Formaldehyde in High Performance Homes with Outdoor Air Intakes

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Translating Research into Healthy Homes Improvements Series

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Study Partners

- HUD Office of Healthy Homes and Lead Hazard Control
- Advanced Energy
- National Institutes of Environmental Health Sciences (NIH)
- UNC School of Medicine Center for Environmental Medicine, Asthma, and Lung Biology
- Habitat for Humanity

Outline

- Why formaldehyde?
- High performance house context
- Study Hypothesis
- Intervention specifications
- Measurement method
- Results
- What does that mean?
- Next steps

Why Measure Formaldehyde in Houses?

- Human carcinogen (probable)
- Short term effects
  - > respiratory irritation
  - > eye irritation
- Suggestive evidence of links to respiratory symptoms
- Multiple indoor sources

Formaldehyde Sources Indoors

- Building and Consumer Products
  - > Pressed wood products (urea-formaldehyde resins)
  - > Urea-formaldehyde foam insulation
  - > Fabric finishes
  - > Paper products
  - > Cosmetics
  - > Detergents
  - > More
- Combustion (heaters or furnaces)
- Secondary reactions
  - > Terpenes interact with ozone to produce formaldehyde and other byproducts
- People

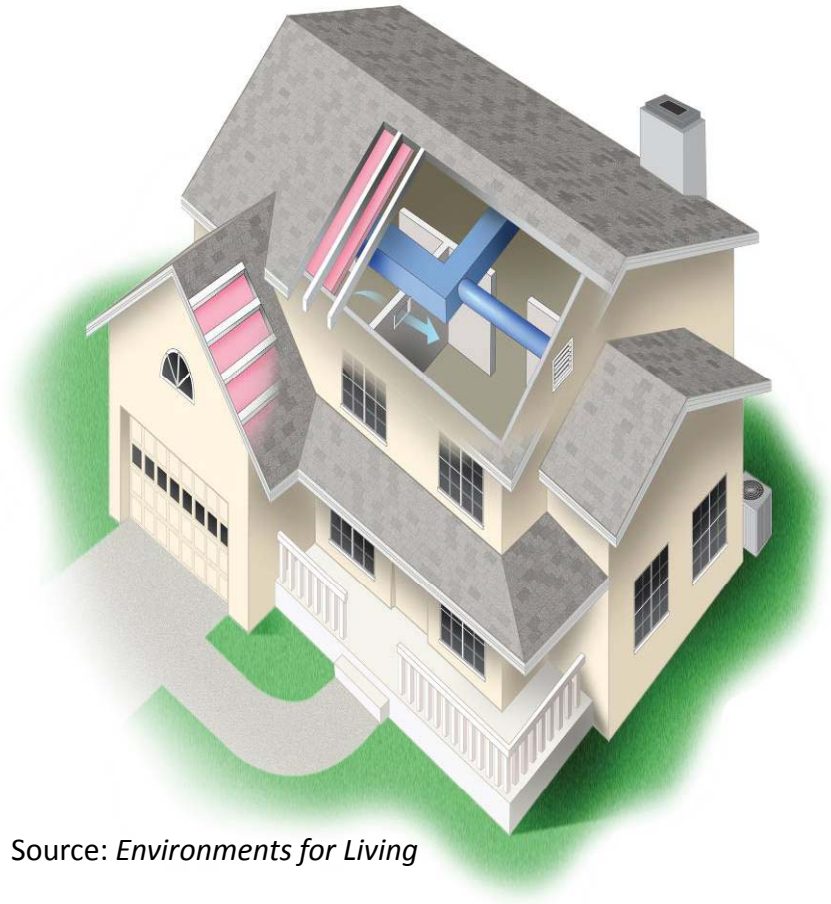
Study Hypothesis

- A high performance home specification can improve the indoor environment related to asthma-relevant outcomes, overcoming homeowner behaviors.
- High performance (in the real world)
  - > Specifications
  - > Construction processes
  - > Quality assurance testing
  - > Feedback loop (comfort & energy guarantee)
  - > Reality, not just modeled performance
- Don't rely on homeowner behaviors

Methods - Study Design

- 36 homes in central North Carolina (mixed humid climate)
- 20 intervention ("healthy homes intervention package")
  - > High performance builder process
- 16 non-intervention homes
  - > Building-code compliant construction
  - > Typical construction

Features of the Intervention



Source: *Environments for Living*

- Tight construction
- Interior moisture management
- Improved insulation
- "Right-sized" HVAC
- Pressure balancing
- Outside air ventilation
- Closed crawl space

Reality-Ready Research

- No source control specified (formaldehyde or other volatile organic compounds).
- Builders used their typical carpets and cabinetry
- Study participants not asked change behaviors

