U.S. DEPARTMENT OF
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Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Effect of Occupant Behavior and Air Conditioner Controls on Humidity in Typical and Low-Load Homes

Panelists
Jon Winkler and Jason Woods, National Renewable Energy Laboratory
Jeff Munk, Oak Ridge National Laboratory

Moderator
Linh Truong – National Renewable Energy Laboratory

December 6, 2017

Building AMERICA
U.S. Department of Energy

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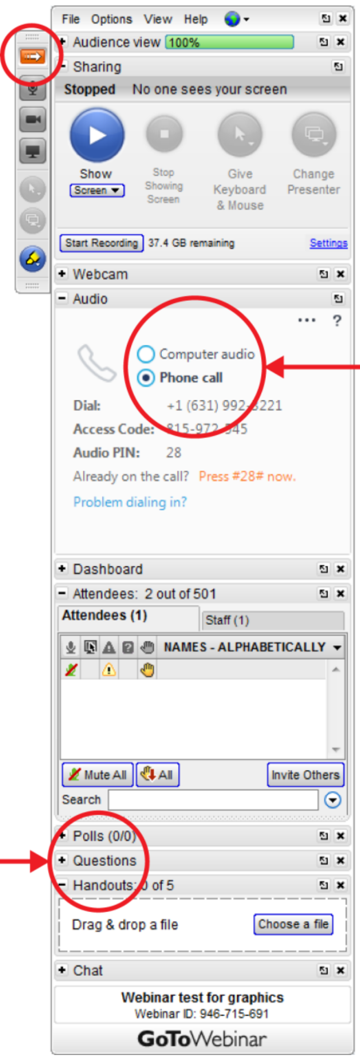

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Housekeeping

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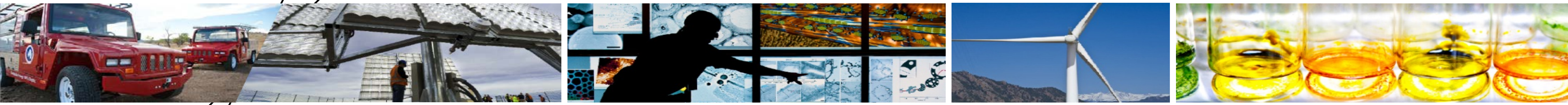
http://energy.gov/eere/buildings/building-america-meetings#current

Agenda

- ✓**Welcome and Introductory Remarks**
- ✓**Overview of Building America (buildingamerica.gov)**
  - Linh Truong – National Renewable Energy Laboratory
- ✓**Speakers**
  - Jon Winkler and Jason Woods, National Renewable Energy Laboratory
  - Jeff Munk , Oak Ridge National Laboratory
- ✓**Questions and Answers**
- ✓**Closing Remarks**

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

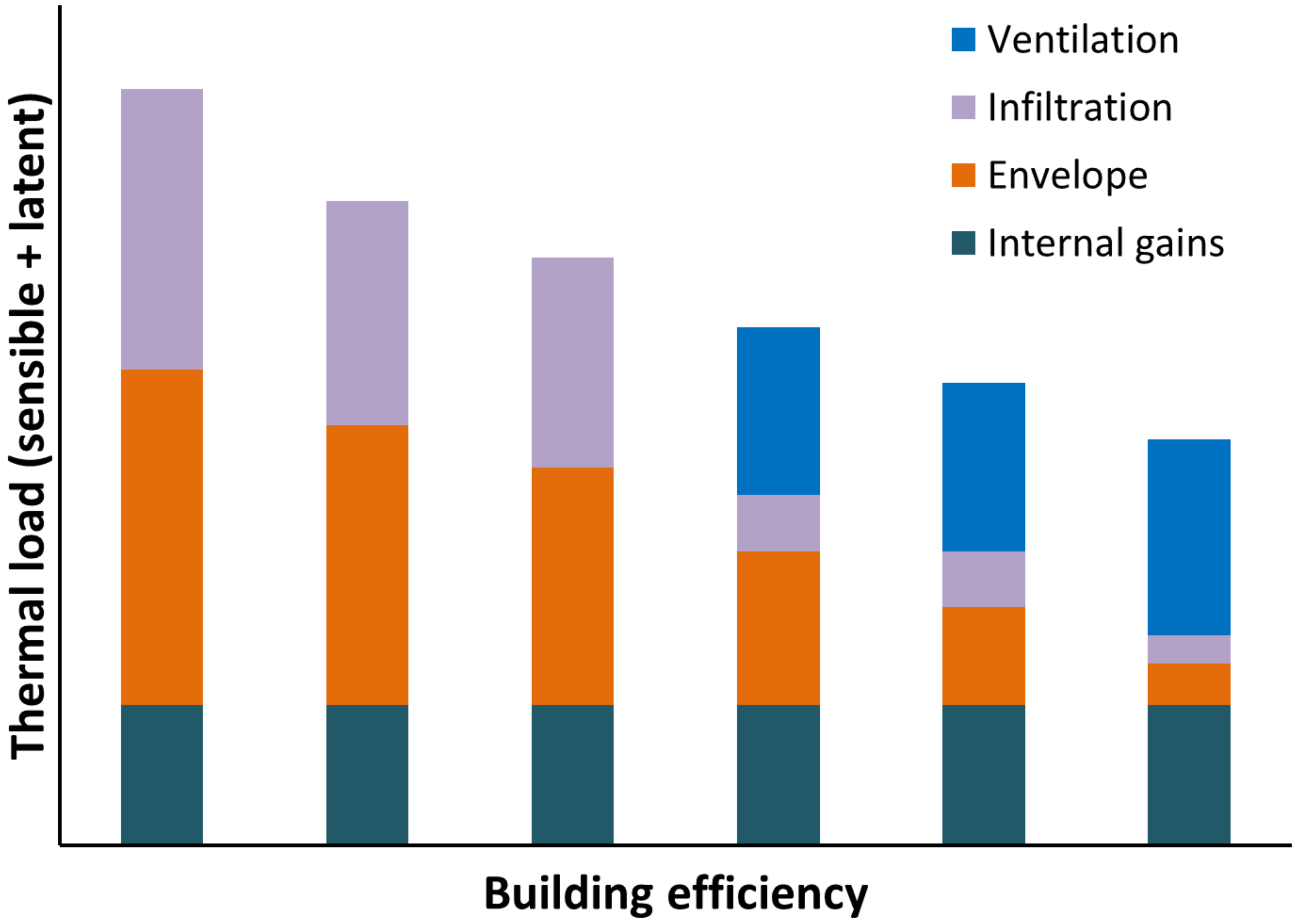


Jon Winkler
Jason Woods

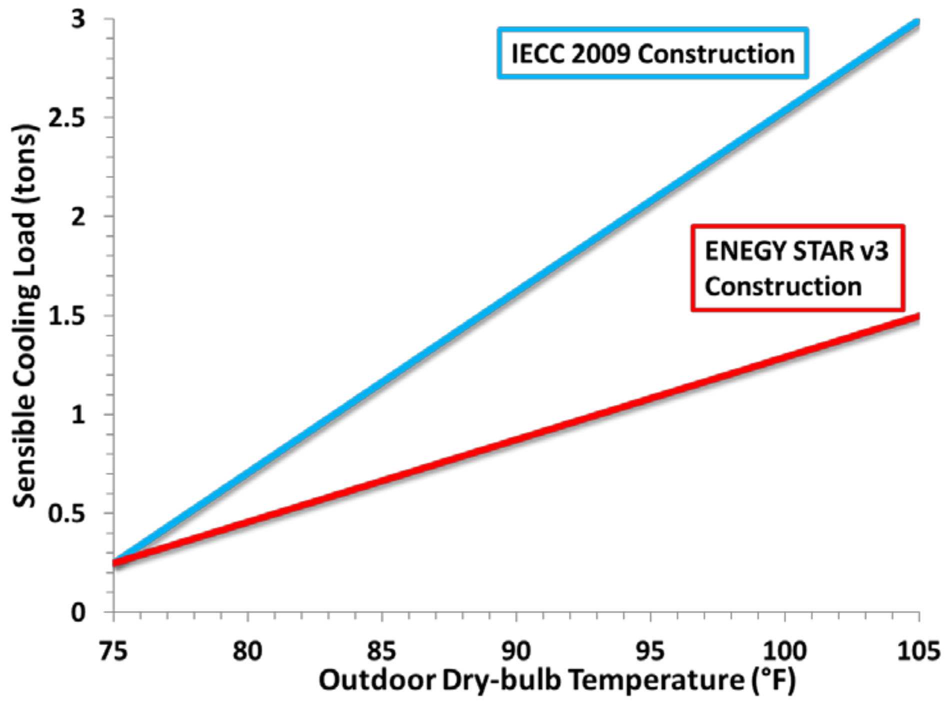
Jeffrey Munk

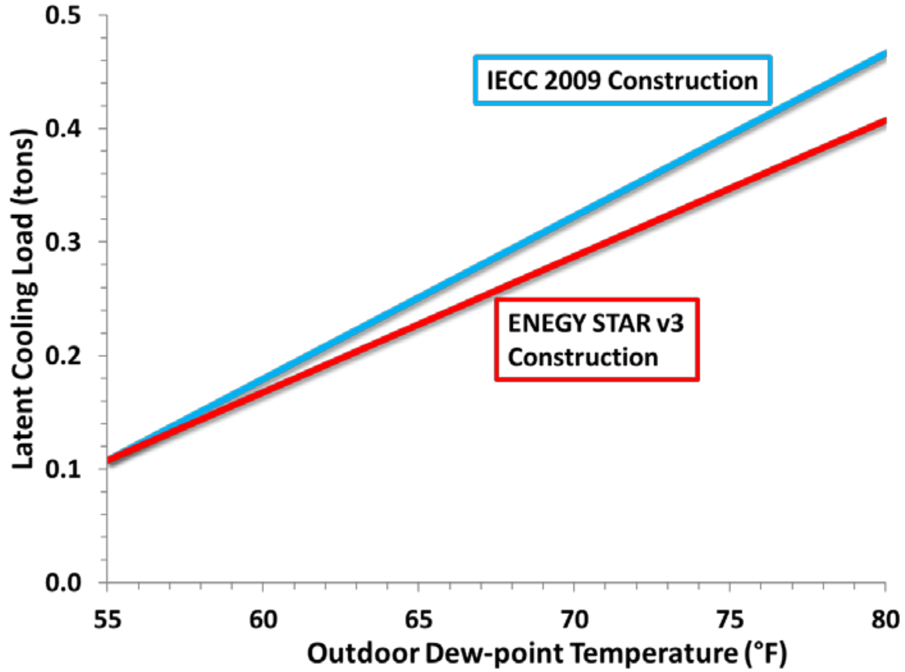
Dec. 6, 2017

The Relative Importance of Loads Is Changing



Percentage of Total Load that Is Latent Is Increasing





Latent and Sensible Loads for Homes

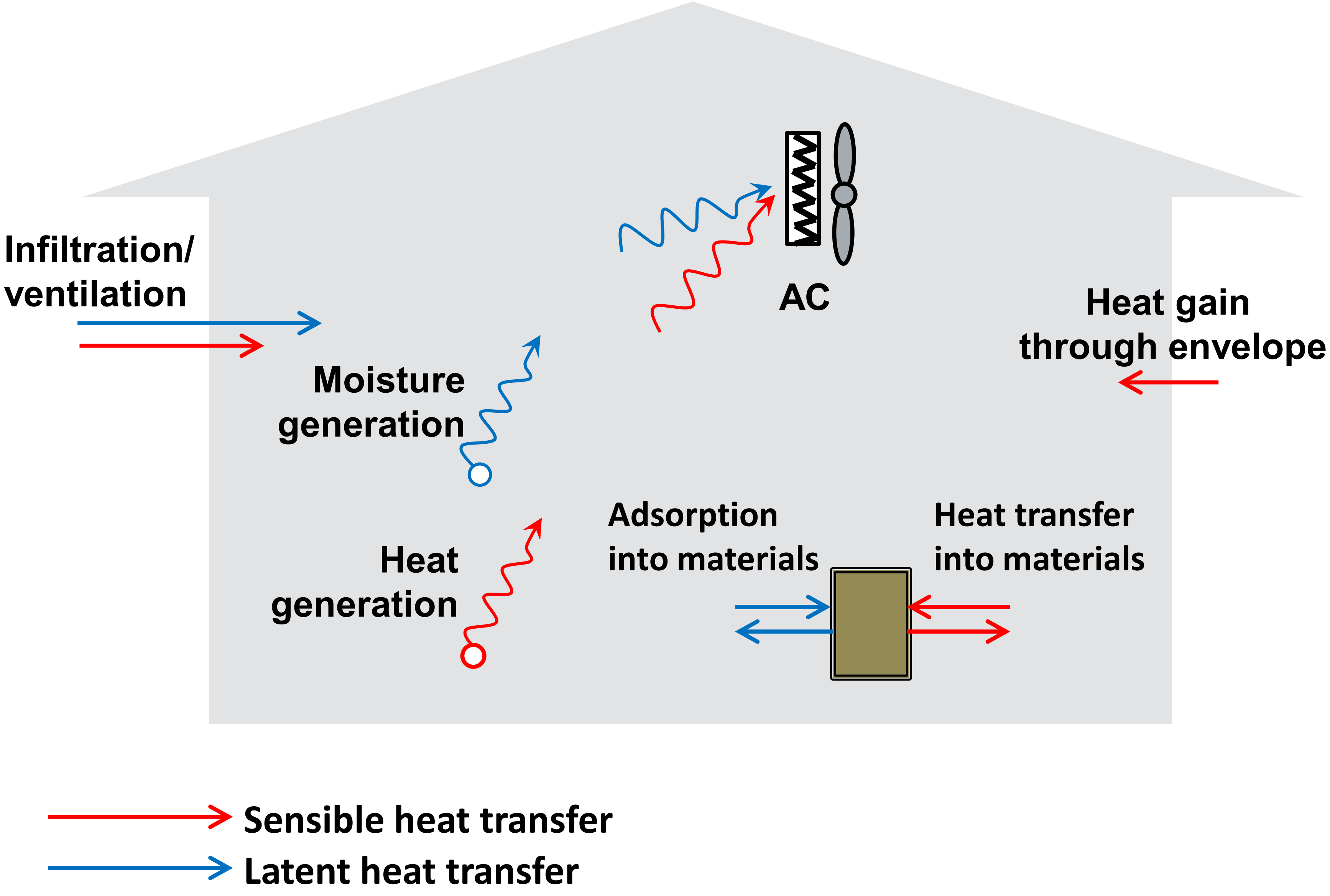
Envelope
- Window SHGC ●
- Wall/roof R-value ●

Infiltration/ventilation ● ●

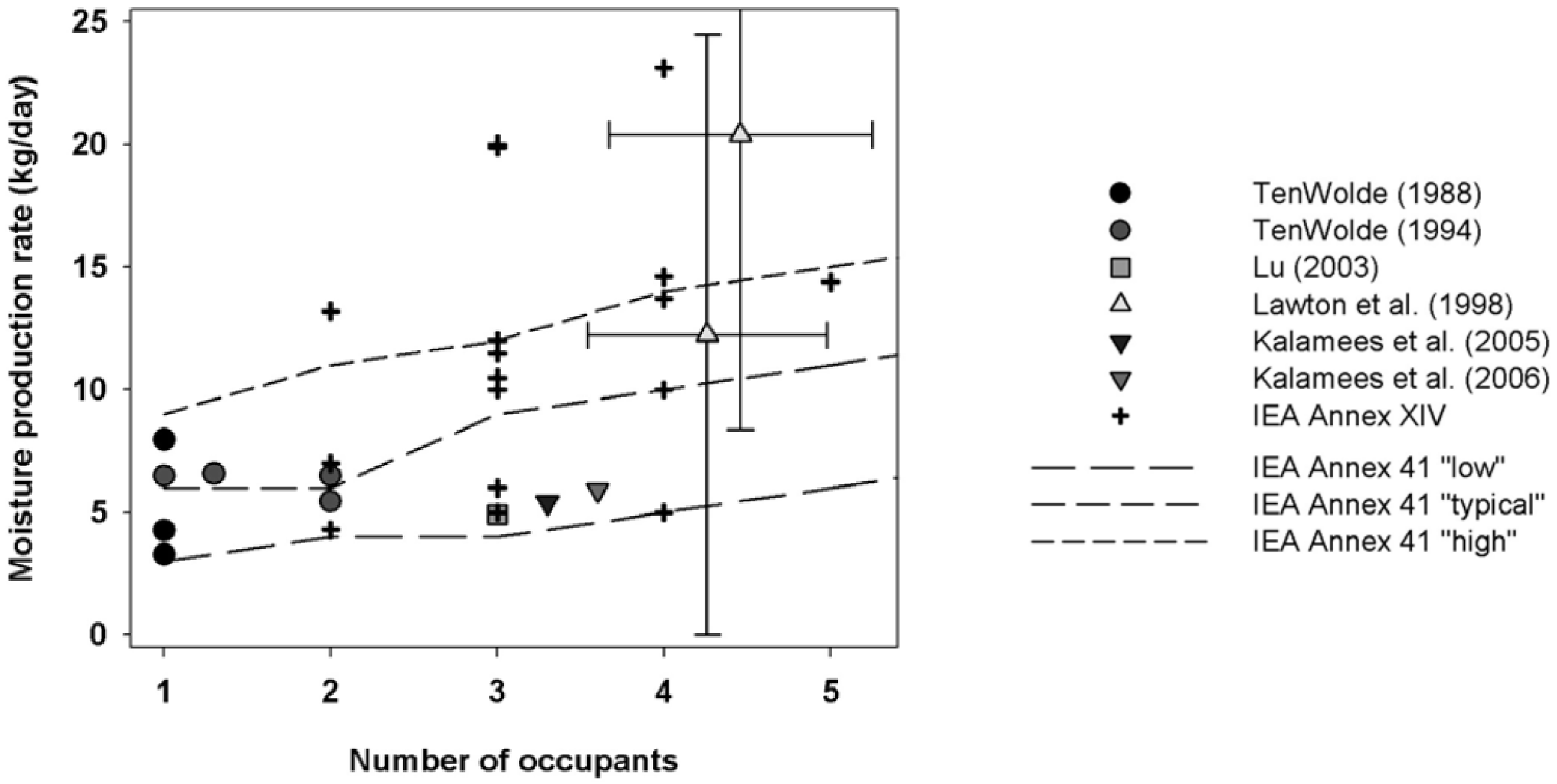
Level of furnishings ● ●

Air conditioner
- Blower off delay ●
- Sizing ●
- Indoor air flow rate ●

Occupants
- Internal gains ● ●
- Window shading ●
- Cooling set point ● ●



Internal Moisture Gains Are Highly Variable and Unknown



Glass, S. and A. TenWolde. 2009. *Review of Moisture Balance Models for Residential Indoor Humidity.*

Objectives

1. Characterizing the sensible and latent cooling loads of typical-construction homes and low-load homes
2. Evaluating the sensitivity of indoor humidity to variations in internal loads, window shading, and air conditioner cooling set point
3. Determining how air conditioner operation affects indoor humidity to guide equipment selection and setup for equipment installers and service technicians

- **Approach:** Utilize EnergyPlus simulation engine with stochastic occupant-related inputs to assess sensitivity on indoor humidity and cooling energy

