An Inherently Healthier Home? -- Investigating A Package of Ventilation, Dehumidification, and Filtration in High Performance Housing

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ABSTRACT

Exposure to damp indoor environments and the allergens that thrive in damp environments has been associated with asthma development, exacerbation, and wheeze and respiratory complications. This paper describes a study that is currently underway to test whether a protocol for building a moisture-managed house with dedicated dehumidification, filtration, and ventilation can reliably and affordably maintain indoor relative humidity levels below allergen supporting levels of 50% largely independent of homeowner behavior in a mixed-humid climate. This intervention has the potential to be integrated into retrofit and new construction programs. The moisture management strategies include a whole house dehumidifier, a building code compliant closed crawl space, localized exhaust ventilation, and construction specifications used in a national high-performance homes program. A MERV 11 whole house filter addresses air filtration and an outdoor air intake system is incorporated for ventilation.

A compelling aspect of this study is the examination of guaranteed-program high performance home specifications compared to houses that are built simply to minimum building code standards. Nationally, the high performance housing sector of the market is growing, with over 175,000 houses built nationally under production built guaranteed performance homes, and over 1,600 houses built in North Carolina under affordable housing guaranteed performance programs. Guaranteed performance housing programs are distinguished not only by their construction standards but also by the quality assurance processes followed for builders and subcontractors during construction.

INTRODUCTION

With recent changes to building materials and processes as well as higher consumer awareness of high-performance, energy-efficient, and green building programs, there is a desire to learn how these differ from standard construction methods. The term “high-performance home” is used in the housing marketplace to distinguish homes in which:

1) the construction (or retrofit) specifications are designed for high energy efficiency

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2) The implementation of the specifications is field-verified by a third party by means of performance tests and quality assurance checks to make sure that the specifications are properly met.
3) A feedback loop is in place to ensure that the builder or retrofitter learns what works and what does not, and that he has incentives to meet the specification. Often that feedback loop is the guarantee issued to the home buyers that their heating and cooling energy bills will fall below a specified value and that the temperature in their rooms will match the thermostat setting (i.e., no rooms that are much hotter or colder than the rest of the house).

In Phoenix Arizona, guaranteed-program high performance homes have been documented that performed twice as well concerning heating and cooling energy use as comparable Energy Star or baseline code compliant homes (Advanced Energy 2005). Anecdotally these results have been validated across North Carolina, but no formal comparison has been made to date. Green and healthier home specifications have been on the minds of government agencies at the national, state, and local levels as they are being incorporated into construction programs, often with high performance home standards as the baseline. Therefore, this examination of high performance and healthier housing standards in Central North Carolina is timely.

METHODS

Specific housing retrofits were performed on otherwise comparable houses in order to look at end points related to the study hypotheses. Two groups of new houses were enrolled.

In order to reduce variables, we only enrolled houses that were built at least to Energy Star standards of envelope and duct leakage, but had no other ventilation package (usually this meant that the kitchen and bath exhaust fans were low-performing and no outside air was ducted to the HVAC return). At the enrollment visit, we conducted building performance testing and excluded any homes that did not meet house and duct tightness specifications. We also conducted a visual survey, and excluded any homes that had moisture damage, standing water in the crawl space, signs of past water damage or other indicators of irreparable moisture damage. Of those remaining, we used a commercially available house dust mite swab to screen for levels of existing house dust mites. The original study design called for us to enroll only houses with detectable dust mite levels. The literature led us to expect that at least a majority of houses would have detectable dust mites. However during the August through October enrollment visits, we found very few houses with detectable mites. We hypothesized that this is a result of the extended drought that North Carolina is experiencing. We therefore enrolled houses as long as they met the other study criteria.

Participating houses are all less than 10 years old and are located in 2 neighborhoods in the Piedmont area of North Carolina (mixed humid climate zone).

The study design grouped the study population into pairs based on location, house airtightness, and the presence and type of pets. Twenty-two houses were able to be closely matched based on house performance, presence of pets, and location. Each house in the pair was randomly assigned to either the intervention or non-intervention group. Eleven houses had the intervention package installed at the end of 2007.

Ventilation.

The objective of outside air ventilation is to dilute with outside air the chemical pollutants that homeowners emit – everything from carbon dioxide from breathing to volatile organic compounds (formaldehyde and others) emitting from furniture, air fresheners, and personal care products.. The ventilation package in this study, which incorporates reduced house and duct leakage, is based on the methods followed in the North Carolina affordable housing guaranteed performance homes program.

