage

1" wide galvanized metal straps are anchored into the walls where the trusses attach to the exterior walls as shown in Figure 5.9.

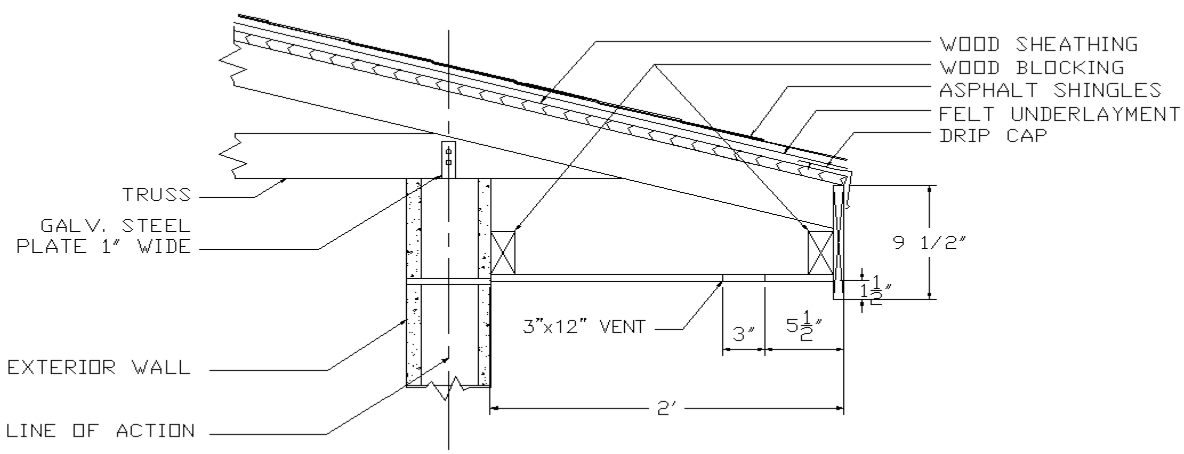


Figure 5.9: Typical corner section in the house

5.3 Attic Space and Vent Details

The attic is an unconditioned space ventilated by three gable end vents, soffit vents and three ridge vents. The soffit vents along the eaves are 3x12" in size, and have insect screens and rounded ends. They are spaced approximately 4 ft apart. On the drywall ceiling there is approximately, 3 to 5 in. thick blown fiberglass insulation. This insulation is of variable thicknesses with numerous gaps where the ceiling surface is completely exposed.

The insulation also has been blown into the attic Figure 5.10. However, there is no insulation in the attic space over garage and also there is no ridge vent. Protruding nails through OSB sheathing can be seen all over the roof. The layout of HVAC in the test house is shown in Figure 5.11.

Figure 5.10: Blown Insulation and protruding nails from sheathing

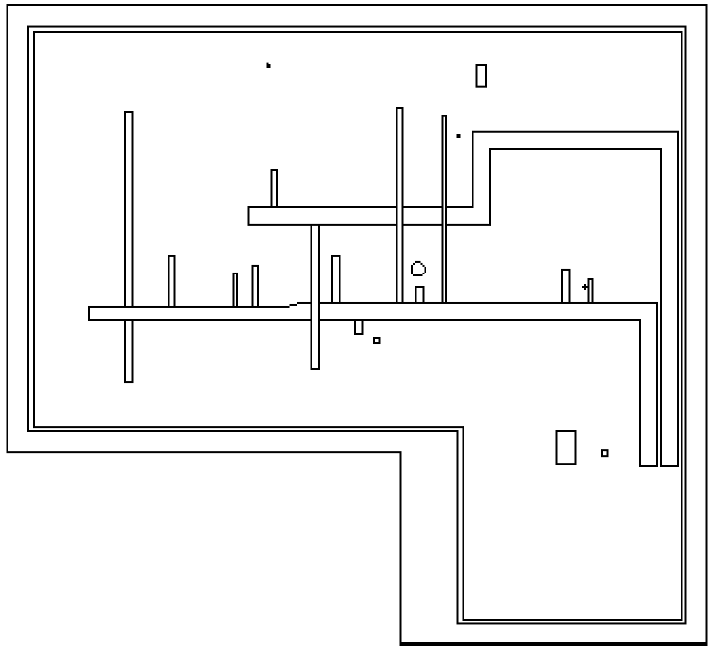


Figure 5.11: HVAC Layout in the attic of test house

6. ROOF INSPECTION OF ATTIC AND ROOFING

In January 2010 the test house was inspected by a licensed professional roofing contractor to evaluate the current condition of the roof prior to the foam installation. The roof sheathing was found to be in good condition, with no active leaks or water stains observed. As part of the inspector the roofer suggested the following:

- Provide Moisture strip paper to detect moisture intrusion. To alleviate concern for leakage after foam installation there paper strips can be installed at critical areas (penetrations, transitions, valleys, or areas that had past leaks). The paper would turn a different color and alert the owner of a potential leak problem.
- Consider stiff paper barriers around all roof penetrations (plumbing, chimneys, heat pipes). The barrier would limit the contact of foam at these penetrations and allow water to flow away from the wood. Critical areas could be exposed for a visual inspection at any time.
- Install rulers or tags to measure ccSPF foam thickness. Owner should be assured that fillet sizes and thickness of layers are adequately maintained throughout the roof.

The roofer also inspected the asphalt shingle roofing system, which was installed about 16 years ago. The tiles generally showed no significant curling cuts or tears and there were no immediate areas of concern. The roofer recommended that a roof with ccSPF should be aggressively maintained to ensure any signs of leakage or failed flashing or shingles are promptly repaired.

6.1 Thermal Inspection

Thermo-Scan Inspections (TSI) inspected the test house on 05/24/2010 (prior to ccSPF installation) and 06/29/2010 (post ccSPF installation) to determine the baseline thermal performance.

Pre ccSPF installation inspection

- Blower door test was performed to measure the total air infiltration in the house. The total air leakage measured was 3290 cubic feet per minute (CFM) (at 50 Pa).
- Major and minor areas of air leakage were identified and sealing options recommended. An infrared scan was also performed to check the wall and attic insulation. The images are attached in Appendix E.
- Duct blaster test to determine the total and outside duct leakage was performed. The total duct leakage measured was 206 CFM (at 25 Pa) with 123 CFM on the return side and 83 CFM on the supply side. The amount of leakage to the outside of the house was 160 CFM (at 25 Pa).

Post ccSPF installation inspection

- Pressure diagnostics were performed on the test house to determine the pressure differences in Pascals between the house and outside, and the house and attic. Pressure readings between the house and the attic indicate that the house is under a slight positive pressure when the air conditioner is switched on possibly because of leaky returns in the attic or garage.
- Infrared scanning was performed to check the ceiling temperature and insulation anomalies after foam installation. However, a small temperature difference between the ambient and inside made it difficult to determine any such anomaly.

7. CCSPF INSTALLATION IN THE TEST HOUSE

A Level 2 ccSPF structural retrofit was installed in the test house in May 2010, by technicians from Florida Foam Adhesive of Cape Coral, FL. Attic insulation was used to block the soffit vents and limit escape of the foam. The gable vents were sealed with the plastic sheeting to prevent overspray.

The technicians started to spray the foam from the far end (north side) of the attic and moved towards south end. Attic space over the garage was sprayed at the end. The entire spraying process was completed in about 5 hours. An exhaust fan was used to eliminate the fumes created during the foam application. The resulting work had some areas of non-uniform thicknesses and fillets along the wood joints that were less than minimum specifications. The foam installers had to return later with additional foam to correct those spots with insufficient foam application.

8. INSTRUMENTATION OF TEST HOUSE

Sensors were installed to measure the temperature, humidity and moisture content within the attic space. Energy measurement devices were installed to monitor the electricity and gas consumed in heating/cooling of the house. A weather station was installed to provide a continuous record of the ambient weather conditions that affect attic temperatures. Finally, additional small footprint temperature/relative humidity sensors were installed at the interface between the ccSPF layer and the underside of the OSB sheathing to monitor surface conditions. Table 8.1 lists the number and installation dates of various sensors in the test house followed by a detailed description of the instrumentation of the test house.

Table 8.1: Date of installation of the instruments.

Parameter	Instrument	Number	Date of Installation
Temperature/RH	LogTag Temp/RH sensors	8	11/08/2009
	EK-H4 Temp/RH sensors (for surface temp/RH in attic)	7	06/08/2010
Energy	Digital Gas Meter (Elster AC 250)	1	04/06/2010
	Enetics AESG 1203 Energy Recorder	1	04/23/2010
Weather	Davis Vantage Pro2 Plus 6162 Weather Station	1	04/02/2010

8.1 Temperature and Relative Humidity Monitoring

Eight data loggers, called LogTag humidity & temperature recorder (HAXO-8) and seven wired EK-H4 temperature and humidity sensors (manufactured by Sensirion) were placed at different locations inside and outside the attic (Figure 8.5). The latter sensors (EK-H4) took readings at 15 minute intervals that are directly downloaded to a laptop computer. The LogTag sensors are stand-along data recorders set to record data every 15 minutes. With a memory capacity of over 8,700 point, the LogTag recorders were left in place for 3 month intervals during which it continuously recorded data every 15 minutes.

Figure 8.1 shows the LogTag humidity and temperature recorder and the LogTag interface to transfer the recorded data to a laptop. Installed sensors at two different locations have been shown in Figure 8.2

a) LogTag temperature & humidity recorder b) LogTag interface

Figure 8.1: LogTag sensor and Interface

a) Attic b) Outside (south wall)

Figure 8.2: LogTag sensor installed in the attic and outside the house

Figure 8.3 shows a schematic of the location of these temperature and humidity sensors throughout the attic. The sensors in the attic are located around 1 ft. below the roof decking.

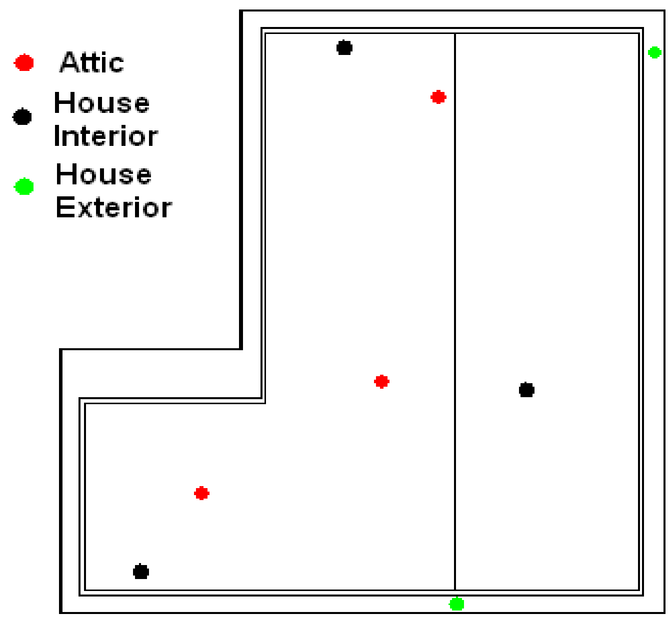


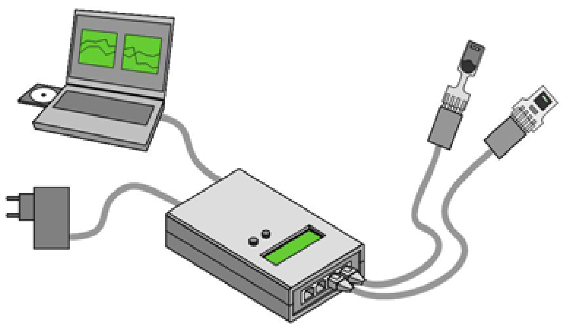
Figure 8.3: Position of LogTag Temperature/Humidity sensors in the attic

EK-H4 evaluation kit for temperature and relative humidity measurement comprises of:

- One EK-H4 multiplexer box which has 4 channels for sensor cables, one port for power supply cable and one port for optional USB interface with a computer,

- Four Pin type SHT71 sensors,
- Four SMD (Surface Mount Device) type SHT21 sensors and,
- Four sensor cables with RJ45 plug for connecting sensors with multiplexer box.