Outline

- **Modeling approach and assumptions**
  - House model inputs and assumptions
  - Moisture buffering model
  - Air conditioner model
  - Stochastic approach to occupant behavior
- **Brief Q&A**
- **Results and discussion**
  - Sensible and latent cooling loads
  - Humidity sensitivity results
  - Cooling system design and controls impact on humidity
- **Conclusions**
- **Additional Q&A**

Modeling Approach and Assumptions

Envelope

- Window SHGC
- Wall/roof R-value

Infiltration/ventilation

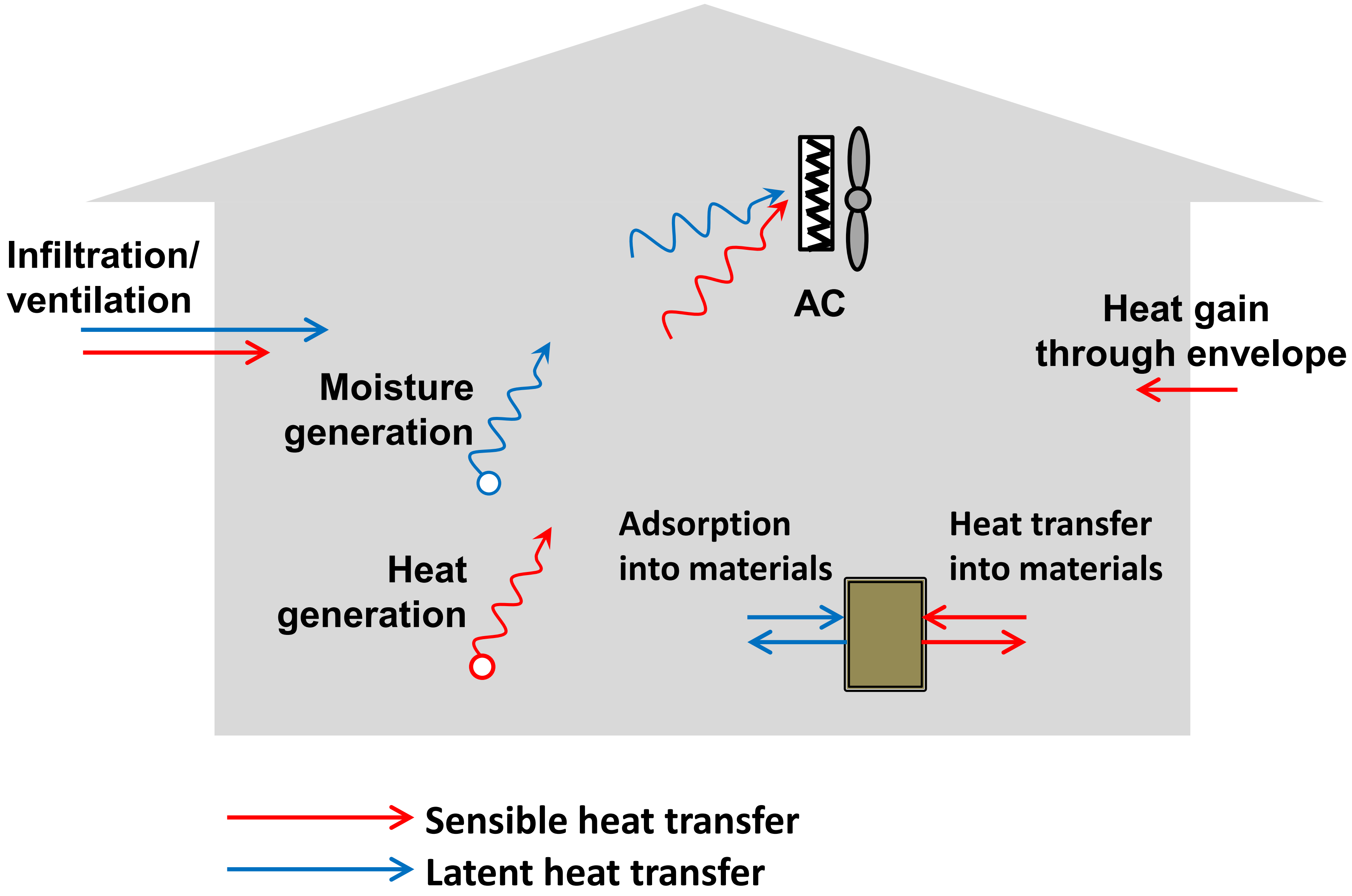
Level of furnishings

Air conditioner

- Blower off delay
- Sizing
- Indoor air flow rate

Occupants

- Internal gains
- Window shading
- Cooling set point



Envelope

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Infiltration/ventilation ● ●

Level of furnishings ● ●

Air conditioner

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Occupants

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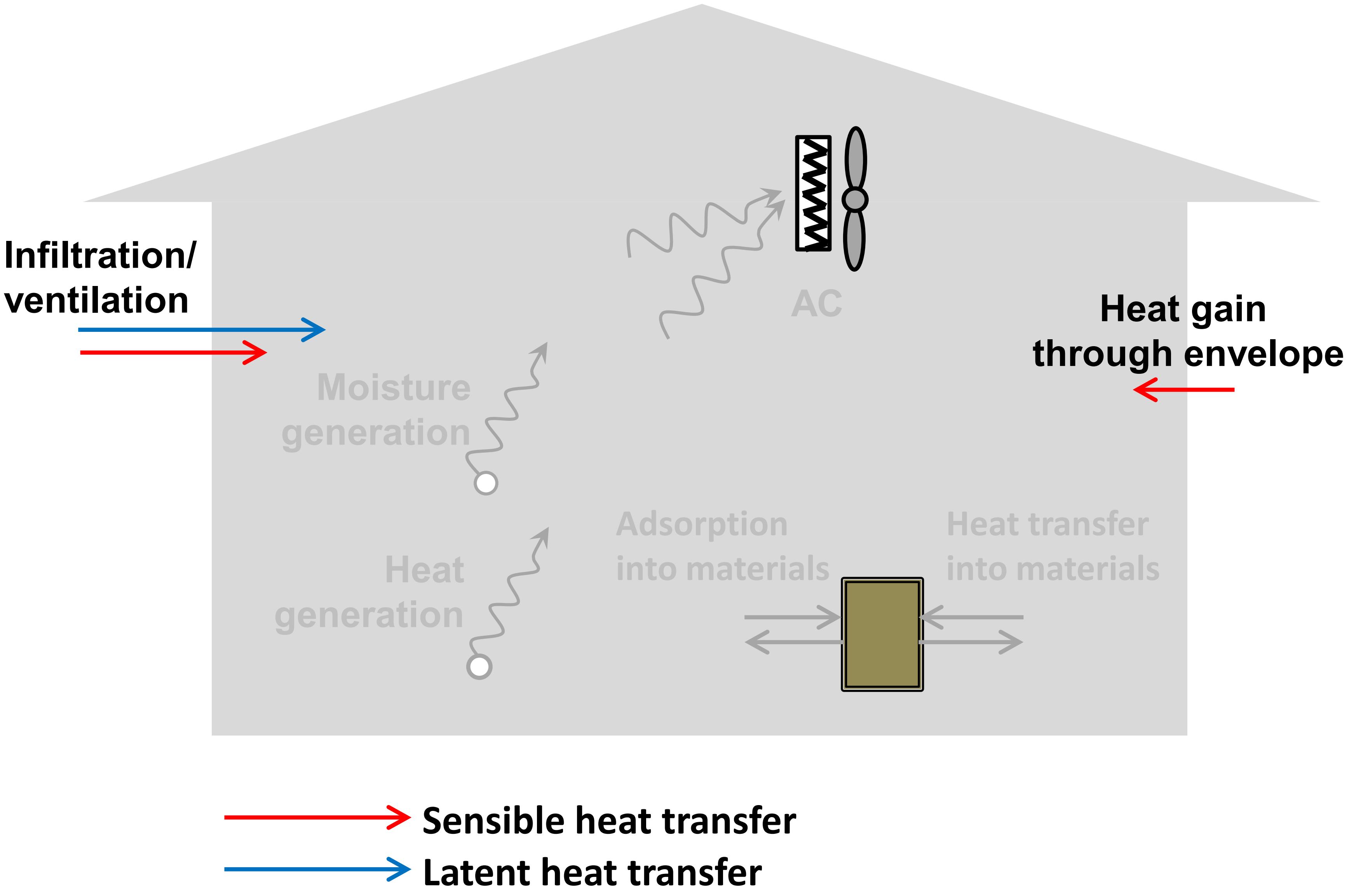
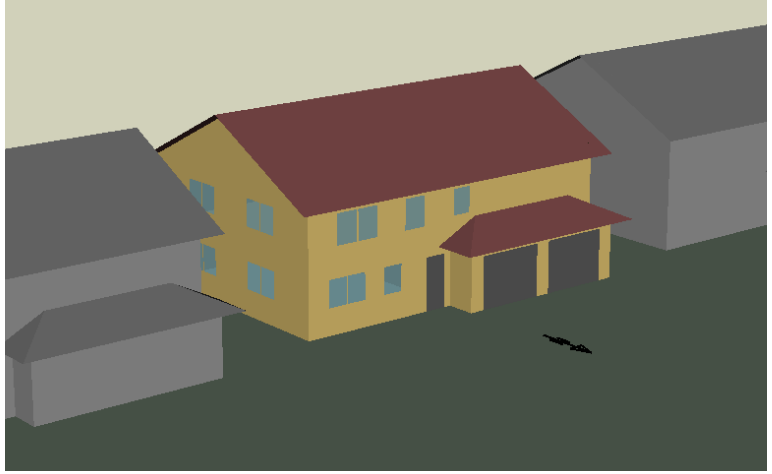
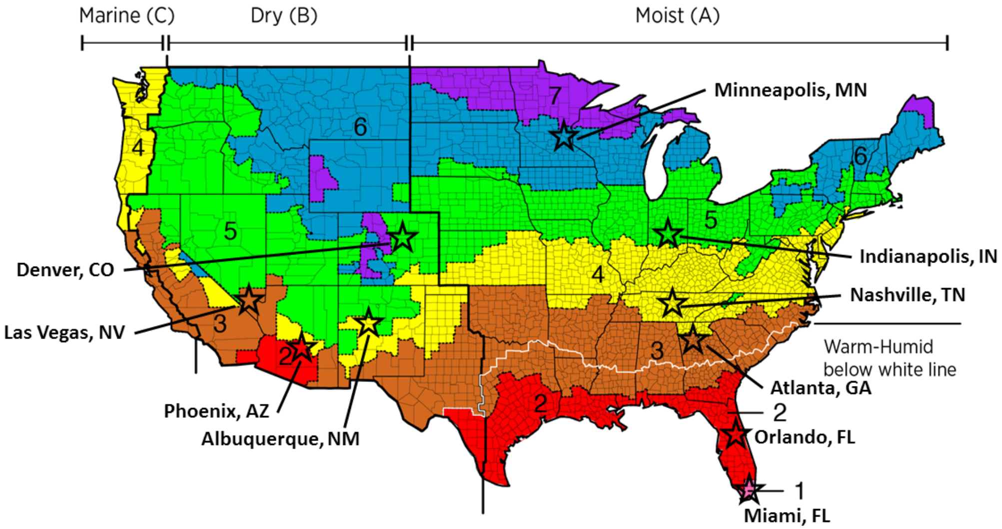


House Geometry and Climates





New construction; single family; 2,500 ft^2; 3 bed + 2 bath

- Construction inputs and foundation type varied based on climate
  - Houses in climate zones 1-3 were assumed to be slab-on-grade
- IECC 2009 home: standard efficiency based IECC 2009 requirements
  - Duct location was based on the Building America House Simulation Protocols (HSP)
  - Homes did not have whole-house mechanical ventilation
- Low-load home: high efficiency home based on DOE Zero Energy Ready requirements
  - Ducts were assumed to be located in conditioned space
  - Whole-house exhaust fan running continuously per ASHRAE 62.2-2013

Key House Construction Characteristics

IECC 2009 Home

City	Climate	Wall R-Value	Ceiling R-Value	ACH_{50}	Window U-Value	Window SHGC	Duct Location	Ventilation
Miami, FL	1	R-13	R-30	4.75	0.37	0.30	Attic	Spot vents per GIHM profiles
Orlando, FL	2							
Phoenix, AZ								
Atlanta, GA	3			4.6				
Las Vegas, NV								
Nashville, TN	4		R-38	4	0.35	0.44	Crawlspace	
Albuquerque, NM							Attic	
Indianapolis, IN	5	R-13+5					Basement	
Denver, CO								
Minneapolis, MN	6		R-49					

Low-Load Home

City	Climate	Wall R-Value	Ceiling R-Value	ACH_{50}	Window U-Value	Window SHGC	Duct Location	Ventilation
Miami, FL	1	R-13	R-30	3	0.37	0.25	Conditioned Space	ASHRAE 62.2 + Spot vents per GIHM profiles
Orlando, FL	2		R-38					
Phoenix, AZ								
Atlanta, GA	3	R-13+5		2.5	0.30	0.25		
Las Vegas, NV								
Nashville, TN	4		R-49		0.30	0.40		
Albuquerque, NM								
Indianapolis, IN	5			2	0.27	0.46		
Denver, CO								
Minneapolis, MN	6	R-13+10						

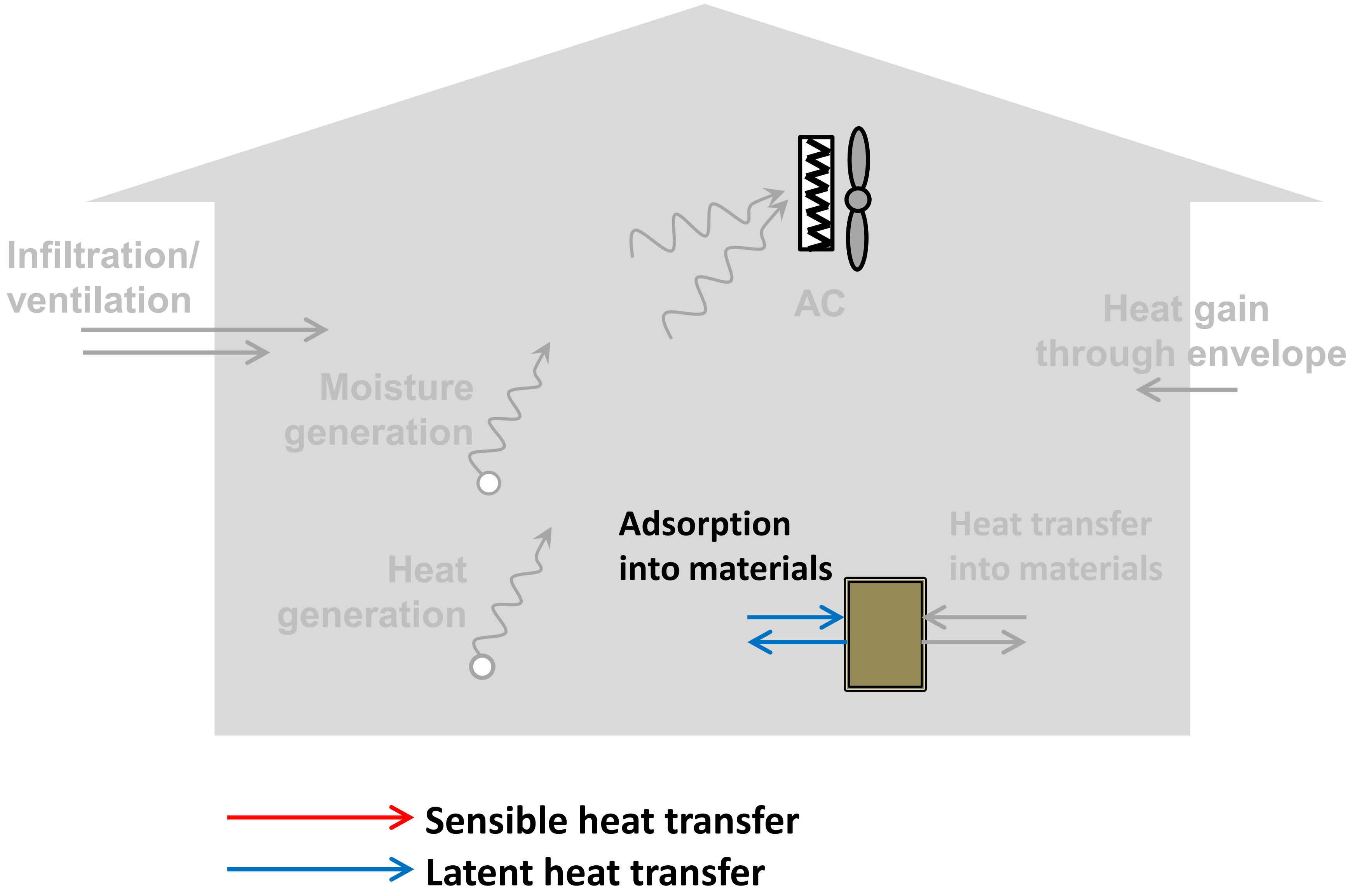
Envelope
- Window SHGC ●
- Wall/roof R-value ●

