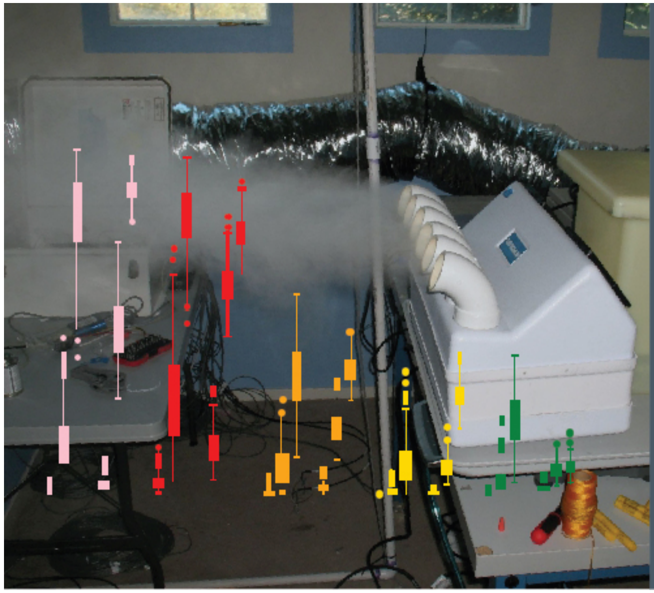
Residential Building Comfort System Research



National Renewable Energy Laboratory
Jon Winkler, PhD
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Project Summary

Timeline:

Start date: 10/1/2015

Planned end date: 9/30/2019

Key FY18 Milestones:

1. 3/30/2018: Draft journal publication – Impact of occupant-related internal gains on cooling loads
2. 6/30/2018: Draft journal publication – Sensitivity analysis on HVAC system installation fault impacts at a national scale
3. 9/30/2018: Draft journal publication – Assessment of thermal comfort model sensitivity to indoor humidity

Budget:

Total Project $ to Date: $1,394k

- DOE: $1,394k
- Cost Share: $0

FY18 Project $: $519k

Total Project $: $1,944k

- DOE: $1,944k
- Cost Share: $0

Key Partners:

Oak Ridge National Laboratory
Building America Teams

Project Outcome:

- Annual simulation and design tools to ensure year-round humidity control and well-distributed comfort
- Optimal space conditioning solution guidance for low-load homes, which includes:
  - Sensible load control
  - Latent load control
  - Comfort distribution

Challenge

Problem Statement

- High-performance, low-load homes face unique space conditioning challenges
- Majority of HVAC systems are improperly installed increasing energy use 20-30%[1]
- Residential construction industry makes negligible investments in R&D

Meeting BTO RBI goals to reduce space conditioning and water heating energy use by 40% from 2010 levels by 2025 requires solving these problems

Project Goals

- Develop and utilize physics-based computer models for researching residential interzonal airflow dynamics, comfort system heat transfer characteristics, and occupant thermal comfort science
- Create the knowledge to overcome technical risks facing high-performance homes

High-Performance Home Impacts[2]

- ~$350 Billion – 1+ Trillion utility bill savings
- ~$90 Billion - $270 Billion annual construction revenue
- ~120,000 – 360,000 persistent new jobs

[1] *Domanski et al. 2014. Sensitivity analysis of installation faults on heat pump performance.*
[2] *Impacts based on internal DOE analysis assuming 30% high-performance new and existing homes by 2025.*

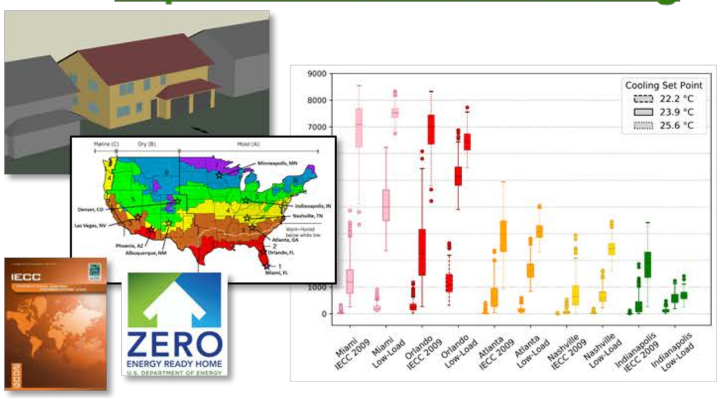
Approach: FY18 Research Subtasks

Residential building comfort systems must address:

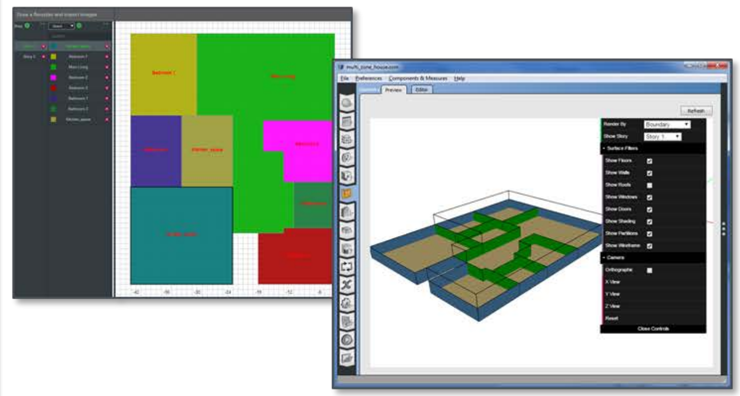
1. Effective part-load temperature and humidity control during all occupied times
2. Effective air distribution and temperature control throughout all occupied spaces
3. Optimally installed systems to achieve expected performance

Key Research Activities

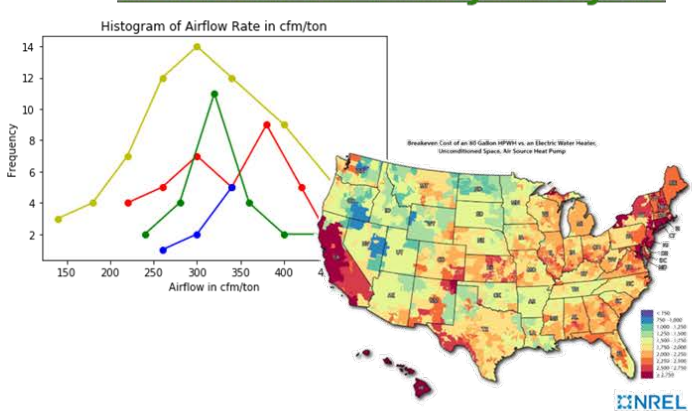
Improved Moisture Modeling



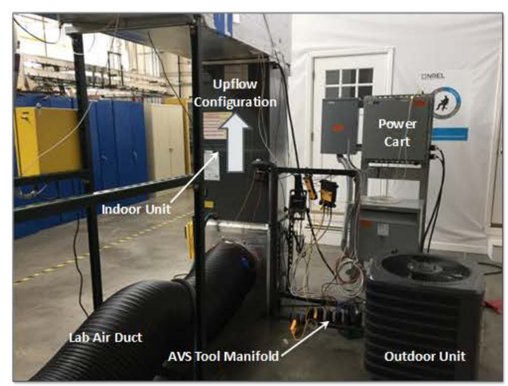
Home Zoning Research

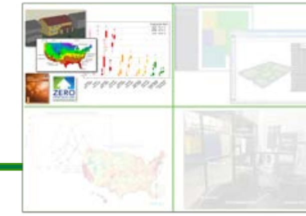


Installation Quality Analysis



Installation Quality Experiments





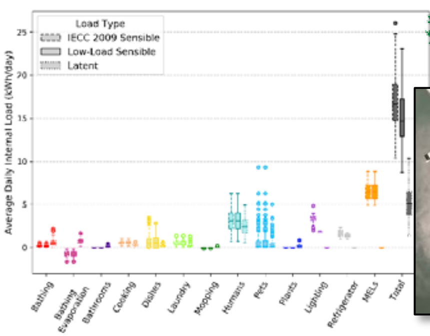
Improved Moisture Modeling: Approach

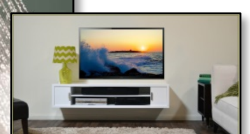
Key Research Question: What is the impact of occupant-related internal gains on indoor humidity and cooling loads in energy-efficient, low-load homes?

2 House Types; 10 Climate Types

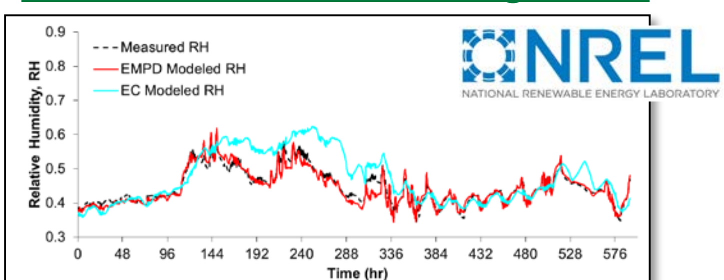
1000 Stochastic Internal Gain Profiles

OAK RIDGE National Laboratory





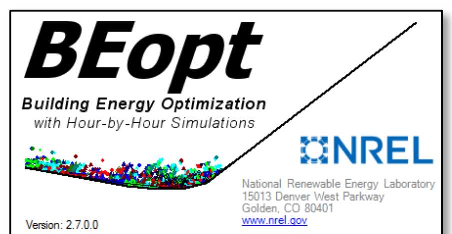
Accurate Moisture Buffering Model



Simulation Cases

- Moisture buffering levels
- Thermostat set point
- Blower air flow rate
- Blower-off delay
- Air conditioner sizing