The Ventilation Package

- Goal is to provide outside air to dilute pollutants generated indoors
- Offset the reduced infiltration through the envelope and ducts when house is tightened
- Used in 2 successful high performance homes programs

Exhaust Ventilation

- Spot exhaust
- Performance tested
  - > Kitchen (exhausts >100 cfm)
  - > Baths (exhausts >50 cfm)

Dilution

- Outdoor air intake with Air Cycler
- 20 minutes per hour
- Flow
  - > 10 cubic feet per minute (CFM) in each bedroom plus 10 CFM.
  - > A 3 bedroom house → 40 CFM
  - > Equivalent to ASHRAE 62.2 on intermittent basis

Outdoor Air Intake Configuration

- Six-inch flex duct
- Vent at the foundation connected to return air plenum
- Six-inch manual balancing damper in flex duct near outside intake
- Damper performance tested
- Cleanable filter installed at intake

Home Characteristics

	Intervention	Non-intervention	% Difference (I from N)
Duct leakage	34 (3.0%)[1]	122 (10.4%)[1]	72% tighter
Home leakage	862 (0.25)[2]	1142 (0.31)[2]	25% tighter
Floor area	1143 ft^2	1192 ft^2	4% smaller
Envelope area	3466 ft^2	3619 ft^2	4% smaller

[1] Percentage represents CFM25 duct leakage per square foot floor area.
6% to outdoors is the Energy Star Program standard

[2] Number in parentheses represents CFM50 home leakage per square foot envelope area

Exhaust

	Intervention	Non-Intervention	% Difference (I from N)
Kitchen exhaust	106 cfm	0	n/a
Bath 1 exhaust	58 cfm	38 cfm	53% higher
Bath 2 exhaust	56 cfm	37 cfm	52% higher

Is the Ventilation Reducing Chemical Pollutants?

- Seven-day formaldehyde sample
- 40-day period beginning August 2005 (all humid season)
- Length of time to offgas varied
  - > Median age of the intervention homes was 10 months (minimum 5 months)
  - > Median age of non-intervention homes was 20 months