Infiltration/ventilation ● ●

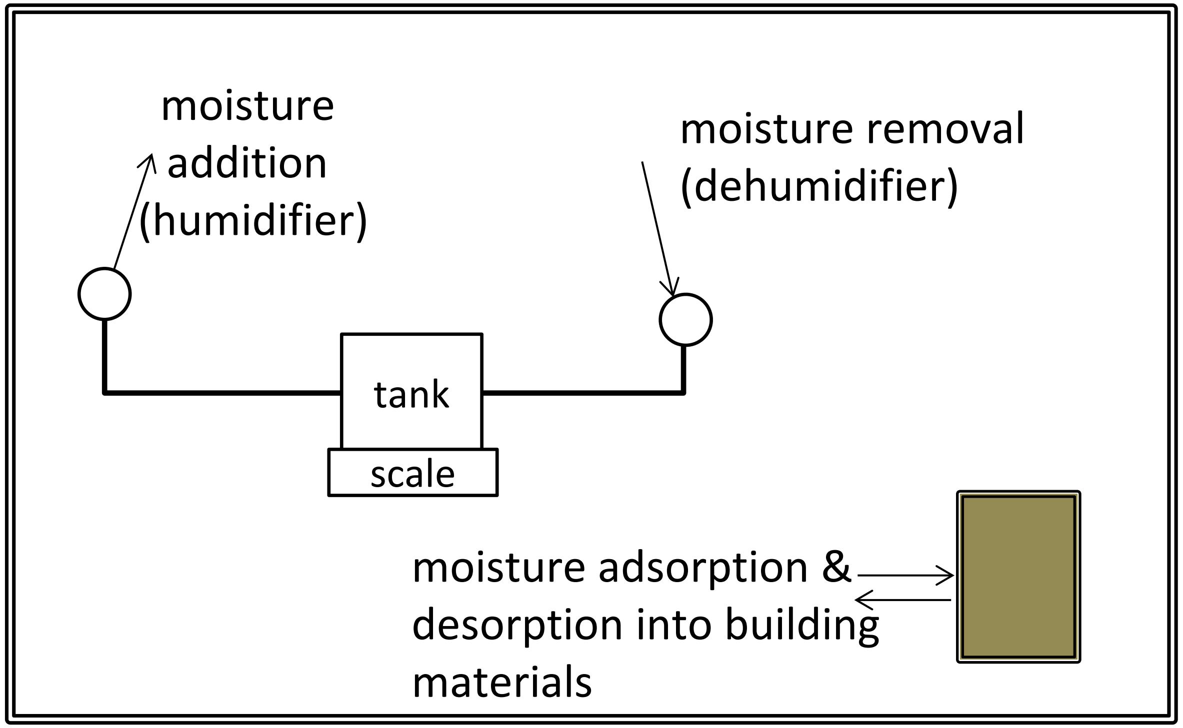
Level of furnishings ● ●

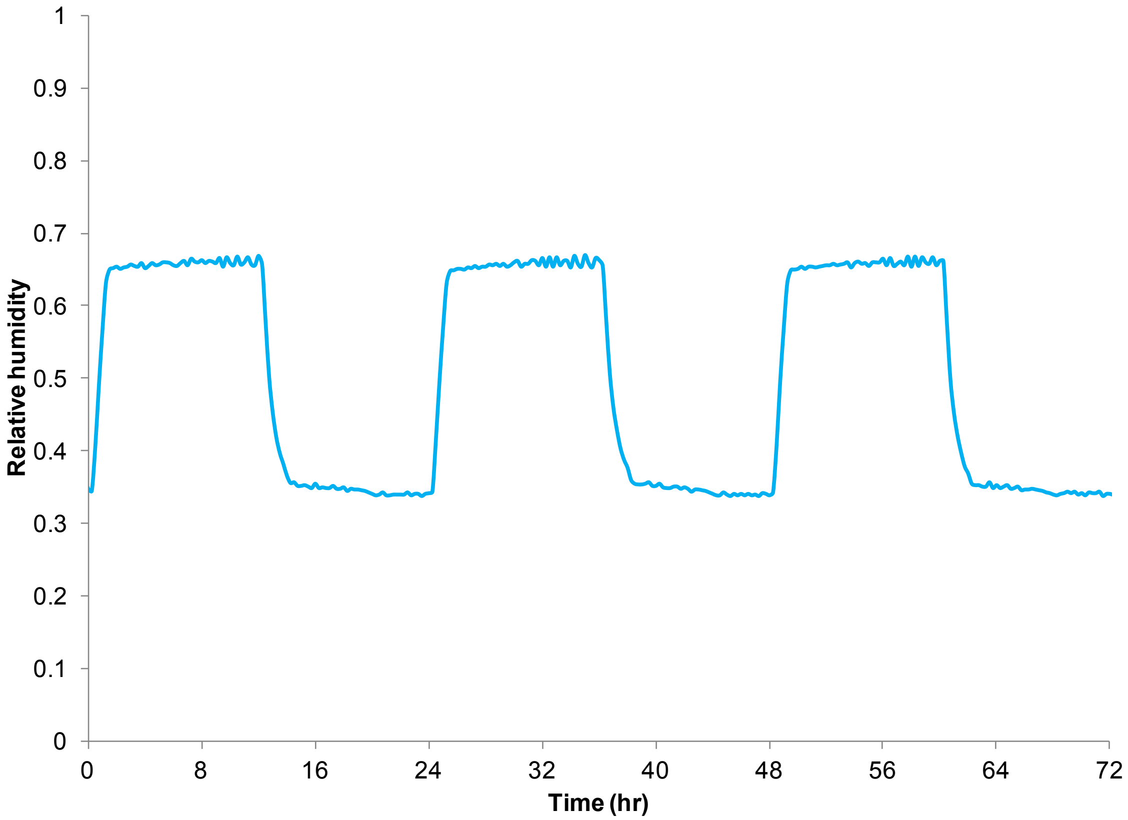
Air conditioner
- Blower off delay ●
- Sizing ●
- Indoor air flow rate ●

Occupants
- Internal gains ● ●
- Window shading ●
- Cooling set point ● ●

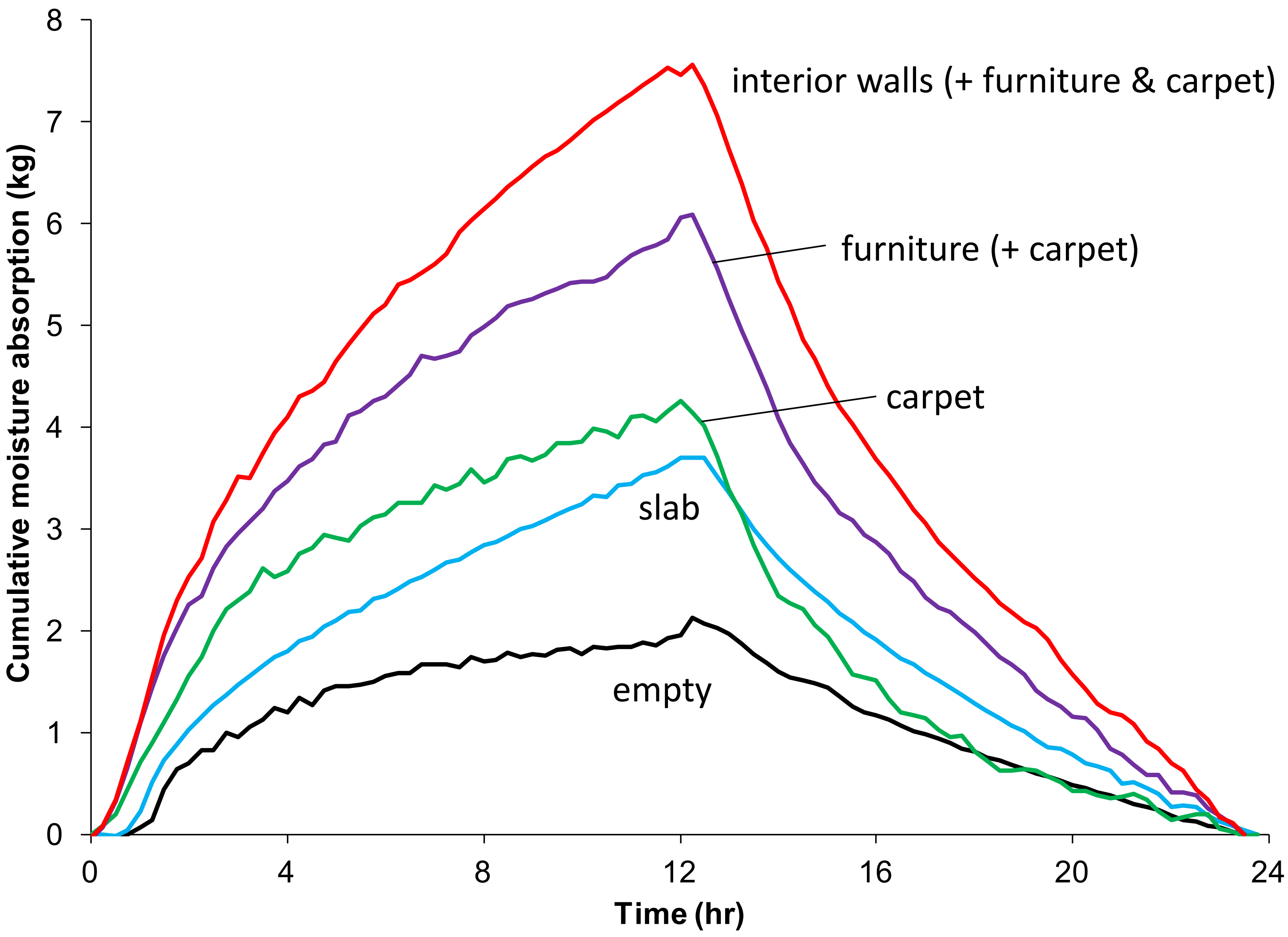


Moisture Buffering Field Tests



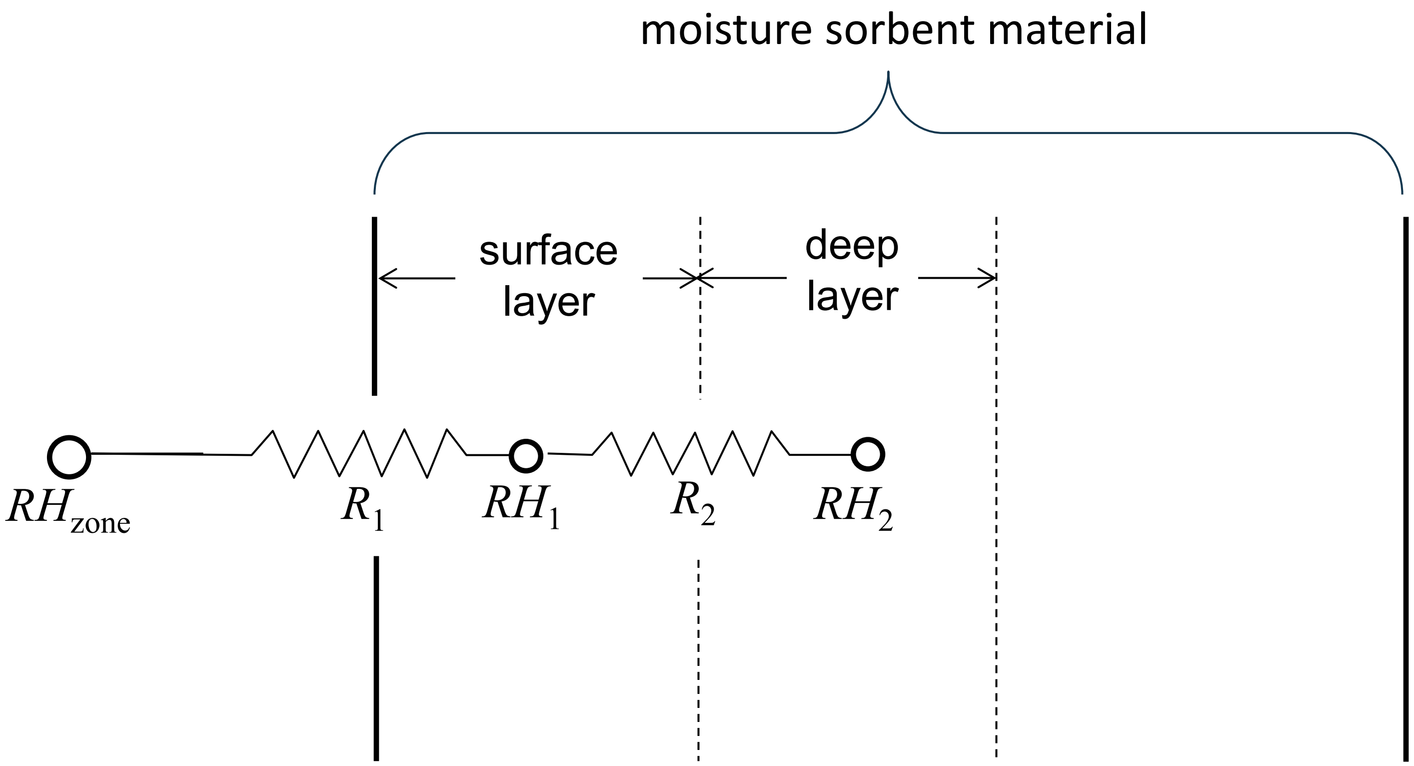


What Parts of a Home Adsorb Moisture?



Effective Moisture Penetration Depth Model

- Our building simulations use a **two-layer effective moisture penetration depth model** to account for moisture buffering in building materials.



Multiple Field Datasets Used to Validate Model

Ft. Wayne, IN

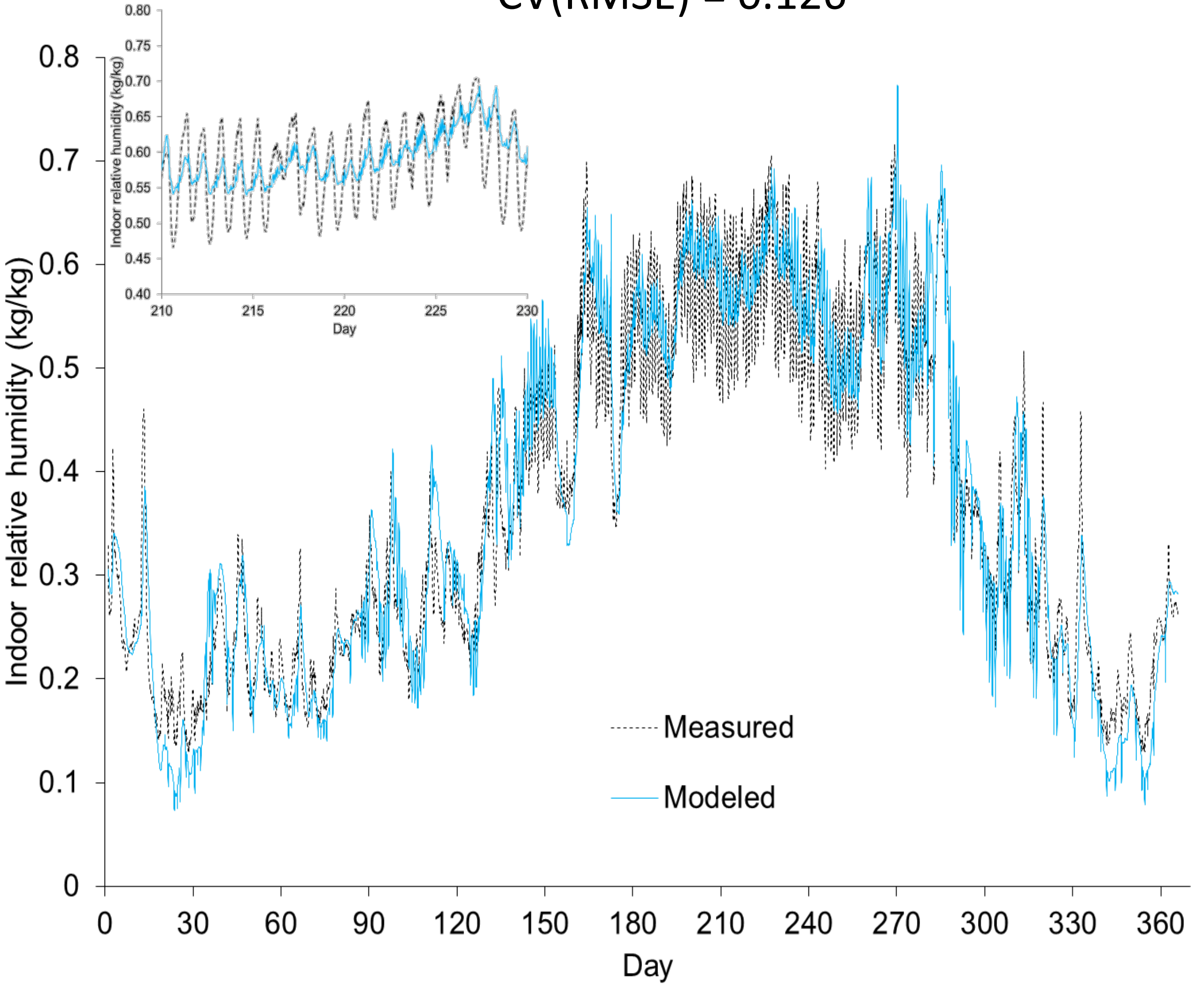
Stockton, CA

Stockton, CA

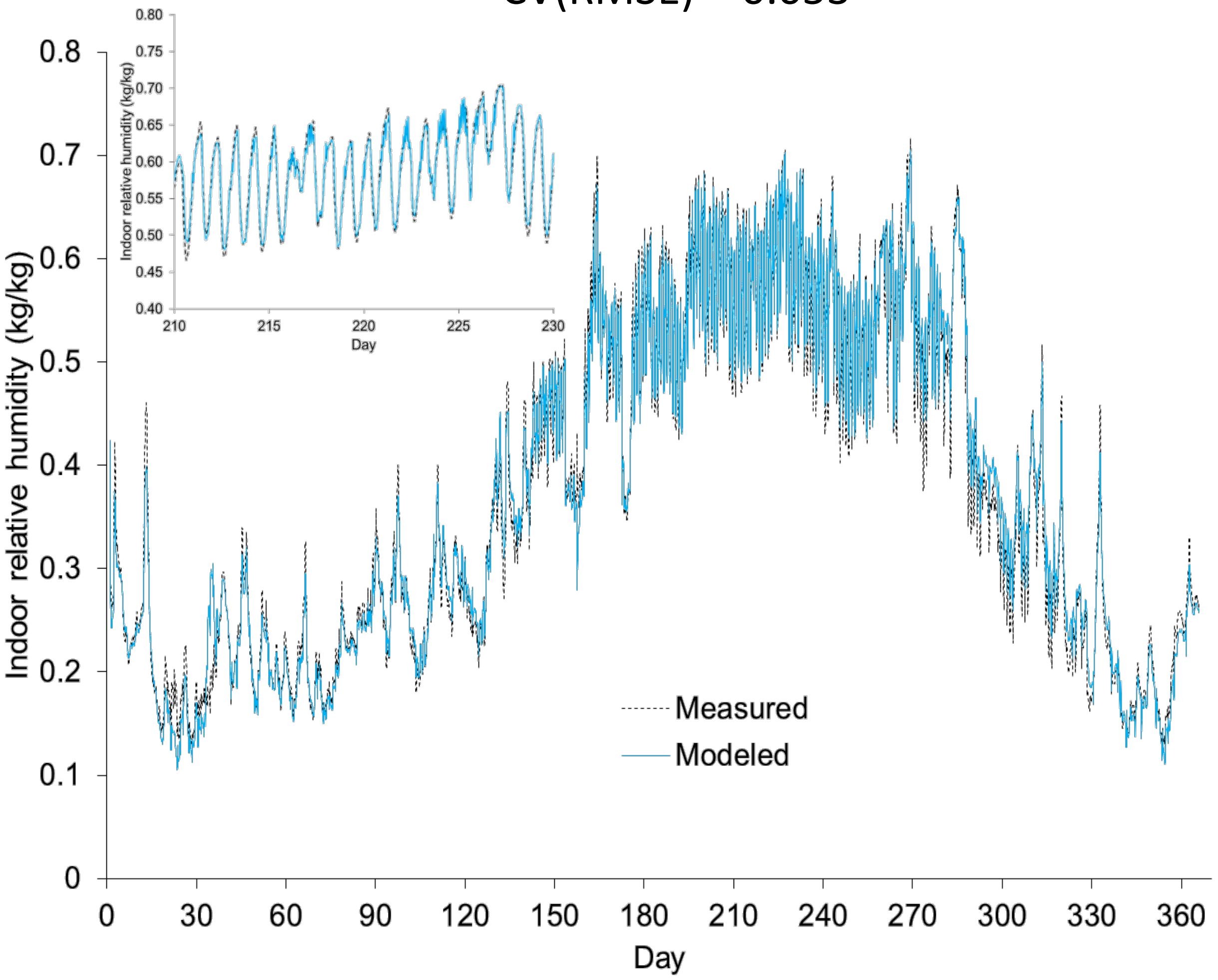
Cocoa, FL

Comparison of Model to Measured Data

Effective capacitance model
CV(RMSE) = 0.126



EMPD model
CV(RMSE) = 0.053



Moisture Buffering Levels

- **Three buffering levels were modeled to investigate sensitivity**

Buffering model input	Low	Baseline	High
Drywall to finished floor area multiplier (m^2/m^2)	2.04	2.92	3.80
Floor carpet fraction	0.3	0.6	0.9
Furniture to finished floor area multiplier (m^2/m^2)	0.25	0.75	2.25
Wood to finished floor area multiplier (m^2/m^2)	0.31	0.31	0.31

