Thermal and Moisture Performance of Buried Ducts

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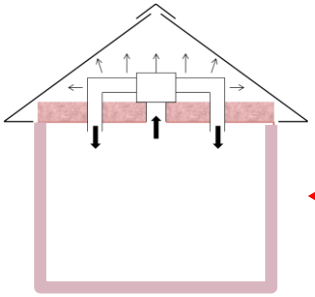
Buildings XIII Conference, Dec X 2016

Outline

- Background for the study
- Buried ducts in building codes
- Approach
- Results
- Discussion and conclusions

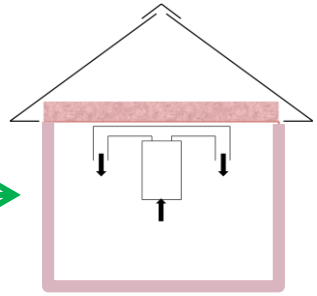
High Performance Attic & Duct Solutions



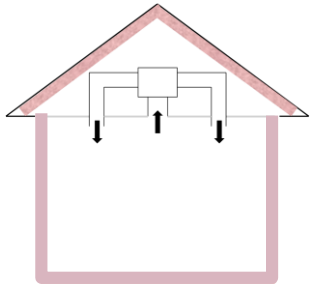
← **CURRENT PRACTICE**

Ducts in Vented Attic

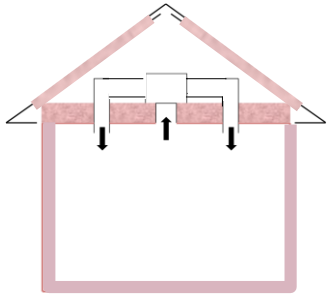
HIGH PERFORMANCE ATTICS & DUCTS →



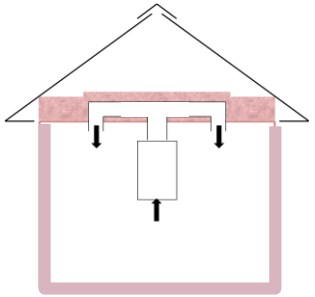
Ducts in Conditioned Space



Unvented Attic

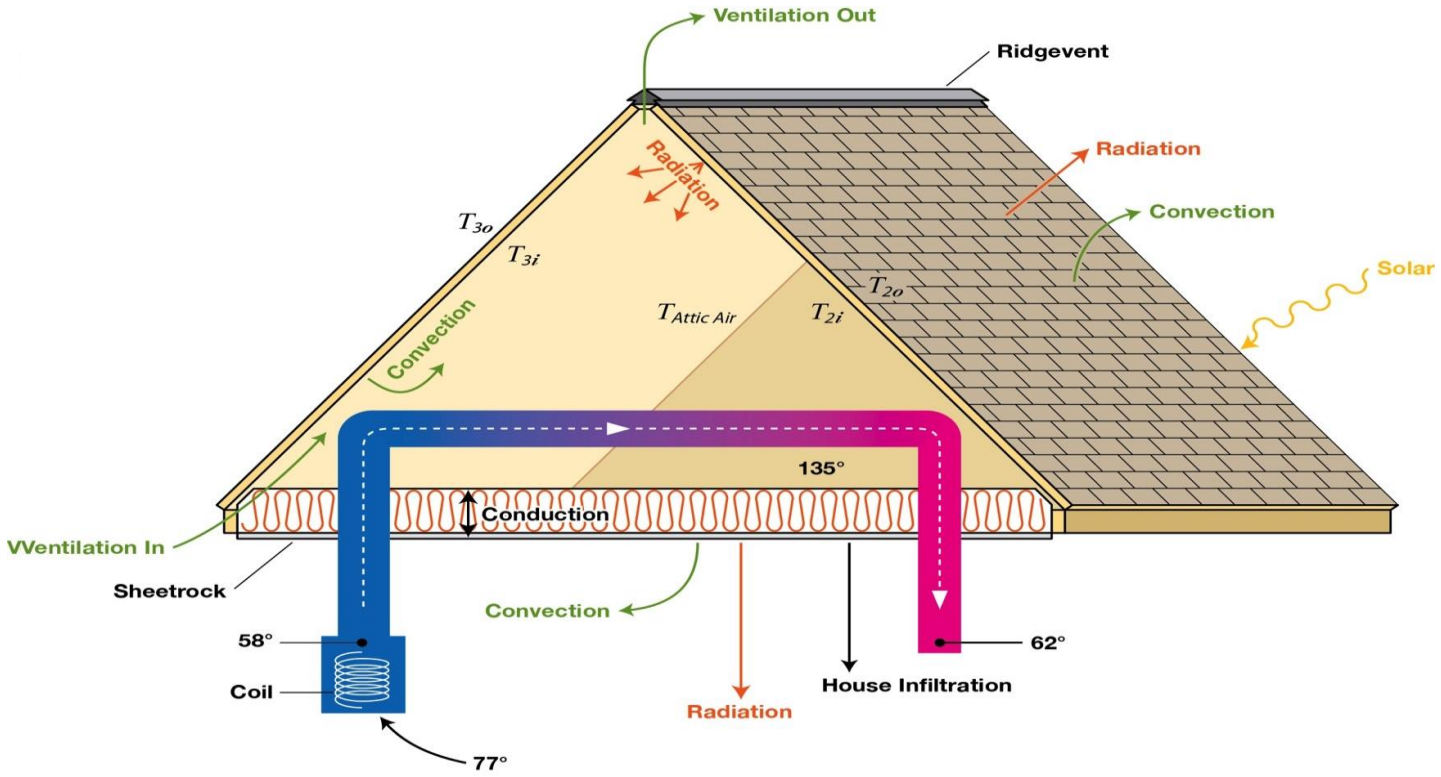


Hybrid Attic



Buried Ducts

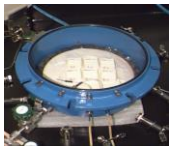
Energy & Moisture Physics



Bill Miller, ORNL

Building Science (System Approach)

