U.S. DEPARTMENT OF ENERGY

PNNL-22327

Test Plan to Evaluate the Relationship among IAQ, Comfort, Moisture, and Ventilation in Humid Climates

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March 2013

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Executive Summary

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)'s standard 62.2, "Ventilation and Indoor Air Quality in Low-Rise Buildings," is the most commonly referenced and widely accepted residential ventilation standard. It is currently required by ENERGY STAR Version 3 (V3), the 2012 International Energy Conservation Code, DOE's Challenge Home Criteria, many state Weatherization programs, and many other home performance programs. However, ASHRAE 62.2 currently requires ventilation levels that may cause indoor moisture issues in hot humid climates unless mitigated by dehumidification systems, which increase overall energy consumption. The Building America Space Conditioning Standing Technical Committee identifies the need for climate-specific ventilation strategies in the hot humid climate.

In FY13, Pacific Northwest National Laboratory (PNNL) will coordinate with Florida Solar Energy Center (FSEC), Florida Home Energy and Resources Organization (F L HERO), and Lawrence Berkeley National Laboratory (LBNL) to evaluate the impact of ventilation rate on interior moisture levels, temperature distributions, and indoor air contaminant concentrations. Specifically, the research team will measure concentrations of indoor air contaminants, ventilation system flow rates, energy consumption, temperature, and relative humidity in ten homes in Gainesville, FL to characterize indoor pollutant levels and energy consumption associated with the observed ventilation rates. Indoor air contaminant levels in the homes with less than ASHRAE 62.2 levels of ventilation will be compared to homes that meet the standard.

In support of this research objective, PNNL and FSEC have collaboratively prepared this experimental test plan, which describes:

- background and context for the proposed study;
- the experimental design;
- specific monitoring points, including monitoring equipment, and sampling frequency;
- key research questions and the associated data analysis approach;
- experimental logistics, including schedule, milestones, and team member contact information; and
- roles and responsibilities of each team in support of project objectives.

The collaborative report is attached, with separate cover page, to fulfill both FSEC and PNNL's respective deliverables and formatting requirements. The results of the completed study will be provided in the form of a technical report, as well as journal articles and Building America Solution Center content describing the findings, installation instructions, and guidance for providing appropriate ventilation in hot humid climate. The findings will contribute to the debate of how best to provide ventilation in the hot humid climate, weighing the impact of excessive moisture against that of other indoor contaminants. This question must be resolved to help increase the penetration of high-performance homes in this climate.

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BUILDING TECHNOLOGIES PROGRAM

Test Plan to Evaluate the: Relationship among IAQ, Comfort, Moisture, and Ventilation in Humid Climates

Eric Martin and Sarah Widder

March 2013

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Acronyms

AC	Air conditioner, air conditioning
ACH	Air changes per hour
ACH50	Air changes per hour at 50 pascals
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
BAPIRC	Building America Partnership for Improved Residential Construction
BSC	Building Science Corporation
CFM	Cubic feet per minute
CT	Current transducer
DOE	US Department of Energy
EPA	US Environmental Protection Agency
FL HERO	Florida Home Energy and Resources Organization
HERS	Home Energy Rating System
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
NREL	National Renewable Energy Laboratory
PFT	Perfluorocarbon tracer
PNNL	Pacific Northwest National Laboratory
Qn_{out}	Duct leakage to outside at 25 Pascals depressurization divided by the conditioned square footage of the home
RH	relative humidity
SEER	Seasonal energy efficiency ratio
TVOC	Total volatile organic compounds
Wh	Watt hours

1 Problem Statement

1.1 Introduction

Recently, EPA Energy Star V3 and DOE Challenge Home have begun to require compliance with ASHRAE 62.2-2010, which calls for significantly greater amounts of ventilation than what hot humid climate builders of high performance homes and their contractors have grown accustomed to, and are comfortable with. There is universal concern amongst the regional industry around the implications associated with introducing larger volumes of humid outside air, compared to the potential indoor air quality benefits, which are not fully documented or demonstrated. These implications include the potential impact on IAQ, energy use, comfort, durability, and both first and operating costs. It is necessary to make field based screening measurements relating the impact of ventilation rate on these parameters.