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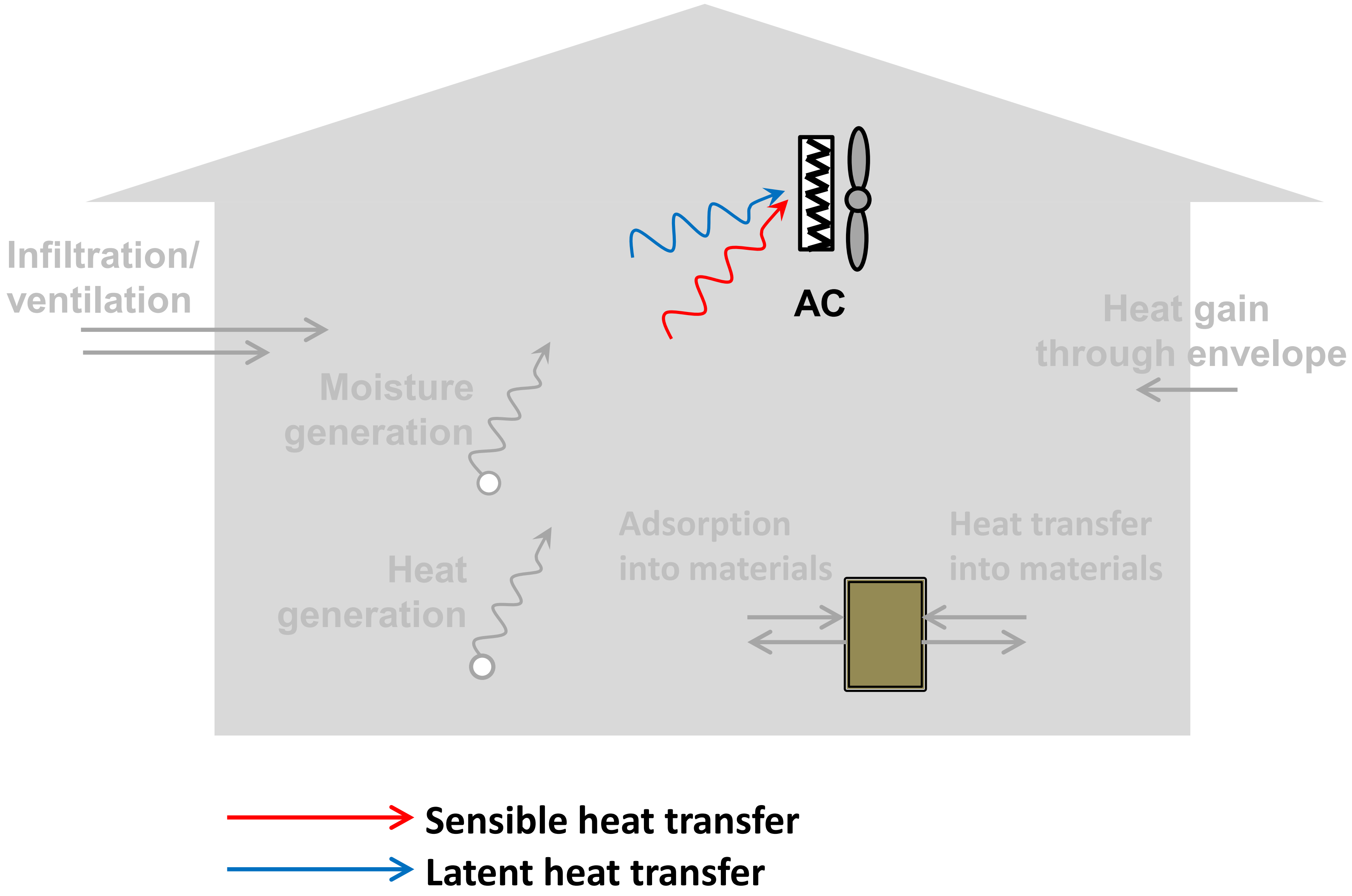


Space Conditioning Equipment Type

- **Type and efficiency of equipment for each house selected based on climate zone and efficiency level of home**

Climate Zone	City	IECC 2009 Home	Low-Load Home
1	Miami, FL	14 SEER/8.2 HSFP	18 SEER/9.3 HSPF
2A	Orlando, FL	14 SEER/8.2 HSFP	18 SEER/9.3 HSPF
2B	Phoenix, AZ	14 SEER/80% AFUE	18 SEER/80% AFUE
3A	Atlanta, GA	14 SEER/8.2 HSFP	18 SEER/9.3 HSPF
3B	Las Vegas, NV	14 SEER/80% AFUE	15 SEER/92.5% AFUE
4A	Nashville, TN	14 SEER/8.2 HSFP	18 SEER/9.3 HSPF
4B	Albuquerque, NM	13 SEER/80% AFUE	15 SEER/92.5% AFUE
5A	Indianapolis, IN	13 SEER/80% AFUE	15 SEER/95% AFUE
5B	Denver, CO	13 SEER/80% AFUE	15 SEER/95% AFUE
6	Minneapolis, MN	13 SEER/80% AFUE	15 SEER/95% AFUE

Space Conditioning Equipment

- **Evaluate the impact of 3 design/setup parameters**
  - Equipment sizing
  - Blower airflow rate
  - Blower-off delay

Air Conditioner Sizing

- **Based on ACCA Manual J**
- **2x**
- **Effects of oversized equipment**
  - Increased cycling
    - Reduced efficiency
    - Increased latent degradation associated with blower-off delay
  - Reduced runtime
    - Decreased duct conduction losses

Air Conditioner Blower Air Flow Rate

- **High = 450 cfm/ton**
- **Baseline = 400 cfm/ton**
- **Low = 350 cfm/ton**

<u>Increase in cfm/ton results in:</u>

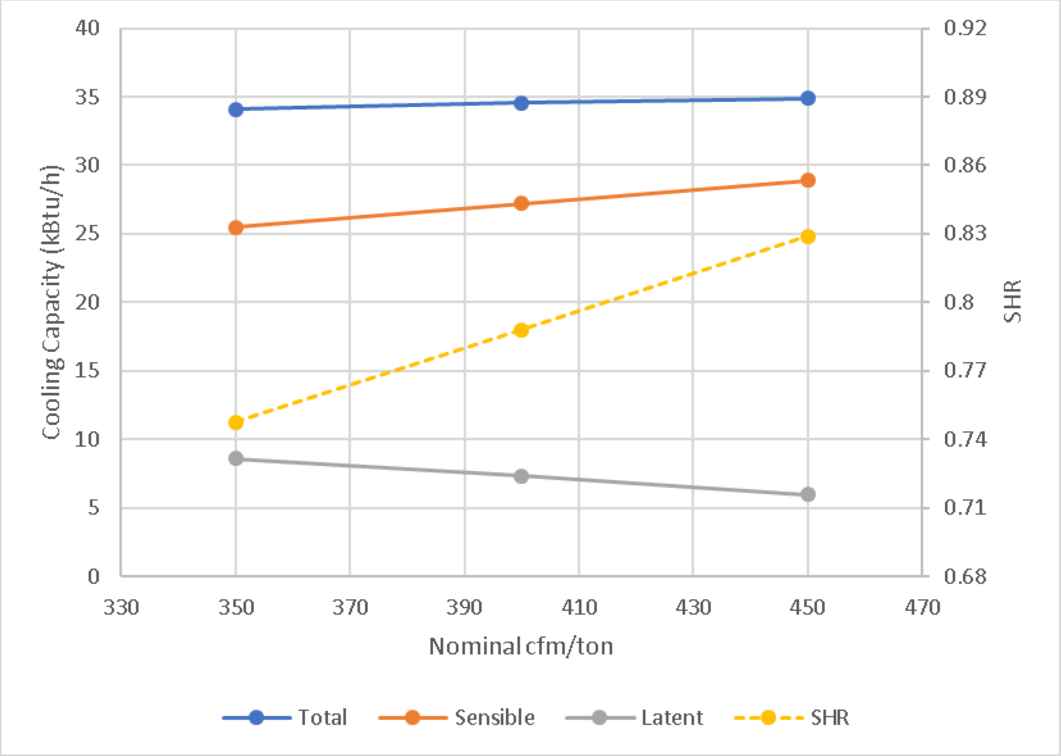
-Decrease in latent capacity

-Increase in sensible capacity

-Increase in sensible heat ratio (SHR)

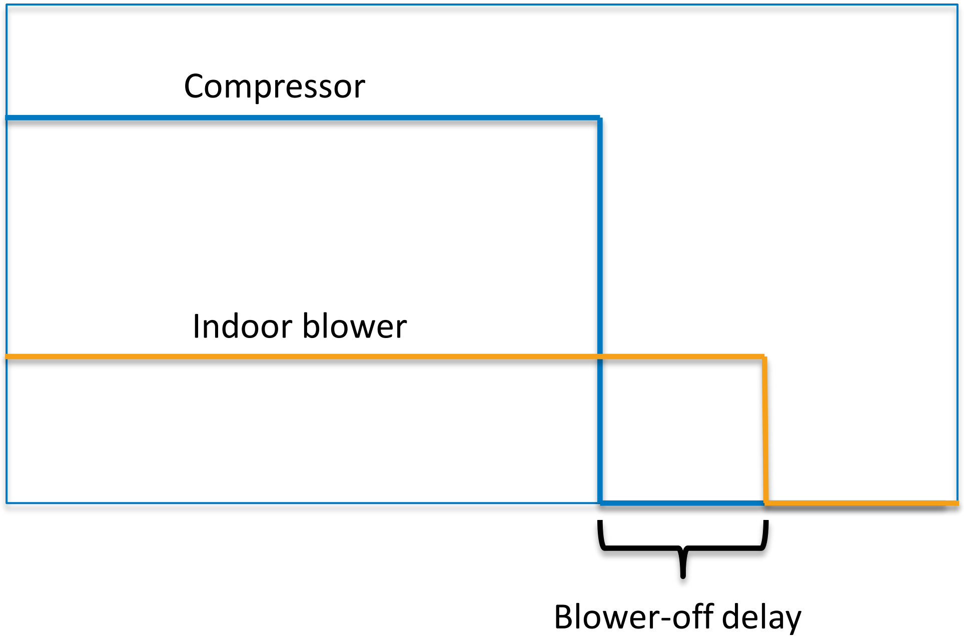
Manufacturer's Performance Data

EVAPORATOR AIR CFM	EWB °F (°C)	75 (23.9) Capacity MBtuh Total	75 (23.9) Capacity MBtuh Sens‡	75 (23.9) Total System KW**	85 (29.4) Capacity MBtuh Total	85 (29.4) Capacity MBtuh Sens‡
1050	72 (22.2)	40.58	21.42	2.31	38.93	20.83
	67 (19.4)	37.70	26.94	2.31	36.20	26.34
	63 (17.2)††	35.48	26.09	2.32	34.08	25.48
	62 (16.7)	34.87	32.22	2.32	33.53	31.59
	57 (13.9)	34.27	34.27	2.33	33.16	33.16
1200	72 (22.2)	40.97	22.55	2.37	39.26	21.96
	67 (19.4)	38.15	28.79	2.37	36.60	28.19
	63 (17.2)††	35.99	27.83	2.38	34.54	27.22
	62 (16.7)	35.60	35.60	2.38	34.41	34.41
	57 (13.9)	35.56	35.56	2.38	34.36	34.36
1350	72 (22.2)	41.20	23.64	2.43	39.44	23.04
	67 (19.4)	38.46	30.60	2.43	36.86	29.99
	63 (17.2)††	36.36	29.53	2.43	34.86	28.90
	62 (16.7)	36.61	36.61	2.43	35.33	35.33
	57 (13.9)	36.57	36.57	2.43	35.29	35.29



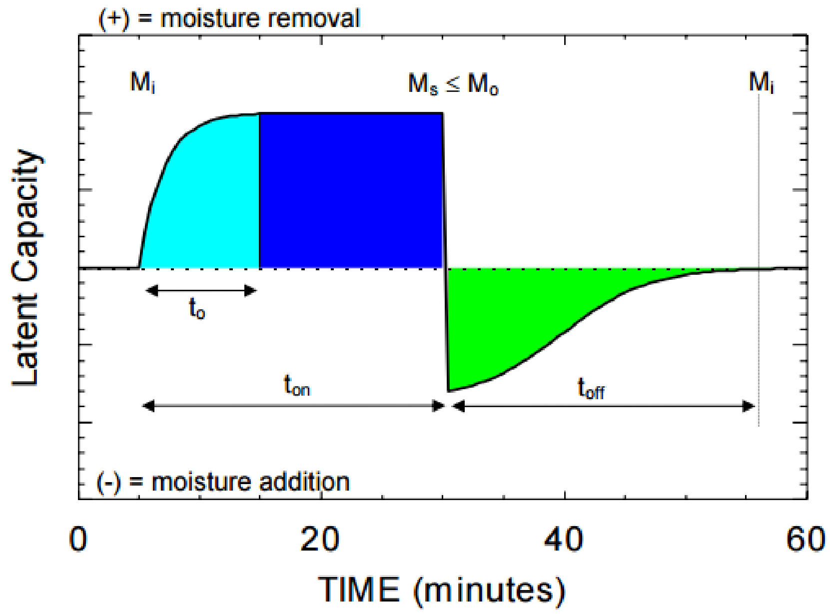
Air Conditioner Blower-Off Delay

- High = 90 s
- Med = 45 s
- Low = 0 s
- Continuous Fan



<u>During the blower-off delay:</u>

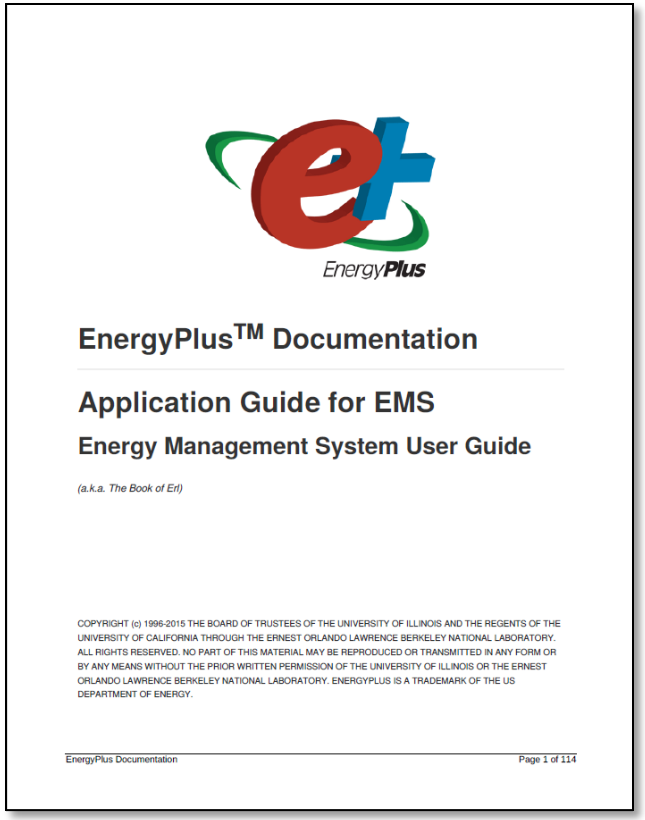
- Evaporative cooling due condensate evaporation
- Sensible cooling
- Negative latent cooling



Shirey, D. B., III, Henderson, H. I., III, and Raustad, R. A. 2006. Understanding the Dehumidification Performance of Air-Conditioning Equipment at Part-Load Conditions. FSEC-CR-1537-05.

Air Conditioner Blower-Off Delay

- **EnergyPlus does not natively support blower-off delay latent degradation calculations**
- **Used EMS program**
- **Adds moisture and sensible cooling due to evaporation during blower-off delay and off-cycle**
  - Fan "off" airflow rate assumed to be 0.1% of fan "on" airflow to account for natural convection



EnergyPlus

EnergyPlus™ Documentation

Application Guide for EMS

Energy Management System User Guide

(a.k.a. The Book of Erl)

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FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

Understanding the Dehumidification Performance of Air-Conditioning Equipment at Part-Load Conditions

Final Report
FSEC-CR-1537-05

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Hugh I. Henderson, Jr.
Richard A. Raustad

January 2006

DOE/NETL Project No. DE-FC26-01NT41253

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Envelope
- Window SHGC ●
- Wall/roof R-value ●

Infiltration/ventilation ● ●

Level of furnishings ● ●

Air conditioner
- Blower off delay ●
- Sizing ●
- Indoor air flow rate ●

Occupants
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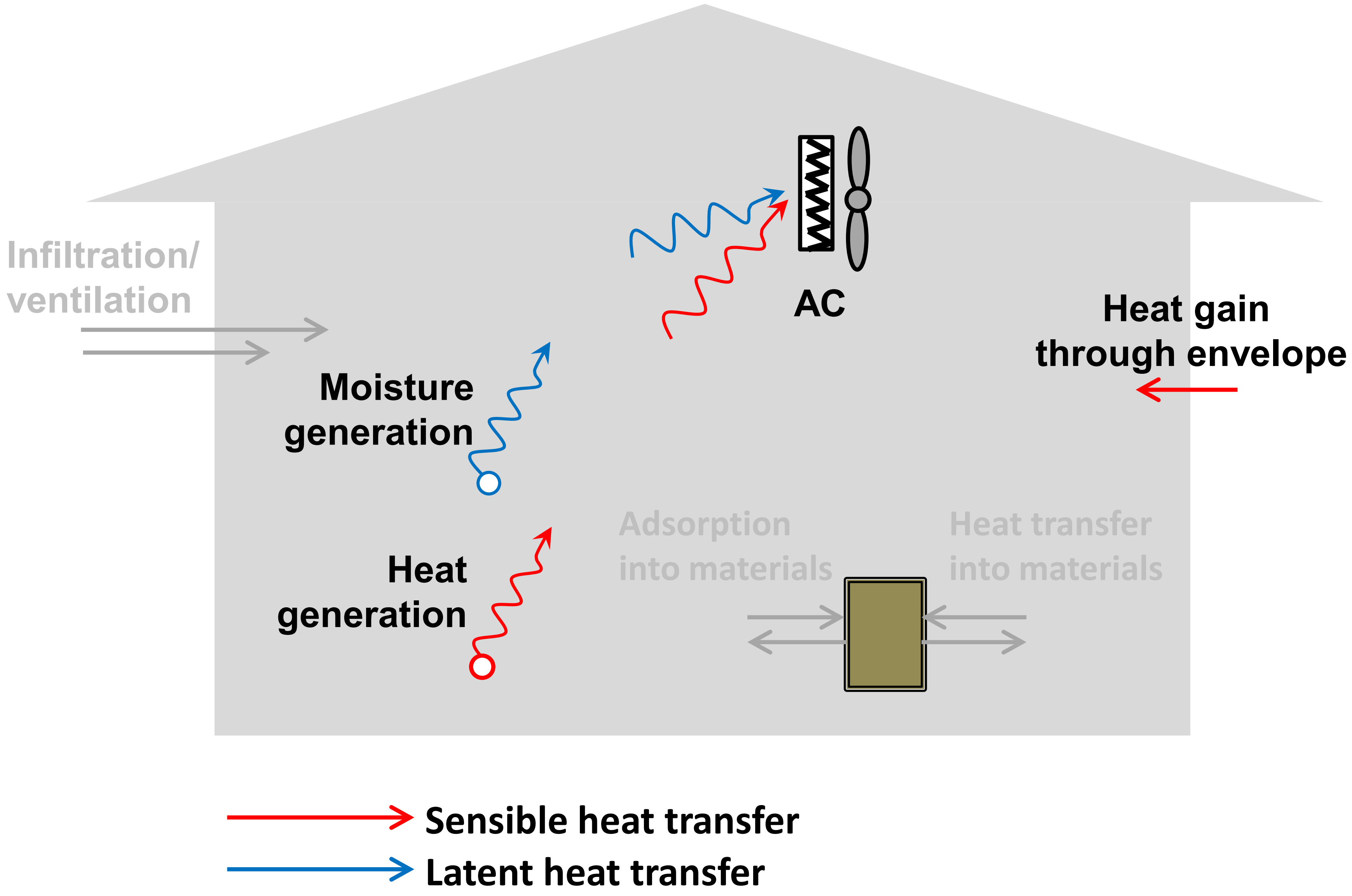
- Window shading ●
- Cooling set point ● ●