Figure 8.4a) shows the configuration of the multiplexer and sensors and their connection to a laptop for data acquisition and their location in the attic is shown in Figure 8.5



a) Configuration of EK-H4 multiplexer and sensors

b) Sensor being installed on foam surface

Figure 8.4: EK-H4 temperature/RH sensors for measuring surface temperatures

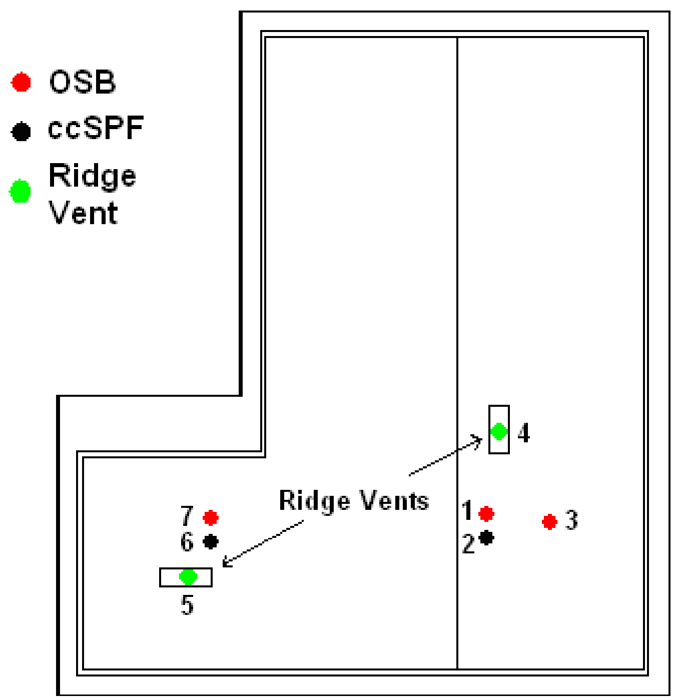


Figure 8.5: Position of EK-H4 Temperature/Humidity sensors in the attic

Table 8.2 lists the identification of all the EK-H4 sensors located in the attic. The two multiplexers which can support four sensors each are identified as communication channels 4 and 6 in the EK-H4 Viewer software. Four sensors are connected to the four ports in communication channel 4 and 3 sensors are connected to the communication channel 6.

Table 8.2: EK-H4 sensor identification

Sensor Number	Sensor Location	Communication Channel	Port # on Multiplexer
1	OSB	4	1
2	ccSPF	4	2
3	ccSPF	4	3
4	Ridge Vent	4	4
5	Ridge Vent	6	1
6	ccSPF	6	2
7	OSB	6	3

8.2 Energy monitoring

The Enetics LD-1203AESG SPEED™ (Single Point End-use Energy Disaggregation) recorder (Figure 8.6) was used to record the electricity and gas consumption of the test house. The LD-1203AESG unit is wired directly to the circuit breaker panel using current transformers that generates the impulses in the unit. The recorder is compatible with standard 200A, 120/240V, 3-wire, 60Hz electrical services.

The Enetics energy recorder has an input port that interfaces with the pulse output from a gas meter to measure gas consumption. As such a Elster American Gas Meter AC-250 (with standard 2 feet drive meter) was installed along with an IMAC domestic meter pulser (2 pulses per revolution resulting in 1 pulse/ft^3 of gas consumed).

Once installed, the recorder:

- Measures voltage and current on each service leg (incoming electricity in the house) and from the Alternate Energy Source (AES)
- Records and stores aggregate whole premises (grid + AES) kW; and, independently, generated AES kW at user-selectable intervals
- Records and stores aggregate whole premises (grid + AES) kWh consumption; and, independently, generated AES kWh for time of use

- Records on/off events; (if the combined load (Watt + VAR) change is greater than a configurable threshold, the recorder records the magnitude of the change, time stamp and the service leg on which the event occurred)
- Calculates and stores V_{rms}, I_{rms}, Watts and VARs (both aggregate grid/AES and alternate energy source)
- Communicates with the SPEED Field Station or SPEED Master Station software to upload data, view latest readings and obtain latest configuration settings.

The software supplied with of the monitoring unit called Master Station processes the data and analyses the electrical properties of different appliances in the circuit. These signature properties are matched against those in a standard appliance electrical load library to be identified. The load library can be modified to include the loads/appliances which have not been included. Once the loads are identified, SPEED Analysis Station software is used for data analysis and to obtain electricity consumption separately for each appliance and for the building premises as a whole. Gas consumption data is stored as "Aux1" in the SPEED database and can be extracted using MS Excel. Electricity and gas consumption was recorded at every five minute interval throughout the duration of project. Figure 8.7 shows the installed recorder in the test house.

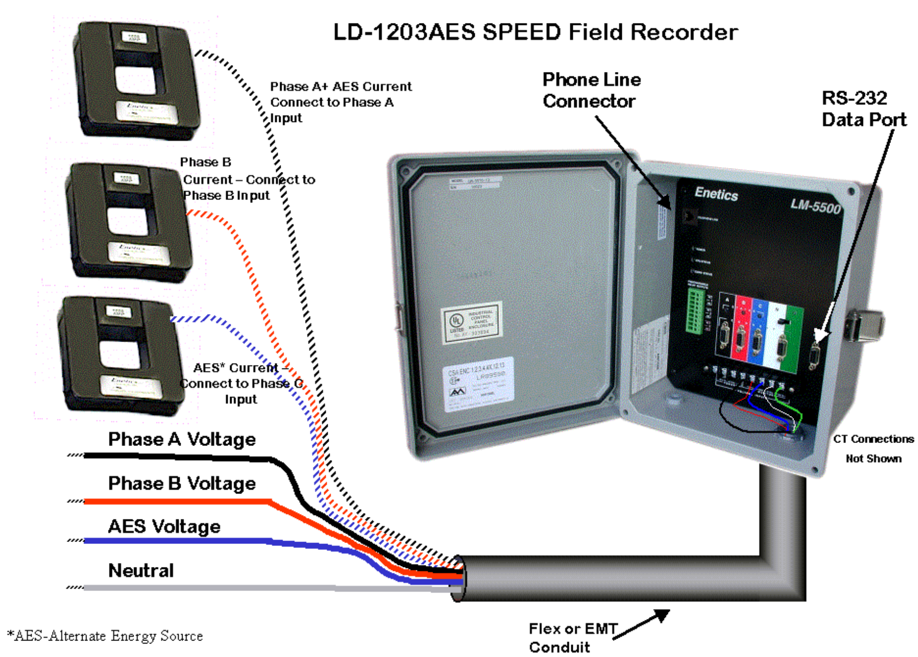


Figure 8.6: Configuration of LD-1203AESG recorder components

Figure 8.7: Enetics LD-1203AESG recorder installed in the test house

Figure 8.8: Gas Meter with digital pulsar (right) placed in parallel with existing meter (left)

8.3 Weather Station

A Davis Instrument's Vantage Pro2 Plus 6162 weather station (Figure 8.9) was installed in the house premises to continuously record the weather data. This station has an Integrated Sensor Suite (ISS) and a wireless receiver that wirelessly transmits all data to the receiver located within the house. The ISS consists of temperature and humidity sensors, rain collector, anemometer, solar radiation sensor, UV sensor and solar panel. The update interval for weather parameters vary with the sensors and all are listed in Table 8.3.

Table 8.3: Update interval for data transmission from the ISS to the receiver.

Weather Parameter	Update Interval
Temperature	1 min
Humidity	1 min
Barometric Pressure	1 min
Dew Point	10-12 seconds
Rainfall	20-24 seconds
Wind Speed	2.5-3 seconds
Wind Direction	2.5-3 seconds
Solar Radiation	50-60 seconds
UV Radiation	50-60 seconds

Figure 8.9: Installed weather station at the North-East corner of building premise

The data from the receiver is logged using the in a computer WeatherLink software at every 15 min interval. The weather data is constantly logged on a laptop in the test house and also continuously uploaded on http://www.wunderground.com/ website. The weather station name on this website is NW Gainesville with a station ID of KFLGAINE15.

Figure 8.10: Installed laptop and weather station console

Figure 8.10 shows the installed laptop and the wireless weather station console. The laptop logs the data from weather station, EK-H4 temperature/RH sensors and the energy meter.

9. RESULTS

9.1 Temperature Data

A complete set of the data collected is provided in Appendix C. The monthly temperature and humidity variations for November 2009 is shown in Figure 9.1. Note that ambient sensor was relocated to interior of the house from 16 November through 30 November 2009, highlighted by gray shaded areas in Figure 9.1.

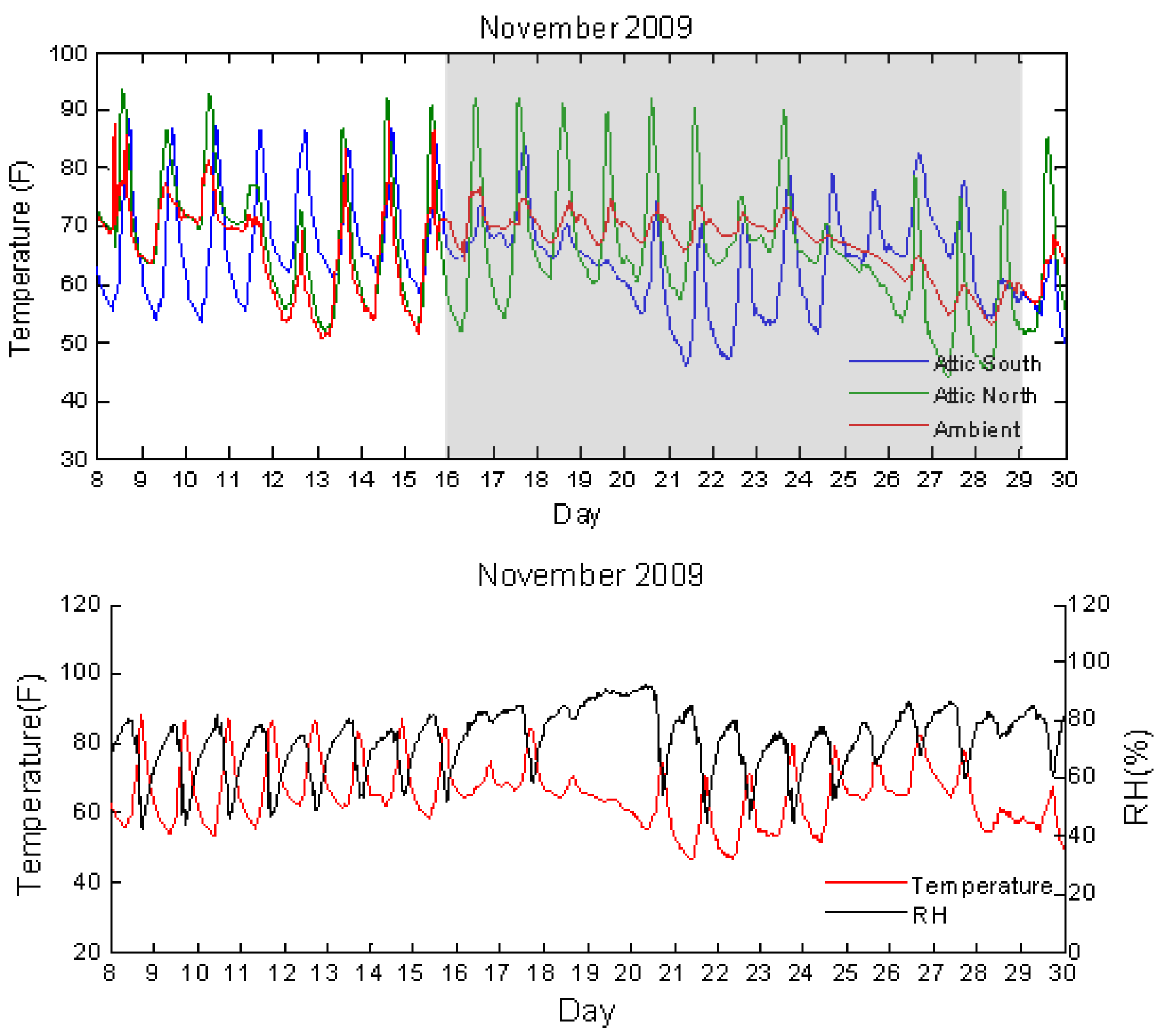


Figure 9.1: Attic & ambient temp (top) and south attic temp/RH (bottom) for Nov, 2009

The temperature/RH sensor in south attic is located near the ridge vent while the one in north attic is located approximately 6 ft. upfront from the gable vent on northern wall. Due to continuous ventilation and air circulation, ambient and north attic sensor are consistent with the trend.

We covered the attic gable vents with plastic sheeting on 8 April 2010 to observe the effect on attic ventilation. We removed the sheeting on 25 May 2010 after the ccSPF was installed. However, we could not observe any significant differences in the attic temperatures due to the gable attic vents. The variation in peak attic and ambient temperatures for the months of May and June 2010, are shown in Figure 9.2.