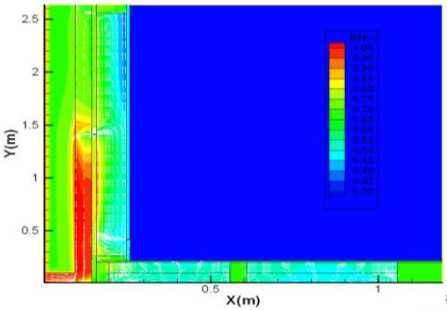
Three critical competencies

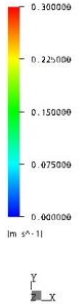






Lab ↔ Modeling ↔ Field



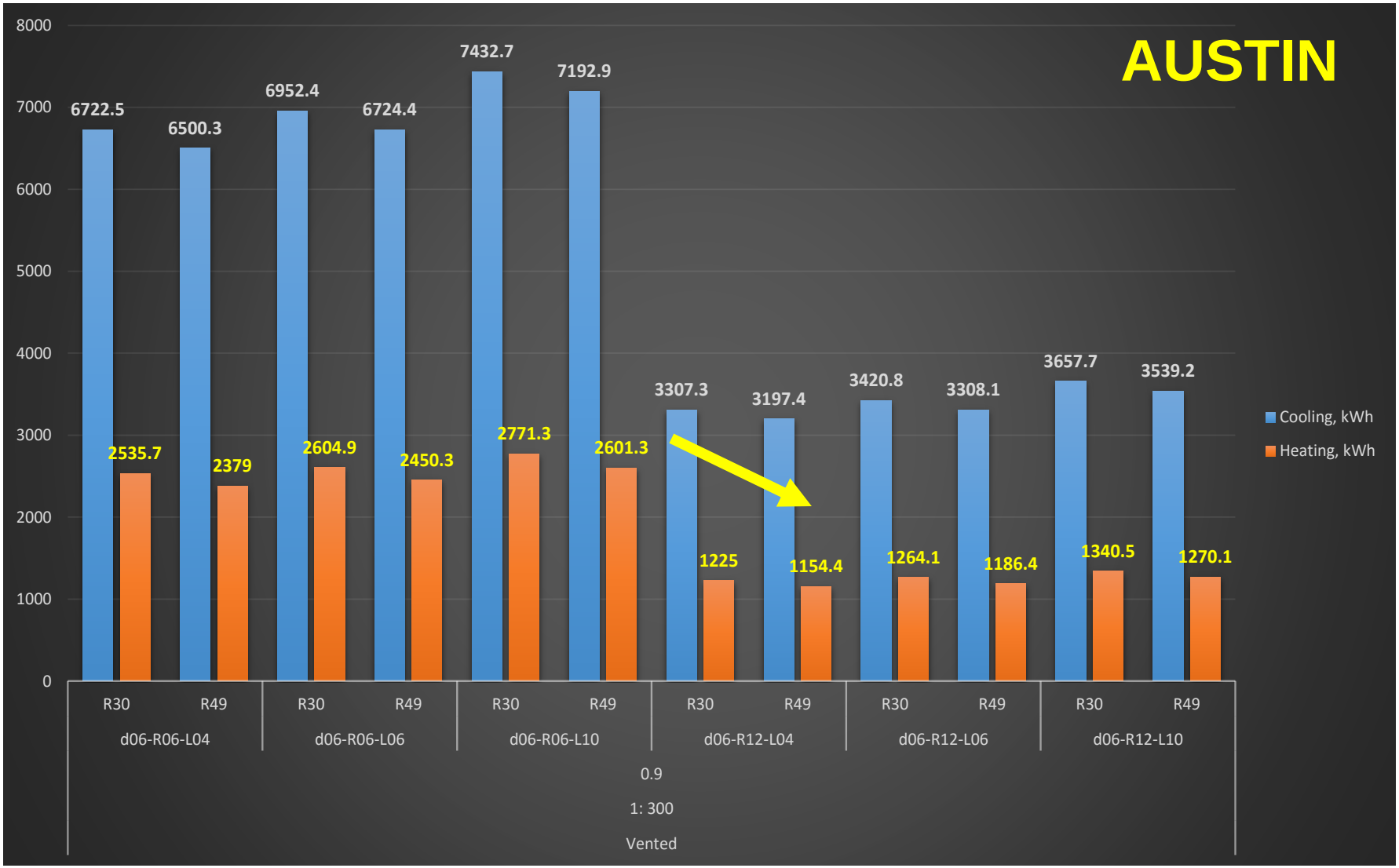






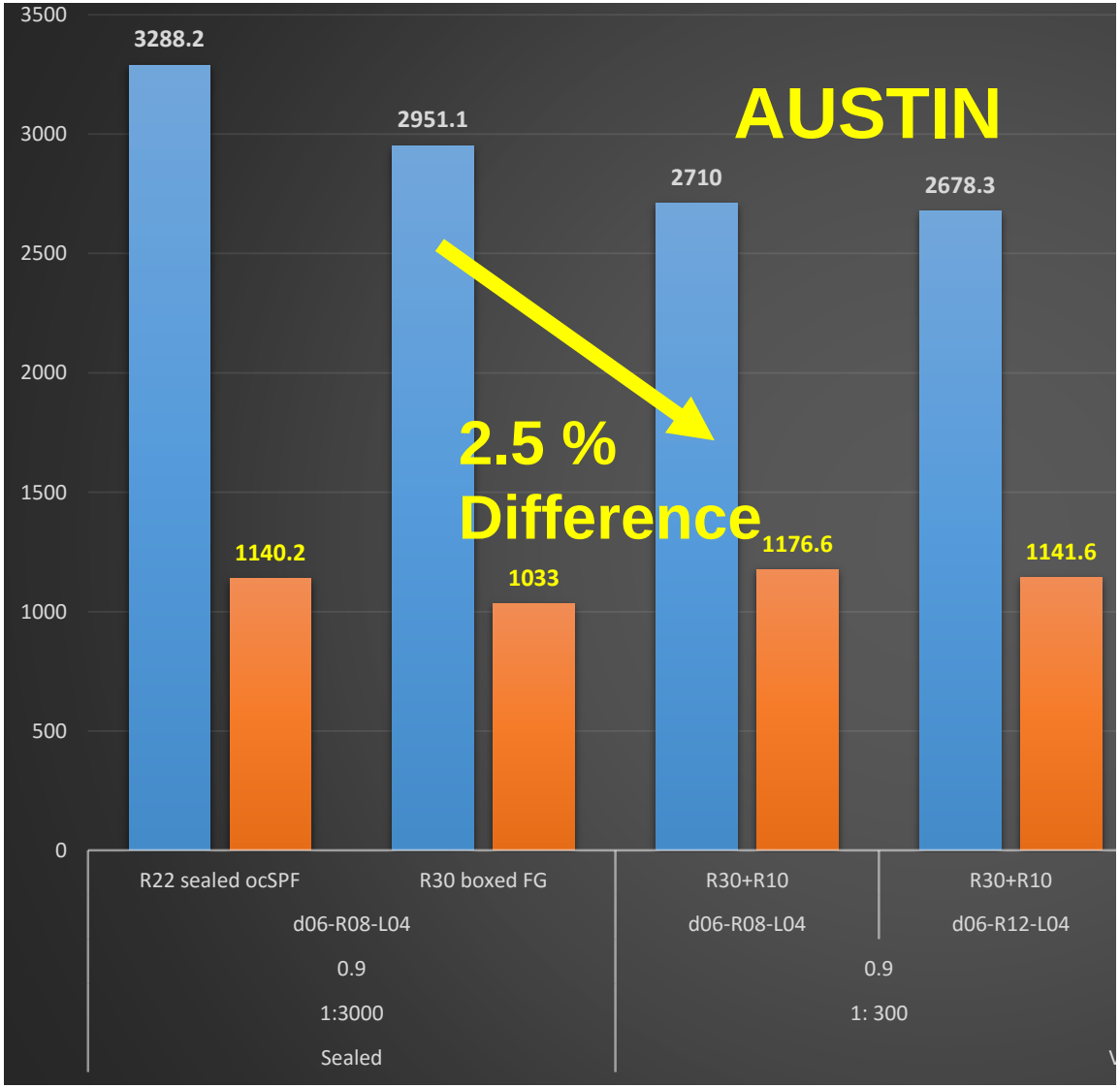
Effect of Duct Insulation !!!

Effect of Attic Insulation Level!!!



Effect of Attic Type (Vented vs Unvented)

Effect of Attic Type (Unvented vs Hybrid)



Background

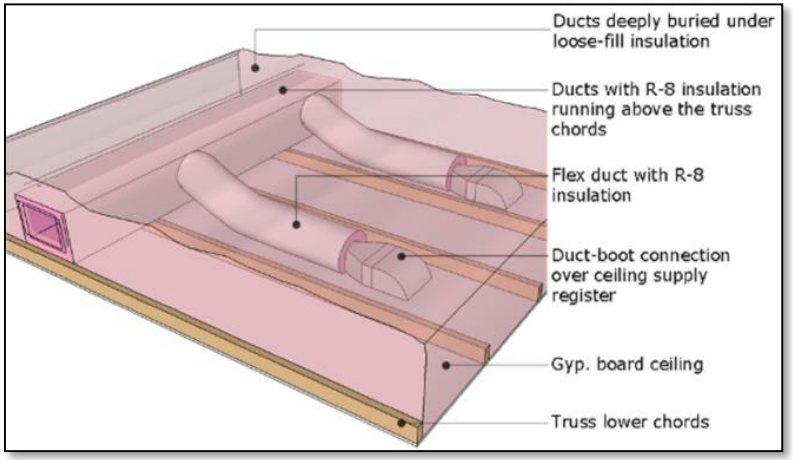
- Ducts in vented attics are penalized by the cold winters and hot summers
  - The energy codes are pushing the idea to bring the ducts into conditioned space
  - Burying the ducts inside the attic insulation in the ceiling would effectively increase the R-value of the duct towards the attic
- The blown-in insulation in the attic is vapor permeable which may cause a condensation risk
  - The condensation risk has been largely not well-known despite of previous studies

Literature on buried ducts previously states encapsulation in moist/humid climates

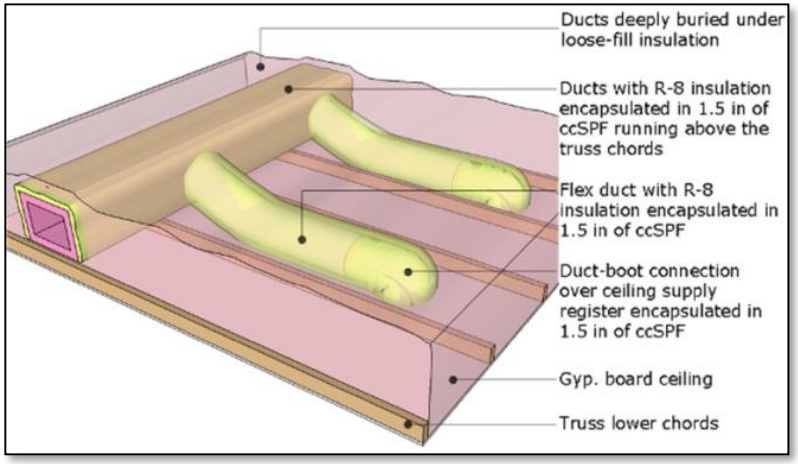
DOE Zero Energy exception to ducts in conditioned space (Apr '14)

In moist and marine climates minimum of R-8 duct insulation with min. 1.5" of closed-cell spray foam encapsulating the ducts

U.S. Dept. of Energy Building America Measure Guideline (Aug '13)



Buried Ducts (dry climate)

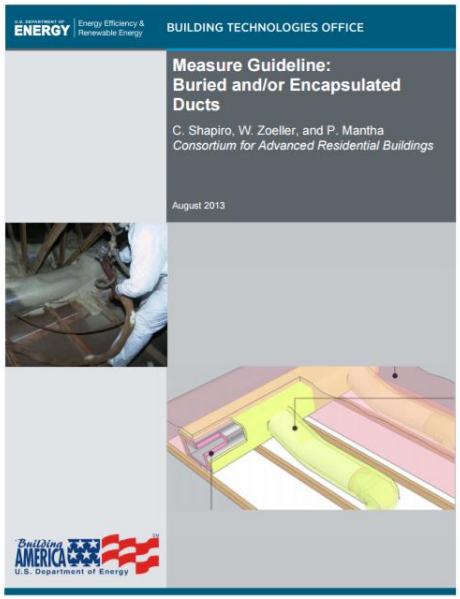


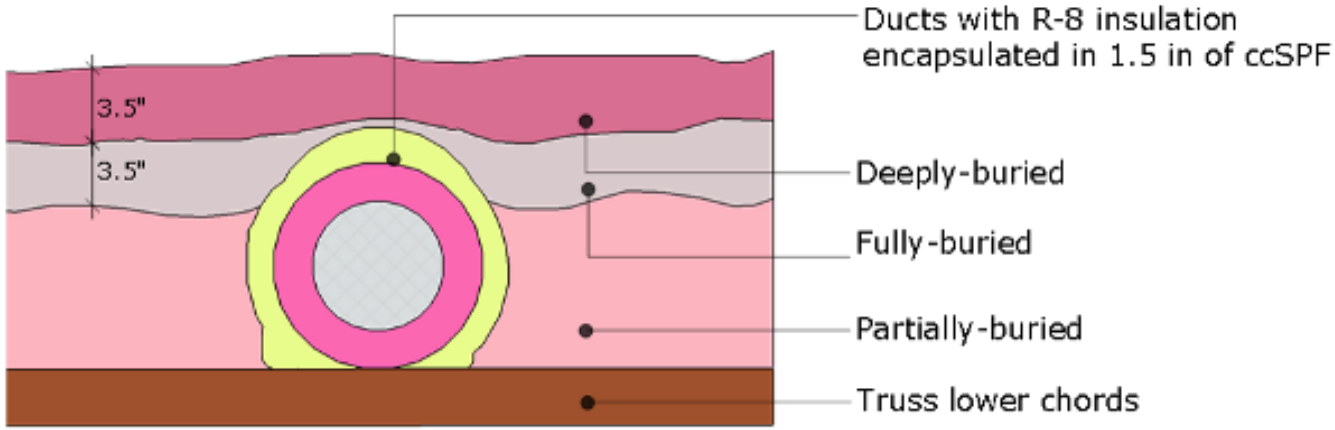
Buried and Encapsulated Ducts (humid climate)

Determine if ducts can be strictly buried in humid climates without condensation concerns

DOE Zero Energy Ready Home National Program Requirements (Rev. 04) April 21, 2014.
Chapiro, C.; Zoeller, W.; and Mantha, P. (2013). Measure Guideline: Buried and/or Encapsulated Ducts. Golden, CO: National Renewable Energy Laboratory.