The 2 ventilation methods that will be examined by this study are:

Intentional Ventilation Strategy (Intervention houses)

- Outdoor air is brought into the HVAC air distribution system whenever the main air handler runs (“outdoor air intake”) plus performance tested exhaust fans.

No Ventilation Strategy (non-intervention houses)

- Poorly-performing spot exhaust fans, no outdoor air intake.

The duct leakage and house envelope leakage in both sets of houses is limited and is comparable across the groups.

The outcome measures of ventilation will be:

- Ventilation rates expressed as envelope leakage and air changes per hour based on blower door measurements
- Ventilation rates calculated using tracer gas measures on a subset of houses
- Formaldehyde levels in the home during an 8-hour time period

Filtration

Particulate pollution has been linked to a variety of adverse health outcomes including asthma, other respiratory disease, and cardiac disease. This intervention package includes a MERV 11 whole house filter that filters air returning from the home to the heating/cooling system air handler. Outdoor air that is introduced as part of the ventilation strategy is brought in upstream of the MERV 11 filter as well. We expect that the filter will reduce particulate levels in homes where it is present. We will also explore whether the filter has an impact on pet allergens, as these allergens tend to be airborne.

We will measure coarse particulate matter (PM) size fractions (both 2.5 and 10) and seek to establish whether there are differences between the matched pairs of homes. These PM 2.5 and PM 10 were selected because they make up one of three recognized particulate size categories in the industry that contribute to adverse respiratory health effects.

Dehumidification

Allergen levels inside homes have been established as important causes of enhanced asthma morbidity especially in children. Humidity and water load of a building have been linked to both exacerbation and severity of asthma and to levels of mite and mold allergens and endotoxin. In a previous phase of this study (2003-2006) we deployed a moisture intervention that we hoped would be adequate to reduce indoor RH below 60%, and we found that it consistently did not manage to reduce relative humidity to dust-mite safe levels inside the homes. It did effectively manage moisture in the crawl space robustly, thereby preventing mold and other foundation moisture issues. Therefore in the current phase of this study (2006-2009), we designed the intervention to include energy efficient mechanical dehumidification integrated with the forced air duct work.

We will test whether the whole house mechanical dehumidification consistently maintains RH below 50% in the Central North Carolina climate. It has been demonstrated to do so in Ohio, but not in a mixed-humid climate (Arlian 2001). The consensus in the field is that we can reliably “muscle down” relative humidity to below 50% and keep it there, so we are confident that we will be able to accomplish that target. The interesting issue here is whether the energy efficient dehumidifier, operating in a house with tight ducts and tight envelope, provides a system that can be run affordably. We believe that asthmatics with dust mite allergy will be more willing to invest in dehumidification where the operating costs are predictable and affordable. The documentation of dehumidification performance will be by way of indoor relative humidity readings and allergen level measurements to confirm that dust mite populations are under control in the intervention houses.

Table 1 summarizes the study hypotheses, environmental outcomes, and exploratory data that we will examine in this study. Table 2 summarizes the measurement methods and frequency of sampling.

Table 1. Hypotheses, Mechanism, and Outcomes

	Hypotheses and Exploration Areas	Mechanism	Environmental Outcome
Ventilation	Intervention houses have overall higher ventilation rates than non-intervention houses in winter/summer (when windows tend to be closed)	Outdoor air intake dilutes house air with outdoor air; upgraded exhaust fans exhaust room air.	Measure ventilation levels in houses (blower door test plus air flow into the outdoor air intakes)
	Intervention houses have lower levels of harmful VOCs than non-intervention houses.	Outdoor air intake dilutes house air with outdoor air; upgraded exhaust fans allow homeowner to exhaust pollutants they generate	Formaldehyde and acetaldehyde levels
Filtration	Intervention homes have reduced levels of particles relative to non intervention	Whole house MERV 11 filter	Total particulates or particulates in targeted size ranges.
	Intervention homes have reduced cat and dog allergen levels.	Whole house filter captures airborne pet allergen, leading to lower allergen on surfaces.	Allergen levels in settle dust.
Moisture	Dehumidification and ventilation strategy can be delivered without excessive energy use compared to control houses.	Tight envelope and ducts, closed crawl space, and properly charged air conditioning ensure the dehumidifier does not have to run excessively	Kilowatt hours used by dehumidifier
	The intervention package maintains indoor relative humidity at or below 50%.	The suite of moisture management reduces RH (dehumidifier, simple closed crawl, exhaust fans) below the level where HDM thrive.	Average house relative humidity
	The intervention package prevents or retards re-establishment of house dust mites (HDM) over time relative to non intervention.	Indoor RH < 50% will suppress HDM	Given current drought conditions in NC, HDM levels in control houses may be suppressed. We will document levels in order to 1) meet programmatic needs of sponsor 2) document a typical set of exposures of Habitat Homeowners.
	The intervention crawl spaces maintain wood moisture below 16% (wood boring insect suppressing)	Dry ambient air in crawl reduces wood moisture	Wood moisture in center beam supporting floor joists (crawl space)
	Visible moisture damage/visible mold will be less frequent in intervention houses	Moisture management	Visual inspection by field staff
	The Intervention maintains crawl space relative humidity below 70% RH (mold-suppressing)	Crawl liner reduces ground moisture entry, closed vents, air supply dries air	Relative humidity readings in crawl space
	Dehumidification and ventilation strategy can be delivered without excessive energy use compared to control houses.	Tight envelope and ducts, closed crawl space, and properly charged air conditioning ensure the dehumidifier does not have to run excessively	Kilowatt hours used by dehumidifier