1.2 Background

While ventilation air is important to maintain good IAQ by diluting concentrations of indoor air pollutants, in high performance housing, humidity control is also becoming increasingly important to maintain good IAQ, comfort, and durability. In hot humid climates, reduced sensible loads in new and existing houses call for reduced space conditioning capacity and therefore incidental dehumidification from air conditioning is reduced. The potential for introduction of larger volumes of outside air may result in increased prevalence of mold and dust mites, which may become a critical issue along with reduced comfort unless supplemental dehumidification is included. Supplemental dehumidification carries an additional first cost, energy cost, and maintenance cost.

Since 1997, in order to balance factors related to IAQ, comfort, energy use, and moisture control, builders of high performance homes in the hot humid climate have utilized a supply based whole house mechanical ventilation strategy linked to runtime of the central HVAC system - runtime vent (Chandra, 2008). A schematic of the system is shown in Figure 1.

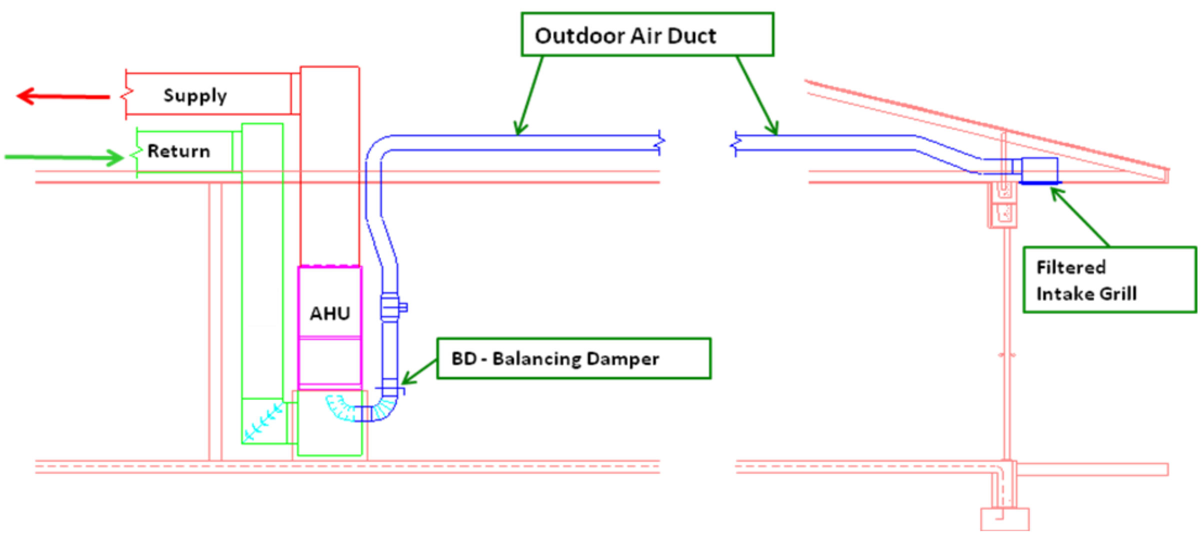

Figure 1. Schematic of runtime ventilation system.

During that time, BA-PIRC builder partners have implemented the approach in over 1,500 homes. Outdoor air flow rates, and hence ventilation air volumes, have varied[1] but design intents for most systems focus on commissioning to achieve 0.5 – 1 Pascals positive pressure in the home with respect to the outside, enhancing natural air exchange during periods of prolonged window closure, and minimizing first cost and energy use associated with the space conditioning system. As this approach has worked successfully for the builders and customers alike based on perceptions, increasing mechanical ventilation rates to comply with ASHRAE guidance and labeling programs including Energy Star and Challenge Home is met with hesitation and questions related to justification of this requirement and consequences on home durability and occupant health. The industry is looking to Building America to provide design guidance and documented benefits based on data.

Some data has previously been collected in homes utilizing the runtime vent system, and homeowners surveyed have expressed universal satisfaction with resulting temperature and relative humidity. For example, Figure 2 shows representative data from a PNNL study involving ten recently constructed high performance homes in Gainesville, FL[2].