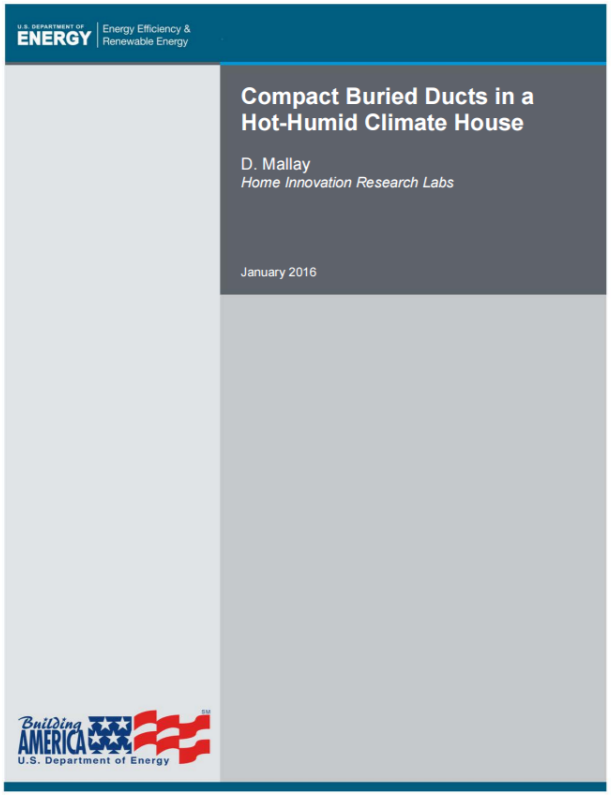
Previous Work (Building America-Steven Winters)





Duct configuration	R-4.2 ducts	R-6 ducts	R-8 ducts
Encapsulated (1.5 in.) and partially-buried beneath fiberglass	18.4	19.7	21.0
Encapsulated (1.5 in.) and fully-buried beneath fiberglass	22.6	23.8	25.0
Encapsulated (1.5 in.) and deeply-buried beneath fiberglass	29.6	30.3	31.1

Previous (Building America-HIRL D. Mallay)



Develop design criteria for buried ducts that use common materials and do not rely on encapsulation using spray foam or disrupt traditional work sequences.

- The monitored data from the South Carolina test house indicates that R-8 duct insulation appears to be sufficient to prevent condensation.

- Regarding energy loss, the leakage rate of 1-2 CFM/100SFcfa for the attic ducts was selected as a reasonable and achievable target.

- The buried ducts delivered colder air during cooling than the attic ducts that were not buried (on average nearly 7°F colder). The lower delivery temperature results in increased energy savings and improved occupant comfort.

- Simulations predicted 21% annual heating/cooling site energy savings compared to conventional insulated attic ducts. The compact duct component contributed approximately 13% of this energy savings, and the buried duct component contributed approximately 8%

Is Encapsulation Needed?

- Previous studies by others resulted in a requirement to seal the ducts with 1.5” of closed cell spray foam insulation in addition to the existing duct insulation
- Consider that existing homes already have short “buried” duct section where the duct connects to the duct boot to supply air through ceiling
  - No condensation issues
- The existing requirements for buried ducts have likely been overly cautious

Approach (Three Prong Approach)

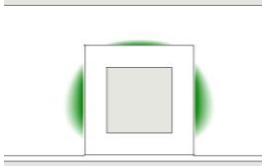
- Hygrothermal **modeling** of buried ducts exposed to constant and varying climatic conditions (**DYNAMICS**)
- Small-scale **laboratory** study
- **Field** testing

Modeling

Thermal and moisture analysis for condensation

- Relative humidity
- Vapor pressure
- Temperature
- Dew point
- Square vs round ducts

- OH climate (5A)
- SC climate (3A)



Lab-Scale

Lab-scale buried duct mimic evaluating %RH and condensation

- Duct type
- Duct R-value
- Loosefill R-value
- "Attic" temperature and % RH
- Duct temperature

Field Evaluation

Monitoring residential buried duct installations for condensation

- OC – monitoring buried ducts in Cleveland, OH model home

- Plus: HIRL – monitoring compact buried ducts in Lady's Island, SC.

Simulation Results

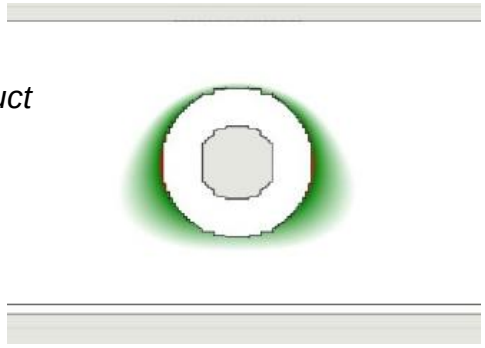
Buried Ducts in Hot and Humid Attic

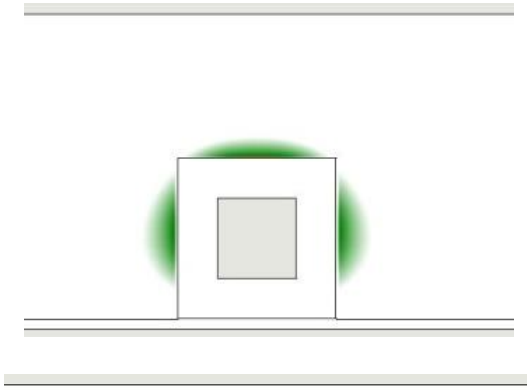
2-D Hygrothermal Model

- Attic = 130°F, 30%RH (90°F dew point)
- Duct = 55°F
- Held constant for 1 week.

- Round and square have different effective R-values vs Nominal R-value
- Location where duct may condense is typically mid-depth of blown insulation or above duct where vapor drive is coming from.

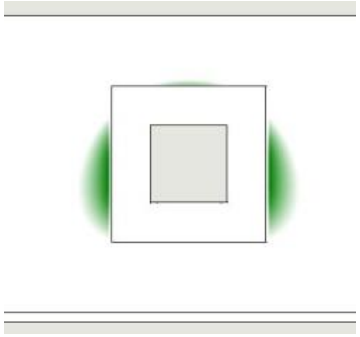
4” R-8 round duct

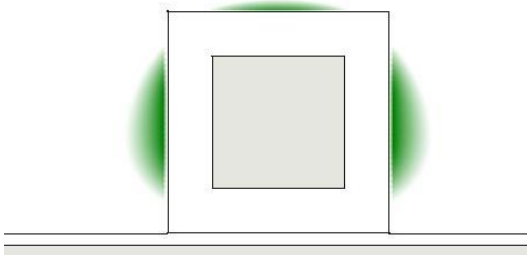




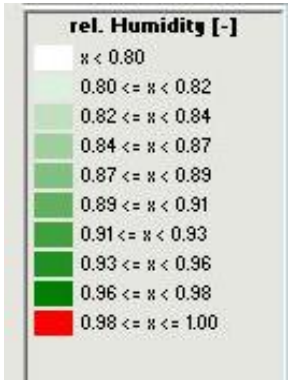
4” R-8 square duct, deeply buried

4” R-8 square duct





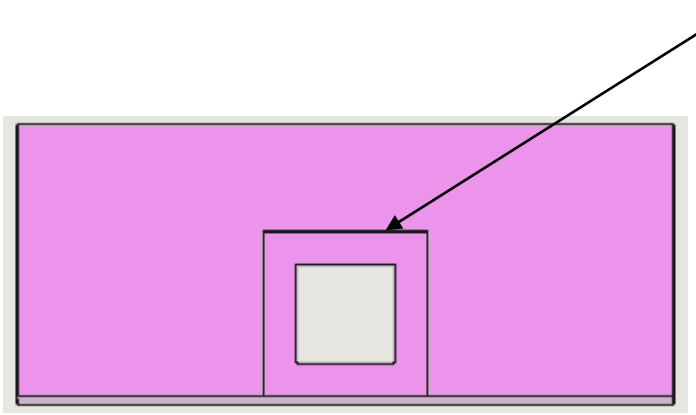
8” R-8 square duct, deeply buried



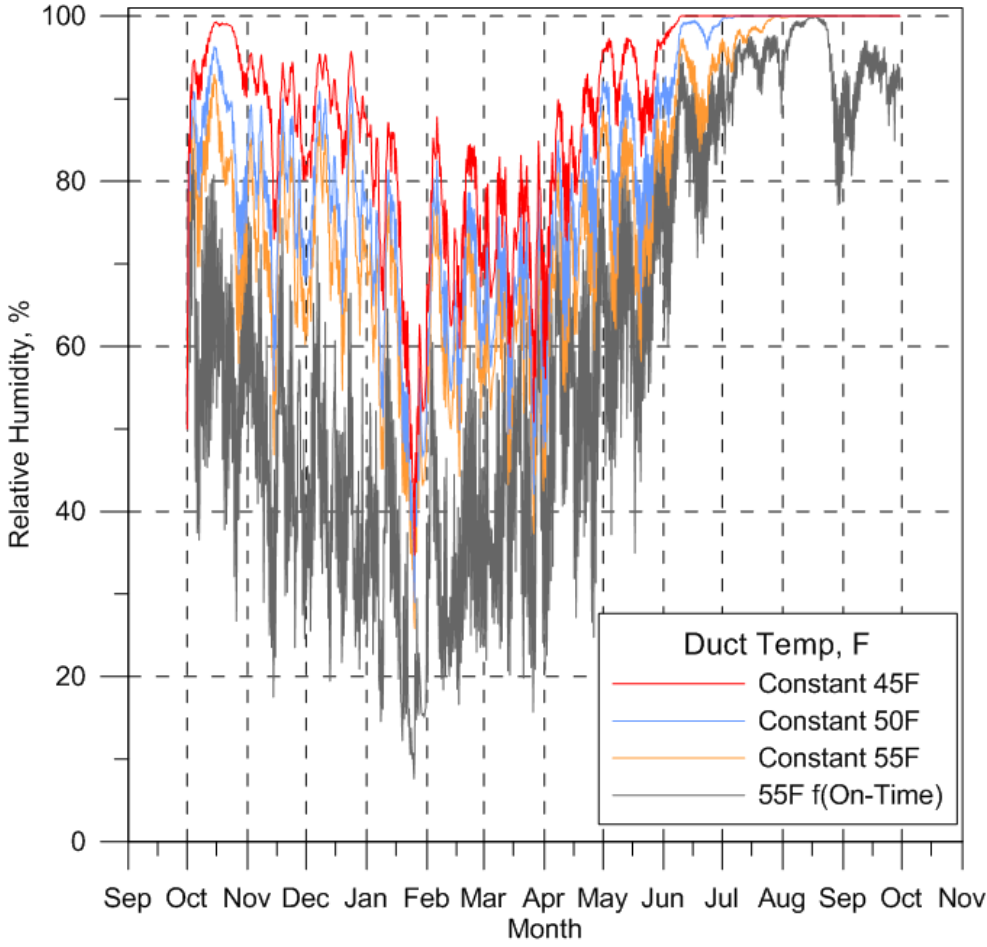
Simulations in Climatic Conditions

Full year simulation for Charleston, SC

- Constant duct temp. (45F, 50F, 55F)
- On-Off schedule (55F on-time)



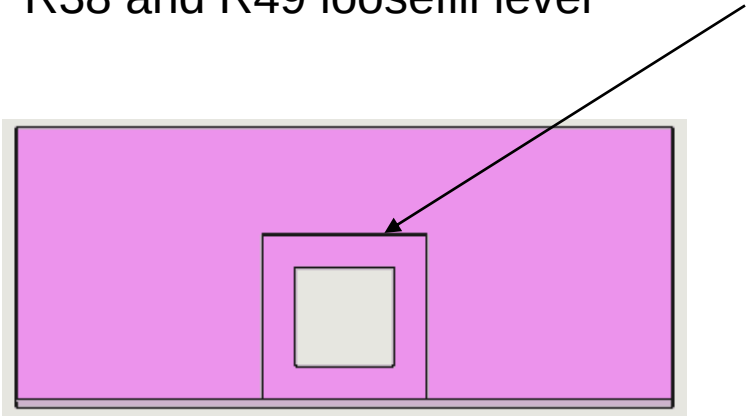
- Mid-summer is not necessarily the most severe time of the year for condensation.
- Early fall may be most severe time.