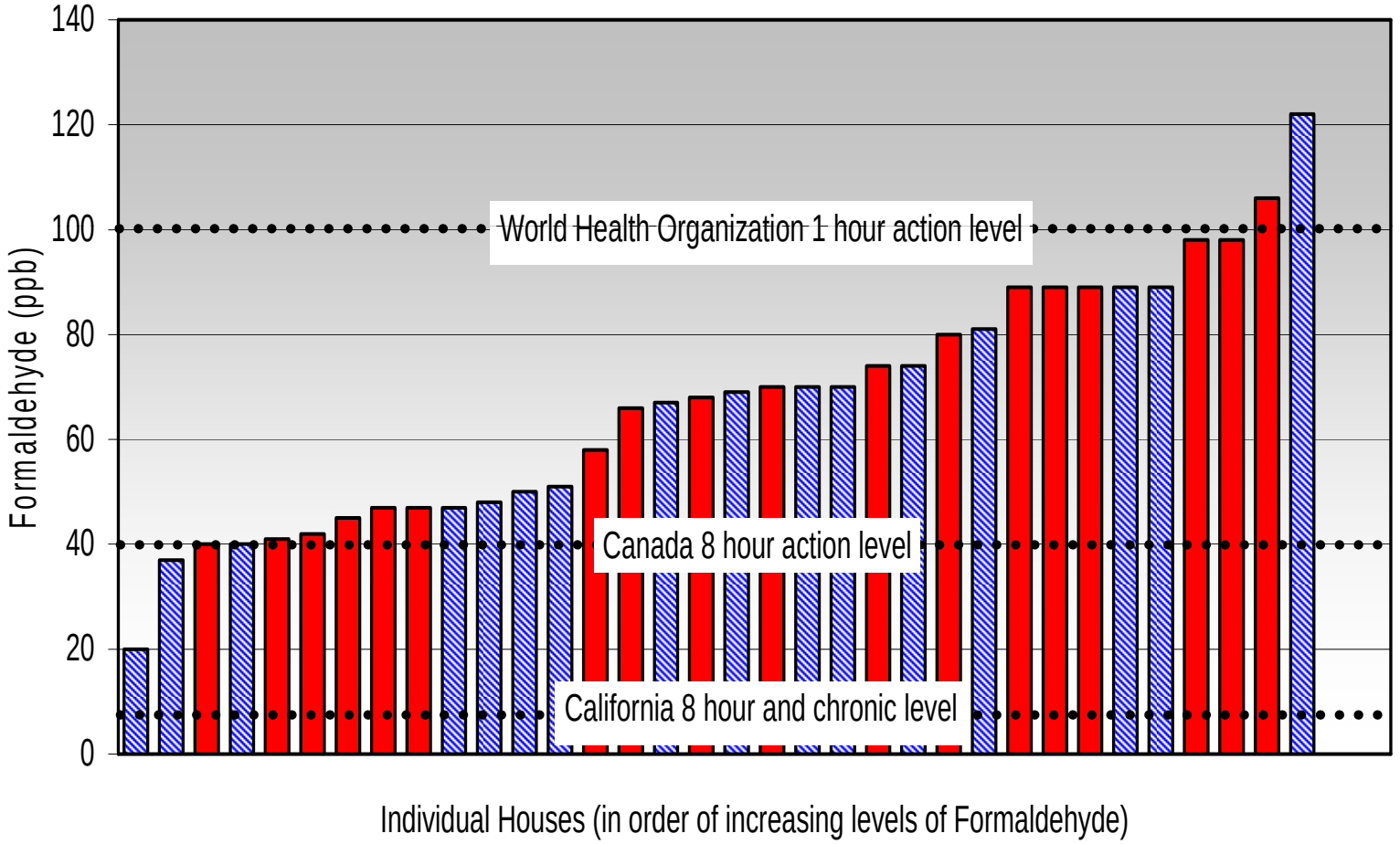
Average Formaldehyde Levels

Status	Weight [ppb]	St Dev [ppb]
Intervention	69	22
Non-Intervention	64	25
All	67	25

Available Guidelines

- 100 ppb action level (Health Canada and the World Health Organization)
- 40 ppb eight-hour average (Health Canada)
- 7 ppb eight-hour and chronic Reference Exposure Level (California)

Home by Home



Summary

- The high performance program didn't harm the homeowners
  - > Tight envelope and tight ductwork did not create higher levels of formaldehyde …
  - > Compared to homes with unplanned ventilation (duct and envelope leakage).
  - > Ventilation package seems to have compensated for reducing the infiltration & leakage
- But formaldehyde levels are still above guidance standards
  - > At 10 months after move-in for intervention homes
  - > At 20 months after move-in for non-intervention homes

What Can We Do to Reduce Formaldehyde *(and the rest of the chemicals in the soup)?*

- Continuous ventilation may be “enough” outdoor air to dilute formaldehyde
- How do we get “continuous” without moisture overload?
  - ERV
  - Ventilating dehumidifier
  - Other?
- Considerations:
  - > Tradeoff between moisture and dilution
  - > How much moisture is introduced?
  - > Energy penalty?
  - > Initial and operational costs?

Source Control

- Formaldehyde in wood products may drop
  - > California regulations
  - > EPA intends to regulate
- Formaldehyde in other products?
- Other VOCs in building materials and consumer products…

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- Following are additional slides with supplementary information that will be discussed further in final report and articles

Hypothesis Testing

- Is the ventilation sufficient to:
  - > Do no harm?
  - > Create BETTER indoor air quality than in houses with leaky shells and ducts?

Field Research in Occupied Houses

- Challenges
  - > Scheduling large sample of homes – weekend/evenings
  - > Ensuring pickup in acceptable time window