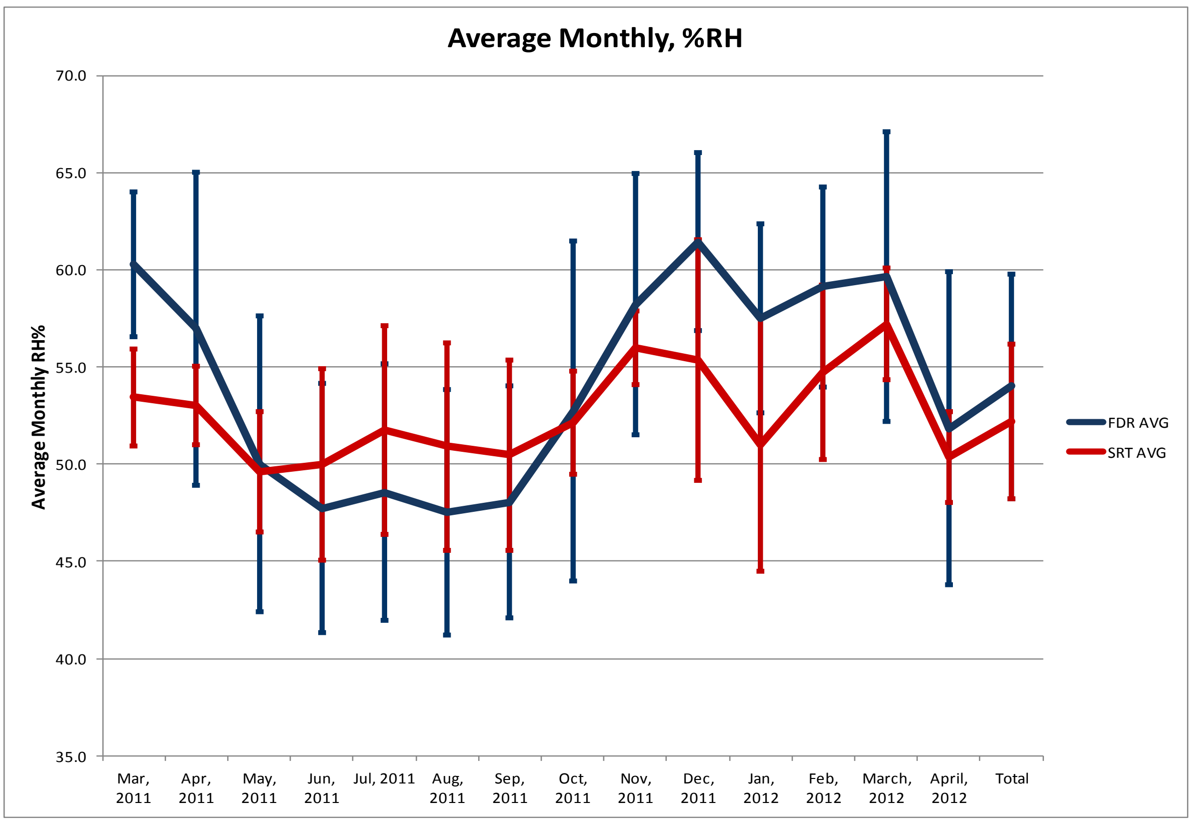

Figure 2. Average and range of monthly RH for fully ducted return (FDR) and single return with transoms (SRT) homes with runtime vent system in Gainesville, FL

[1] Test results from hundreds of homes show that systems commissioned to deliver approximately 50% of ASHRAE 62.2-2010 continuous ventilation rate during system runtime.

[2] Widder S and K Fonorow. 2013 [unpublished]. "Don't Waste Your Money: The Performance of Passive Transom Returns as a Return Air Strategies in High Performance Homes."

As seen in the figure, RH is maintained well below 60% during months with consistent air conditioner operation. Excursions approaching and exceeding 60% are evident during swing season months with inconsistent and little air conditioner operation. Additional ventilation during this time without supplemental dehumidification could result in comfort issues. RH is also elevated during the winter months with only sporadic heating operation. Additional ventilation during this period could actually lower interior RH.

BSC has conducted numerous studies involving runtime based ventilation systems[3], including quantifying the energy cost of supplemental dehumidification to maintain interior RH below 60% (Rudd, 2005 & 2008). However, there is a lack of available data from homes incorporating full ASHRAE 62.2-2010 ventilation in the hot humid climate, and no known data comparing performance to simple, regional standard runtime vent systems.

Recently, yet unpublished, results from Building America and ASHRAE research projects, as well as yet unpublished and published (Fang, 2011) results from NREL research projects have simulated the performance of ASHRAE 62.2-2010 compliant systems in the hot humid climate using models. In general, hours above 60% RH have been found to be significant, in the range of 2,000 hours per year. However, increased ventilation rates have been found to be only one of many factors contributing to the potential for elevated interior RH, and lack of certainty about certain modeled parameters lead to some level of uncertainty in the results, reinforcing the need for field studies. Some uncertainties include:

- Interior moisture generation rate
- Accuracy of models for interior moisture capacitance of materials

1.3 Relevance to Building America's Goals

Optimizing mechanical ventilation is critical to the overall goal of the Building America program involving reduction in energy use up to 50% (compared to 2009 energy codes for new homes and pre-retrofit energy use for existing homes), while increasing comfort, safety, and durability."[4] The BA Space Conditioning Standing Technical Committee also has a ventilation specific milestone built into its critical path aiming to develop best practice guidance for mechanical ventilation in high performance homes and retrofits.