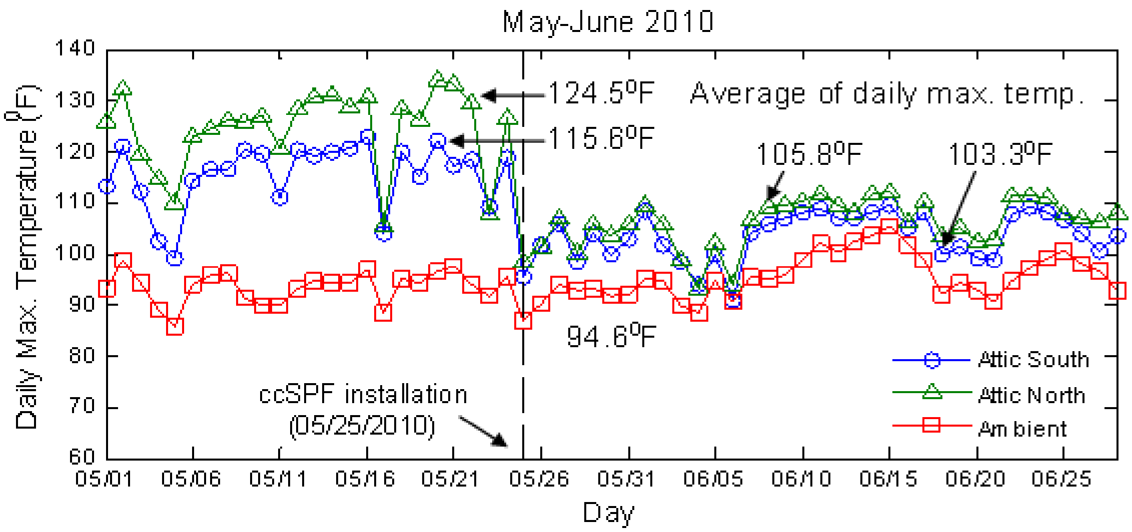


Figure 9.2: Daily maximum temperatures for May and June, 2010

The mean of daily maximum temperatures for May and June, also fell by about 15 and and 21^{0}F respectively at the north and south attic after installation of ccSPF Table 9.1.

Table 9.1: Mean of daily maximum temperatures before and after ccSPF installation

	Temperature (^{0}F)	
	05/01-05/24 (Before foam installation)	05/25-06/08 (After foam installation)
Attic South	115.5	103.3
Attic North	124.5	105.8
Ambient	93.5	95.4

Table 9.2. provides the maximum and mean temperature difference between the attic and ambient temperatures are listed in During November 2009 – May 2010.

Table 9.2: Temperature difference between attic and ambient during a month

Month	Attic South-Ambient		Attic North-Ambient	
	Maximum Difference (^{0}F)	Mean Difference (^{0}F)	Maximum Difference (^{0}F)	Mean Difference (^{0}F)
November, 2009	30.6	8.4	22.0	5.6
December, 2009	24.3	8.7	17.0	4.8
January, 2010	48.4	13.0	20.5	6.2
February, 2010	26.2	8.4	27.2	7.8
March, 2010	25.2	7.0	33.1	7.7
April, 2010	32.6	7.7	39.7	9.5
May, 2010	32.4	7.2	43.0	9.7

9.2 Relative Humidity

The relative humidity plots for sensors in the attic and ambient are shown in Appendix F. The ambient relative humidity is scattered over a wider range as compared to that in the attic. The peaks in relative humidity of south attic in winter months explain the drop in attic temperature, which is lower than ambient at times.

9.3 Electricity Consumption

Total energy consumption[1] of the house is recorded as "Premises" in the Enetics recorder and the recorded daily consumption is shown in Figure 9.3. The heat pump draws out about 51% of the total electricity used in the house as shown in Figure 9.4. Electricity consumed under "Residual" is by the appliances which are not identified by the Master Station software and account for power use by lighting systems, computers, exhaust fans, etc. Figure 9.5 shows the daily power consumption by heat pump which is consistent with pattern followed by the total house electricity consumption.

[1] These results presented are preliminary in nature, representing very short time period and taken with a new measuring device. Independent checking, validation and additional quality checks on the data are in progress and will be presented in a future ME thesis and peer-reviewed journal papers.

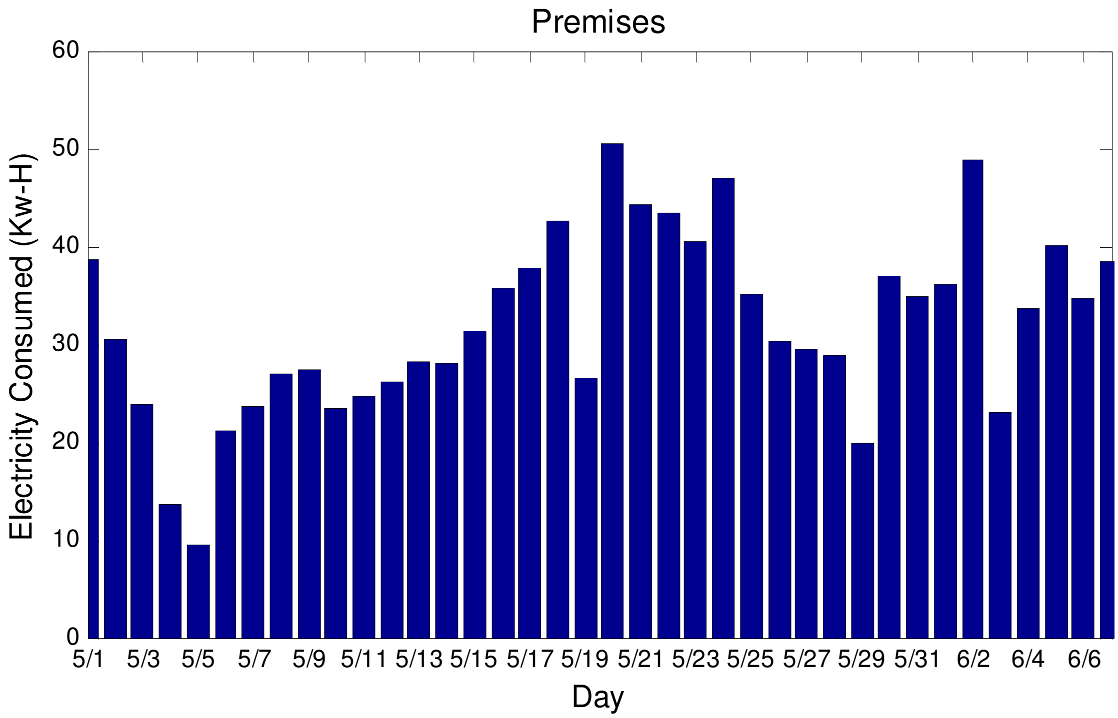


Figure 9.3: Electricity consumed by test house as recorded by Enetics recorder

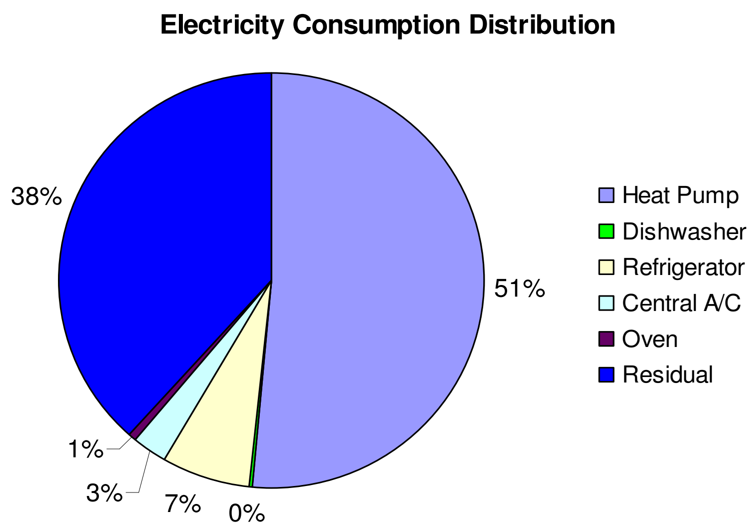


Figure 9.4: Distribution of electricity consumed by appliances

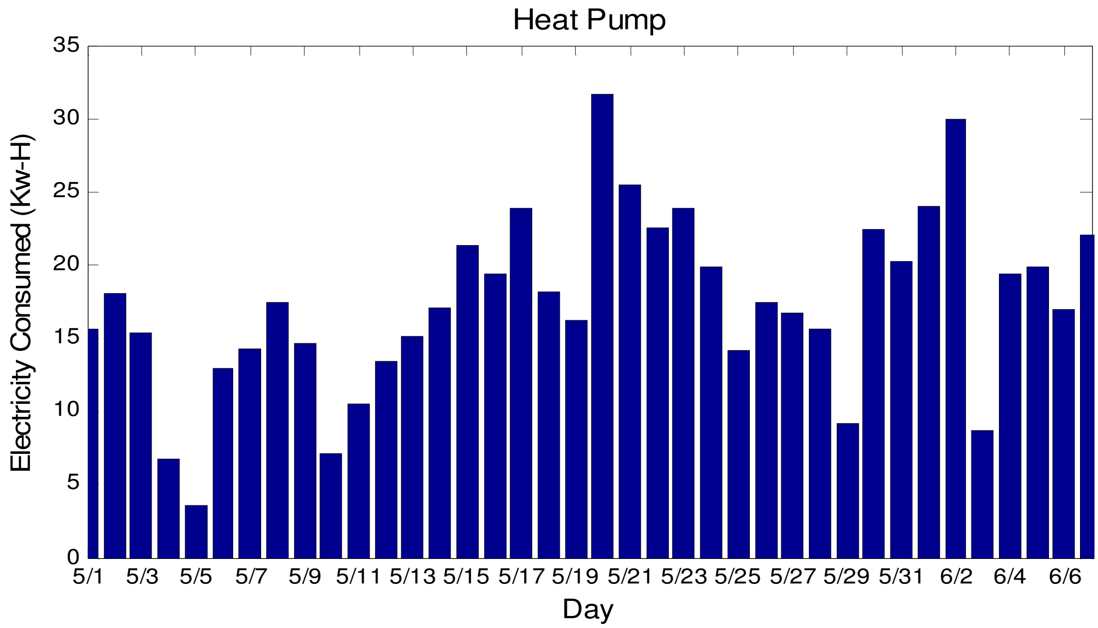


Figure 9.5: Electricity consumed by heat pump

The average daily electricity consumption by heat pump a week before and for a week after the installation of ccSPF is tabulated in Table 9.3.

Table 9.3: Electricity consumption a week before and after ccSPF installation

	Before (05/18-05/24/2010)	After (05/25-05/31/2010)	Percentage Reduction (%)
Premises (kWh)	42.2	30.8	27.0
Heat Pump (kWh)	22.5	16.5	26.7
Refrigerator (kWh)	2.1	2.0	0.4

The reduction in average daily electricity consumption by about 27% suggests the effectiveness ccSPF in possible energy savings besides being a structural retrofit. Long term monitoring of energy consumption and calibration against the ambient weather (temperature and solar radiation conditions) is necessary before definitive answers can be stated.

Figure 9.6 shows the monthly electricity consumption data of the test house as obtained from local electrical utility company, Gainesville Regional Utilities (GRU). The bill cycle runs from 11th of a month to 10th of the next month.

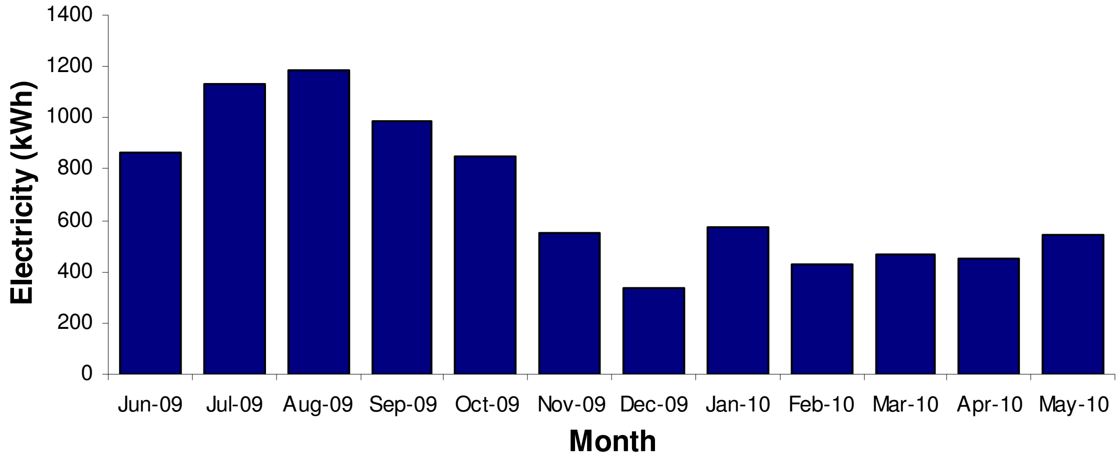


Figure 9.6: GRU electricity consumption data of test house during June-09 to May-10

9.4 Gas Consumption

The test house has a gas furnace, and gas water heater that uses natural gas. During the test period the owners also installed a gas dryer on 13 April 2010. Figure 9.7 shows the daily gas consumption in the house for May 1, 2010 through June 6, 2010, as recorded by the Enetics recorder. Total gas consumed during May 2010 was 1573 cu. ft, or approximately 51 cu. ft per day. The house was unoccupied during the 2 to 8 May 2010 and there was a near-constant gas consumption of around 40 cu. ft. We observed no change in the gas consumption rate after foam insulation installation. This is expected as the installed period of the gas meter was not in the heating season (December through March) when the majority of gas would be used to power the furnace.