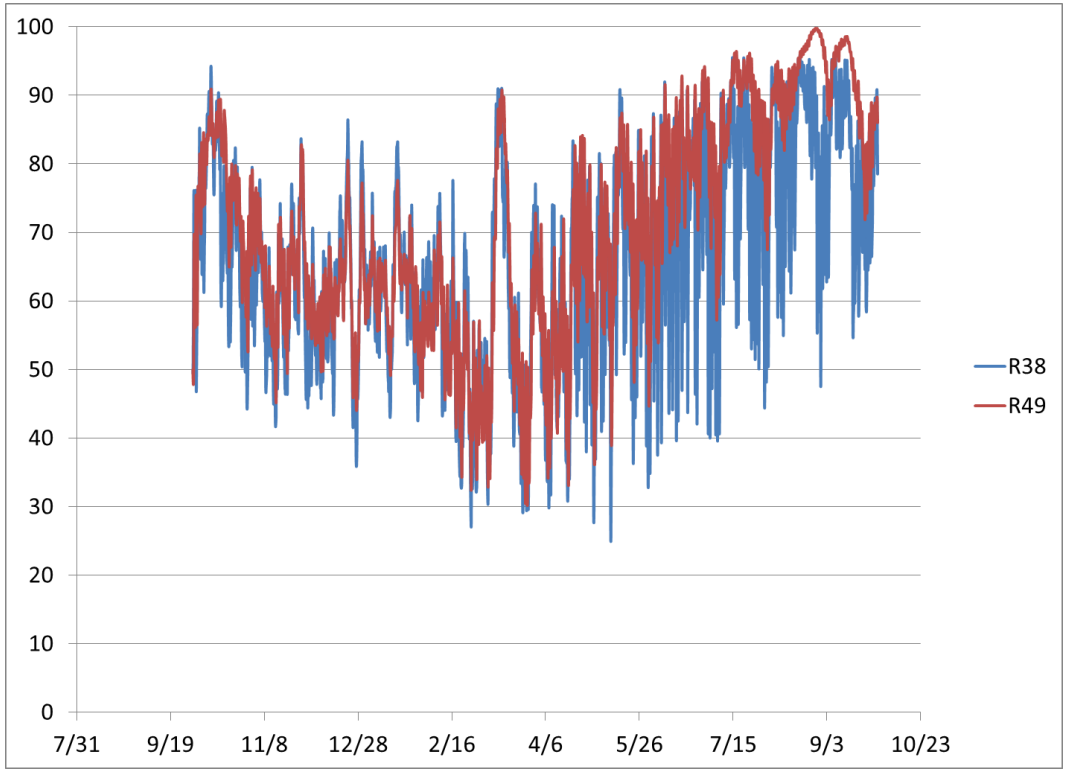


Simulations in Climatic Conditions

Full year simulation for Cleveland, OH

- Simulated attic conditions
- Constant duct temp. (55F)
- R38 and R49 loosefill level





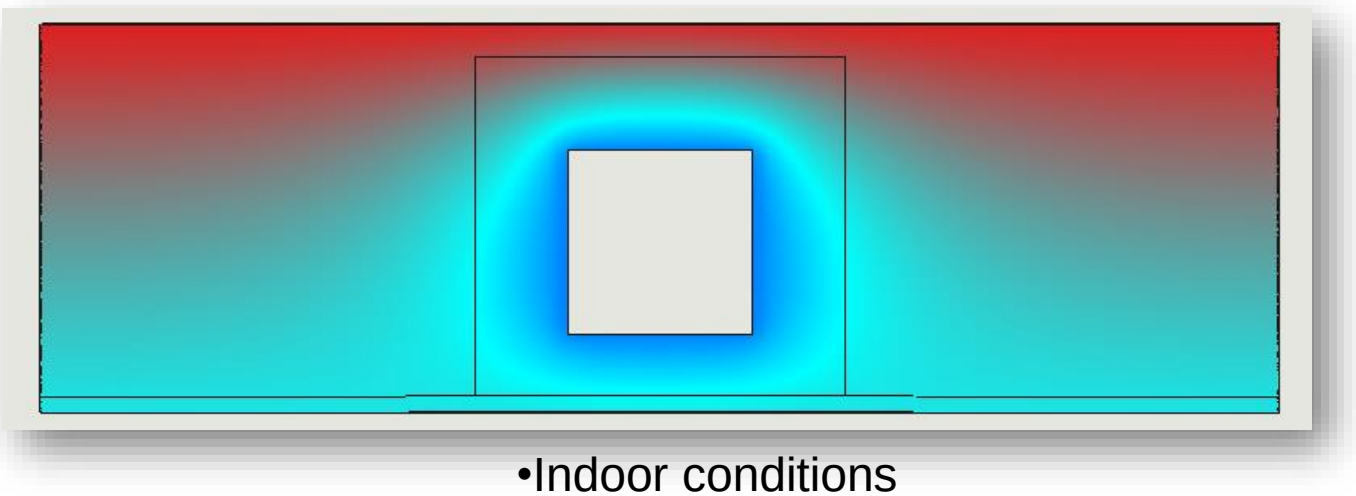
- End of August is when highest %RH occurs on top of the duct.

Duct Buried in Insulation

Duct Condensation Analysis – Charleston SC
R8 vs R12 (6” square duct)

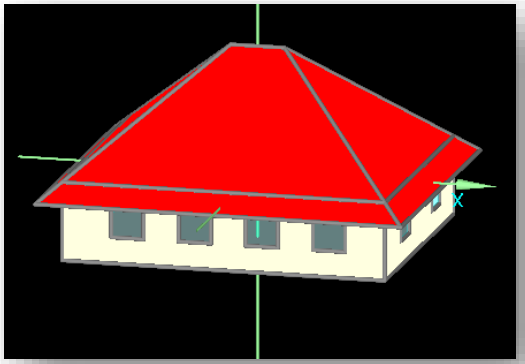
- 12” Loose Fill
- R8 all around vs. R8 bottom+R12 on sides and top