  - > Ensuring samples labeled accurately and observational data collected accurately in often-chaotic environment

Snapshot of Ventilation Rates (Air Changes Per Hour) *excluding* impact of air cycler and ventilation fans

Group	Average ACH at 50 Pa (measured)	Average ACH Natural (calculated)
Intervention	5.7	0.3
Non-Intervention	7.2	0.4

Sampling Method

- UMEx 100 Passive Samplers (3M)
- Level of detection of 0.03 ug (2 ppb)

Formaldehyde Sampling

- Deployed in the central hall of the homes

- Transported on ice, stored in refrigerator

7 Steps to high-performance housing

- Standards
- Plan Review
- Contractor/Subcontractor training
- On-site quality control
- Performance testing
- Certification/Guarantee
- Servicing the Guarantee

TOTAL INTERVENTION COST*		
Upgrade	Study cost per house [2003] Materials & installation	Market cost per house [2007] Materials & installation
SystemVision	$1,725 per house	$1,920 - $2,100 per house
SystemVision fee	$1,050	$1,050
Closed crawl space	~$2.50 per square foot [$3,00 for 1200 square foot house]	$1.00 - $2.50 per square foot [$1,200 for 1200 square foot house]
Aprilaire	$170 [Spaceguard filter & frame] $200-$800 [installation]	Same
Total per house	$6,145	$4,540

*Based on 1200 square foot house at lowest estimate



SYSTEMVISION UPGRADE ESTIMATES*			
Standard	Upgrade	Study estimate per home [2003]	Market estimate per home [2007]
1	Proper blocking and building air tightness	$75	$100
2	Whole-house mechanical ventilation	$200	$100
	Bath and kitchen exhaust upgrades	$300	$300
3	Proper insulation installation	$300	$150
	Attic insulation increase to R-38		$100
	Raised heel trusses	$250	$250
	Low-E windows	$150	$150
4	Outdoor thermostat[s] on heat pump[s]	$100	
	14 SEER heat pump		$600
	90% Efficient furnace with 13 SEER air conditioner		$400
	Proper duct sealing	$100	$100
5	Pressure balance and relief	$150	$150
6	Electric or gas water heater efficiency upgrade	$100	$100
7	Carbon Monoxide detector if applicable		$20
Total	Electric package total [per home]	$1,725	$2,100
	Gas package total [per home]	$1,725	$1,920