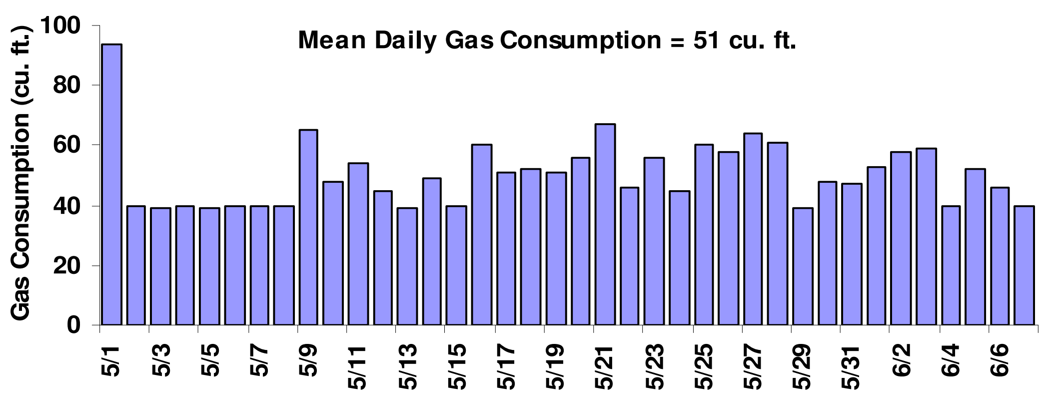


Figure 9.7: Gas consumption of the test house during May and June 2010 as recorded by Enetics recorder

Table 9.4: Average daily gas consumption a week before and after ccSPF installation

	Before (05/18-05/24/2010)	After (05/25-06/06/2010)
Gas (cu. ft.)	53.3	52.7

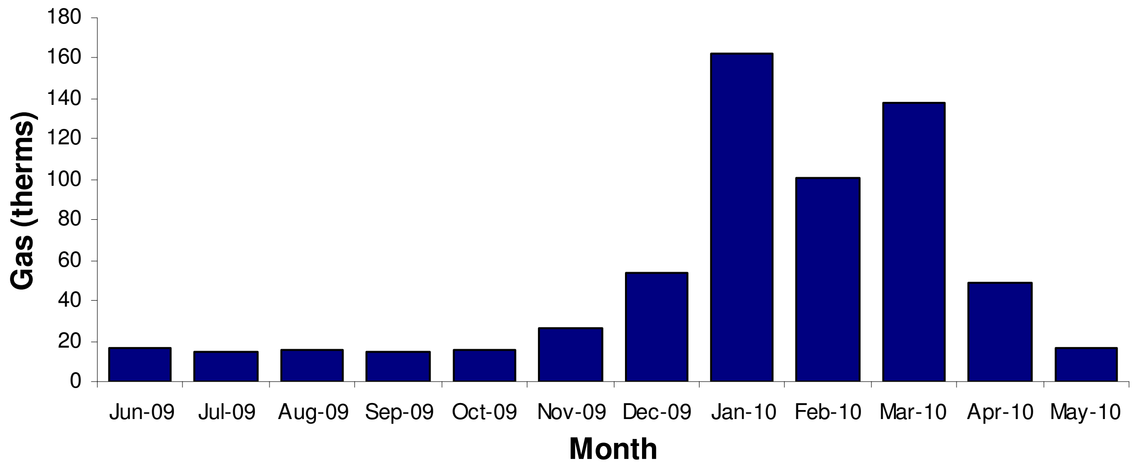


Figure 9.8: GRU gas consumption data of test house during June-09 to May-10

During June-November, average monthly electricity consumption is 928 kWh while it is 468 kWh during rest of the year. An opposite trend is observed for gas consumption. During June-November, average monthly gas consumption is 18 therms (1800 cu. ft) while it is 87 therms (8700 cu. ft.) for the other six months.

10. CONCLUSIONS AND DISCUSSIONS

The roof of the test house was carefully inspected by a professional roofer prior to initiating this project. Having confirmed the roof was in structurally sound condition, the research proceeded to install the ccSPF structural retrofit. The Level II protection used (1 in. layer plus a 3 in. fillet at framing members) was shown by previous testing to provide a reasonable increase in wind uplift capacity (about 2 time increase for this roof system). The researchers caution strongly that long-term performance testing is still needed to verify that ccSPF retrofit of wood roofs do not lead to unforeseen premature deterioration due to water intrusion. As such, regular maintenance and inspections of the roofing system, flashing is recommended to increase likelihood that any leak location is identified and promptly repaired.

A second focus of this research was to evaluate the energy benefits of the ccSPF structural retrofit. The work tested the hypothesis that a significant reduction in the attic temperature will result in reduced energy usage to cool the home. The hypothesis is based on the assumption that the condition of the air ducts, particularly in older homes, there is a possibility that hot air from the attic can be drawn into the ductwork and thereby make the HVAC system work harder to maintain the set temperature. The results showed that the house is under slight positive pressure relative to the attic, which could be caused by leaky returns in the attic or garage. The performance of this HVAC system was not as severe as it could be because we are told by the homeowner that the ducts had been re-sealed within the past 18 months.

As expected in a 37-year old house, air leaks were found in several places in the building envelope, which if sealed, could improve the energy efficiency of the home. The unique benefits of this research is that it will provide baseline energy usage data on the house, and by installing the energy-monitoring devices, in future projects the instrumentation is already in place to conduct real-time comparison of the benefits of different retrofit strategies.

From our observations of the foam installation, careful training of technicians is required. At best, residential attics are typically hot, uncomfortable places but during the installation the technicians must manipulate long hoses and direct a chemical spray that is at or near 140 degrees Fahrenheit. Quality control devices would be helpful to check the dimensions of the fillet and to confirm the minimum thicknesses of the foam layer are provided. It was found that the spray foam (as applied overhead) in this roof attic, is not as uniform an application as was observed in previous laboratory testing. At this time, the effect of application method or uniformity of structural capacity is unknown, but is the focus of a related ongoing research study at the University of Florida.

Preliminary data have shown that application of a Level II Protection of ccSPF reduced the mean peak attic temperatures by 15 to 20^{0}F. The research was not able to determine the cause of the 5 degree difference in attic temperature, except that the sensor showing the lower peak temperature was located close to the roof ridge, and may have benefitted from convective cooling.

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[13 FL DCA Product Approval FL#9975 "Evaluation Report of NCFI Polyurethanes "Insulstar Plus" Insulating Foam Spray Adhesive for Florida Product Approval", http://www.floridabuilding.org/pr/pr_app_dtl.aspx?param=wGEVXQwtDquHrTiajU87x3W2n4kyUbbFV9rOsZ4jaxdSzNjadCmJ%2fviWI0OzDeU%2b94Et53A4oSN5PzWDuUoHy3tyf%2fg5R5hC9kIrxICZAFqj4ETWiCNaVw%3d%3d.

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APPENDIX A: BASELINE SURVEY REPORT OF THE TEST HOUSE BY THERMO-SCAN INSPECTIONS PRIOR TO CCSPF INSTALLATION.

TSI THERMO-SCAN INSPECTIONS

5-24-10

University of Florida
David Prevatt
365 Weil Hall
Stadium Rd.
Gainesville FL 32611

Dear David:

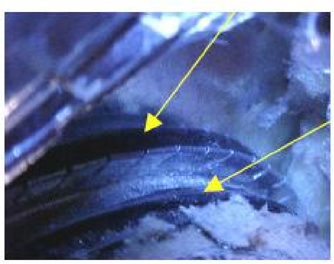
TSI recently performed a series of energy efficiency inspections on the single family residence located at [redacted]. TSI was contracted to conduct baseline testing prior to the attic roof deck insulation project. TSI also identified air leakage and insulation issues in the home that might result in comfort problems and high utility bills.

TSI performed a blower door test using a Model 3 Minneapolis Blower Door with DG-2 gauges to measure the total air infiltration in the house. The total air leakage measured 3,290 CFM50.

The following leakage sites were identified and should be sealed:

<u>Major</u> :

1) Returns---from the attic seal gaps around metal ductwork going through drywall with caulk or foam. When the attic ducts were sealed the insulation was sealed to the metal ductwork. This method does not decrease the duct leakage. It allows it to leak into the insulation. The proper way to seal these areas would be to cut and pull back the insulation and mastic the gap between the collar and metal trunk and the seams in the ductwork connections. (See thermal image number16).



(Photo taken from file)

2) Exterior doors---Adjust or replace weather stripping. The garage access door currently has no weather-stripping installed. Seal trim to drywall then seal gaps between trim pieces.

Ph: 317-846-4655, Fax: 317-846-4672, www.thermo-scan.com, P.O. Box 705, Carmel, IN 46082

3) Fireplace---consult manufacturer for recommendations for repairs of fireplace damper. Seal firebox to brick, pull ceiling and wall trim and seal brick to drywall with heat resistant material. (See thermal image 14).
4) Can lights---seal gaps between can light housing and drywall with heat resistant material. Go to http://www.ccl-light.com/docs/indoor/recessed/subindex.html for can light recommendations.
5) Sliding glass door---consult manufacturer.
6) Kitchen exhaust vent---seal penetration through drywall with caulk or foam.
7) Trim---seal trim around interior and exterior doors (including sliding glass door) and windows to drywall. Then seal gaps between trim.
8) Windows--- Caulk window frames to drywall and ledges where caulk is cracking or missing.
9) House attic access---attach insulation to the back of the panel then weather-strip or caulk shut.
10) Outlet and switches on exterior walls---install gaskets behind covers then install plugs in outlets not being used.

<u>Minor</u> (typical air leaks that could be sealed to further improve air leakage rate):

11) Baseboards--- pull carpet and seal gap between the bottom plate and slab and between the bottom plate and drywall with caulk or minimal expanding foam. On non-carpeted floors caulk trim to floor, and then seal all gaps in the wood trim.
12) Plumbing---seal penetrations through drywall with caulk and or foam.
13) Supplies--- The seams along the trunk line in the attic were sealed with Mastic on the top and sides, they did not do the underneath side of the trunk line. These should be sealed to insure a tighter duct system.

Duct Leakage

TSI tested the duct leakage to determine both the total and outside leakage using a Series B Minneapolis duct blaster with DG-700 digital gauges.
The total duct leakage test was performed by taping off all of the supply and return registers and installing the duct blaster fan to the hall return.
The duct leakage to the outside test is performed by using the blower door in conjunction with the duct blaster. With the house under a negative pressure the attic and garage will be under a positive pressure. The duct work will build up a positive pressure related to the amount of leaks in the system. The duct blaster is then used to bring the pressure in the duct work to a zero balance. This is then converted into Cubic Feet per Minute of air.
The total duct leakage measured 206 CFM25 with 123 CFM25 on the return side and 83 CFM25 on the supply side.
The amount of leakage to the outside of the house was 160 CFM25.

Insulation

1) The attic currently has R-10 to R-19. The recommendation for your region is a minimum R-30.
2) Insulate ductwork in attic to minimum R-19.

Health and safety

1) TSI recommends that a combustion safety test be conducted on the natural gas appliances to verify safe and efficient operation. TSI recommends that atmospherically vented natural gas appliances be replaced with sealed combustion or forced draft equipment.

Other opportunities for energy efficiency improvements

1) Install compact fluorescent lights in fixtures that are on for more than two hours per day.
2) Install pipe wrap insulation on the hot water pipes. Leave eight inches of clearance between pipe insulation and flue pipe.
3) Check furnace filter monthly and replace as needed.
4) Replace older appliances including furnace with newer energy star certified appliances.

While on-site we conducted an infrared scan using a Flir E-65 infrared camera to check the wall and attic insulation. The light colored areas are warm (indicating poorly insulated or air infiltration) and the dark colored areas are cold (properly insulated). The minimum temperature difference between the inside and outside of the home for scanning purposes is 18 degrees F. At the time of the inspection the outside temperature and relative humidity was 78 degrees and 67% ,with an inside temperature and relative humidity of 73 degrees and 43%. The attic temperature and relative humidity was 89 degrees and 53%. This small temperature difference makes it difficult to find insulation anomalies.