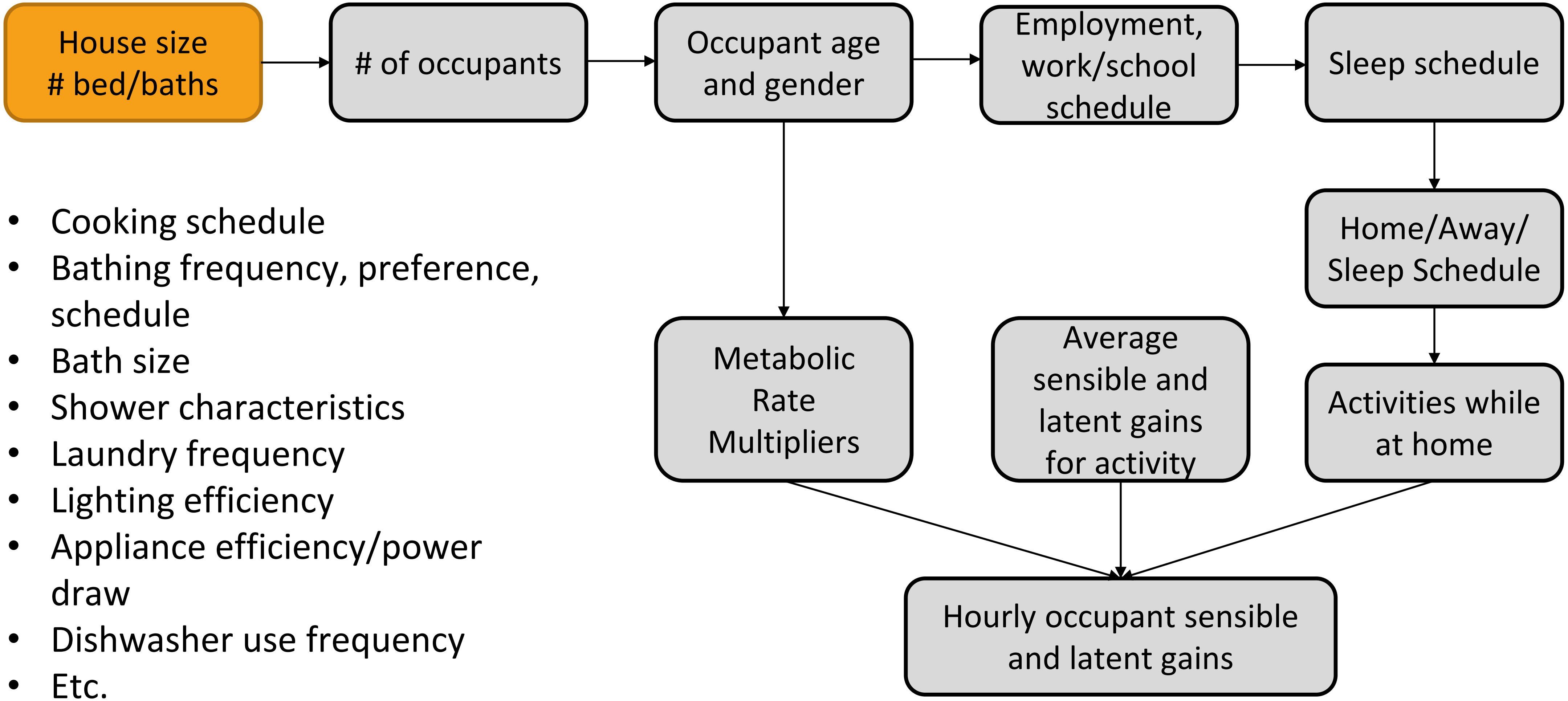


Occupancy and Internal Gains

- **The number of occupants and occupant behavior can have a large effect on the sensible and latent internal gains**
- **National average internal gain profiles do not provide any insight into how indoor humidity varies due to different occupancy**
- **Generation of Indoor Heat and Moisture (GIHM) tool developed at ORNL**
  - Developed to evaluate envelope moisture durability risks
  - Similar to Building America Domestic Hot Water Generator for internal loads

GIHM Tool

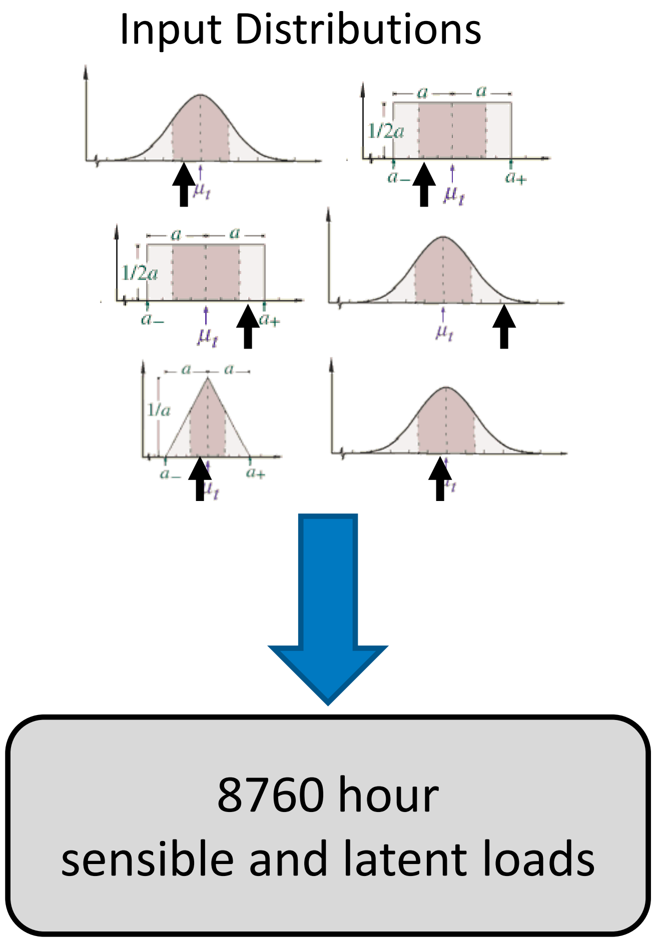
Example data flow for determining hourly sensible and latent gains for occupants



- Cooking schedule
- Bathing frequency, preference, schedule
- Bath size
- Shower characteristics
- Laundry frequency
- Lighting efficiency
- Appliance efficiency/power draw
- Dishwasher use frequency
- Etc.

GIHM Tool, cont.

- **Data sources**
  - Residential Energy Consumption Survey
  - Bureau of Labor and Statistics
  - American Time Use Survey
  - Census data
  - House Simulation Protocol
  - ASHRAE Fundamentals Handbook
  - In-house experiments
  - Others
  - Engineering judgement



Internal Gain Profiles

- **Used GIHM tool to generate 200 internal gain profiles for a ~2500 sq. ft. house with 3 bedrooms and 2 bathrooms**

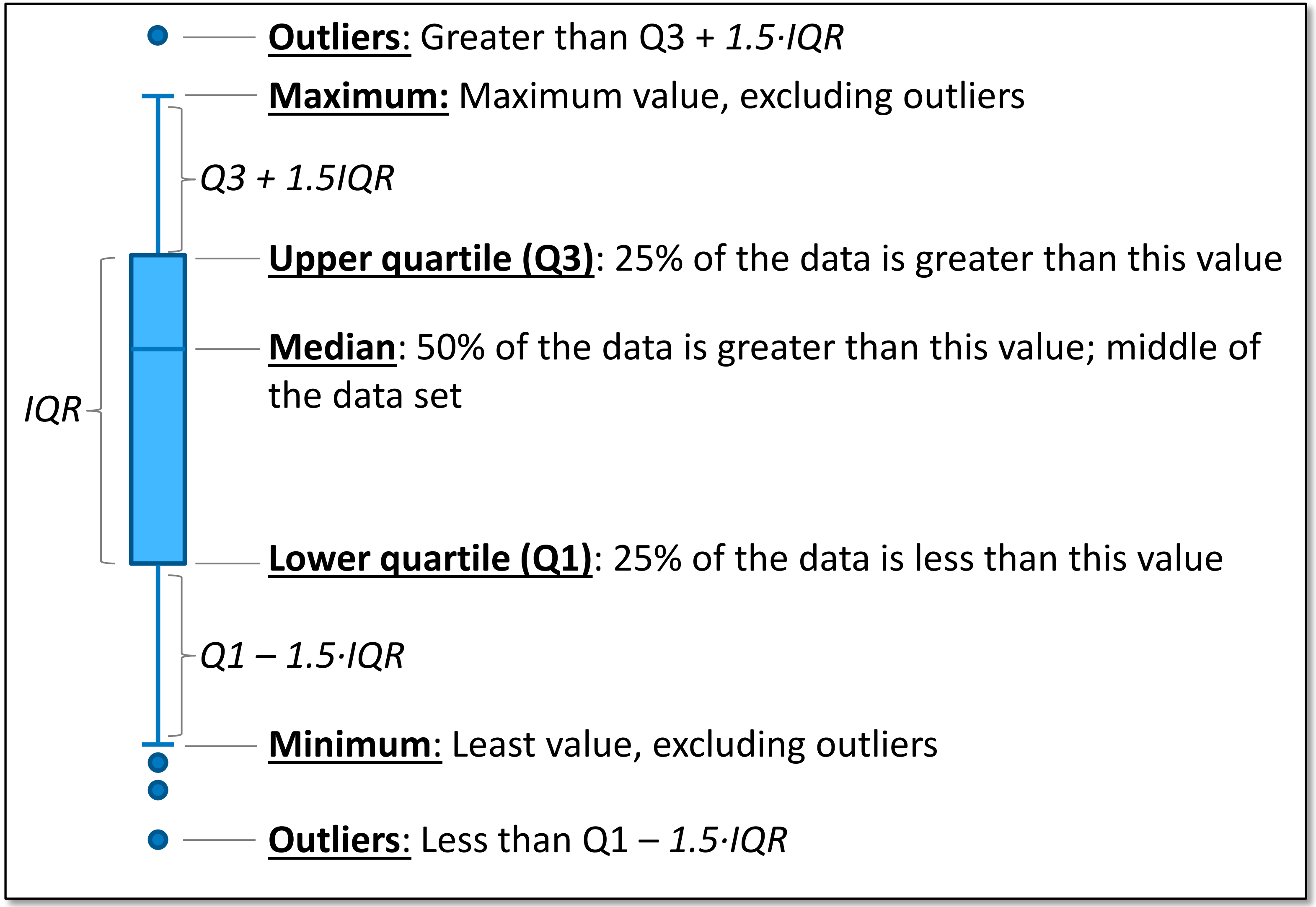
Number of Occupants (% of Profiles)	Avg. Latent Load (lb/day)	IECC 2009 Home Avg. Sensible Load (kWh/day)	Low-Load Home Avg. Sensible Load (kWh/day)
1 (5.8%)	7.5	12.3	10.4
2 (26.0%)	12.0	14.6	12.6
3 (21.4%)	15.9	16.3	14.3
4 (24.3%)	19.5	18.0	16.1
5 (12.1%)	22.8	19.5	17.7
6 (10.4%)	25.9	21.2	19.2

- **Low-load home included more efficient lighting and appliances**
- **Building America House Simulation Protocol loads for 3 occupants**
  - Sensible = 18.0 kWh/day
  - Latent = 12.2 lb/day

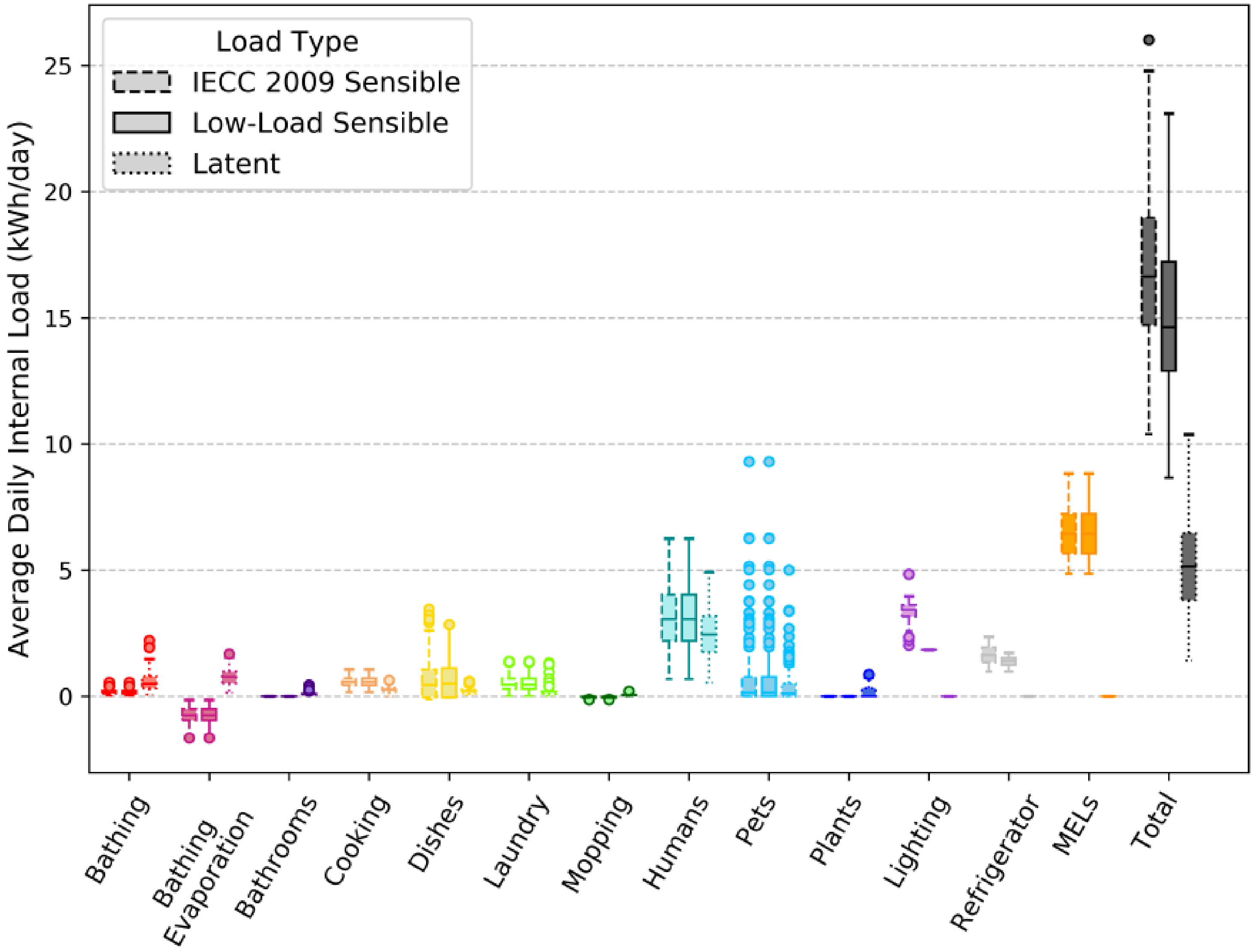
Box and Whisker Plot Introduction

Box-and-whisker plot is a method of displaying a distribution of data

- **Key quantities:**
  - Median
  - Lower quartile
  - Upper quartile
  - Interquartile range (IQR)
  - Lower whisker value
  - Upper whisker value
  - Outliers

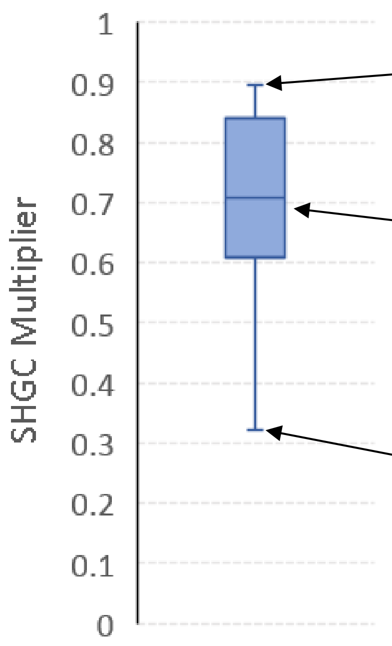


Occupant Internal Gains



Window Shading

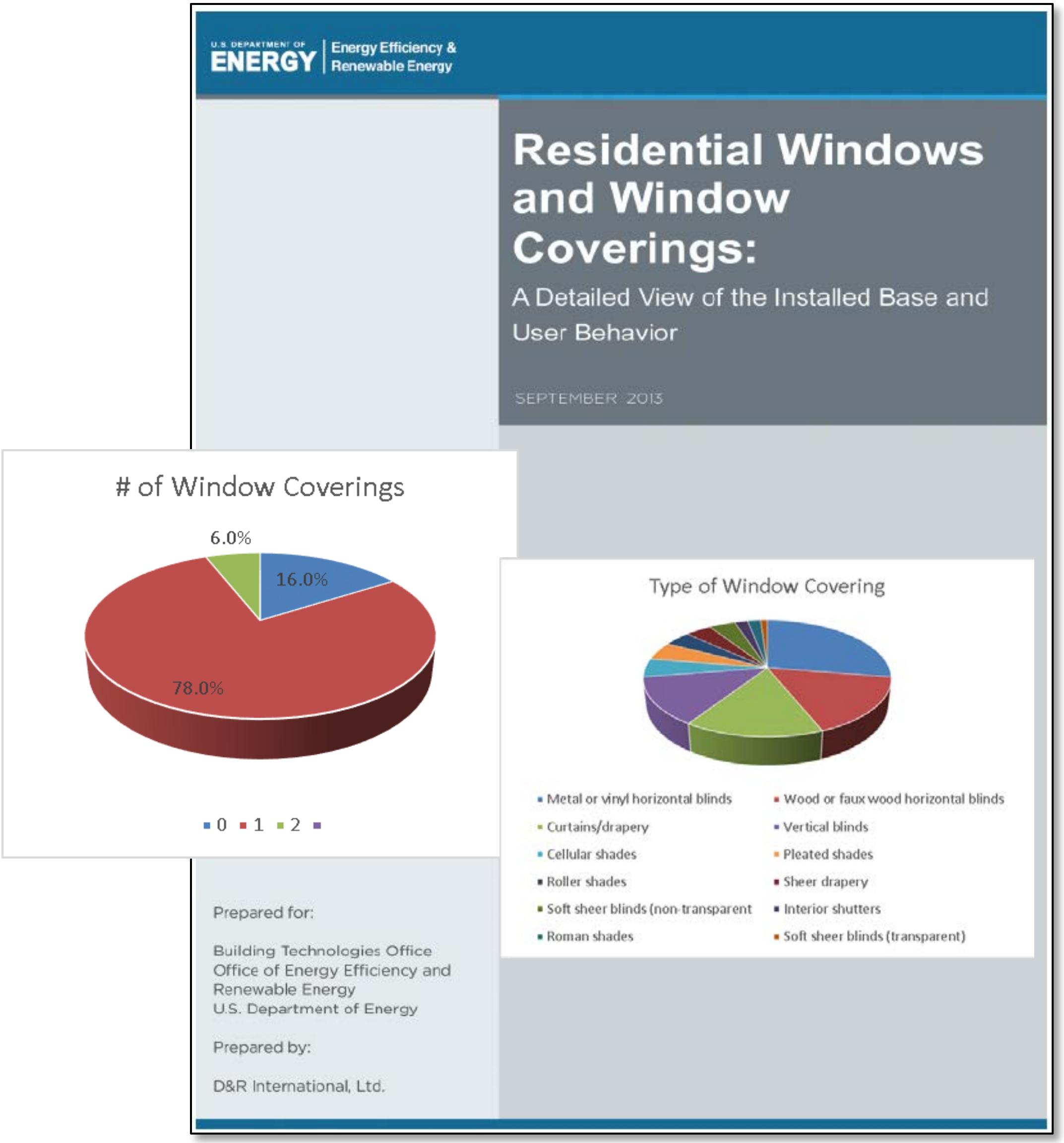
- **Used solar heat gain coefficient (SHGC) multiplier**
- **Multiplier determined for each house**
  - No seasonal or daily variations