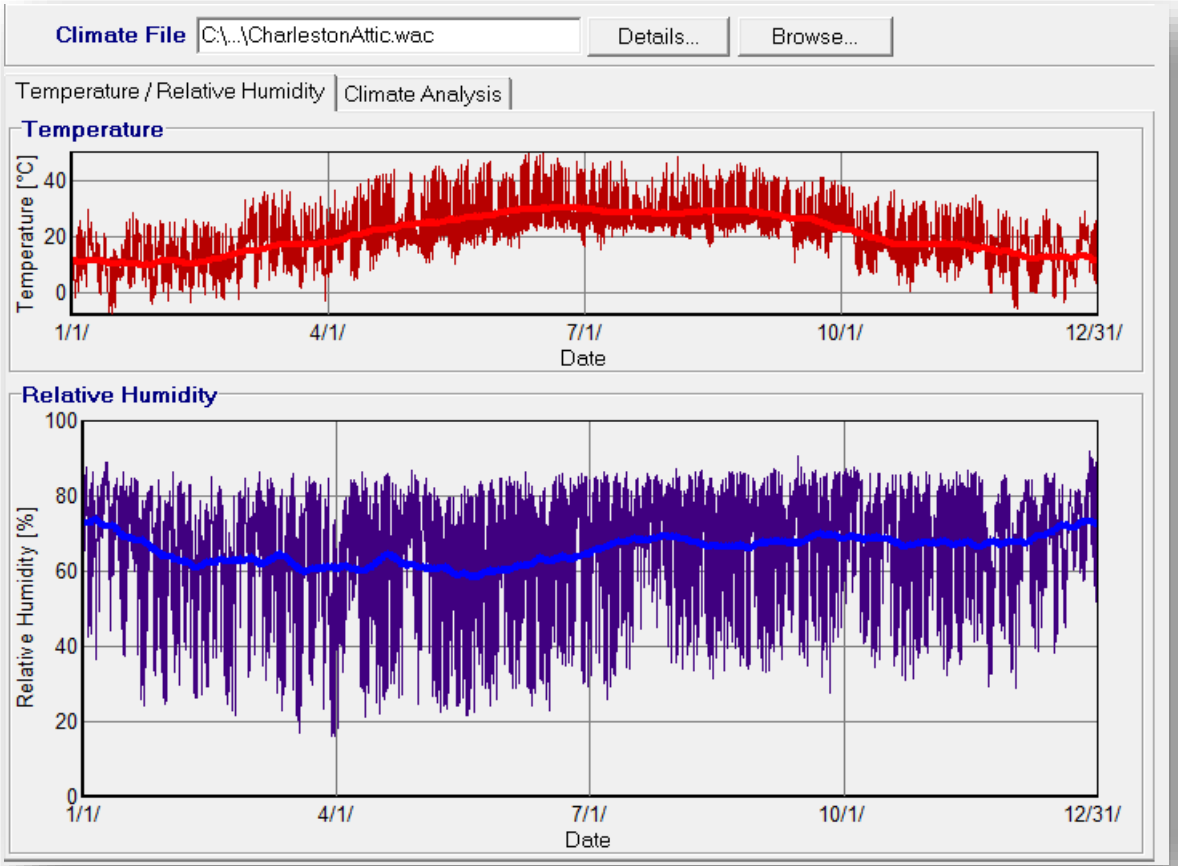
•Attic conditions



•Indoor conditions

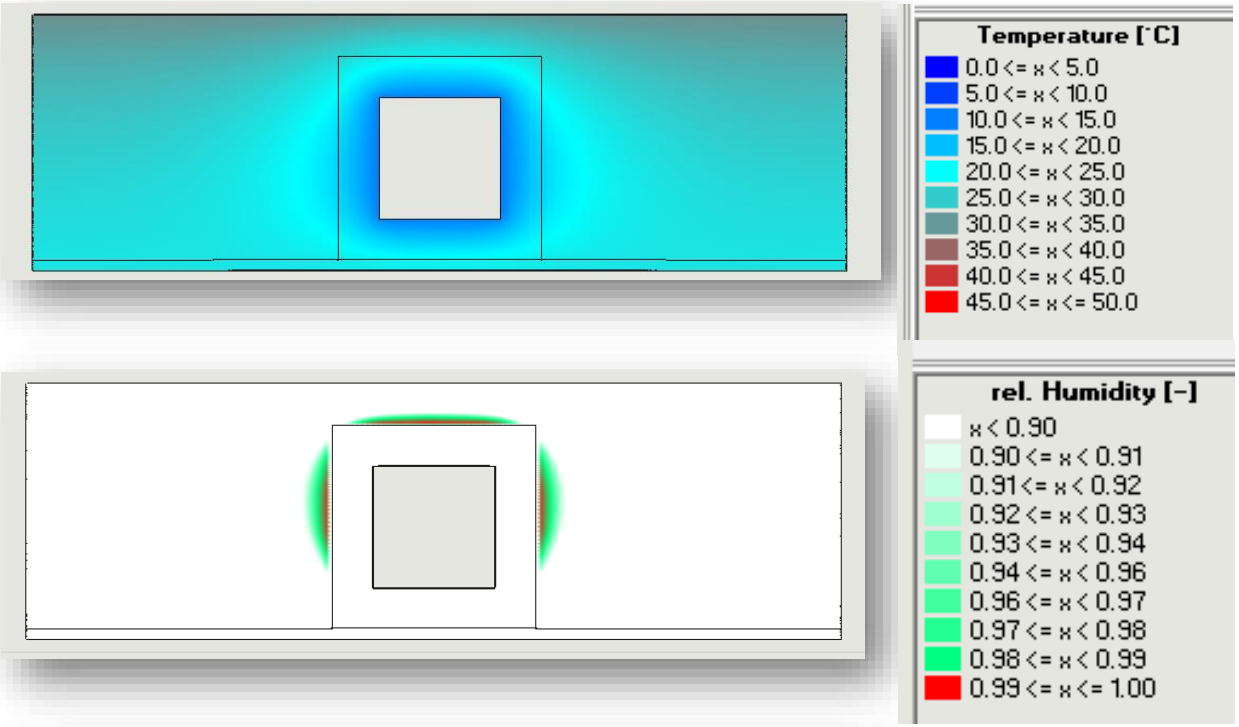
Attic Conditions





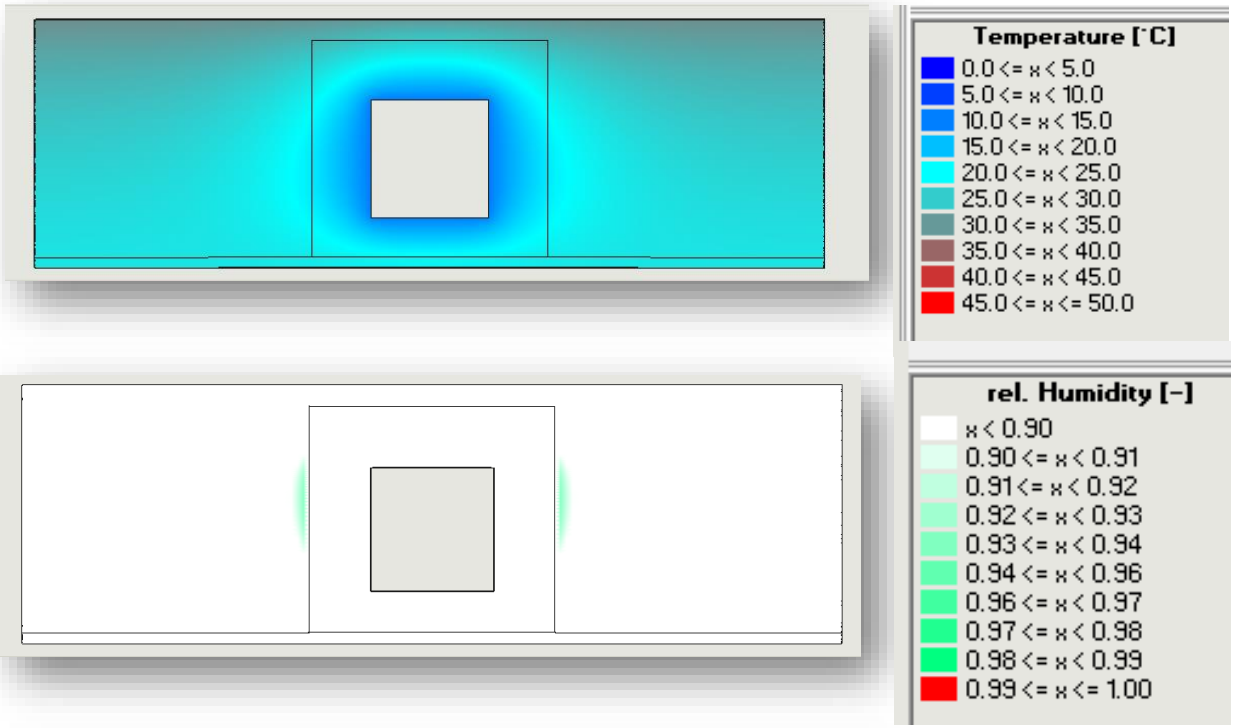
•Temperature and Relative Humidity in the attic simulated with WUFI-Plus for a vented attic in Charleston SC