1.4 Cost-Effectiveness, Tradeoffs, and Other Benefits

Implementation of ASHRAE 62.2-2010 ventilation in the hot humid climate is a design and implementation issue involving maximizing occupant health while minimizing energy consumption. However, the issue relates to cost-effectiveness in a number of very important ways. Maximizing health will minimize associated health care costs, but such metrics are outside the scope of Building America. What is within the scope of Building America is to minimize energy use, and hence cost, without adversely affecting health and safety. In addition to energy cost, affordability of home ownership is also of concern, from initial purchase through maintenance over the life of the home.

[3] BSC research typically involves systems with components that ensure minimum hourly runtime fractions.

[4] http://www1.eere.energy.gov/buildings/residential/ba_research.html

Recent research at FSEC (as yet unpublished) has determined that installed cost for equipment to provide supplemental latent recovery or active humidity control can vary from a few hundred dollars to a few thousand dollars, and a tradeoff exists among installed cost, effectiveness, and reliability. Simulation studies, including the ones mentioned above, have estimated a 10% increase in space conditioning energy cost when changing from the runtime vent system to ASHRAE 62.2. Adding energy use of a supplemental dehumidifier to control humidity has been estimated to increase space conditioning energy costs by another 10%.

2 Experiment

2.1 Research Questions

The following research questions will be answered by this project.

- What is the difference in space conditioning energy consumption when ventilating with the regional standard runtime vent system and an ASHRAE 62.2-2010 compliant system?

- What is the difference in the concentration of select indoor air pollutants when ventilating with the regional standard runtime vent system and an ASHRAE 62.2-2010 compliant system?

2.2 Technical Approach

The research team will build on previous work completed by PNNL and FL HERO in FY11 and FY12 to characterize the energy efficiency, cost, and thermal comfort impacts of two different return duct designs in ten similar homes in Gainesville, Florida. Temperature and relative humidity were measured in these homes for a full calendar year, from March 2011 to May 2012. These data present baseline temperature and relative humidity measurements for all homes.

The ten homes are evenly split between fully ducted return systems, and centralized return systems that employ over-the-door transoms for passive pressure equalization and return air pathways. This is not expected to have relevance to the current study, as previous results found similar distribution of T and RH in both return air configurations. The homes were all newly occupied in the 2009-2010 timeframe, have similar specifications, and were built to Builders Challenge 1.0 guidelines. All homes are single story, slab-on-grade, with ductwork located in vented attics. The HVAC systems in these homes are SEER 15 or 16 single-stage heat pumps that employ the runtime ventilation system described in section 1.2. The systems have no provisions for enhanced humidity control outside of their standard latent capacity. Additional characteristics are shown in Table 1.

Table 1. Characteristics of the study homes.

Paramater	Range	Average
Conditioned Floor area (sqft)	1,542 – 3,045	1,956
ACH 50	2.4 - 4.6	3.3
Qnout (CFM 25 out/sqft)	0.016 – 0.040	0.027
HERS Index	55-65	58
Runtime ventilation rate (cfm)	10 - 33	23
ASHRAE 62.2-2010 rate (cfm)	45 - 60	50
ASHRAE 62.2-2010 addendum r rate (cfm)	57 - 71	65

Based on the results of the comprehensive audit described in section 2.3, the homes will be divided into two cohorts: (1) homes that will be paired for a side-by-side comparison of two 62.2-compliant homes compared to two unmodified homes for the duration of the study period and (2) six homes that will be flip-flopped between 62.2 compliant ventilation and unmodified ventilation rates. The four most similar homes, determined from initial baseline testing, will be selected for side-by-side assessment. The side-by-side cohort of homes will provide useful data regarding the seasonality of moisture and IAQ levels in homes and may provide additional insights regarding any longer-term affects of increased or decreased ventilation rates. In the remaining six homes, the ventilation rates will be varied, or “flip-flopped,” on a biweekly (every other week) basis, between the unmodified, runtime ventilation, and 62.2 compliant ventilation enabling comparison of the two ventilation rates in the same home during similar weather and occupancy periods.