EnergyPlus Simulations

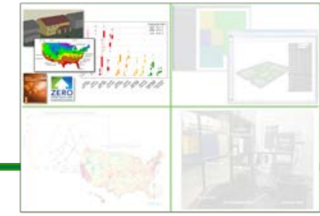


EnergyPlus

Simulation Outputs

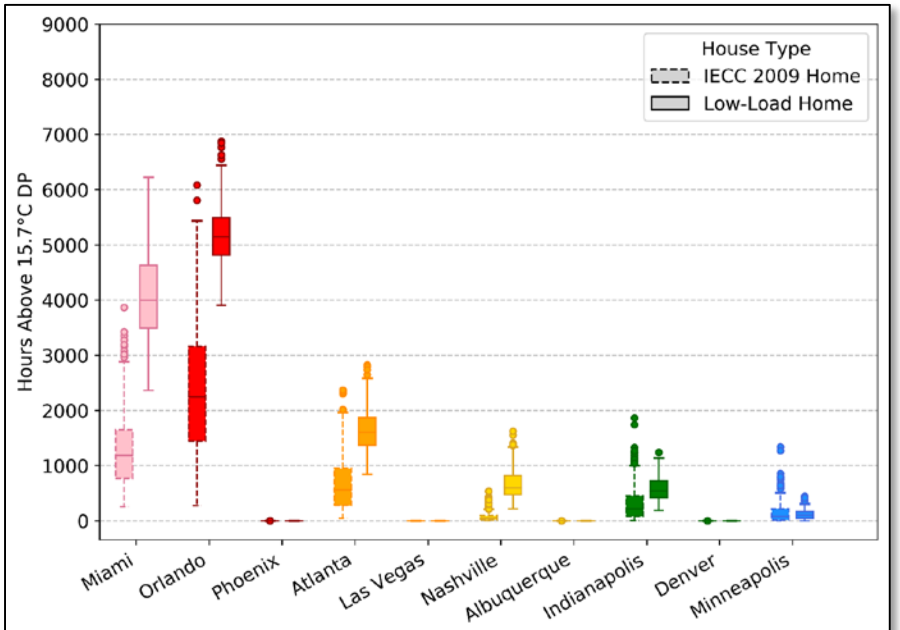
- Sensible and latent cooling loads
- Indoor humidity
- Cooling energy use
- Dehumidification loads and equipment sizes

Improved Moisture Modeling: Results



Accomplishments: Developed and utilized framework to account for stochastic variation in occupant-related internal gains.

FY17 Accomplishments



Baseline humidity results

Energy & Buildings 165 (2018) 364–378

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

ELSEVIER

Effect of occupant behavior and air-conditioner controls on humidity in typical and high-efficiency homes

Jon Winkler[a,*], Jeffrey Munk[b,*], Jason Woods[a]

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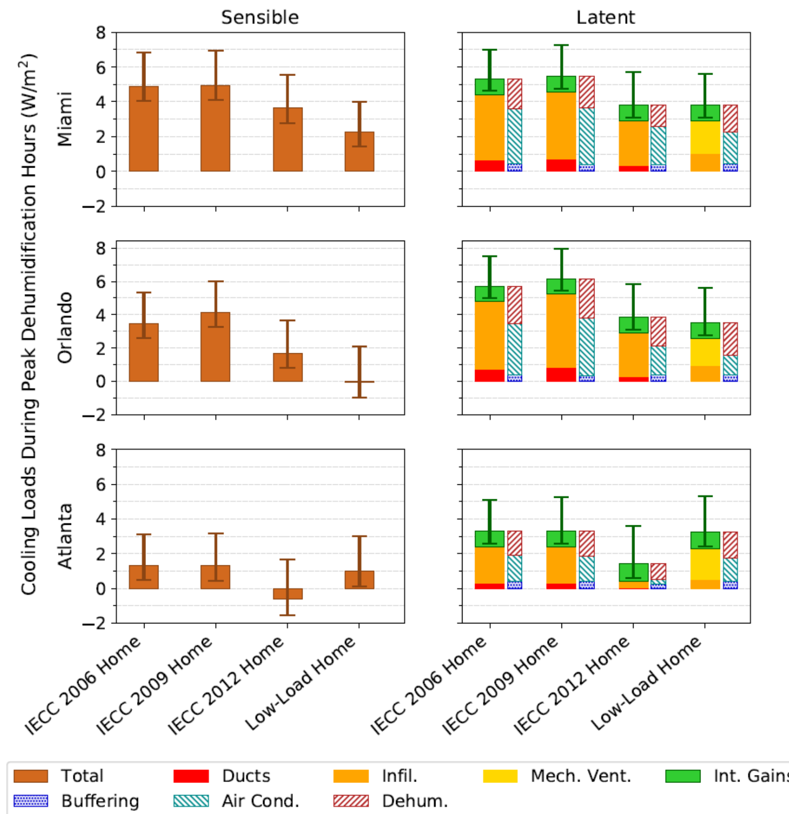
[b] Oak Ridge National Laboratory, 1 Bethel Valley Rd, Oak Ridge, TN 37830, USA