Please reference the attached thermal images.

We appreciate the opportunity to work with you on this project. If you have any questions regarding this report, please call me at 846-4655.

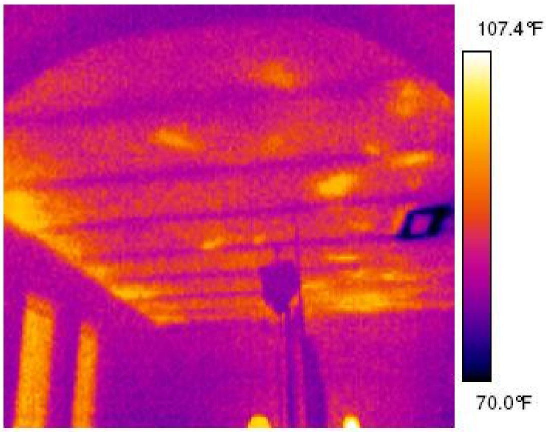
Sincerely,

Chris Maher

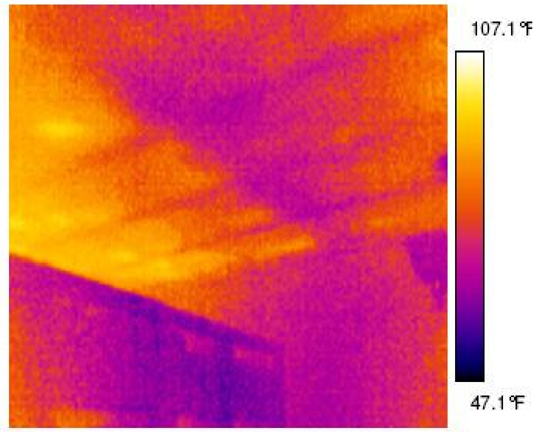
UNIVERSITY OF FLORDIA

[redacted] GAINESVILLE, FL

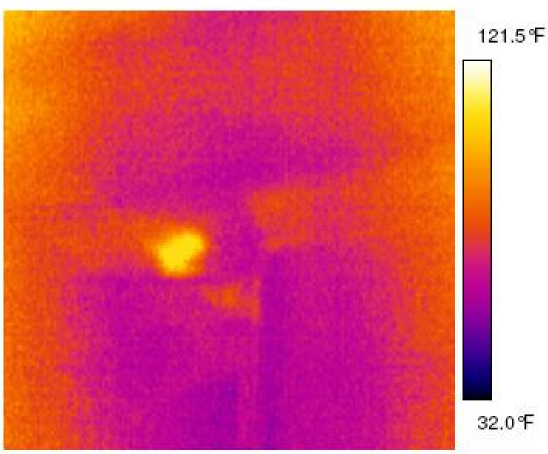
Images were taken with the emissivity set at .90.



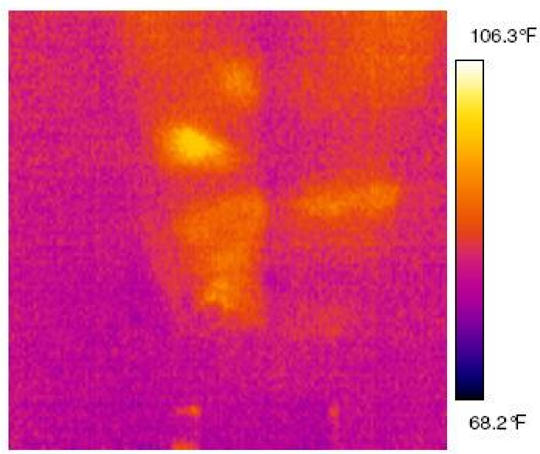
1) Looking north west at studio ceiling



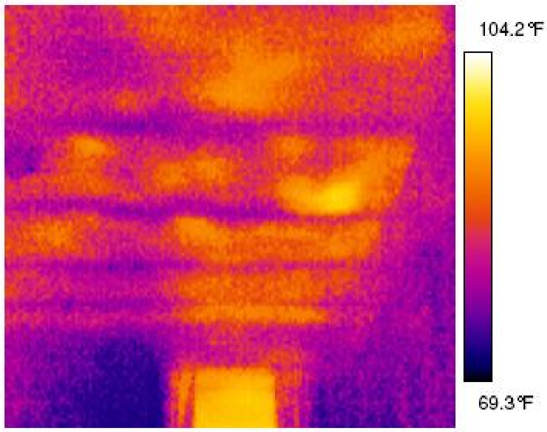
2) Looking north west at studio and dining room ceiling



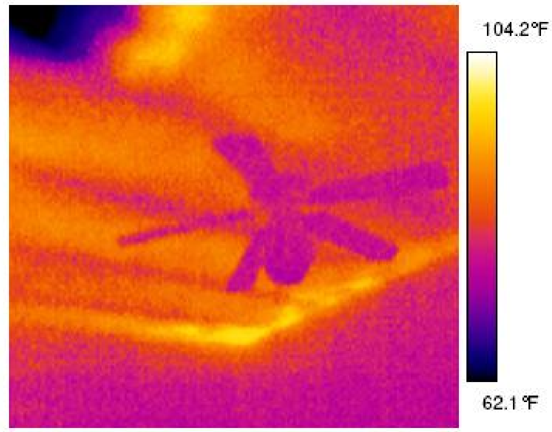
3) Looking south east at front bedroom ceiling



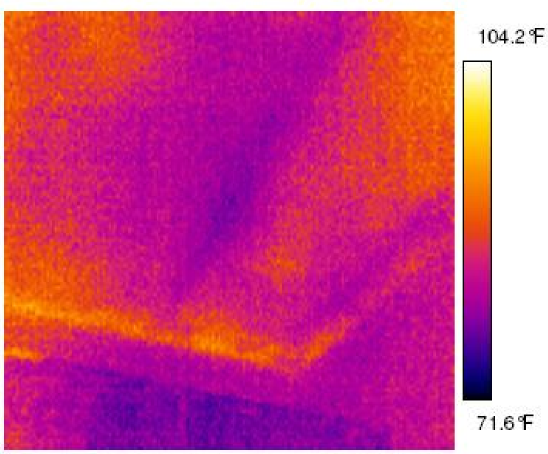
4) Looking east at hall ceiling



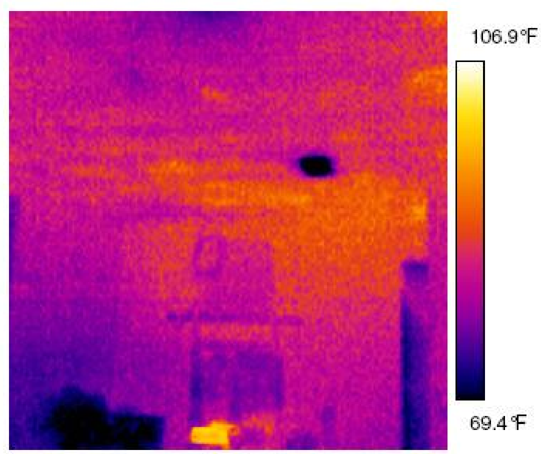
5) Looking north at side bedroom ceiling



6) Looking north east at rear bedroom ceiling



7) Looking east at hall bathroom ceiling



8) Looking south (toward Fireplace) at living room ceiling

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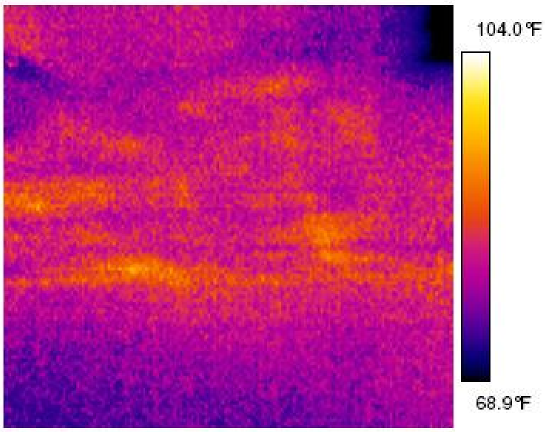
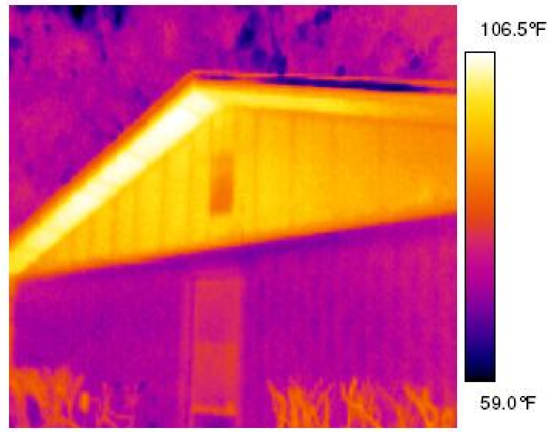
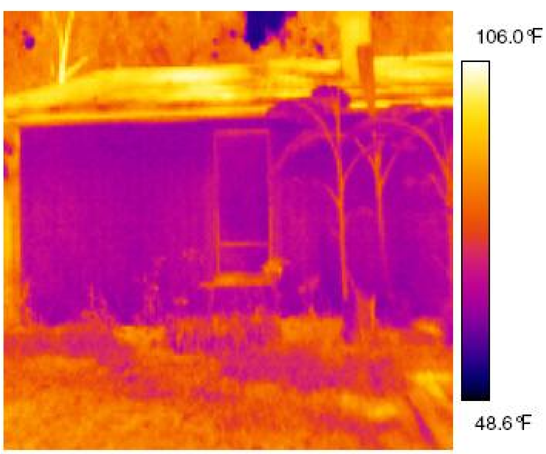
[redacted] GAINESVILLE, FL



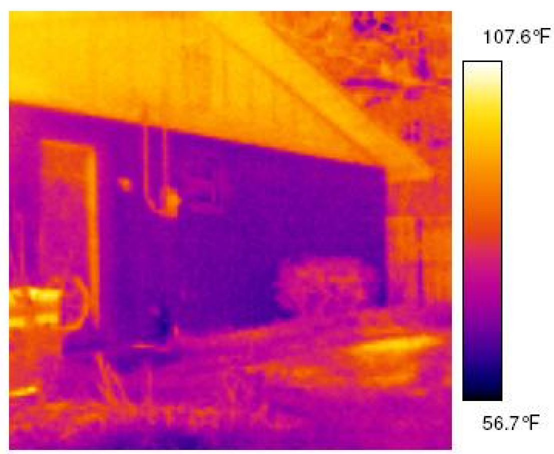
9) Looking south at master bedroom ceiling



10) Looking south east at gable on north end of house. Use to compare attic temperature after work completed



11) Looking west at back (east) side of house. No anomalies



12) Looking north east at south side of house. No anomalies

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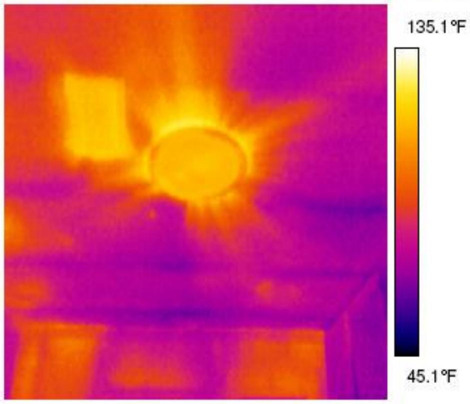
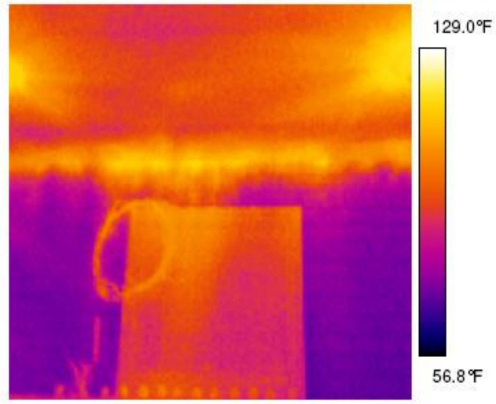
[redacted] GAINESVILLE, FL

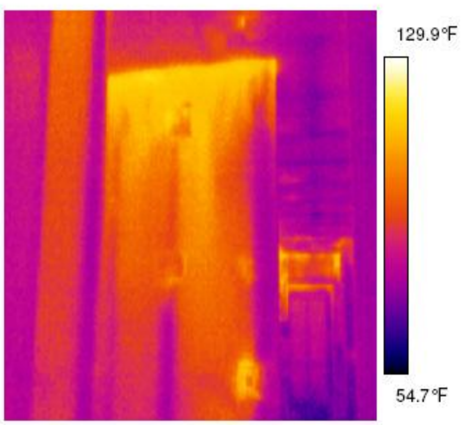
The following images were taken with the house under a negative pressure:



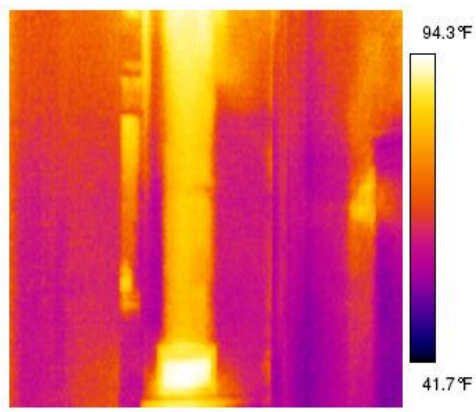
13) Looking north at air infiltration around kitchen skylight



14) Looking south at air infiltration around fireplace trim



15) Looking north at air infiltration into wall between hall and kitchen. Could be from wire holes not sealed in attic



16)Looking west at air infiltration into wall return on north end of hall (typical throughout the house). Gaps around metal ductwork going into wall cavity should be sealed from the attic

APPENDIX B: BASELINE SURVEY REPORT OF THE TEST HOUSE BY THERMO-SCAN INSPECTIONS POST CCSPF INSTALLATION.