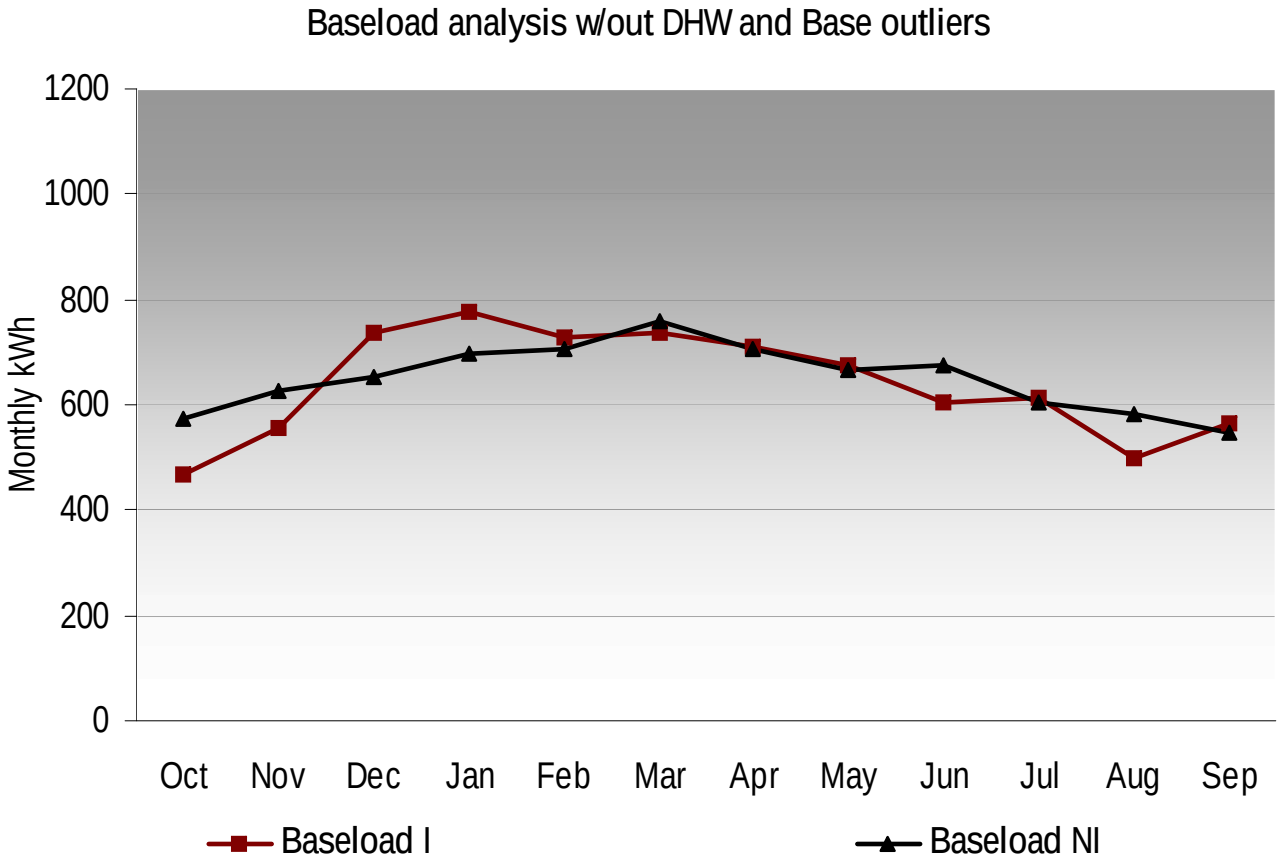


Number of homes submetered

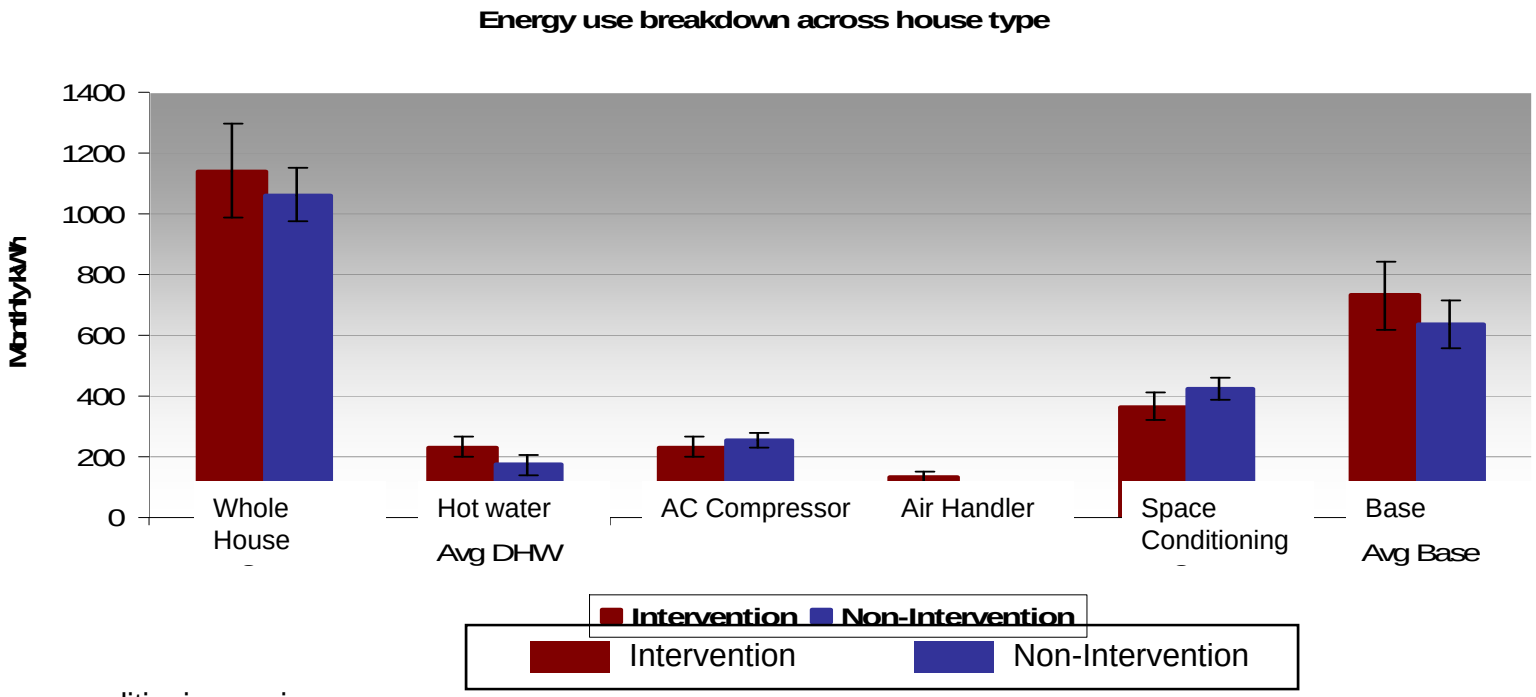
ENERGY PERFORMANCE MEASUREMENT		
House Type	Number in Group	Number Submetered
Non-Intervention w/ Retrofit	7	7
Non-Intervention	7	7*
Intervention	16	8