FY18 Accomplishments

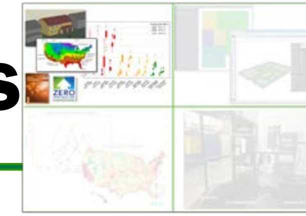


Effect of occupant behavior on peak cooling and dehumidification loads in typical and high-efficiency homes

Jon Winkler[a,*], Jeffrey Munk[b,*]

[a] National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401
[b] Oak Ridge National Laboratory, 1 Bethel Valley Rd, Oak Ridge, TN 37830

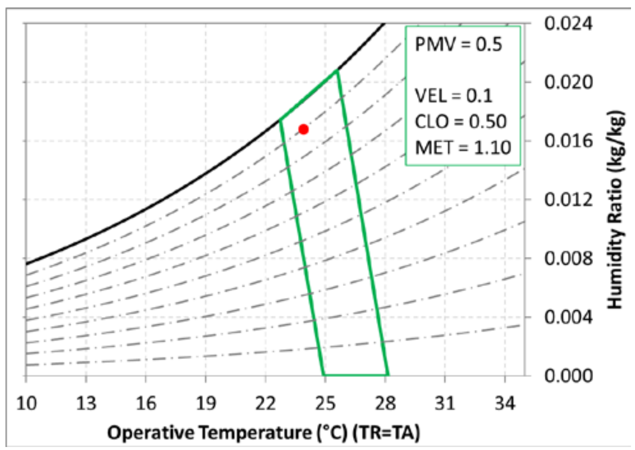
Improved Moisture Modeling: Next Steps



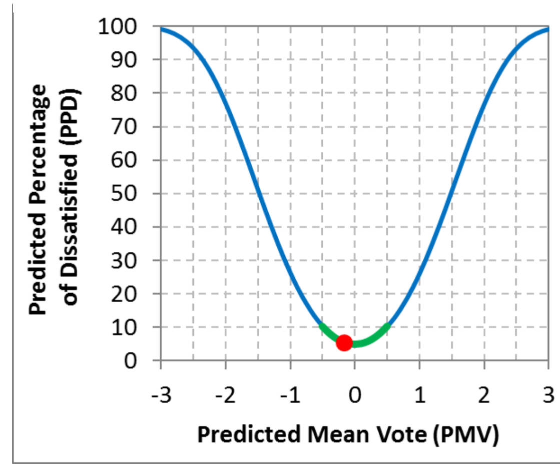
Refine assumptions to better account of impact of humidity on comfort

- Binary metrics, such as counting hours above a threshold, do not accurately predict comfort
- Fanger/ASHRAE 55 model is insensitive to humidity

INPUTS	
Air Temperature (°C)	23.89
Air Temperature (°F)	75
Relative Humidity (%)	90
Air Velocity (m/s)	0.1
Clothing (clo)	0.5
Metabolic Rate (met)	1.1
External Work (met)	0



ASHRAE 55 Comfort Prediction



ASHRAE 55 implies ~95% of people would find this condition comfortable

Next Steps

- Investigate alternative comfort modeling approaches in the literature and assess sensitivity of results using these models

Home Zoning Research: Approach

Key Research Goal: Develop and utilize physics-based computers models for researching residential interzonal airflow dynamics to improve comfort distribution

Background: Why multi-zone simulations?

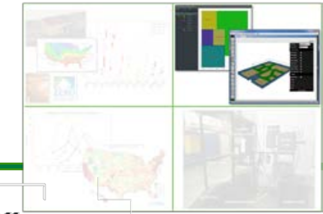
- High-performance, low-load homes look less like single zone buildings and more like multi-zone buildings
- Necessary to evaluate thermal comfort distribution and compare innovative space conditioning systems

Approach Timeline:

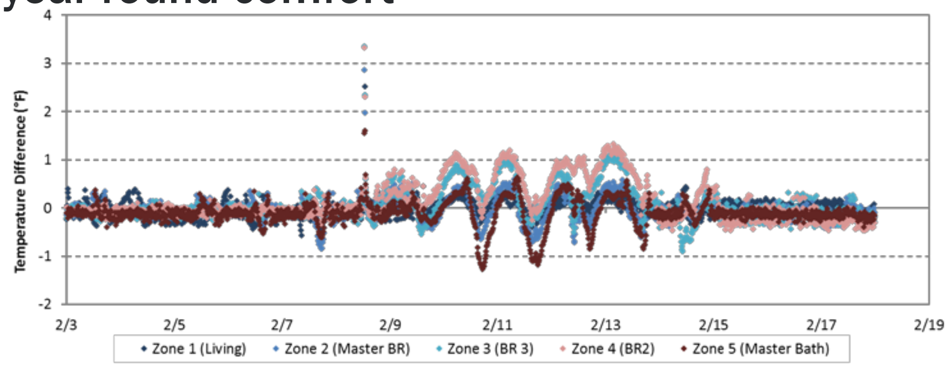
Oct. 2015 | Oct. 2016 | Oct. 2017 | We Are Here