ASHRAE 62.2 ventilation will be induced by continuous operation of an existing bathroom exhaust fan(s). If deemed necessary, adjustments will be made to the fan/damper/ducting system to dial in target flow, or the fans will be replaced with models offering higher rated flow rates. Existing switches that control fan operation will be locked in the “on” position to prevent accidental disruption of the continuous ventilation flow by the occupants. Electronic shut-off dampers may be installed in-line of the runtime vent outside air duct interlocking damper operation with compressor operation. This will prevent over-ventilation, especially during tracer gas testing, as it is expected that air handlers will operate in a “fan on” configuration during this time to ensure adequate mixing. .

The experimental schedule is shown in Table 2. Once each season, in the second week of a two week period (to enable achievement of equilibrium), IAQ sampling and tracer gas injection/sampling will occur.

Table 2. Experimental Schedule

Key: Unmodified | 62.2 — IAQ = week IAQ test is occurring

Season	Month	Week	Home S1A	Home S2B	Home S2A	Home S2B	Home F1	Home F2	Home F3	Home F4	Home F5	Home F6
Spring Swing	4	1										
	4	2	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	4	3										
	4	4	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	5	5										
	5	6										
Summer	5	7										
	5	8										
	5	9										
	6	10										
	6	11										
	6	12										
	6	13										
	7	14										
	7	15										
	7	16	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	7	17										
	8	18	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	8	19										
	8	20										
	8	21										

	8	22										
	9	23										
	9	24										
	9	25										
	9	26										
Fall Swing	10	27										
	10	28										
	10	29										
	10	30	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	10	31										
	11	32	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	11	33										
	11	34										
	11	35										
Winter	12	36										
	12	37	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ
	12	38										
	12	39	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ	IAQ

2.3 Measurements and Equipment

In addition to the original HERS rating conducted on the homes, a comprehensive audit was conducted on the ten homes in late 2010.. Detailed building and equipment characteristics were logged, and testing was performed to determine building envelope leakage (cfm50), duct leakage (cfm25), and runtime ventilation flow (cfm). Occupants were interviewed to determine occupancy characteristics, heating/cooling setpoints, spot ventilation use, and preference for opening windows. The testing will be repeated at the start of this study, and occupants will be asked if there are any updates relating to occupancy and home operation. A radon test will also be conducted to ascertain whether it radon should be include as a component of this IAQ study. The homes are located in EPA radon Zone 2.

Monitoring of temperature, relative humidity, energy, air conditioner condensate generation, and mechanical ventilation fan runtime will occur continuously over the course of the 10-month period from March 2013 to December 2013. The eMonitor platform will be used for many of the measurements, with data automatically downloaded to the FSEC Infomonitors system[5]. Add on components will be utilized for additional measurements that will not be logged by eMonitor, as characterized in Table 3, with periodic manual data downloads.

Interior and ambient CO_2 will be measured continuously during the entire study period, and the research team will pay routine, seasonal visits to the homes to measure concentrations of indoor air contaminants including formaldehyde, acetaldehyde, and TVOC, using passive sorbent badges. Laboratory analysis will yield average concentrations during the sampling week. Perflourocabon tracer (PFT) will be deployed during the sampling week, with laboratory analysis yielding average total ventilation rate (natural + mechanical), or air changes per hour, for the sampling week. During the IAQ sampling visits researchers will conduct a visual inspection for signs of excessive moisture and mold, and homeowners will be interviewed for perceptions of comfort and indoor quality.

Table 3 lists the various measurement parameters, measurement equipment, and sampling rates.

[5] http://www.infomonitors.com

Table 3. Measurement Information.