Exterior insect screens only (no internal shading)

Building America HSP year-round assumption = 0.7

Closed light-colored horizontal blinds + closed interior shutters + exterior insect screens

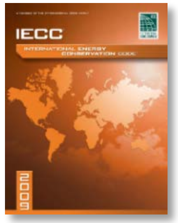


Cooling Set Point

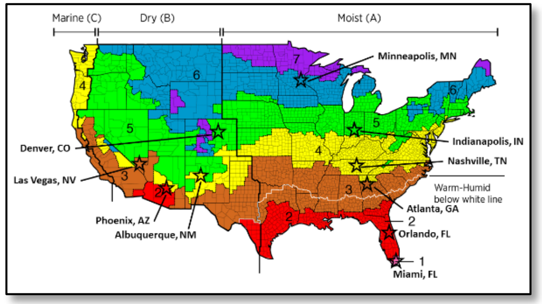
- **Three air conditioner cooling set points were investigated**
  - 22.2°C (72°F)
    - According to EIA RECS data, 46% of homes maintain a cooling set point at or below 22.2°C (72°F)
  - 23.9°C (75°F)
    - Baseline value based on ACCA Manual J
  - 25.6°C (78°F)
    - According to EIA RECS data, 22% of homes maintain a cooling set point at or above 25.6°C (78°F)
- **Constant heating set point of 21.1°C (70°F) was assumed**

Simulation Study Overview

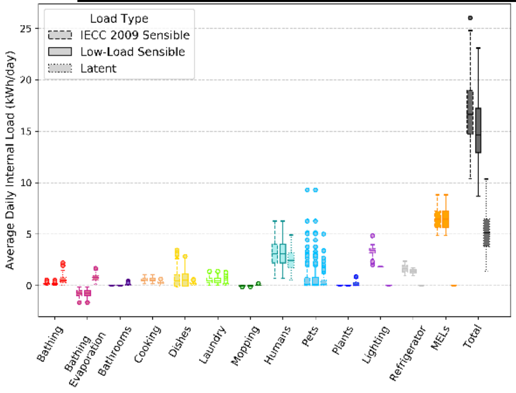
2 Efficiency Levels (IECC 2009 & Low-Load)

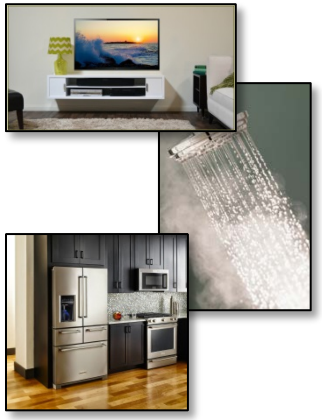


6 Climate Regions (10 cities)



200 Stochastic Internal Gain Profiles

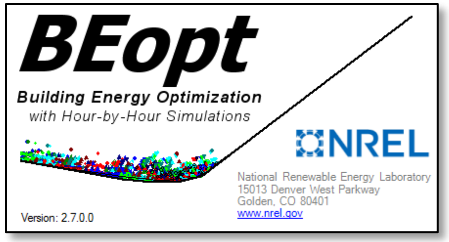




Simulation Cases

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

EnergyPlus Simulations



EnergyPlus

Simulation Outputs

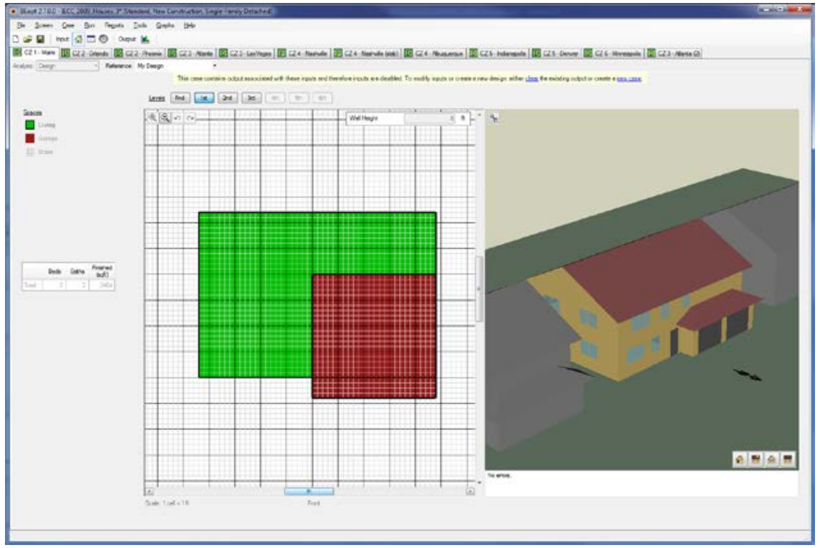
- Sensible and latent cooling loads
- Indoor humidity
- Cooling energy use

Simulation Cases

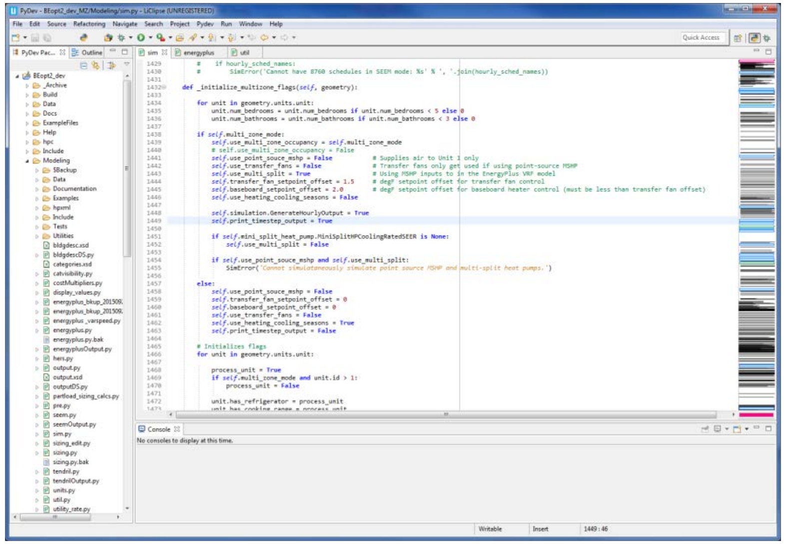
- **Parameters were individually varied to assess sensitivity on indoor humidity and cooling energy use**
  - Baseline values were used for other building characteristics
- **Stochastic internal gain profiles and interior window shading were used for all cases**

Building Characteristic	Low	Baseline	High
Internal gains	200 stochastic simulations		
Interior window shading	200 stochastic simulations		
Moisture buffering	Low	Medium	High
Cooling set point (°C)	22.2	23.9	25.6
Equipment sizing	Manual J		2x
Blower air flow rate (cfm/ton)	350	400	450
Blower-off delay (s)	0	45	90

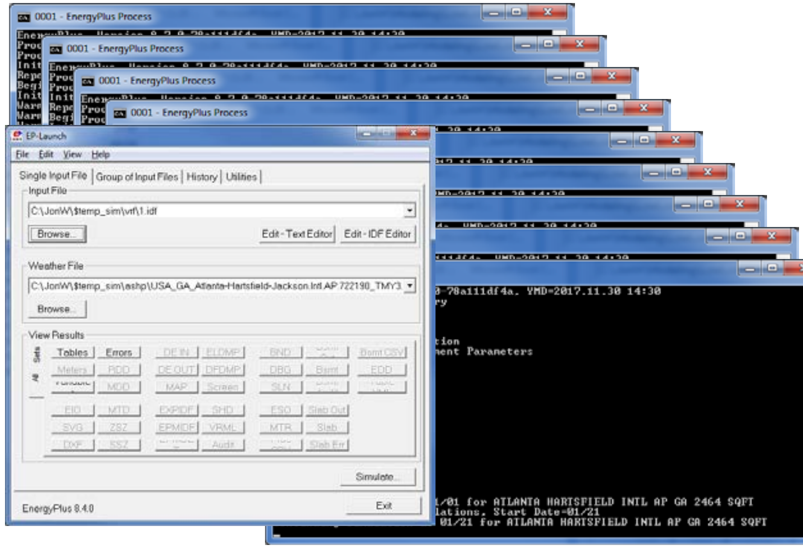
BEopt/EnergyPlus Simulation Workflow



1. Develop BEopt model; export BEopt XML files



2. Execute python scripts to generate EnergyPlus input files using internal gain profile schedule files



3. Run group of EnergyPlus simulation in parallel on workstation

Brief Q&A on Modeling Approach and Assumptions

Results – Building Cooling Loads

Sensible and Latent Cooling Loads

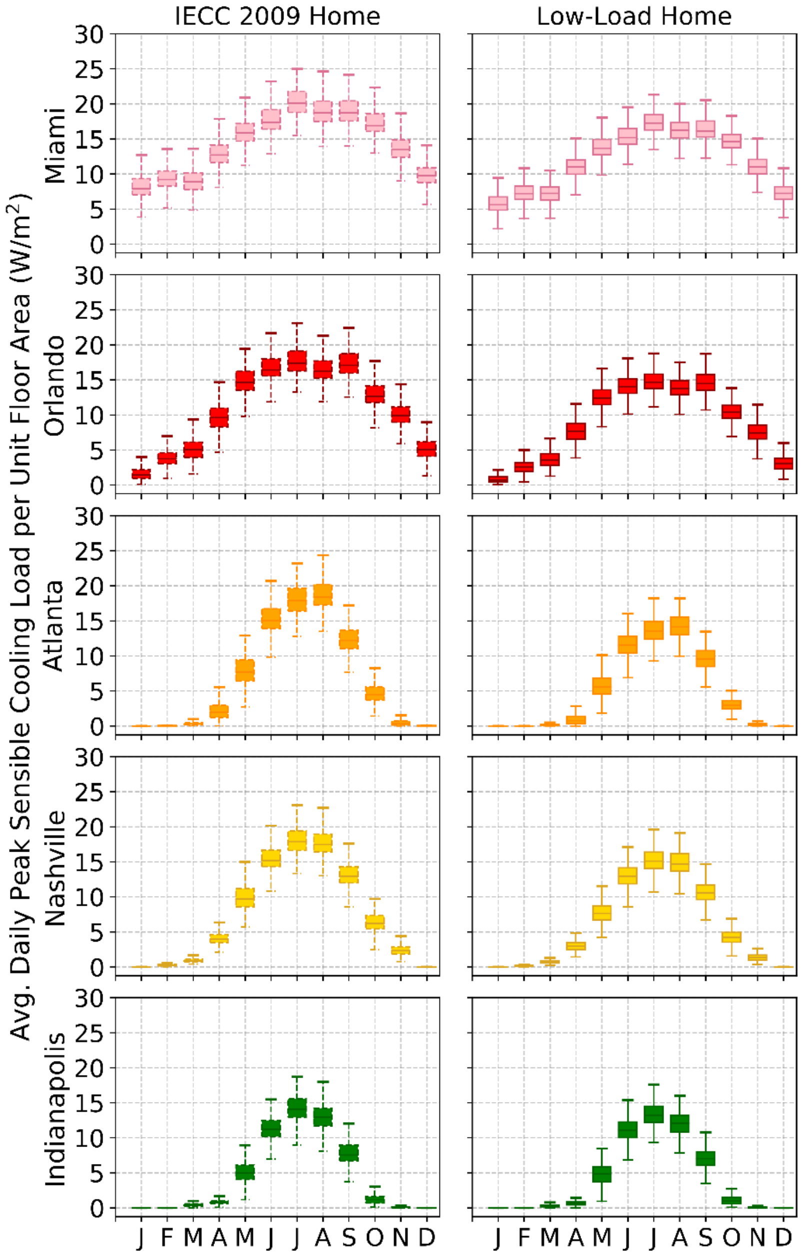
- **Sensible and latent cooling loads were calculated using air conditioner and whole-house dehumidifier capacity**
  - Cooling set point = 23.9°C (75°F)
  - Relative humidity set point = 55% RH
- **Hourly load calculations**

$$\dot{Q}_{bldg,sens} = \dot{Q}_{AC,sens} - \dot{Q}_{dehum,heat,added} - \dot{P}_{blower}$$

$$\dot{Q}_{bldg,lat} = \dot{Q}_{AC,lat} + \dot{Q}_{dehum,lat}$$

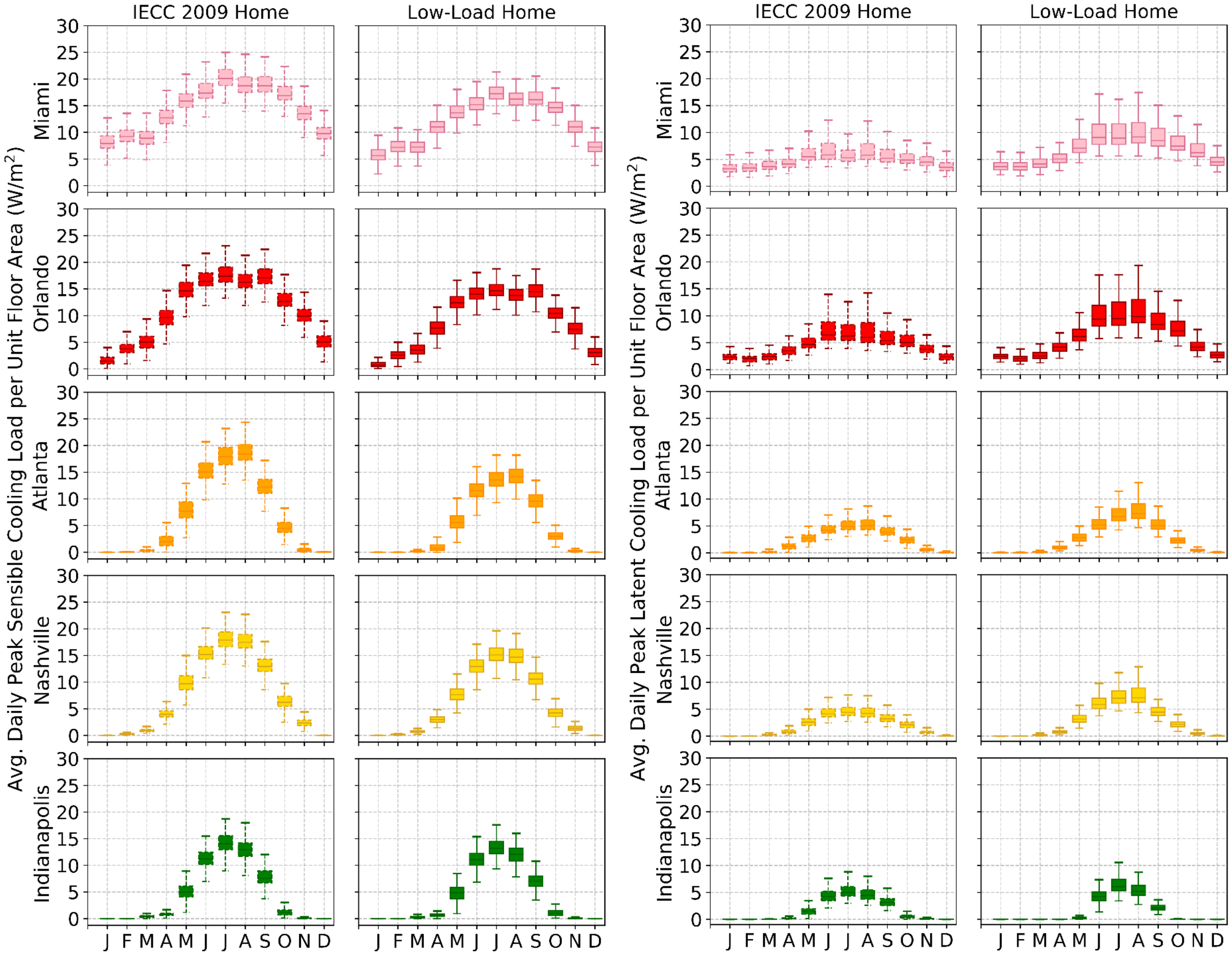
- **Monthly output calculations**
  - Average daily peak load
  - Hourly average sensible heat ratio

Sensible Cooling Loads (Humid Cities)