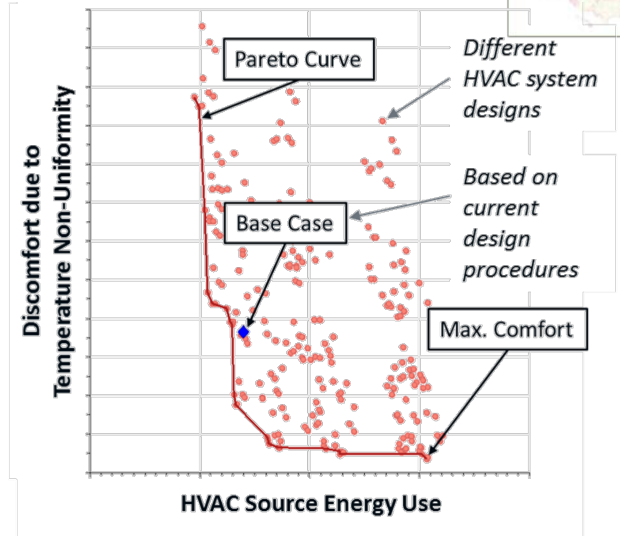
- FY16 – Study advanced EnergyPlus models and inputs
- FY16 – Develop model of multi-zone residential building
- FY17 – Validation using Building America field data
- FY17 – Investigate model use cases and capabilities
- FY18 – Transition models and learnings to Open Studio measures

Home Zoning Research: Progress



FY17 Accomplishments: Validated multi-zone model and demonstrated power of optimizing for year-round comfort





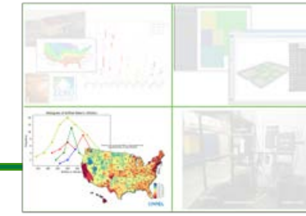
FY18 Accomplishments: Initiated development of Open Studio measures

- Implemented multi-zone residential building in the Open Studio Drawing Tool
- Verified internal gain measures related to appliances, lighting, MELS, and occupants

Open Studio drawing tool with multiple zones and space types

Remaining Steps: Implement residential building Open Studio measures utilizing EnergyPlus Air Flow Network (FY18) and achieve parity with current multi-zone modeling capabilities (future)

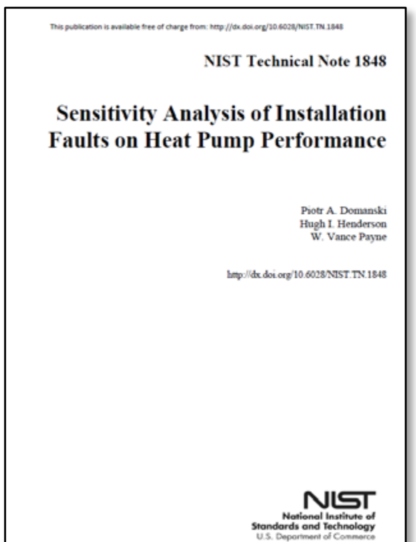
Installation Quality Analysis: Approach



<u>Key Research Question:</u> What is the national impact of residential air conditioner and heat pump installation faults?

Approach: Use advanced, physics-based computer models with previous research to simulate the U.S. housing stock with and without faults

NIST fault-dependent performance curves


This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.TN.1848

NIST Technical Note 1848

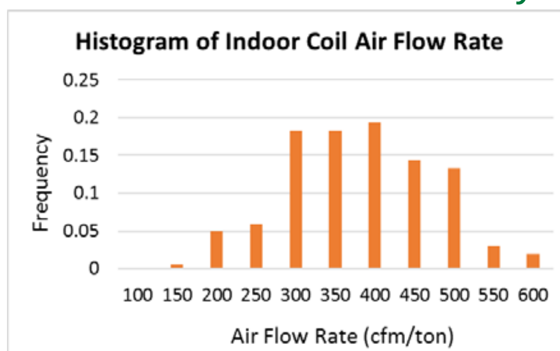
Sensitivity Analysis of Installation Faults on Heat Pump Performance