* Submetered later in the study





Results – energy use

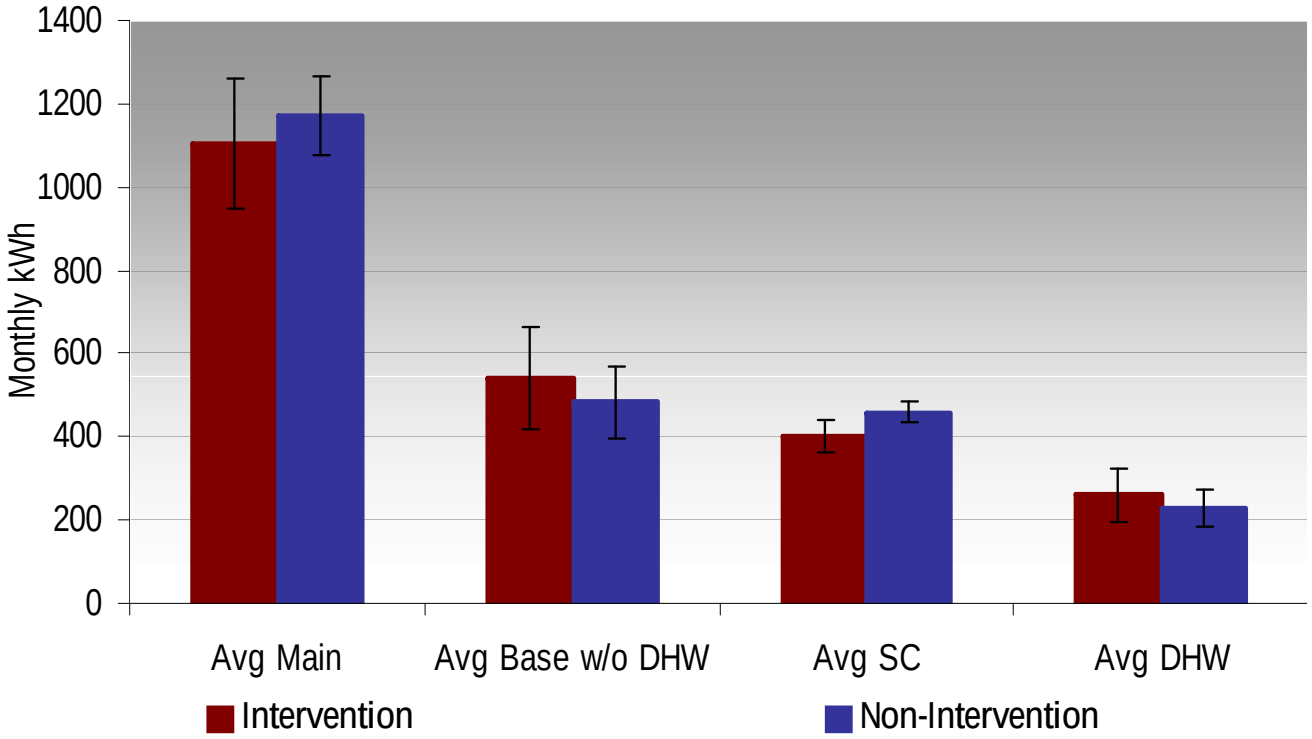


Space conditioning saving

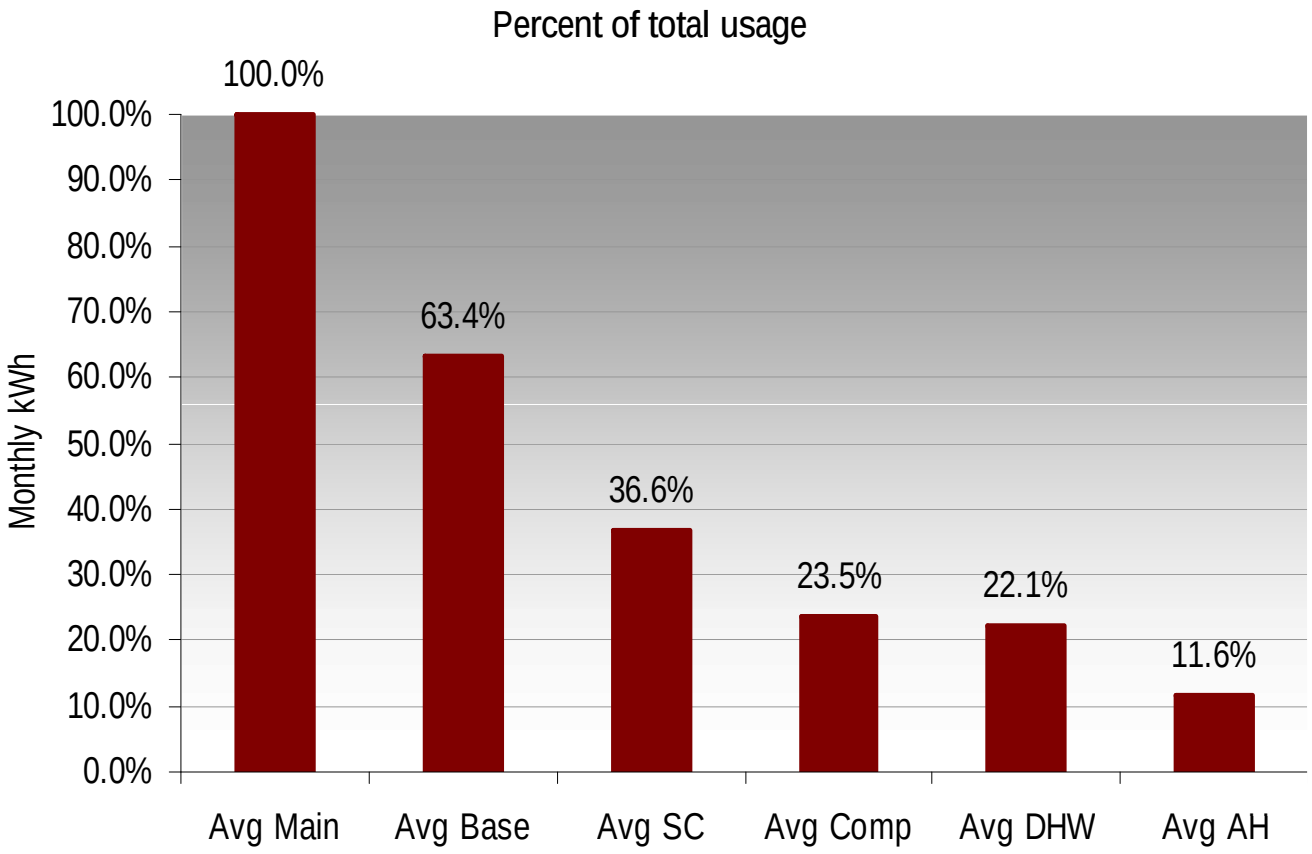
- 13.7% total (~5.8% of total energy savings)
- 3.6% June – August/ 0.8% July – September