Summer T, RH and Water Content



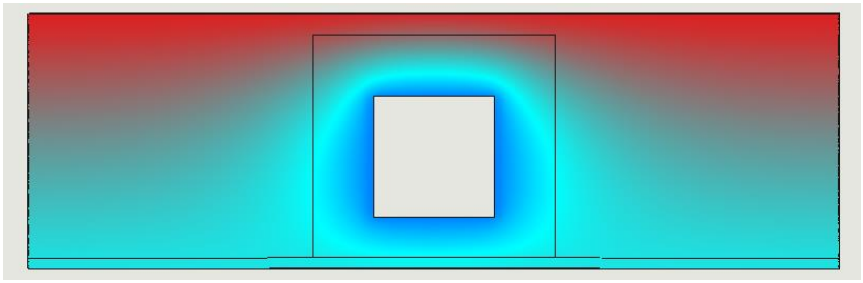
- R8
- 10am in the morning

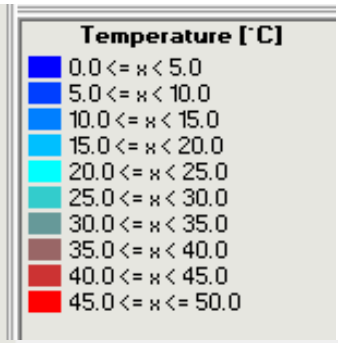
Summer T, RH and Water Content



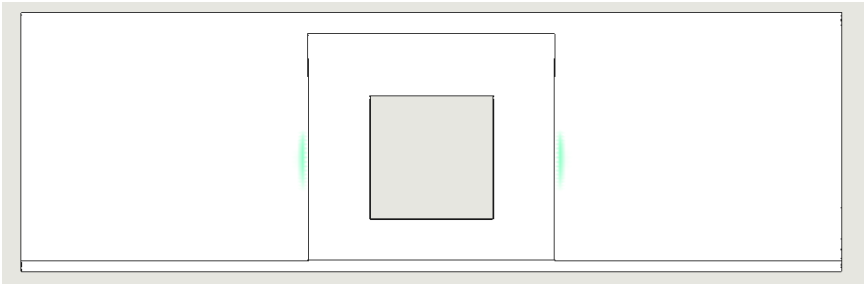
- R12
- 10am in the morning

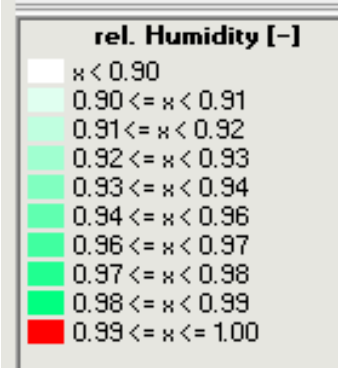
Summer T, RH and Water Content

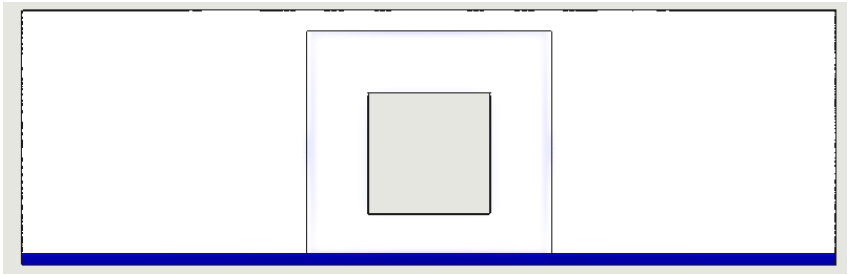


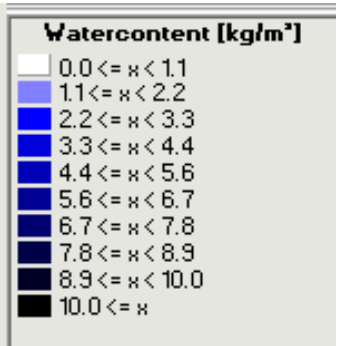


- R12
- 2pm in the afternoon

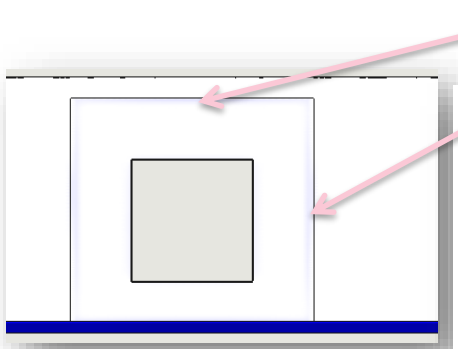




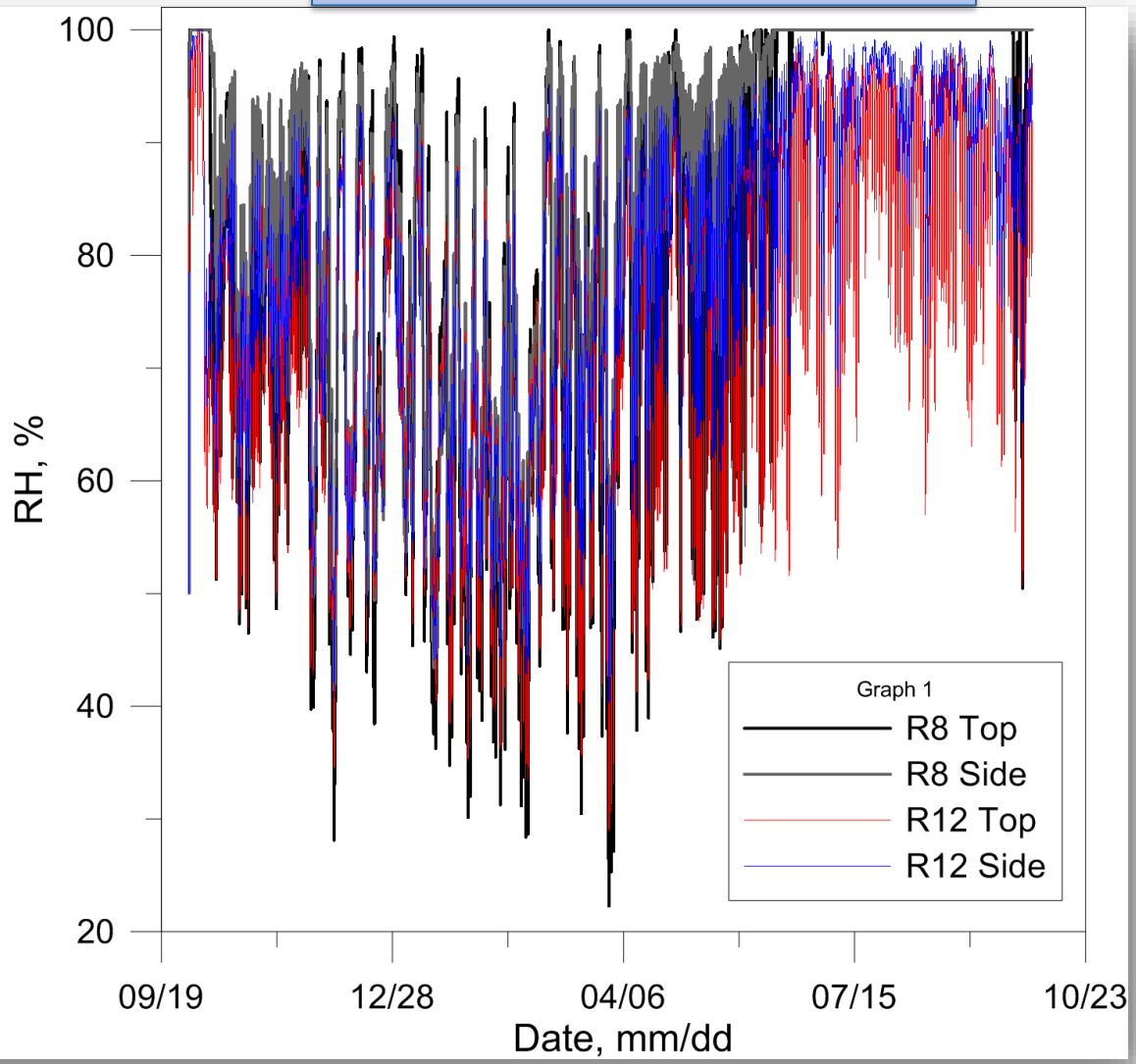




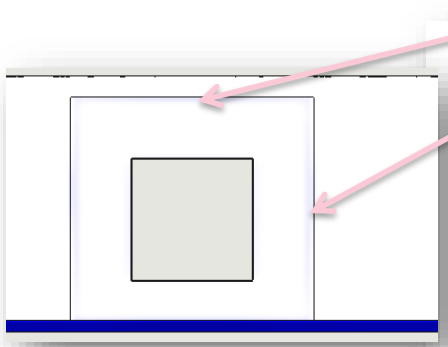
RH on top and side of duct

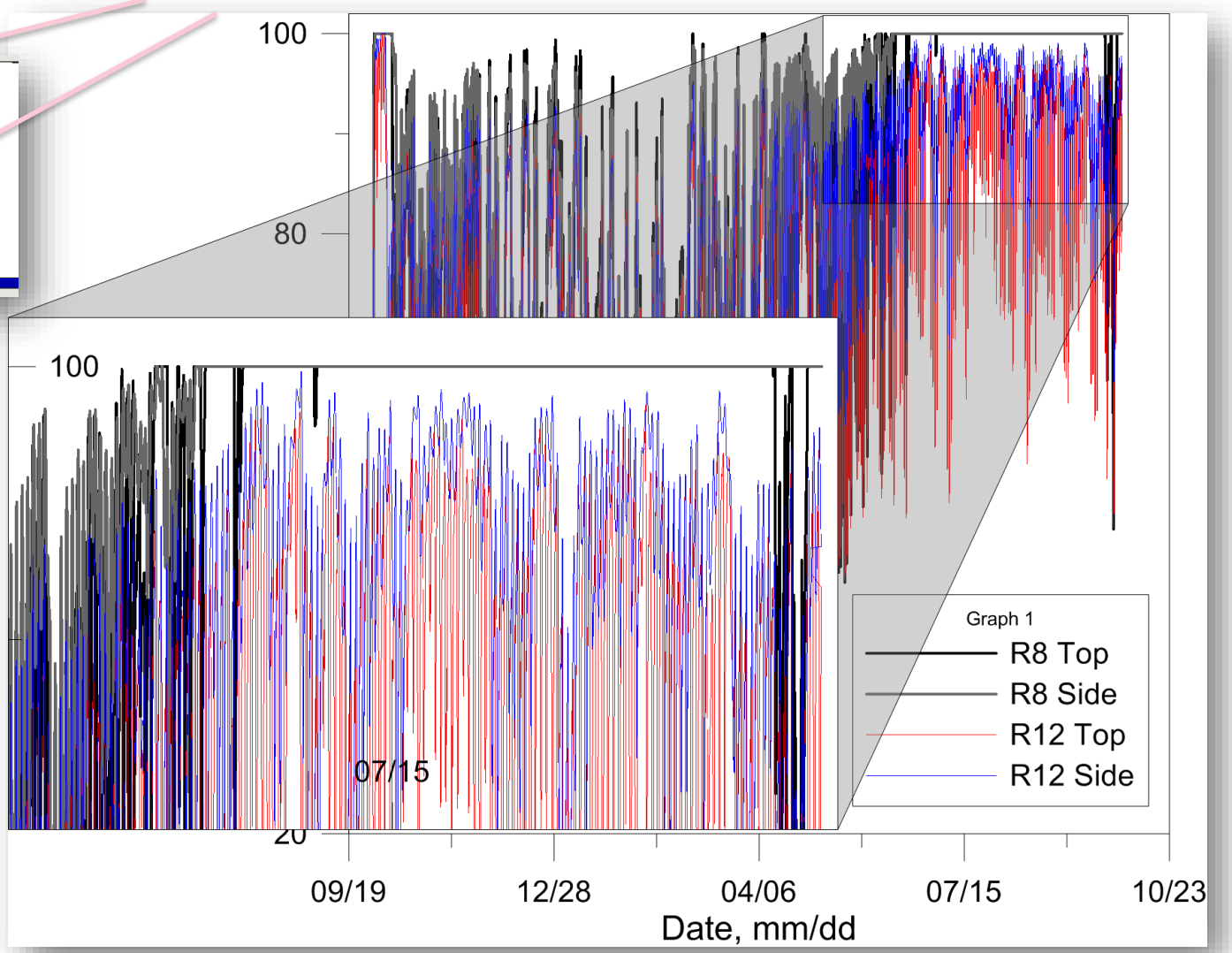


•R8 experiences condensation



RH on top and side of duct

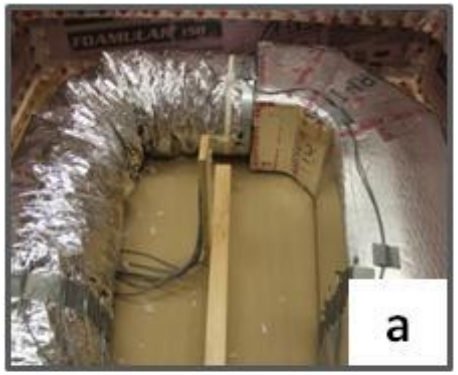


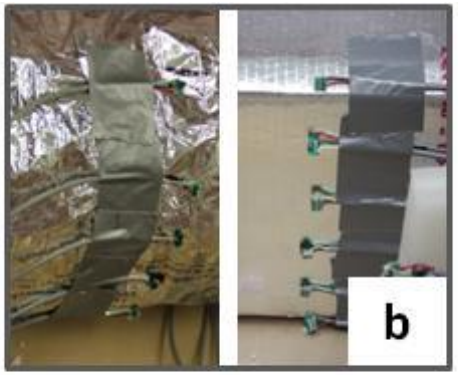


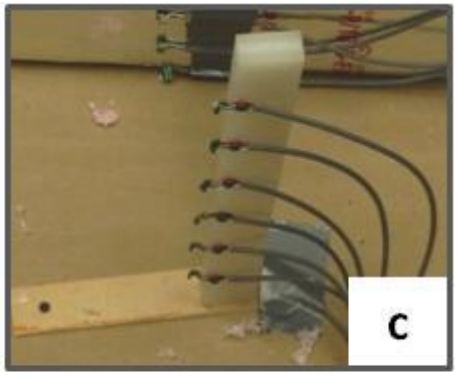
- RH<100%
No condensation with R12

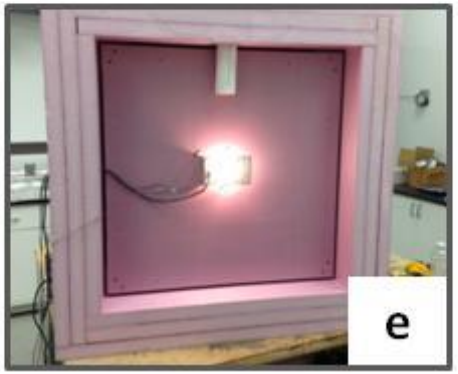
Laboratory Testing

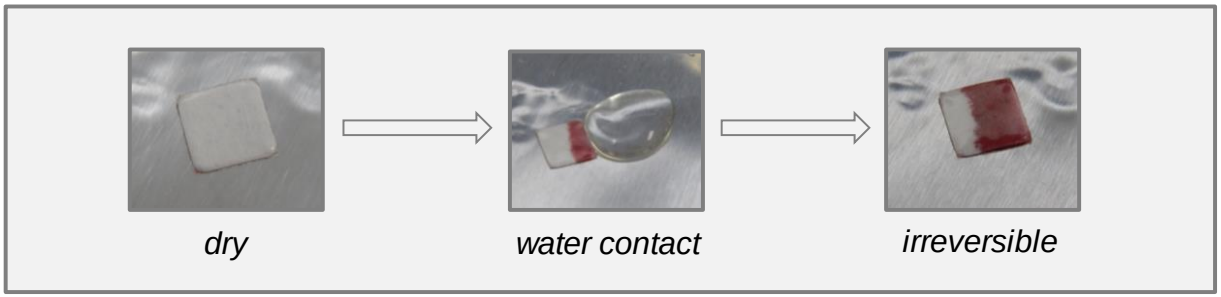
Laboratory testing for condensation











Laboratory testing for condensation

Series of testing with many variables

Variables	Output
Duct temp *(controlled)*	Duct surface temp (2” height increments)
Attic temp *(controlled)*	Duct surface %RH (2” height increments)
Attic %RH *(controlled)*	Visual moisture indication
“Indoor” conditions *(not actively controlled)*	
Loosefill level	
Duct type	
Duct R-value	