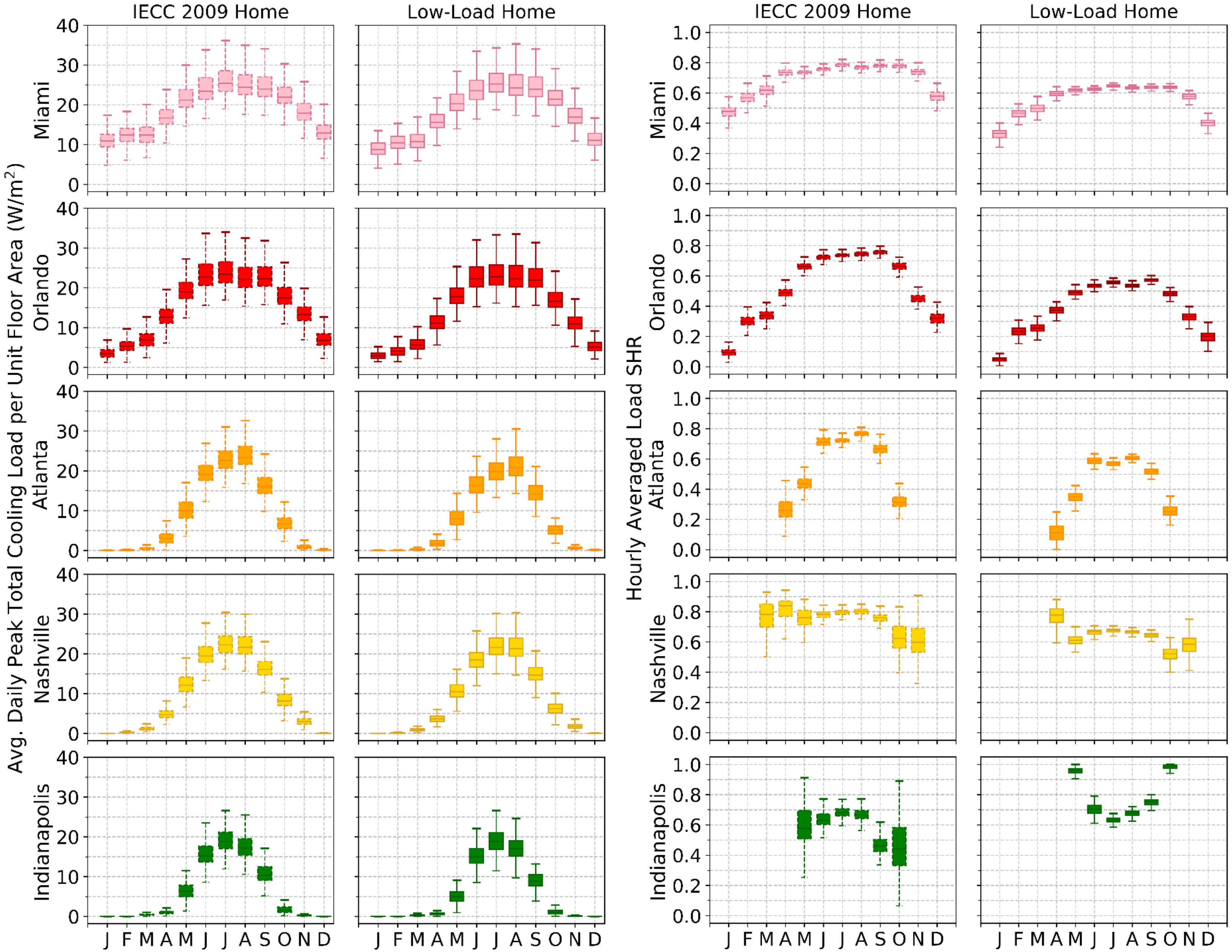
- **Variation in box and whisker plot is due to variation in internal gain profiles and interior window shading**
- **Efficiency measures result in a median sensible load reduction of 16% to 25% for homes in climate zones 1-4**
    - Design total cooling load reduction ranged from ~10% - 50%

Sensible and Latent Cooling Loads (Humid Cities)



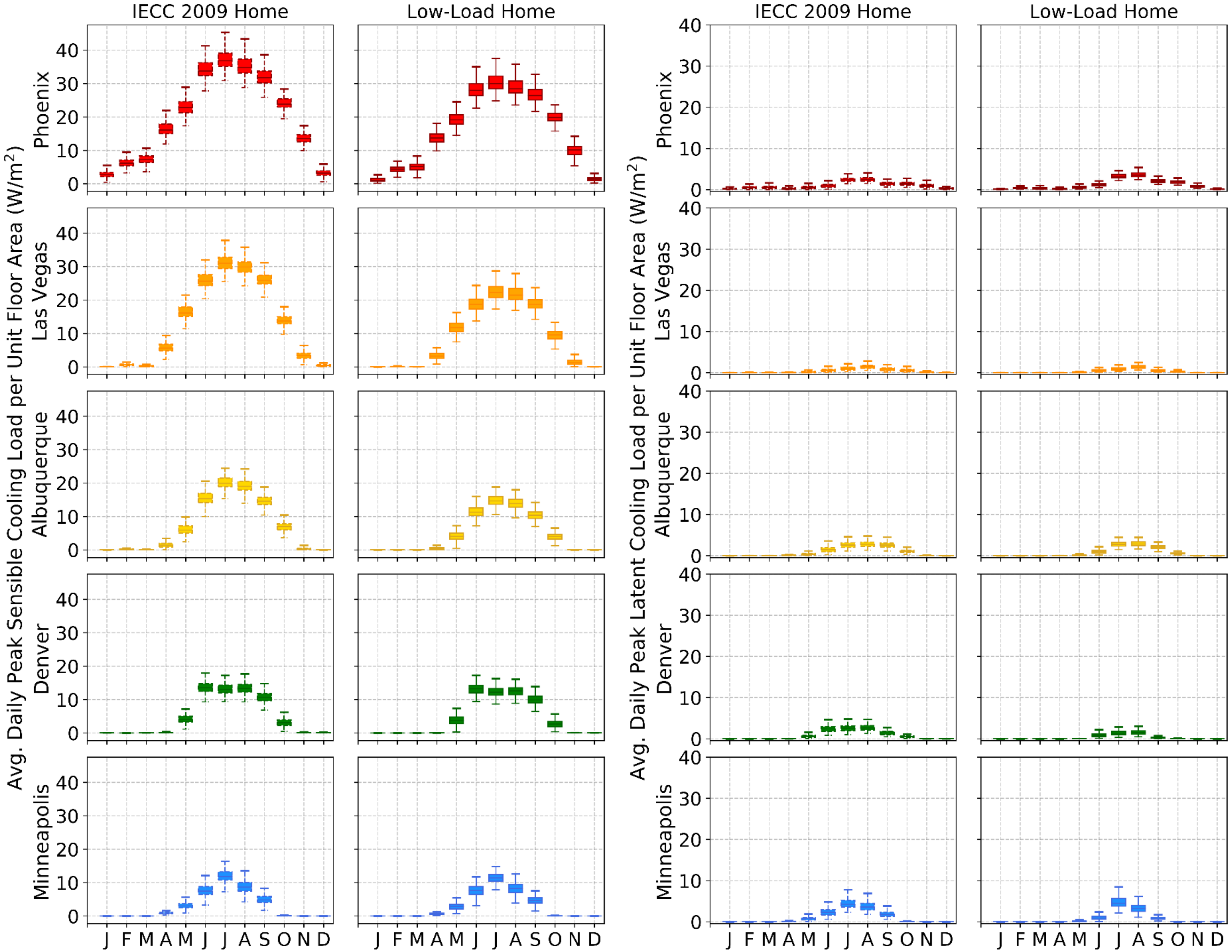
- **Low-load home sees a latent load increase due to mechanical ventilation**
  - Set of internal latent load profiles are identical for the IECC 2009 and low-load homes

Total Cooling Loads (Humid Cities)

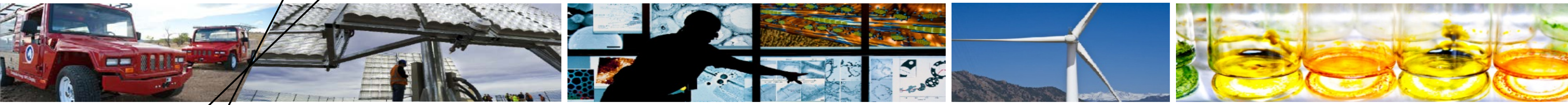


- **For the two houses simulated, total load is similar**
- **Load SHR (during hours with a notable cooling load) decreased in the low-load home by 0.1-0.2**
  - Load SHRs present in the IECC 2009 home align with typical air conditioner SHRs

Sensible and Latent Cooling Loads (Dry & Cold Cities)



- **In dry and cold cities, latent load remains a small fraction of the total load**
- **Total cooling load did decrease in these cities**



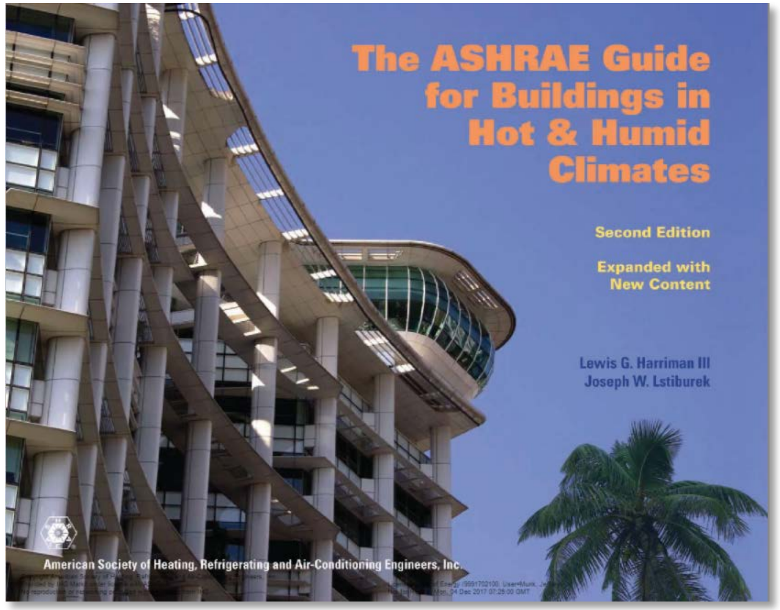
Results – Humidity Sensitivity Analysis

Humidity Metric

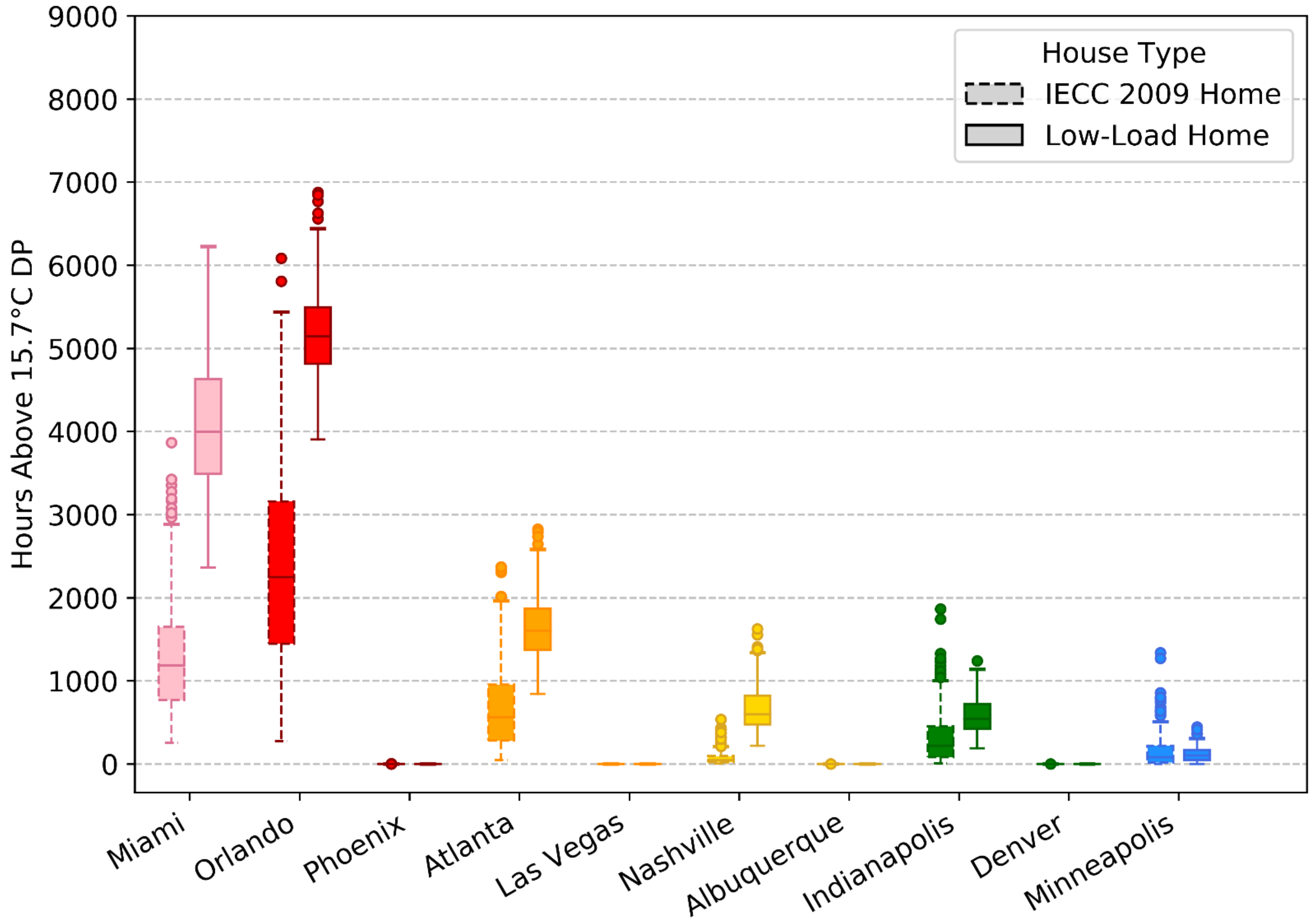
- **What measurement of humidity to use?**
  - % RH, dew point (DP), wet bulb temperature (WB)
- **ASHRAE 55 – Graphical Method upper humidity limit timeline**

1981	1992	1995	2010
16.8°C DP (62.2°F DP)	60% RH	20.0°C WB (68.0°F WB)	16.8°C DP (62.2°F DP)

- **57.0°F DP – *Humidity Control Design Guide for Commercial and Institutional Buildings***
- **55.0°F DP – *ASHRAE Guide for Buildings in Hot & Humid Climates***
- **This study used hours above 15.7°C (60.2°F DP)**
  - 60% RH @ 23.9°C (75.0°F)

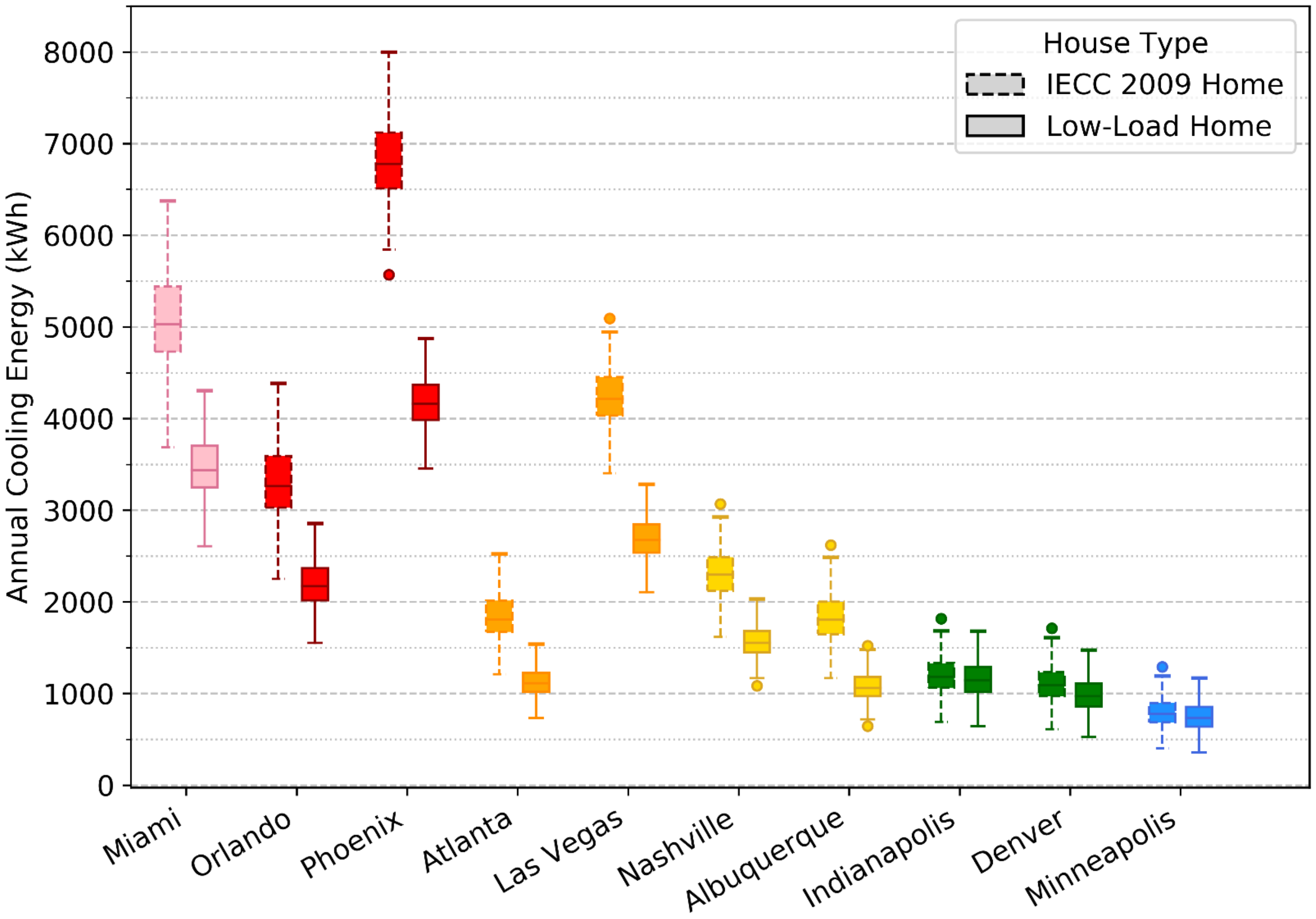


Baseline Case – Indoor Humidity



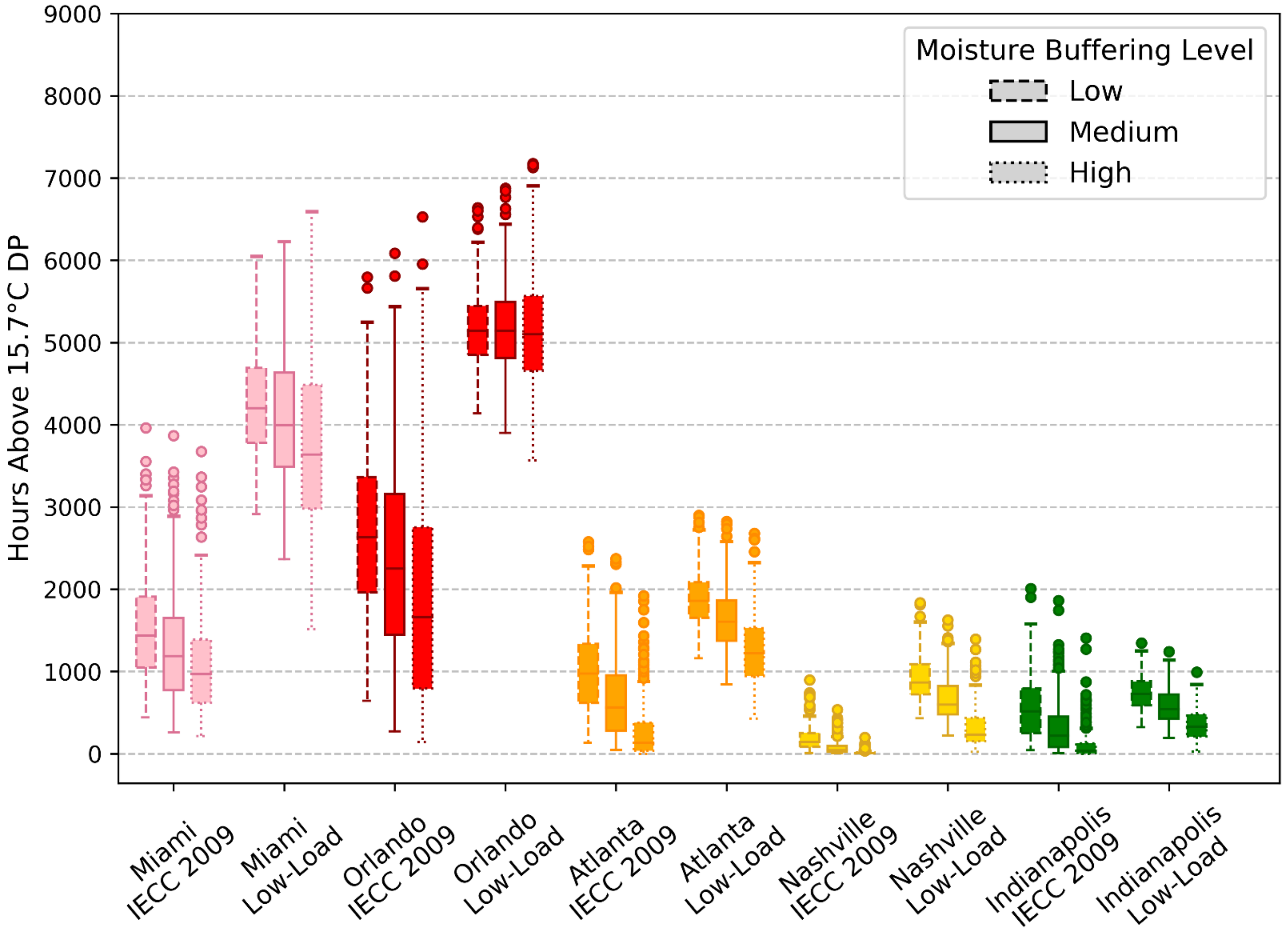
- **Median hours above 15.7°C (60.2°F) increased in all humid cities in climate zones 1-5**
- **Large spread in the box plot indicates occupant behavior can have a larger impact on indoor humidity than building characteristics**