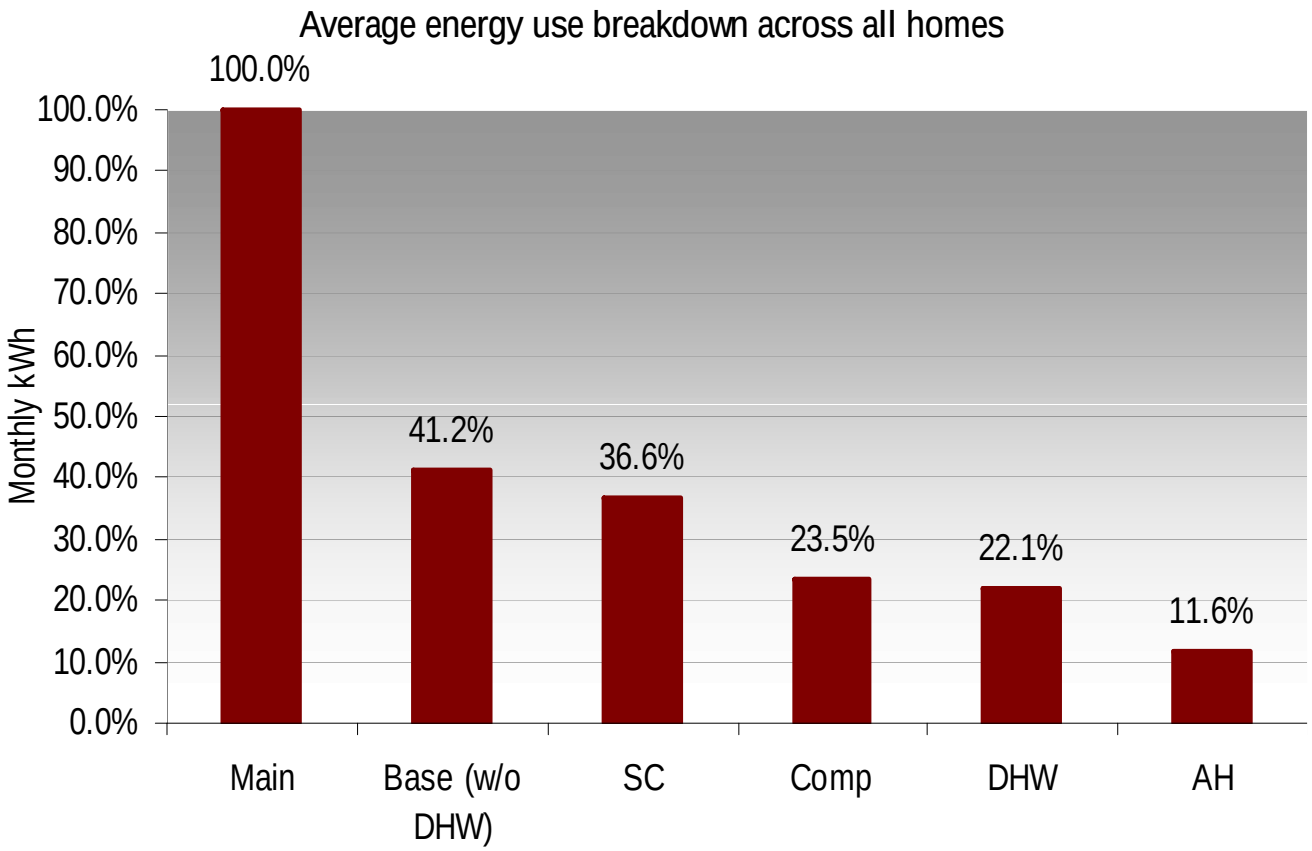
- Intervention homes use more energy in every other category (non-space conditioning)

Energy use breakdown across house type w/out outliers



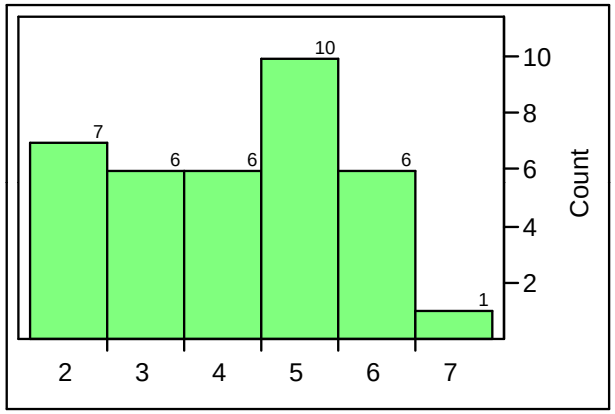
2006-2007 Space conditioning – intervention houses use 13.7% less energy