Measurement	Equipment Needed	Sampling Interval
Total Energy (Wh)	eMonitor (CT)	hourly
Air Handler Energy (Wh) / Runtime (min/hr)	eMonitor (CT)	hourly
Condenser Energy (Wh)	eMonitor (CT)	hourly
Bath Fan Power (Wh) / Runtime (min/hr)	eMonitor (CT) or U-12 HOBO (CT)[1]	hourly
Space T & RH (thermostat)	eMonitor + hub (Intellergy T/RH sensor)	hourly
Space T & RH (4 interior locations)	(1) Extech[2] T/RH/CO_2, (3) U-10 HOBOs	15 min
Ambient T & RH	Extech T/RH/CO2	15 min
AC Condensate (mL/hr)	eMonitor + hub (TR-4 tipping bucket)	hourly
Infiltration (cfm50)	Blower Door	Initial baseline
Infiltration (ACH)	Perfluorocarbon Tracer (PFT)[3]	Weekly, 4 weeks/year
Duct Leakage (cfm25)	Duct Blaster	Initial baseline
Runtime vent flow (cfm)	Powered flow hood	Initial baseline
Exhaust fan flow (cfm)	Powered flow hood	Initial baseline
Interior CO_2(ppm)	Extech CO_2/T/RH	15 min
Ambient CO_2 (ppm)	Extech CO_2/T/RH	15 min
Formaldehyde (ppb)	Passive sorbent badge[4]	Weekly, 4 weeks/year
Acetaldehyde (ppb)	Passive sorbent badge[4]	Weekly, 4 weeks/year
Volatile Organic Compounds (ppt)	Passive sorbent badge[4]	Weekly, 4 weeks/year
Nitrous Oxides/Nitrogen Dioxide (ppb)	Passive sorbent badge[4]	Initial baseline and as necessary subsequently
Radon (pCi/L)	Passive radon test strips	Initial baseline and as necessary subsequently
Mold	Visual inspection	4 weeks/year

[1] Preference is to wire equipment to a dedicated circuit breaker in the panel, and utilize the eMonitor to record energy use. If that is not possible, alternate means to record energy use will be used.

[2] The Extech device uses infrared technology to measure CO_2.

[3] Passive infiltration and IAQ samplers will be mailed to a laboratory for analysis. Analysis will be performed using standard EPA protocols for the identification of volatile organics (TO-17) and formaldehyde/acetaldehyde (TO-11A).

3 Analysis

Analysis will be conducted to determine the following:

- Effective total ventilation rates provided by the two ventilation systems: runtime vent and continuous exhaust, quantified seasonally during the PFT sampling weeks.
- Difference in interior concentration of formaldehyde, acetaldehyde, TVOC and CO_2 measured at the differing ventilation rates, quantified during the IAQ/PFT sampling weeks.
- Difference in monthly, seasonal and annual space conditioning energy use between the two ventilation rates.
- Difference in monthly, seasonal and annual interior RH resulting from differing ventilation rates, including number of hours > 60% and 65% RH.

4 Expected Results

The results of this study will contribute to the debate of how best to provide ventilation in the hot humid climate, weighing the impact of excessive moisture against that of other indoor contaminants. The research will demonstrate the installation and characterize the performance of ventilation systems in hot humid climate, both those compliant and noncompliant with ASHRAE 62.2, including energy penalties associated with each system. The study will enable the DOE Challenge Home, ENERGY STAR Version 3, and Building America projects in the hot humid climate by identifying effective strategies to achieve adequate ventilation and minimize contaminants while limiting additional cost and energy use. This question must be resolved to scale up the penetration of high-performance homes in the hot humid climate, and could have impacts for other climate zones as well. Results will include technical reports and journal articles describing the findings. The reports will include instructions for installing the ventilation systems that are consistent for inclusion in the Building America Solution Center.

5 Logistics

The experiment will be conducted in 10 homes located in the adjoining Longleaf and Willow Oak subdivisions in Gainesville, FL. Table 4 lists contact information for key members of the project team.

Table 4. Contact Info

Company Name	Team Member	Email	Phone
PNNL	Sarah Widder	Sarah.Widder@pnnl.gov	509-372-6396
FSEC	Eric Martin	martin@fsec.ucf.edu	321-638-1450
FSEC	Janet McIlvaine	janet@fsec.ucf.edu	321-638-1434
FSEC	Dave Chasar	dchasar@fsec.ucf.edu	321-638-1453
FL HERO	Ken Fonorow	ken@floridahero.com	352-392-5661

Table 5 lists milestones, due dates, and responsible team members.

Table 5. Milestone table.

Milestone Name	Due Date	Team Member Responsible
IRB Approval	3/17/2013	PNNL
Obtain homeowner agreements	3/22/2013	FL HERO
Conduct baseline testing/home modifications	3/24/2013	FL HERO
Install instrumentation/ begin collecting data	4/1/2013	FSEC
Ventilation flip-flop	Continuous; every 2 weeks	FL HERO
IAQ/PFT sampling/manual data download	Continuous; twice per season	FL HERO & PNNL
Monitor and Collect data	Continuous	FL HERO & FSEC
Data analysis	Seasonally	PNNL & FSEC
Write final report and any associated deliverables	12/31/2013	PNNL & FSEC

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