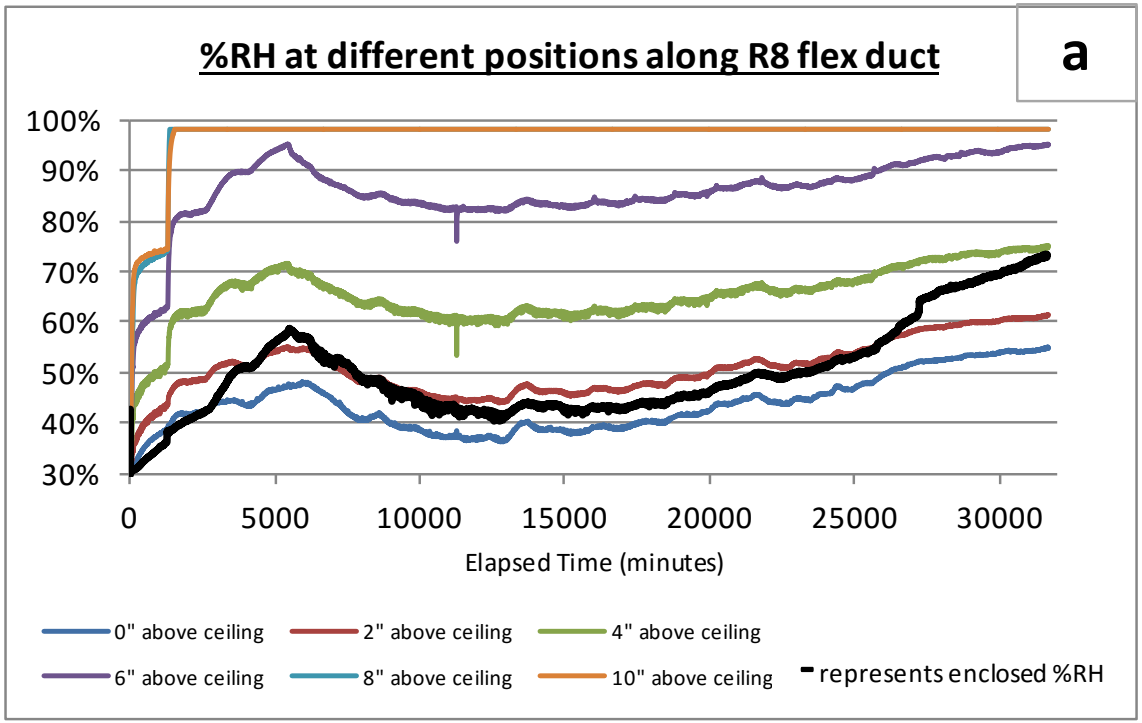
Laboratory testing results

Example buried duct experiment – Extreme S. Carolina conditions

- **Ducts:** R-8 flex, R-8.7 duct board
- **Attic insulation:** R-38 (no mounding)
- **Run time:** 22 days (100% cooling air on)

	Set-Point	Average
Duct conditioning	55°F	54.9°F
Attic conditioning	77°F, 80% RH	78.4°F, 80.7% RH
"Indoor" conditioning	Not controlled	68.5°F, 50.7% RH (min. RH = 38%, max = 73.2%)

- Measured %RH around flex and board
- Black line = %RH within "indoor" space
- 8" and 10" flex sensors maintained max humidity for duration of test



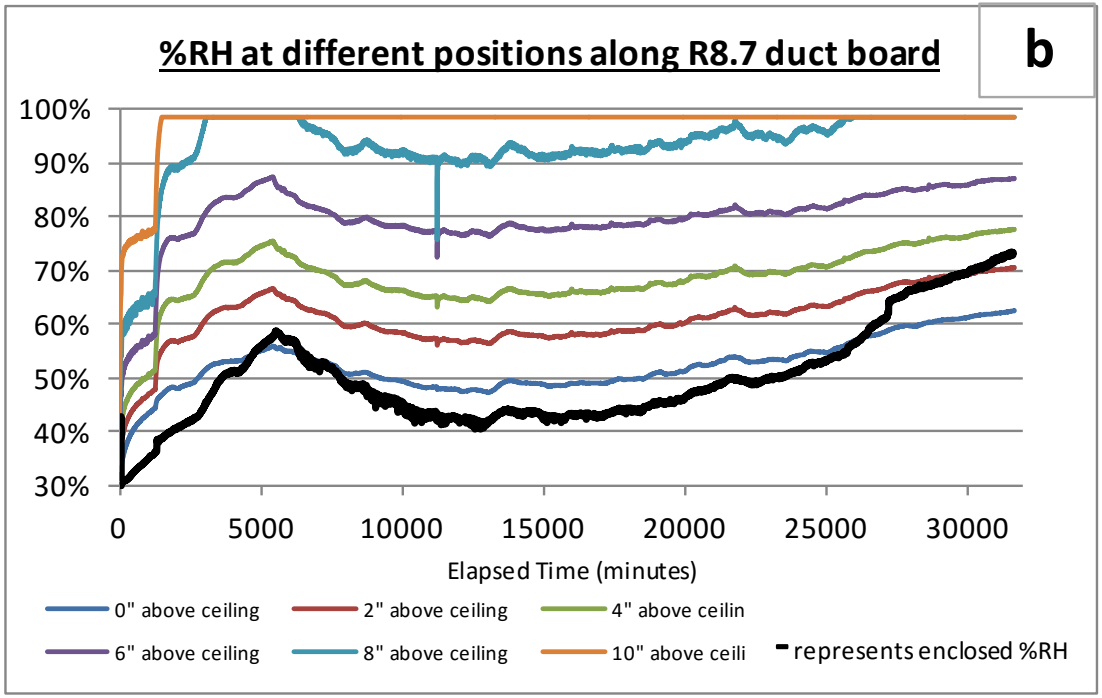
Laboratory testing results

Example buried duct experiment – Extreme S. Carolina conditions

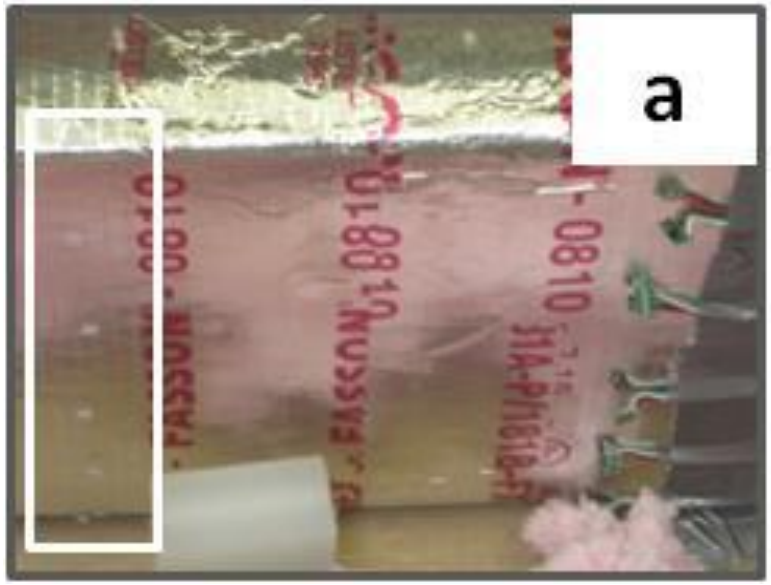
- **Ducts:** R-8 flex, R-8.7 duct board
- **Attic insulation:** R-38 (no mounding)
- **Run time:** 22 days (100% cooling air on)

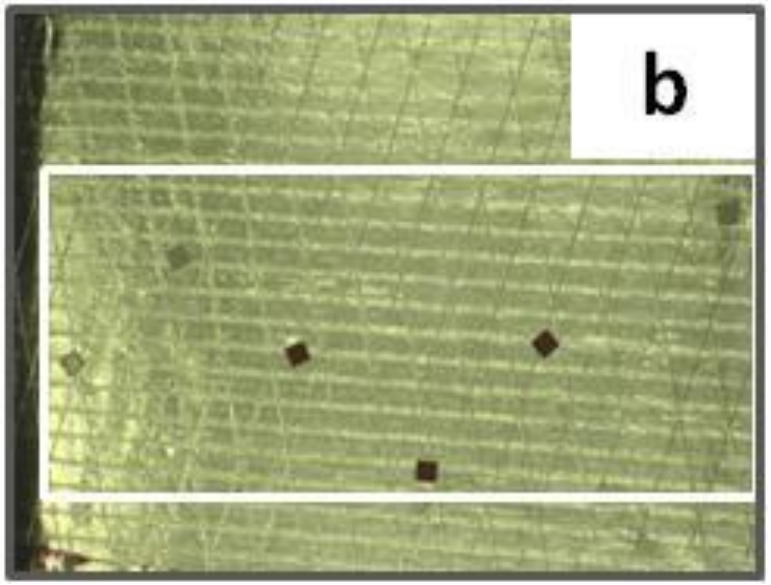
- 10” board sensor maintained max humidity for duration of test
- 8” board sensor reached max humidity during periods of high “indoor” humidity

	Set-Point	Average
Duct conditioning	55°F	54.9°F
Attic conditioning	77°F, 80% RH	78.4°F, 80.7% RH
“Indoor” conditioning	Not controlled	68.5°F, 50.7% RH (min. RH = 38%, max = 73.2%)



Laboratory testing results





- **Flex duct:** visible moisture on surface, loosefill moist in vicinity, but not in all areas. Some indicator pieces unchanged while others turned red.
  - No dripping onto drywall prior to moving ducts during observation.

- **Duct board:** no visible moisture in areas of sensors, did not feel wet. No change in indicator tape near sensors. Moisture along top and edge at elbow. Tape changed to red in top middle.
  - No dripping onto drywall prior to moving ducts during observation.