Piotr A. Domanski
Hugh I. Henderson
W. Vance Payne

http://dx.doi.org/10.6028/NIST.TN.1848

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

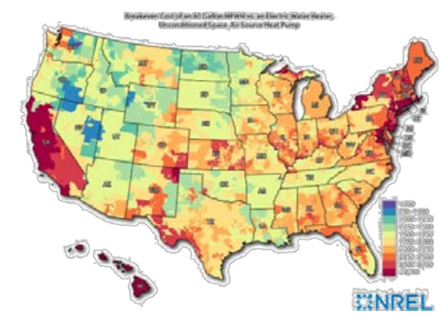
Airflow and charge fault histograms based on NREL FY17 study



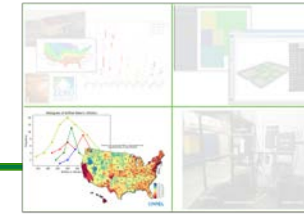
ResStock

EnergyPlus OpenStudio

Identify targeted research needs to address installation quality issues



Installation Quality Analysis: Progress

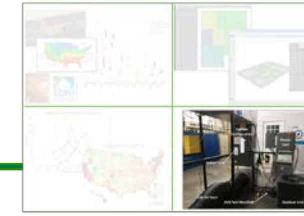


Completed Steps

- Developed aggregate histograms for airflow and charge faults based on previous fault prevalence and severity studies
- Incorporated NIST fault-based performance curves in ResStock/BEopt Open Studio measures

Remaining Steps

- Conduct ResStock runs
  - Baseline run – Run without presence of faults
  - Air flow fault impact – Using indoor coil air flow rate fault prevalence and severity histogram
  - Charge fault impact – Using refrigerant charge fault prevalence and severity histogram
  - Combination of faults
- Author peer-reviewed journal paper

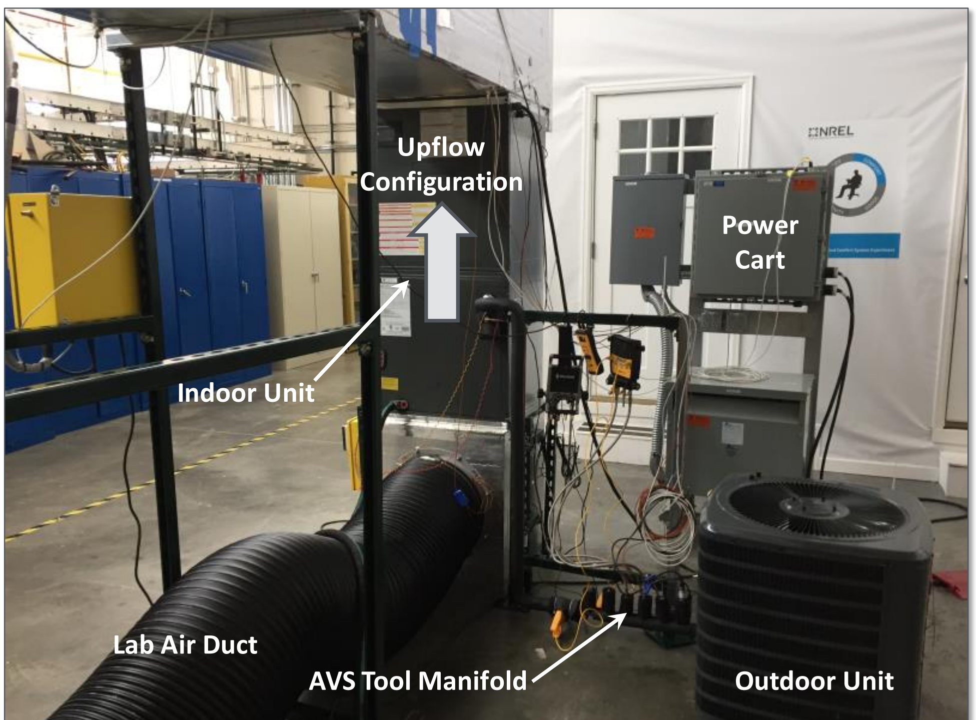


Installation Quality Experiments: Approach

Key Research Goals

- Assess ability of ‘smart’ automated verification system (AVS) tools to discern fault states by introducing a variety of known faults in the laboratory and measuring/characterizing how well the tools identify the faults
- Experiment with a variety of methodologies for assessing AVS capabilities

Experimental Apparatus

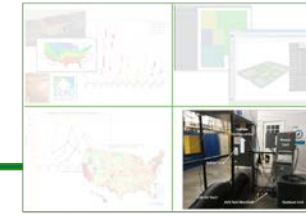


Test Matrix

Fault Type[1]	Fault Range (%)
Indoor coil airflow rate	-50 – 20
Refrigerant charge	-30 – 30
Non-condensable gases	0 – 20
Outdoor face area	-50 – 0