Average energy use breakdown across all homes
Monthly kWh
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
100.0%
41.2%
36.6%
23.5%
22.1%
11.6%
Main
Base (w/o DHW)
SC
Comp
DHW
AH

Number of people per house

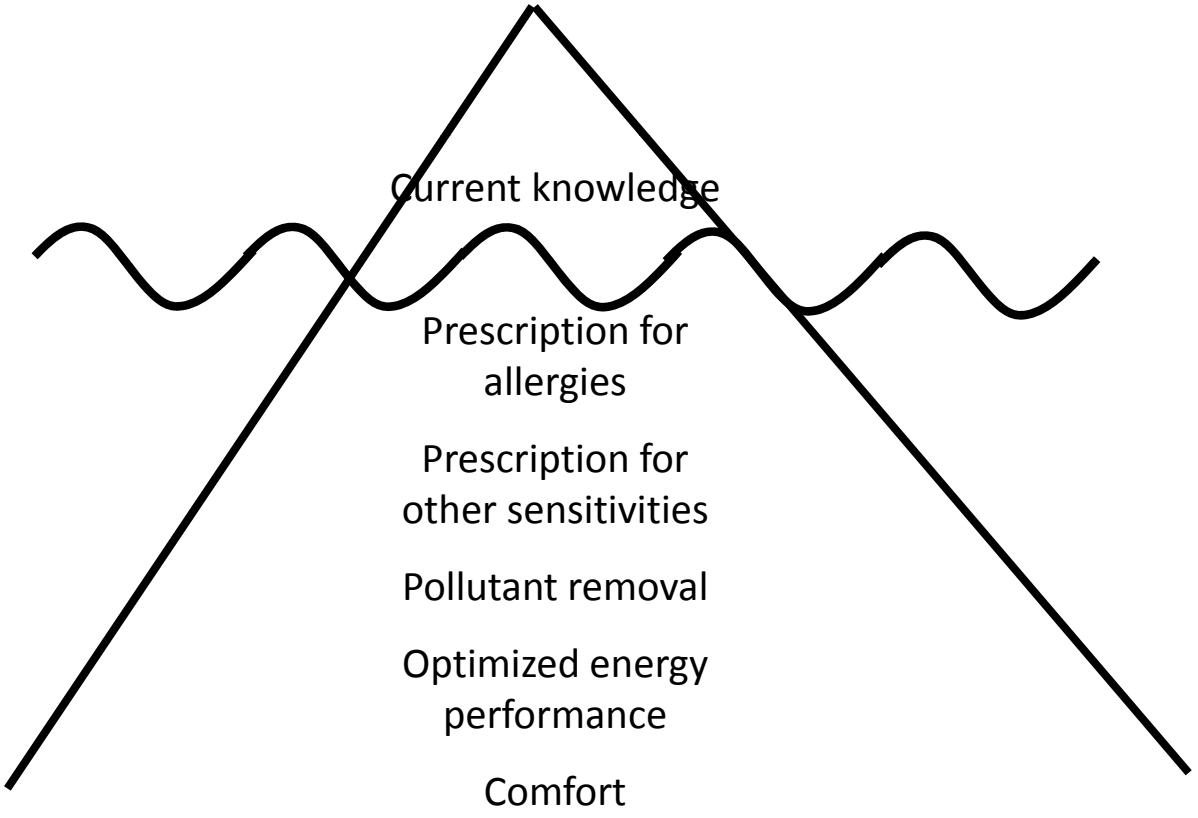
- National household size of 2.57 people
- 2.49 for NC
  - > 2.51 for Wake Co.
    - 2.30 for Raleigh
  - > 2.40 for Durham Co.
    - 2.37 for Durham
- 4.14 for this study



Level	Count	Prob
2	7	0.19444
3	6	0.16667
4	6	0.16667
5	10	0.27778
6	6	0.16667
7	1	0.02778
Total	36	1.00000



Health and Energy Performance – The Tip of the Iceberg



Phase 2 -- Ventilation

- Comparison of houses is more “apples to apples”
  - > Measure tight houses with and without outdoor air (no air cyclers)
  - > Measure tight houses with air cyclers
  - > Measure leakier houses without air cyclers
  - > Older houses – longer to offgas

Next Steps

- Change Intervention Configuration
  - > Mechanical dehumidification (<50% RH)
  - > More affordable closed crawl configuration
- Measure More Precisely
  - > Pollutants
  - > Air changes per hour
  - > Does filtration change anything?