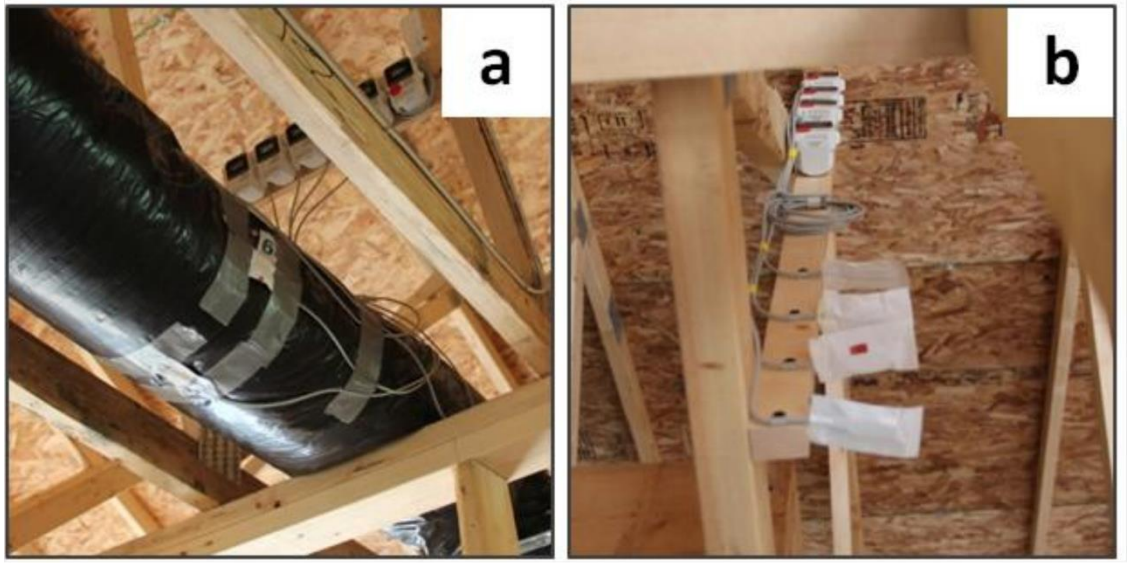
Field Testing

Cleveland OH

Buried duct field testing (Cleveland, OH)

- A model home in Cleveland, OH with buried ducts that was outfitted with sensors for evaluation

Field Evaluation – Data Collection



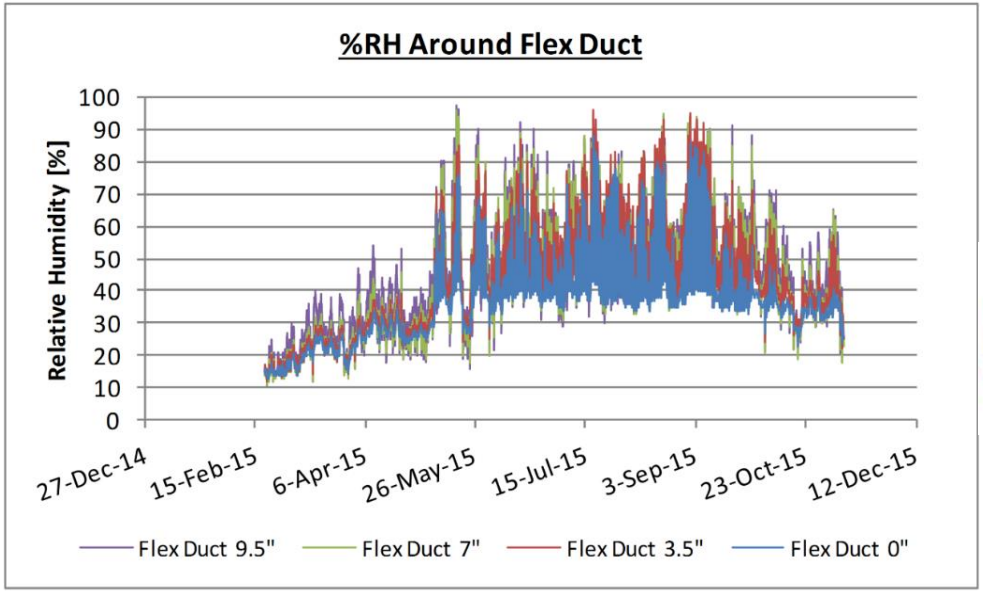
- T/RH sensors installed around R8 flex duct
- T/RH sensors installed through loosefill
- R49 loosefill installed in the attic

Temp / %RH Sensors

- **Flex Duct**
  - 0”, 3 ½”, 7”, 9” *(distance up from bottom of duct)*
- **Loosefill**
  - 0”, 3 ½”, 7”, 9” *(distance up from drywall)*
- **Duct Air** (flex duct core)
- **Attic Ambient** (attic air space)
- **Indoor** (upstairs bedroom)
- **Outdoor** (outside deck)

Buried duct field testing (Cleveland, OH)

Data collection Feb 2016-Mar 2016



During heating season, %RH around flex duct remains low.

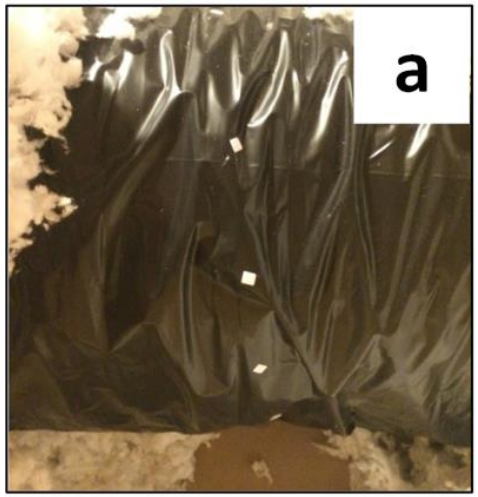
During cooling season, %RH increases

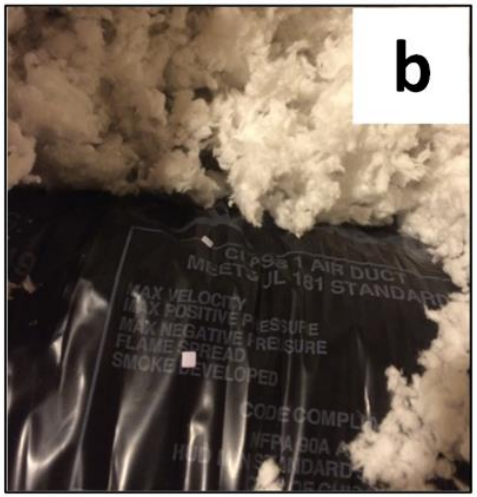
- Elevated humidity (≥ 90%) observed during limited days May – September.
- Measured periods of elevated humidity followed by low humidity.

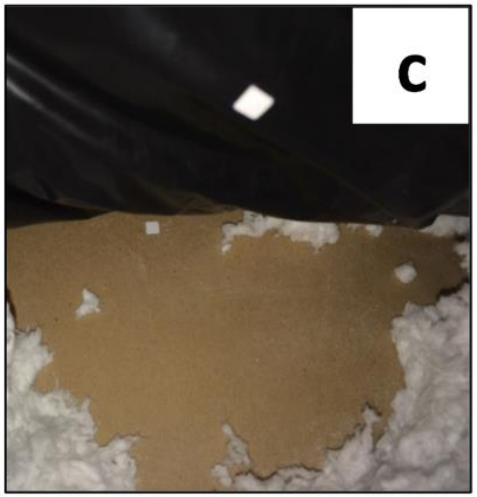
	Maximum Observed %RH	Hours ≥ 80% RH	Hours ≥ 85% RH	Hours ≥ 90% RH	Hours ≥ 95%RH
Flex 0” (bottom)	88%	37	9.5	0	0
Flex 3.5” (middle)	96%	176	74.5	22	2
Flex 7” (middle)	96%	122.5	39.5	12	1
Flex 9.5” (top)	97%	126.5	49.5	13.5	1.5

Condensation Indicators

- No sign of condensation around the flex ducts







Summary

- Attics experience very dynamic conditions
  - Steady-state analyses can be misleading and result in overly conservative designs
- The laboratory and field tests as well as numerical simulations indicate that R-8 duct insulation could be sufficient to avoid condensation problems in deep buried ducts in moist climates
- Simulations and field tests did not show moisture accumulation that would have resulted in dripping water or wet insulation

Conclusions

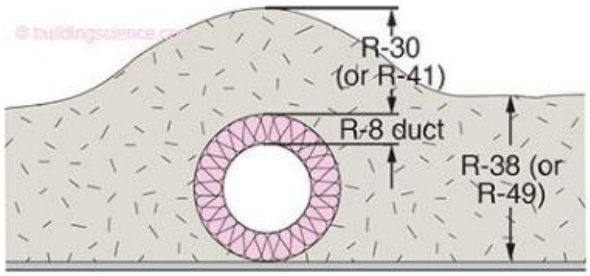
- Currently the majority of residential homes that have ducts in vented attics have buried ducts
  - The hanging ducts that connect to the duct boots through the insulation layer have been working fine
- The results from the work suggest that R-8 buried duct system performs well in Climate Zone 5A
- Cost effective new options to drive energy saving
- Based on multiple studies, new building codes (ICC 2018) will include:

Buried Duct Code Proposal

R403.3 Ducts

R403.3.6 Ducts buried within ceiling insulation

1. Supply and return ducts insulated with ≥ R-8
2. Sum of ceiling insulation R-values above and below duct ≥ R-19 (excluding duct R-value)
3. CZ 1A, 2A, 3A where supply ducts are completely covered with ceiling insulation should be insulated with ≥ R-13 and vapor retarder

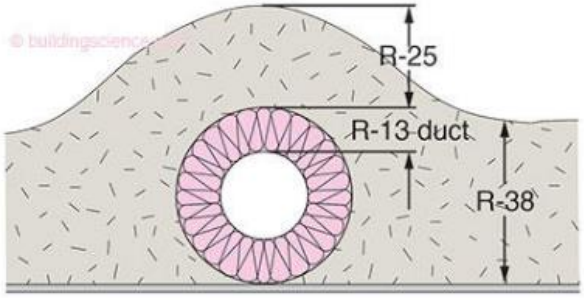


R403.3 Ducts

R403.3.6 Ducts buried within ceiling insulation

R403.3.6.1 Deeply buried effective R-value

1. Installed according to R403.3.6
2. On or within 5.5" of ceiling board and surrounded with ≥ R-30 attic insulation and top of the duct is minimum 3.5" below insulation
3. Claim effective R-value of R-25 for deeply buried section

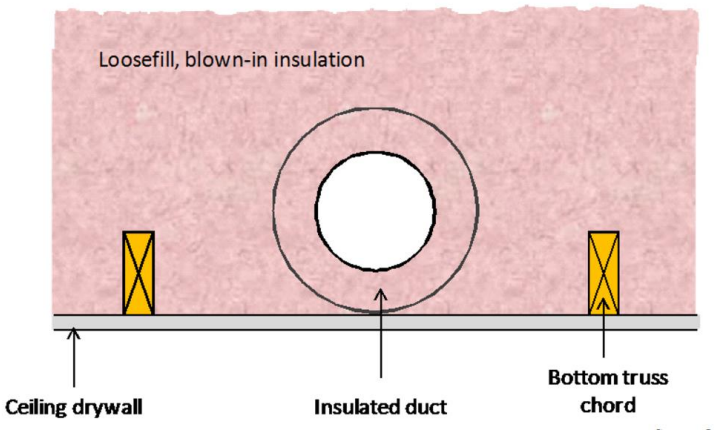


R403.3 Ducts

R403.3.6 Ducts buried within ceiling insulation

R403.3.7 Ducts located in conditioned space

1. Duct system located completely within continuous air barrier and building thermal envelope
2. Installed according to R403.3.6
3. Air handler within continuous air barrier and building thermal envelope
4. Duct leakage (rough-in ducts or post-construction total system to outside) ≤ 1.5CFM/100SF CFA
5. Ceiling insulation immediately above insulated duct ≥ proposed ceiling R-value minus insulated duct R-value



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