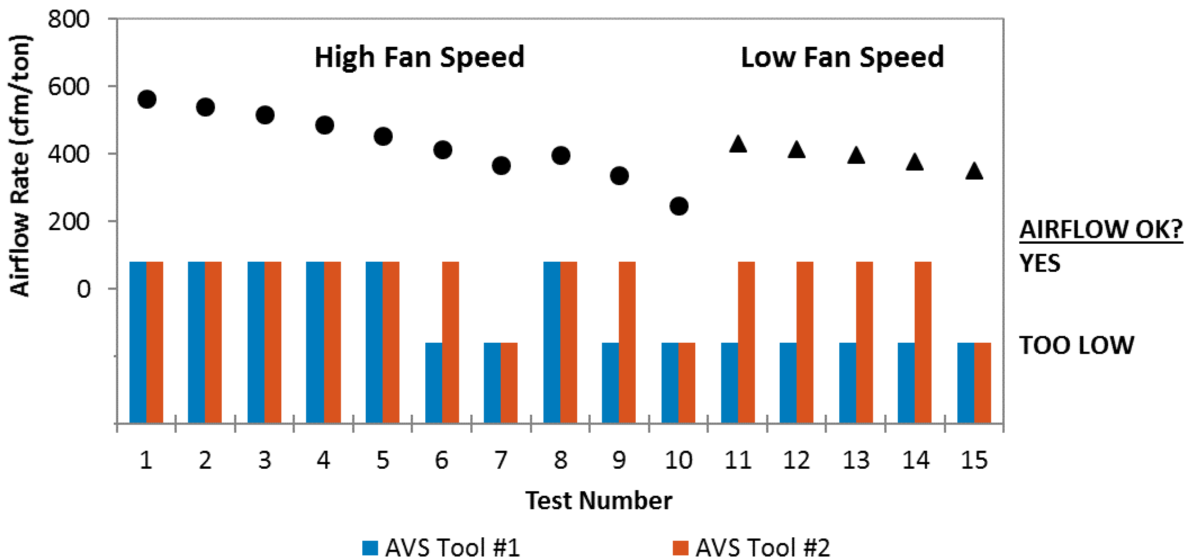
[1] *Fault types and ranges identified by Domanski et al. (2014)*

Installation Quality Experiments: Progress



<u>Completed Steps</u>

- **AVS tools and laboratory setup completed**
- **Two of the three selected AVS tools have been initially assessed at detecting indoor airflow rate faults**
  - AVS tools were inconsistent in detecting low airflow rates
  - High airflow rate faults were not detected at flow rates of 560 cfm/ton
- **Related conclusion: Sensor and algorithm accuracy should be decoupled**