Table 2. Parameters, Methods and Frequency of Sampling

Topic Area	Parameter	Measurement method	Frequency
Ventilation	Amount of outdoor air infiltrating the home Amount of outdoor air intentionally introduced	Blower door, duct blaster, flow pan, pressure gauges	At study enrollment (tight houses = enrollment criteria) After retrofit for intervention houses
	Formaldehyde levels	Active Sampling	8 hour sample indoors and outdoors
Filtration	Particulates	Active Sampling	8 hour sample indoors and outdoors
	Cat Allergen (Fel d 1)	Dust sampling; multiplex assay	Minimum 2 samples: spring, and summer. If results are promising, winter sample will also be assayed.
	Dog allergen	Dust sampling; multiplex assay	Minimum 2 samples: spring, and summer. If results are promising, winter sample will also be assayed.
Moisture Management	House dust mite allergen (Der F1 and DerP)	Dust sampling; multiplex assay	Screening level at enrollment using swab test. Minimum 2 samples: spring, and summer. If results are promising, winter sample will also be assayed.
	Relative humidity in house	RH logger	Logged every 1 hour in house and crawl space
	Visible moisture damage/visible mold	Visual inspection recorded by trained field staff	At enrollment and at study completion
	Relative humidity in home	RH logger	Data logged every minute
	Relative Humidity in Crawl Space	RH logger	Data logged every minute
	Radon – ensure that crawl intervention did not cause unacceptable radon levels.	Radon canister in house and crawl space	Canister installed at time of intervention. Will be removed 3 months later and sent for lab analysis.
Costs	Energy use for dehumidification	Direct measure of dehumidifier kilowatt hour use	Continuous measure
Explanatory Variables	Cleaning frequency; presence of allergen barriers, new furniture	Questionnaire administered at time of sampling	Minimum 2 samples: spring, and summer.
	Presence of indoor smokers and other particulates	Questionnaire administered at time of sampling	Minimum 2 samples: spring, and summer.
	Presence of humidifier or dehumidifier beyond the intervention dehumidifier	Questionnaire administered at time of sampling	Minimum 2 samples: spring, and summer.

House Performance Characteristics

Performance of houses with respect to elements relevant to indoor air quality is a central feature of this investigation. When each new participating house is enrolled, research staff or qualified contractor will conduct a suite of tests. These tests are shown in Table 3.

Table 3. House Performance Characteristics

Characteristic	**Method**	**Measurement Standard**
House tightness	Blower door	Air flow less than or equal to 0.35 CFM50 per sq. ft. of envelope area
Duct tightness	Duct blaster	Total duct leakage air flow shall be less than 3% of the square footage of floor area.
Effective spot exhaust fans	Flow pan	50 CFM measured air flow in bathrooms; 100 CFM air flow in kitchen, vented to outdoors

DISCUSSION

This study will demonstrate methods for incorporating a suite of environmental, public health, and building science upgrades together to assess an intervention package aimed at improving key indoor environment variables.

If the dehumidification intervention is shown effective, we will prepare a fact sheet for dissemination to contractors and builders who install ventilation in high performance and Energy Star homes to ensure they are aware of key take-home message of the study. The fact sheet will use an outreach method focusing on critical details in an easy to read format for the building industry. Another target audience for these data is the medical community. If this intervention is successful, our vision is to create a “prescription” that a medical doctor can hand an asthmatic patient with dust mite allergy for house changes in addition to or in lieu of a drug prescription. This house prescription would be in a form so that the patient can know what equipment to buy to control RH in their home, how to have it installed so that it works, how to reduce air infiltration to reduce moisture so that the dehumidifier is affordable to operate, and how to confirm that the equipment is working.

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