THERMO-SCAN INSPECTIONS

6-29-10

University of Florida
David Prevatt
365 Weil Hall
Stadium Rd.
Gainesville FL 32611

Dear David:

TSI recently performed a series of pressure diagnostics at [redacted] Gainesville, FL. to determine the pressure differences in pascals between the house and outside, and the house and attic.

House to outside baseline	+.3
House to outside with A/C on	+.9
House to outside with A/C and dryer on	+.8
House to outside with A/C, dryer and kitchen exhaust fan on	+.2
House to outside with kitchen exhaust fan on	-.1

House to attic with baseline	.0
House to attic with A/C on	+1.1
House to attic with A/C and dryer on	+.5
House to attic with A/C, dryer and kitchen exhaust fan on	-.3
House to attic with kitchen exhaust fan on	-.9

Pressure readings between the house and the attic would indicate the house is under a slight positive pressure with the A/C on. This could be caused by leaky returns in the attic or garage.

While on-site we conducted an infrared scan using a Flir E-65 infrared camera to check the ceiling temperature after foaming the underside of the roof decking.
At the time of this inspection the outside temperature was 78 degrees, with an inside temperature of 73 degrees. The attic temperature was 80 degrees. For a difference of seven degrees. This small temperature difference makes it difficult to find insulation anomalies.

Please reference the attached thermal images.

We appreciate the opportunity to work with you on this project. If you have any questions regarding this report, please call me at 846-4655.

Sincerely,

Chris Maher

Ph: 317-846-4655, Fax: 317-846-4672, www.thermo-scan.com, P.O. Box 705, Carmel, IN 46082

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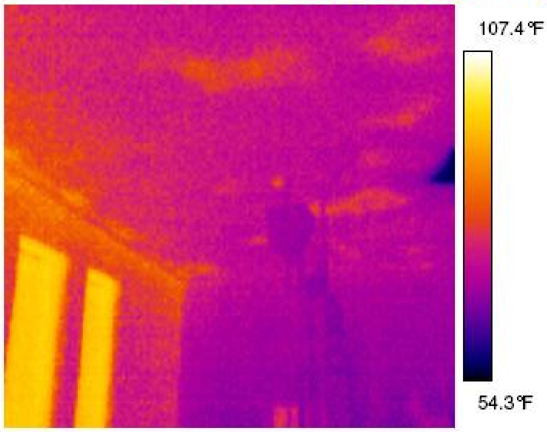
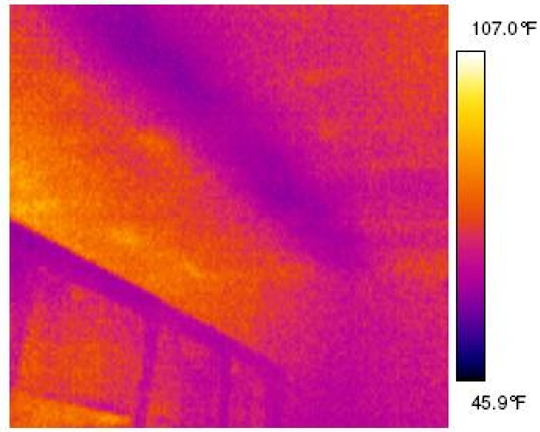
[redacted] **GAINESVILLE, FL**

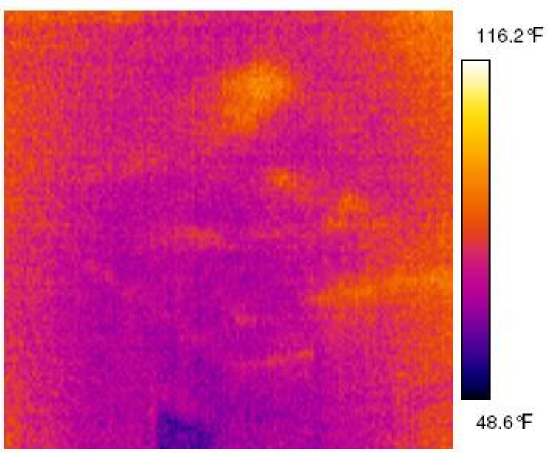
Images were taken with the emissivity set at .90.
6-29-10 After roof decking was foamed.



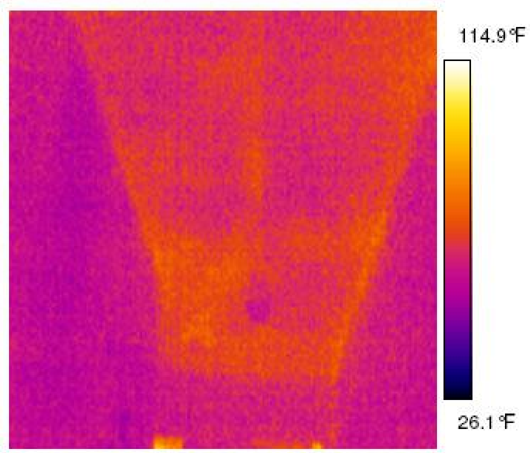
1) Looking north west at studio ceiling



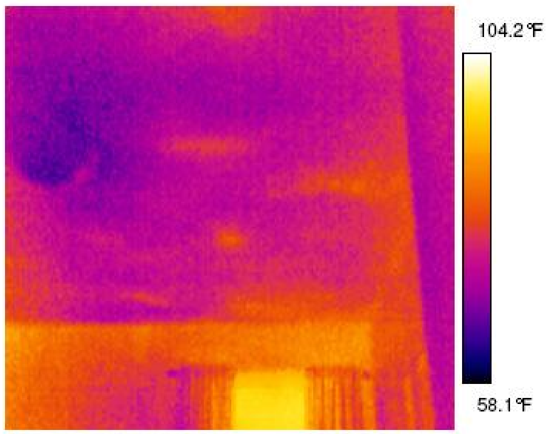
2) Looking north west at studio and dining room ceiling



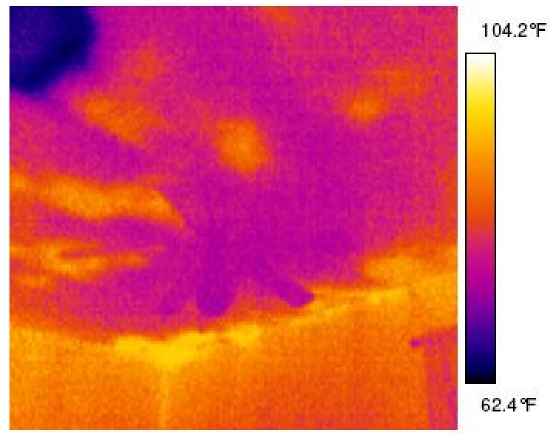
3) Looking south east at front bedroom ceiling



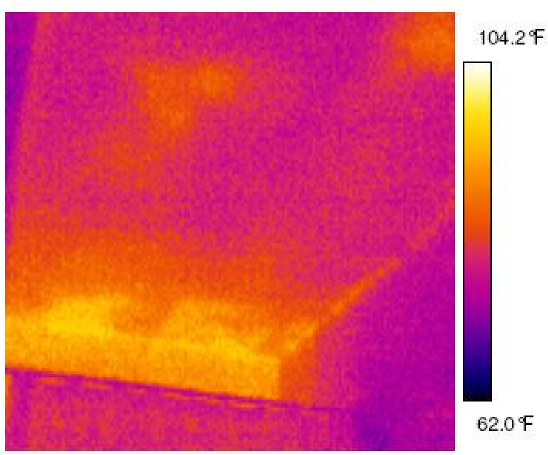
4) Looking east at hall ceiling



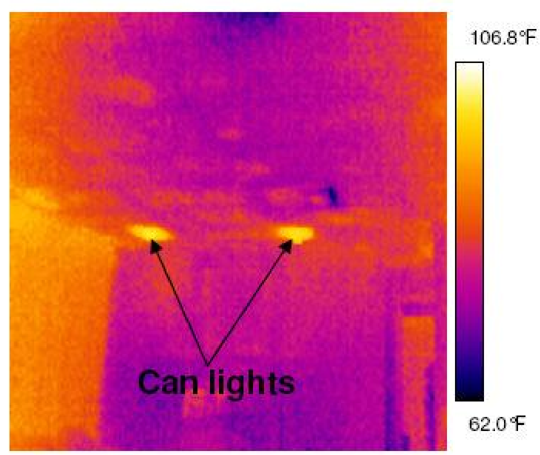
5) Looking north at side bedroom ceiling



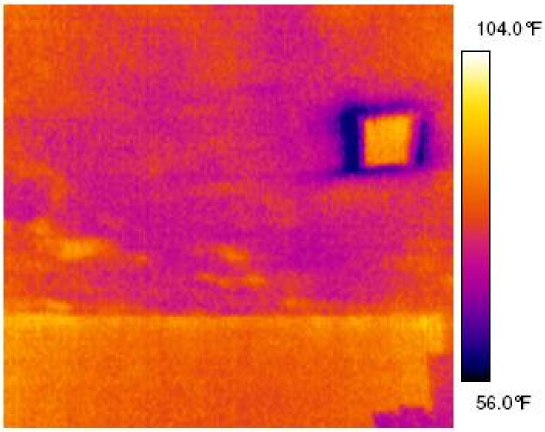
6) Looking north east at rear bedroom ceiling



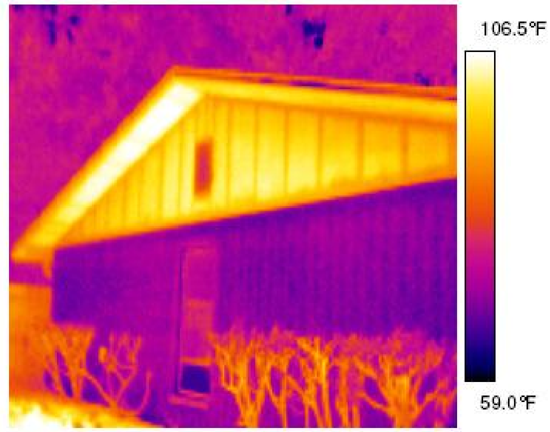
7) Looking east at hall bathroom ceiling



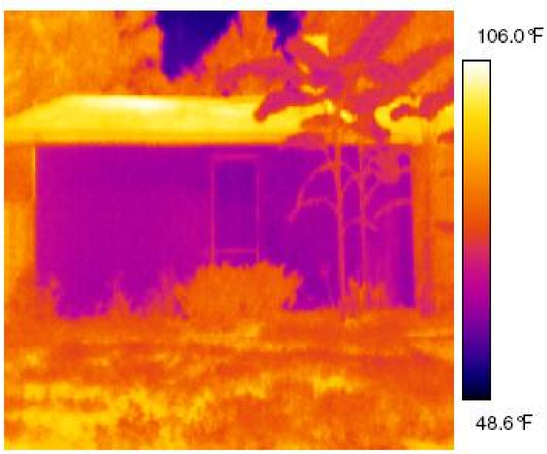
8) Looking south (toward Fireplace) at living room ceiling



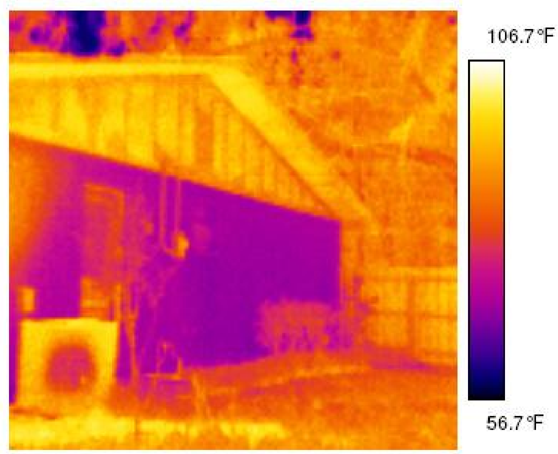
9) Looking south at master bedroom ceiling



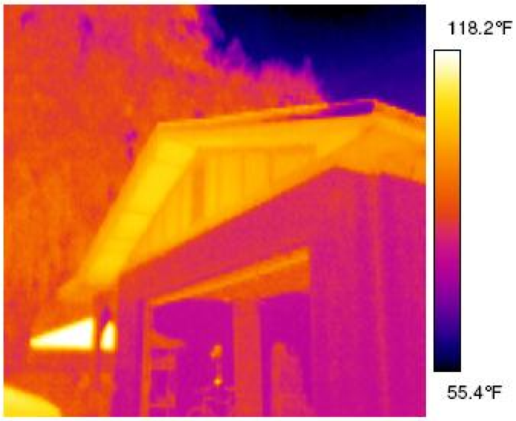
10) Looking south east at gable on north end of house.