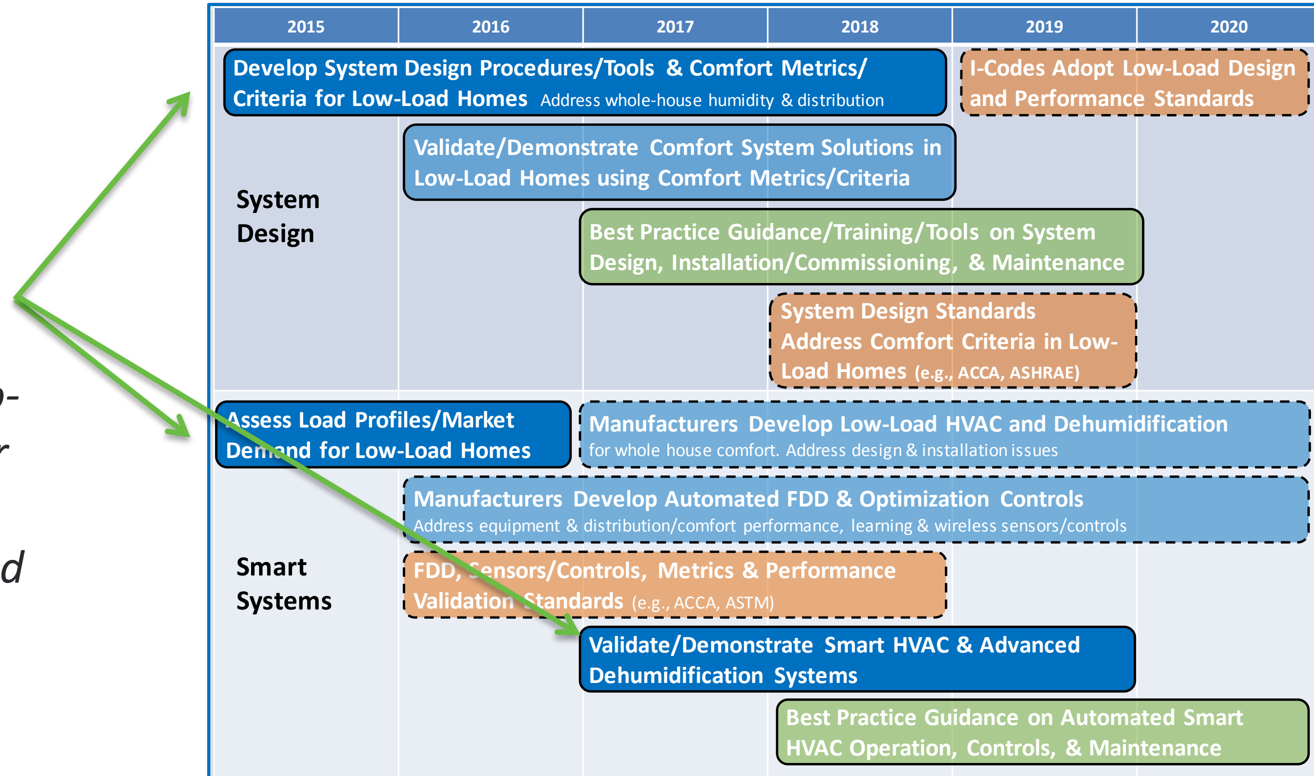


<u>Remaining Steps:</u> **Complete experimental test matrix and document findings**

Impact

BTO RBI Goal: Reduce space conditioning and water heating energy use by 40% from 2010 levels by 2025

Overall Approach:
Use the Building America *Research-to-Market Roadmap for Optimal Comfort Systems for Low-Load Homes* **as a guide**.



Project Impacts:

- Short term: Develop and utilize physics-based computer models for researching residential space conditioning challenges to overcome technical risks facing low-load homes
- Mid term: Stakeholder adoption of key research findings and tools
- Long term: Home builders meet improved efficiency standards without incurring comfort risks

Team Members

PI: Jon Winkler, PhD

NREL

Improved Moisture Modeling

Jeffrey Munk

Role: Co-PI, Internal gains model

Oak Ridge National Laboratory

Jason Woods, PhD

Role: Moisture Buffering model

NREL

Home Zoning Research

Jeff Maguire

Role: OS measure development

NREL

Scott Horowitz

Role: BEopt lead

NREL

Installation Quality Analysis

Lieko Earle, PhD

Role: Fault histogram development

NREL

Eric Wilson

Role: ResStock lead

NREL

Lena Burkett

Role: ResStock runs and analysis

NREL

Installation Quality Experiments

Lucas Phillips

Role: Experiment setup and data collection

NREL

Stakeholder Engagement

- **2018 peer-reviewed journal publications**
  - Woods and Winkler. “Effective moisture penetration depth model for residential buildings: Sensitivity analysis and guidance on model inputs”. Published in *Energy and Buildings.*
  - Winkler, Munk, and Woods. “Effect of occupant behavior and air-conditioner controls on humidity in typical and high-efficiency homes”. Published in *Energy and Buildings.*
  - Winkler and Munk. “Effect of occupant behavior on peak cooling and dehumidification loads in typical and high-efficiency homes”. *Draft completed*.
  - Winkler and Maguire. “A multi-zone EnergyPlus model to assess temperature uniformity in residential buildings”. *Under development.*
- **Presentations and webinars**
  - DOE Webinar: 12/17/2017 – “Effect of Occupant Behavior and Air Conditioner Controls on Humidity in Typical and Low-Load Homes” (>150 Attendees)
  - ASHRAE Annual Conference – Summer 2018 – moisture buffering presentation
- **Professional society engagement**
  - RESNET HVAC working group member to develop installation quality standards
  - ASHRAE technical committee involvement
- **Building America team update and coordination meetings**

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: FY16 - $400k
FY17 - $475k
FY18 - $519k
FY19 - $550k*

Variances: None
Cost to Date: $1,105k
Additional Funding: None

Budget History					
10/1/2015– FY 2017 (past)		FY 2018 (current)		FY 2019 – 9/30/2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,394k	$0k	$519k	$0k	$550k*	$0k

* Subject to appropriations and AOP planning cycle

Project Plan and Schedule

Project start date: 10/1/2015 Project planned completion date: 9/30/2019

Key Milestones:

- Go/No-Go to continue into FY19 based on sufficient progress towards project objectives, 7/15/2018

Project is on schedule and expected to complete successfully

Project Schedule												
Project Start: 10/1/2015	Completed Work											
Projected End: 9/30/2019	Active Task (in progress work)											
	Milestone/Deliverable (Originally Planned)											
	Milestone/Deliverable (Actual)											
	FY2017				FY2018				FY2019			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q3: Technical presentation on FY17 HVAC installation quality efforts			◆									
Q4 (SMART): Technical whitepaper to assess the sensitivity latent and sensible gains on comfort and recommended system sizing				◆								
Current/Future Work												
Q1: Draft journal publication leveraging NREL/ORNL FY17 simulation framework and results further investigating humidity loads						◆						
Q2: Progress update email on OpenStudio measure development for advanced residential, multi-zone simulations						◆						
Q3: Draft journal publication on a sensitivity analysis on comfort system installation fault impacts at a national scale							◆					
Q4 (SMART): Draft journal publication collaborating with ORNL on assessing occupant comfort in residential buildings								◆				