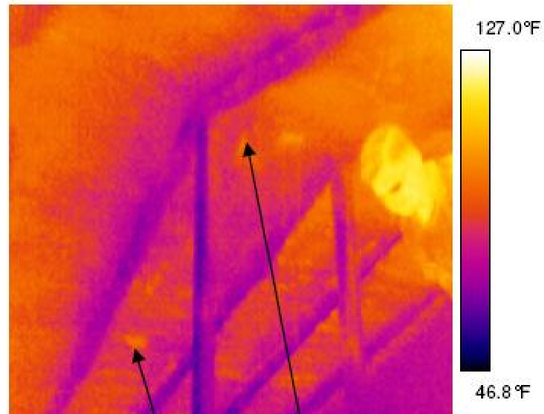
11) Looking west at back (east) side of house. No anomalies



12) Looking north east at south side of house.
No anomalies

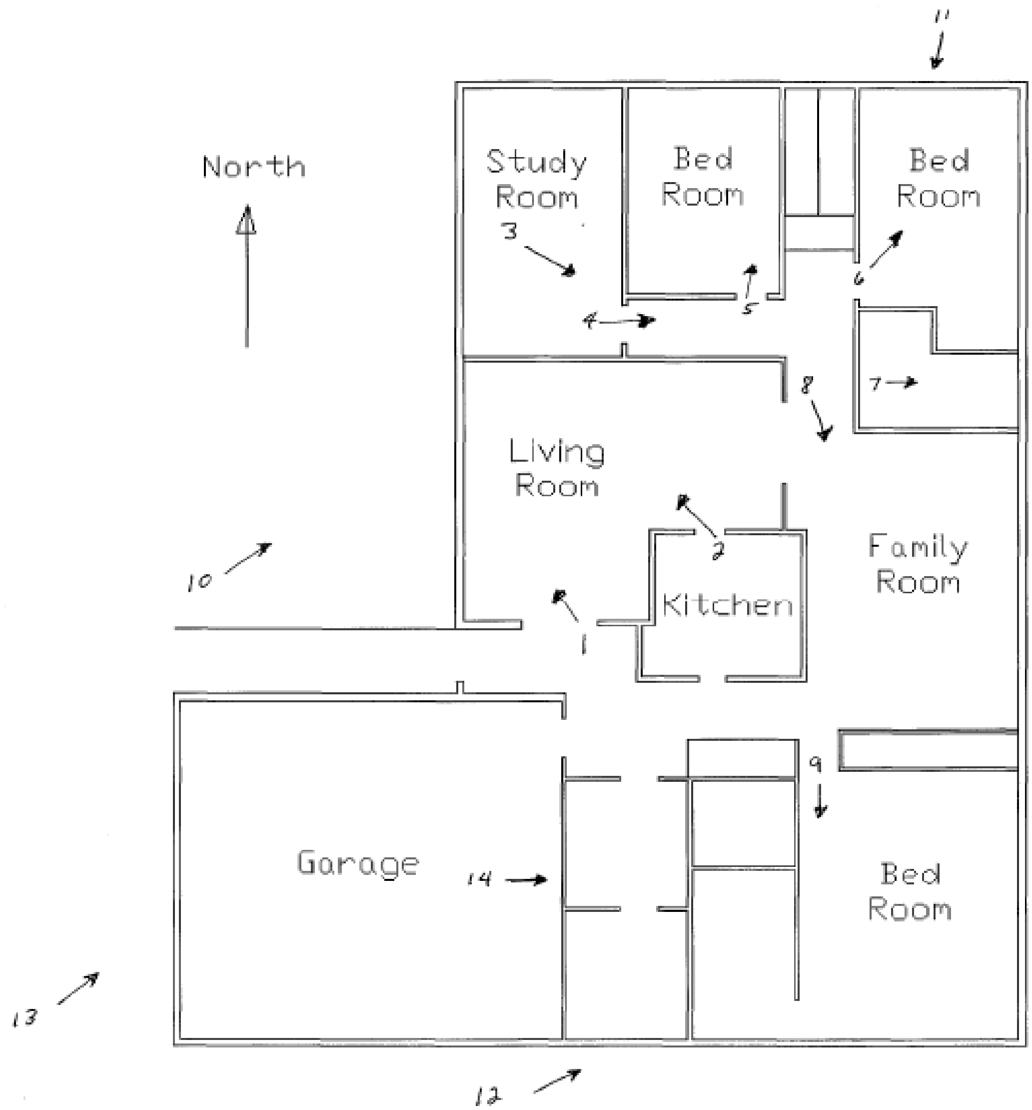


13) Looking east at gable above garage



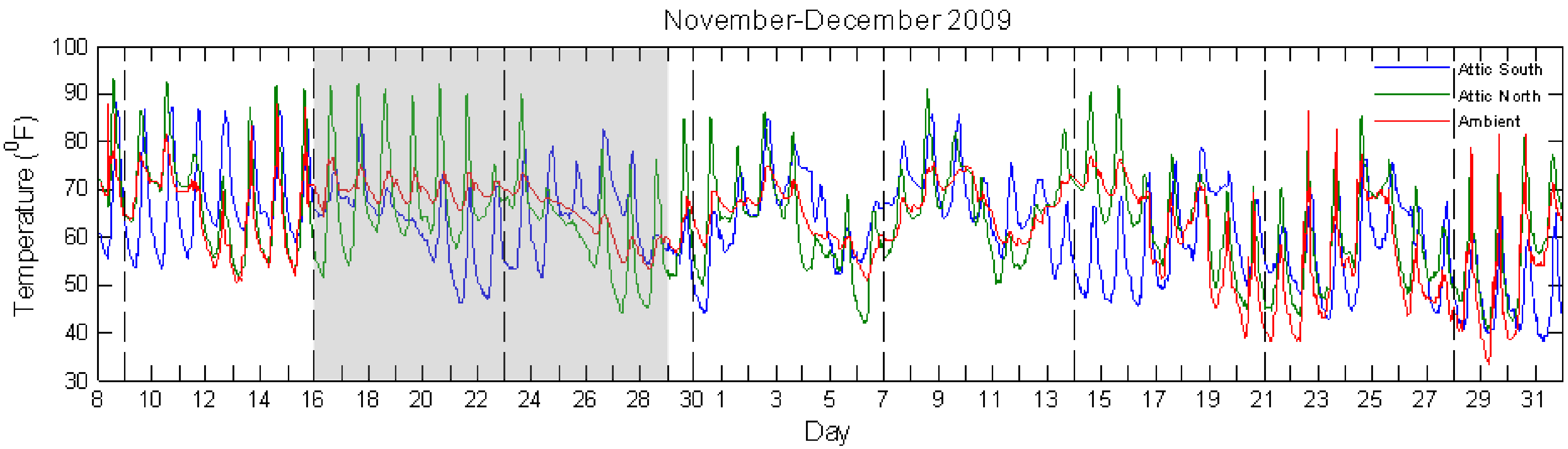
Sensors 88.4 87.7

14) Looking up at foamed roof decking.

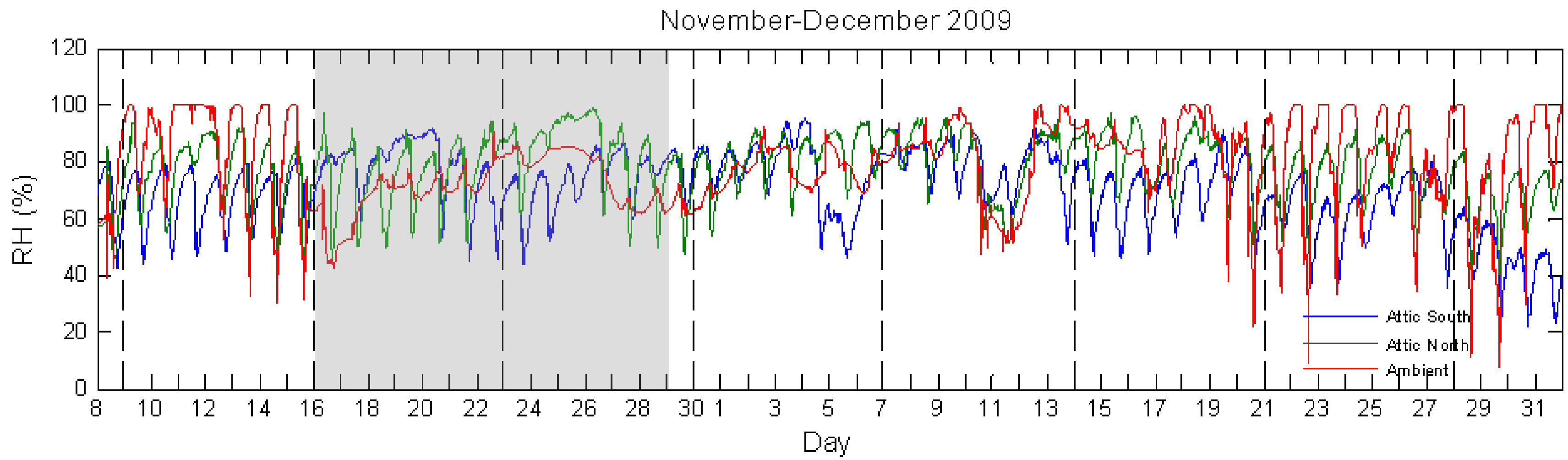


Position of infra-red camera for taking the thermal images

APPENDIX C: BIMONTHLY TEMPERATURE AND RELATIVE HUMIDITY PLOTS

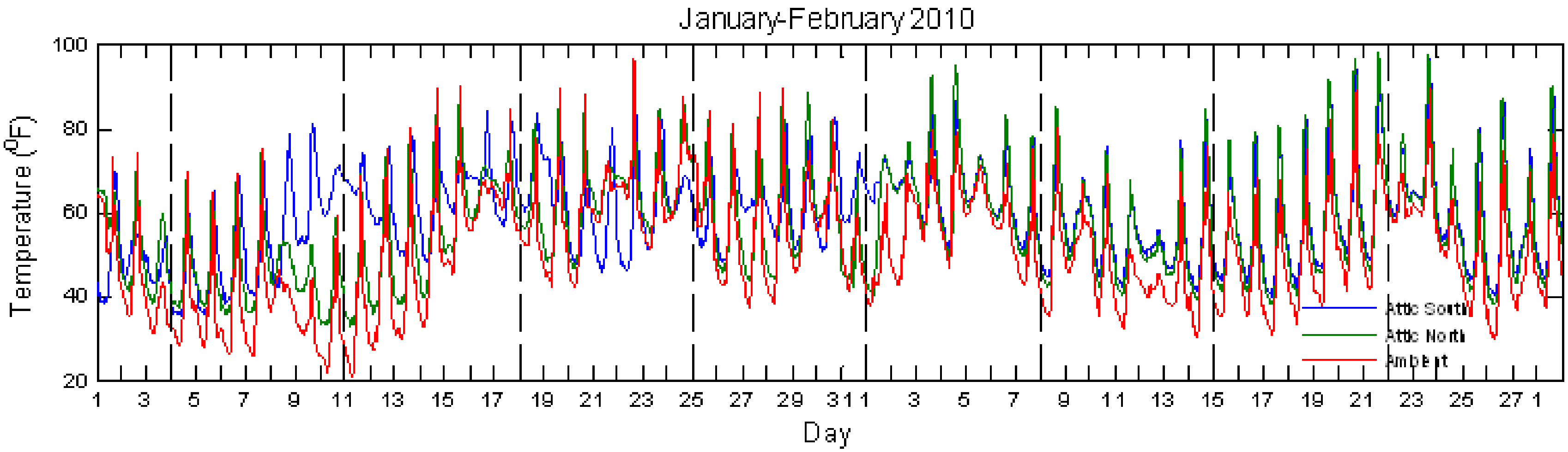


Temperature variation for Nov-Dec 2009

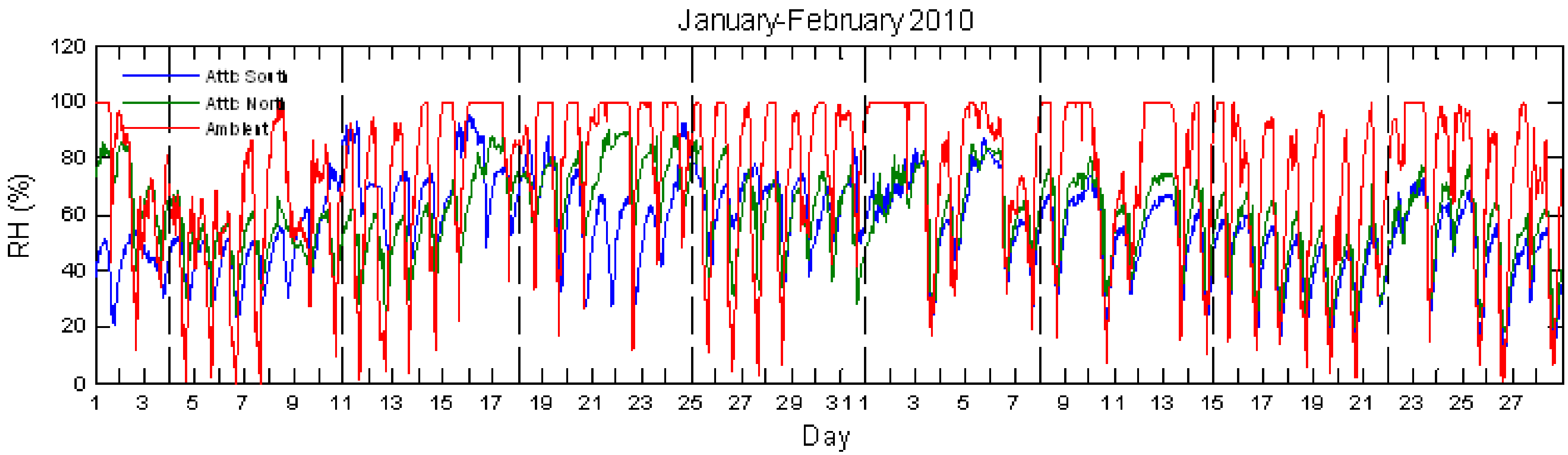


Relative humidity variation for Nov-Dec 2009

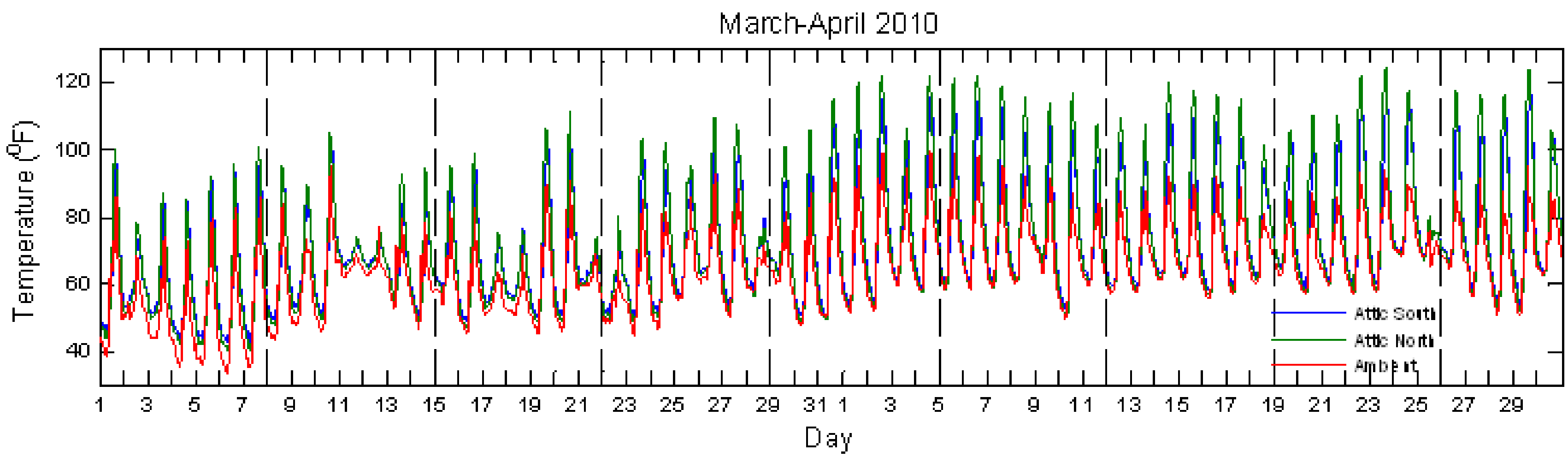
NOTE: The shaded portion in the graphs represent the period when the ambient sensor was placed in conditioned space



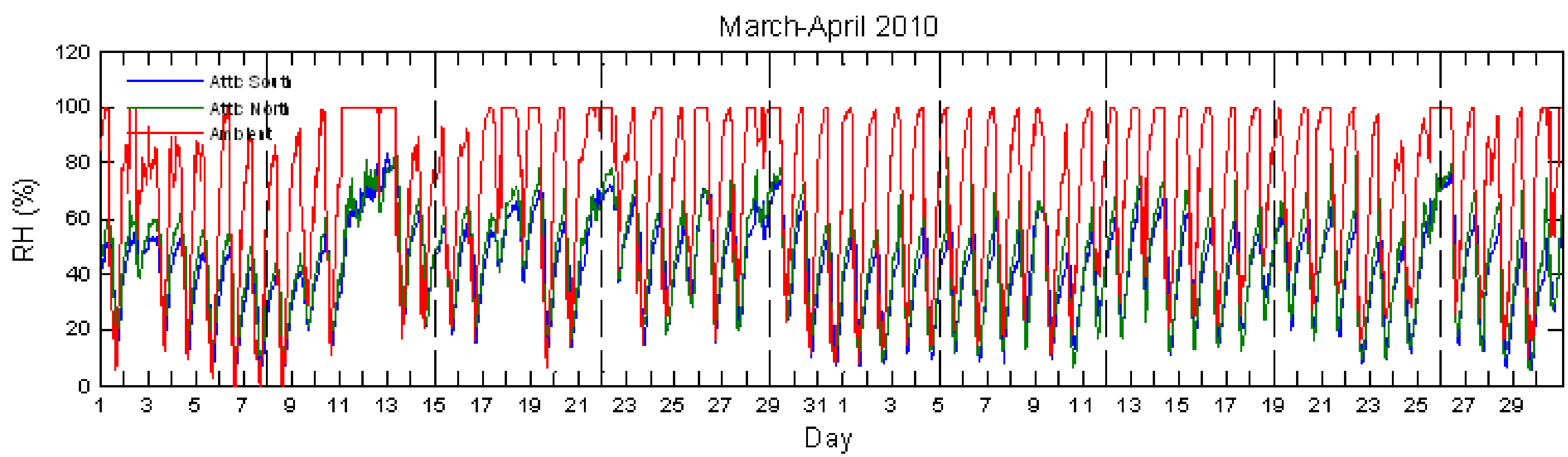
Temperature variation for Jan-Feb 2010



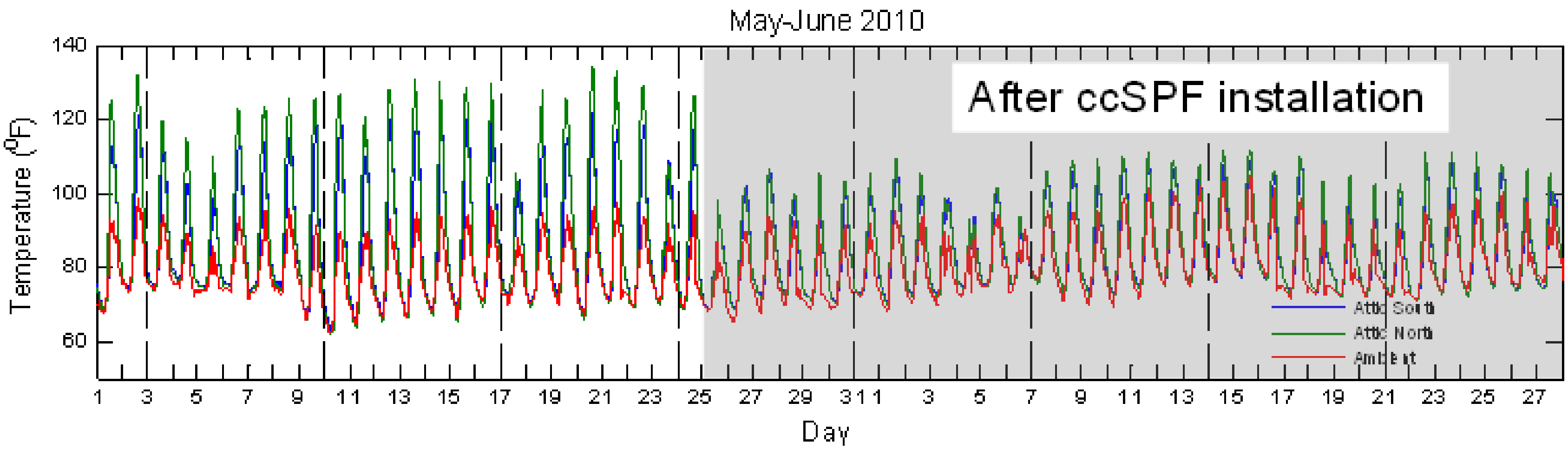
Relative humidity variation for Jan-Feb 2010



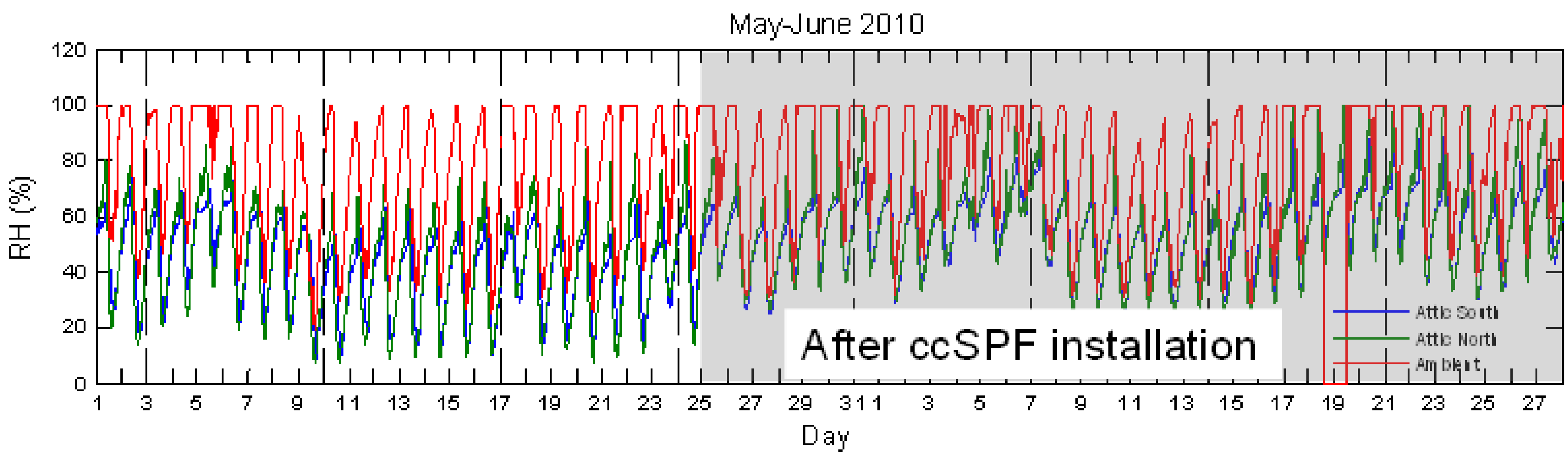
Temperature variation for March-April 2010



Relative humidity variation for March-April 2010



Temperature variation for May-June 2010



Relative humidity variation for May-June 2010