Baseline Case – Cooling Energy



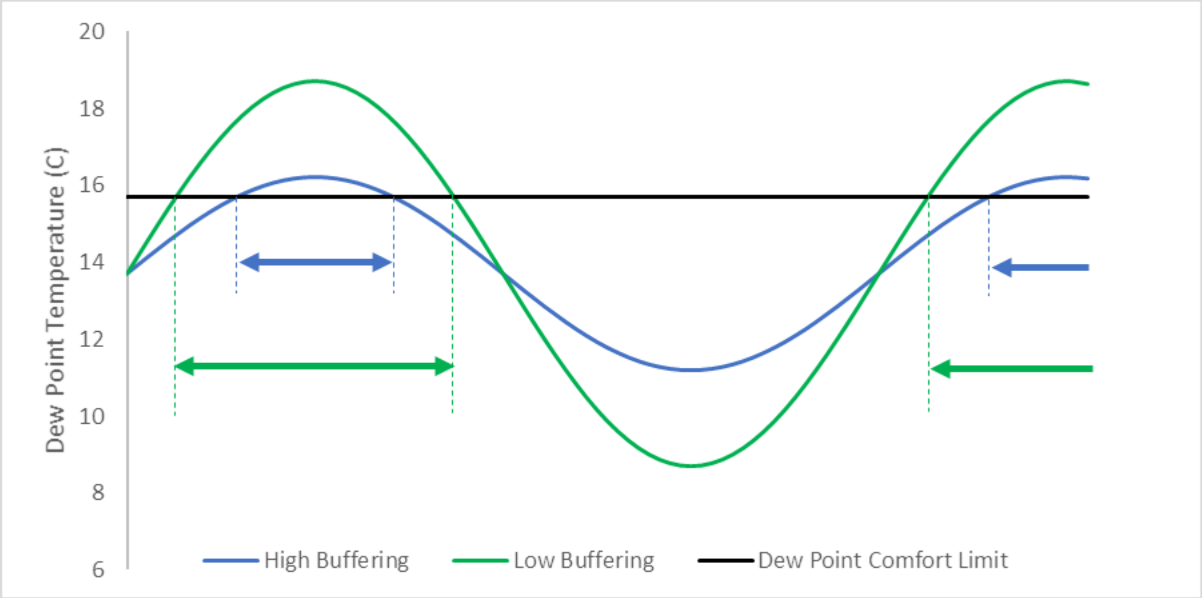
- **Median cooling energy savings of 31%-41% in climate zones 1-4**
  - 50%-75% of cooling energy savings due to sensible load reduction
  - Remainder is due to higher efficiency cooling equipment
- **Variation in occupant behavior can have a larger impact on cooling energy than efficiency improvements**

Moisture Buffering

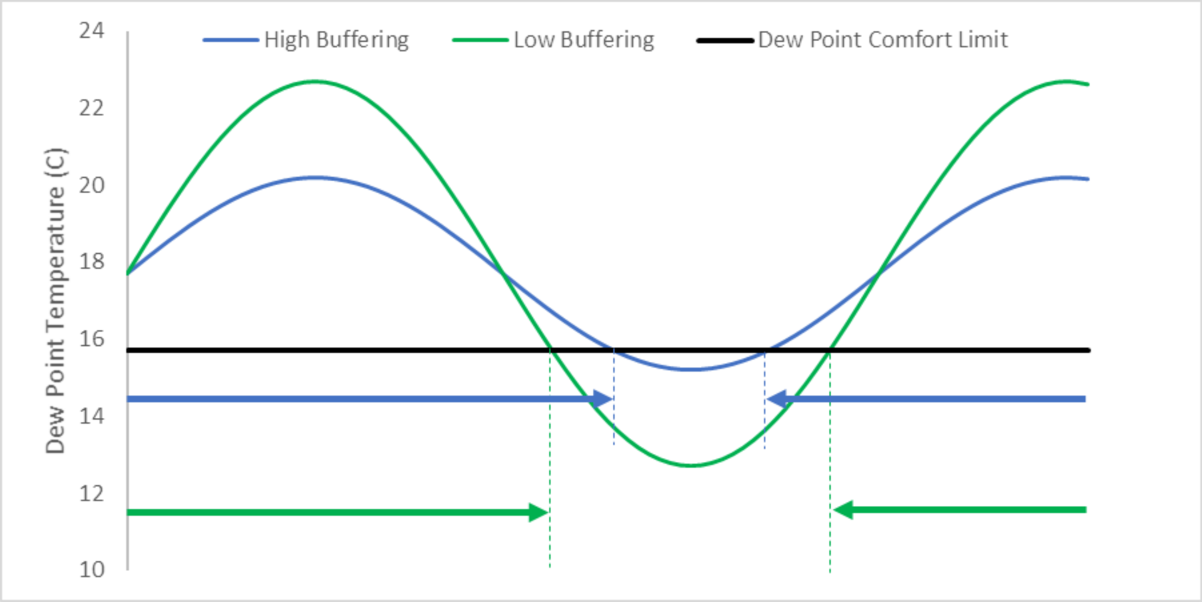


- **Increased buffering reduced median hours above 15.7°C (60.2°F) DP**
- **Buffering level did not impact air conditioner energy use**

Impact of Moisture Buffering

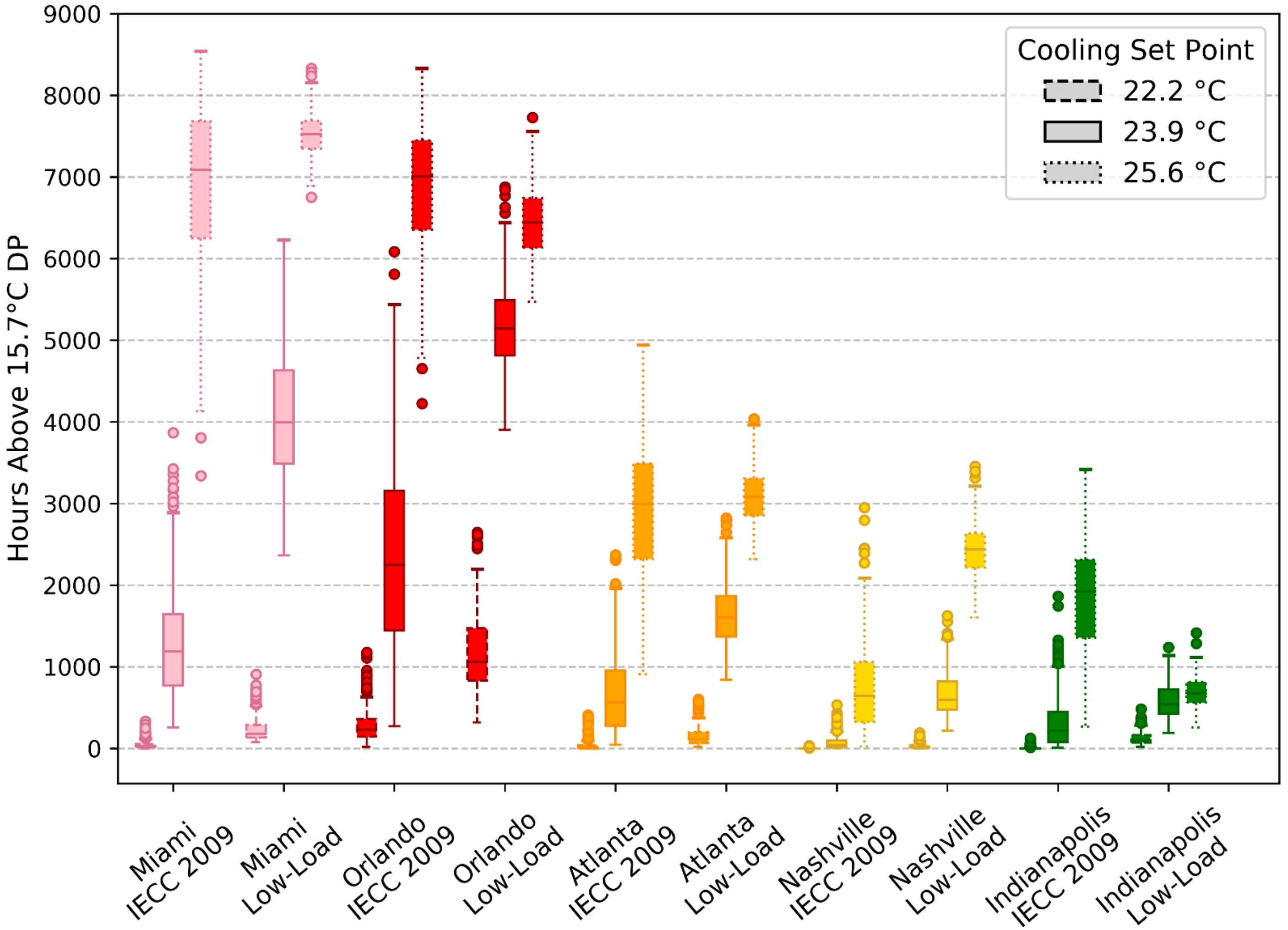


- **Mean humidity is 2°C <u>below</u> dew point comfort limit**
  - Higher buffering reduces hours above the dew point limit



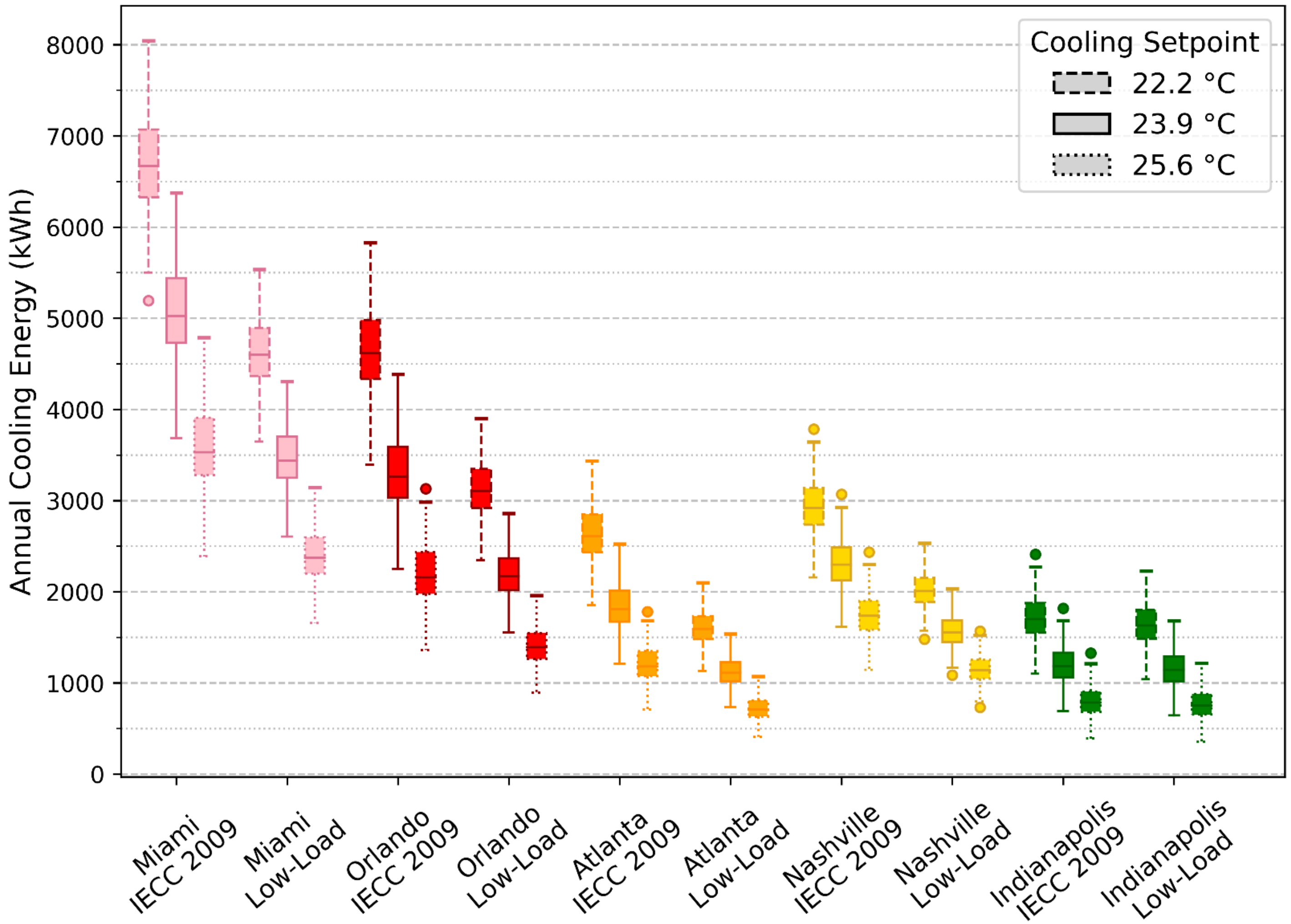
- **Mean humidity is 2°C <u>above</u> dew point comfort limit**
  - Higher buffering increases hours above the dew point limit

Thermostat Cooling Set Point – Indoor Humidity



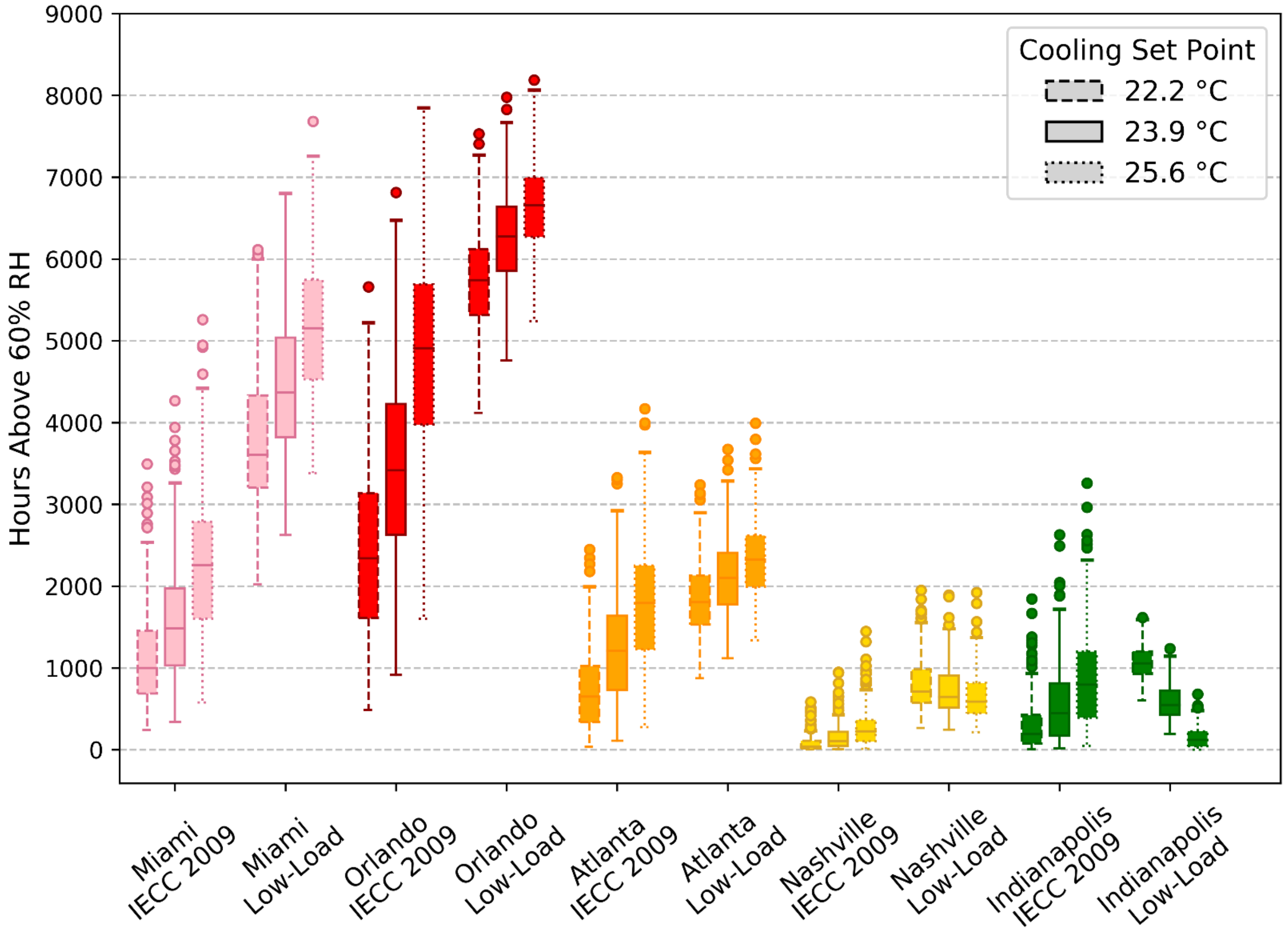
- **Decreasing the cooling set point 1.3°C (3.0°F) reduces the median hours above 15.7°C (60.2°F) DP**
  - IECC 2009 home: 90%-100% reduction
  - Low-load home: 79%-96% reduction

Thermostat Cooling Set Point – Cooling Energy

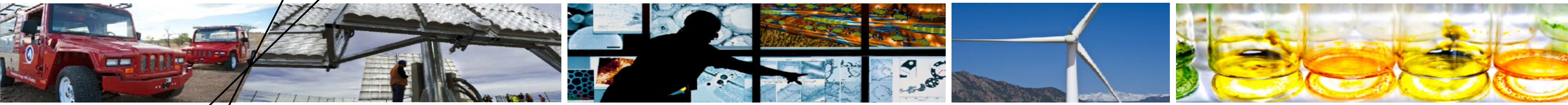


- **Percent increase in cooling energy was similar for both house types**
- **Median cooling energy increased 27%-44% when lowering the thermostat 1.3°C (3.0°F)**

Thermostat Cooling Set Point – Indoor Relative Humidity

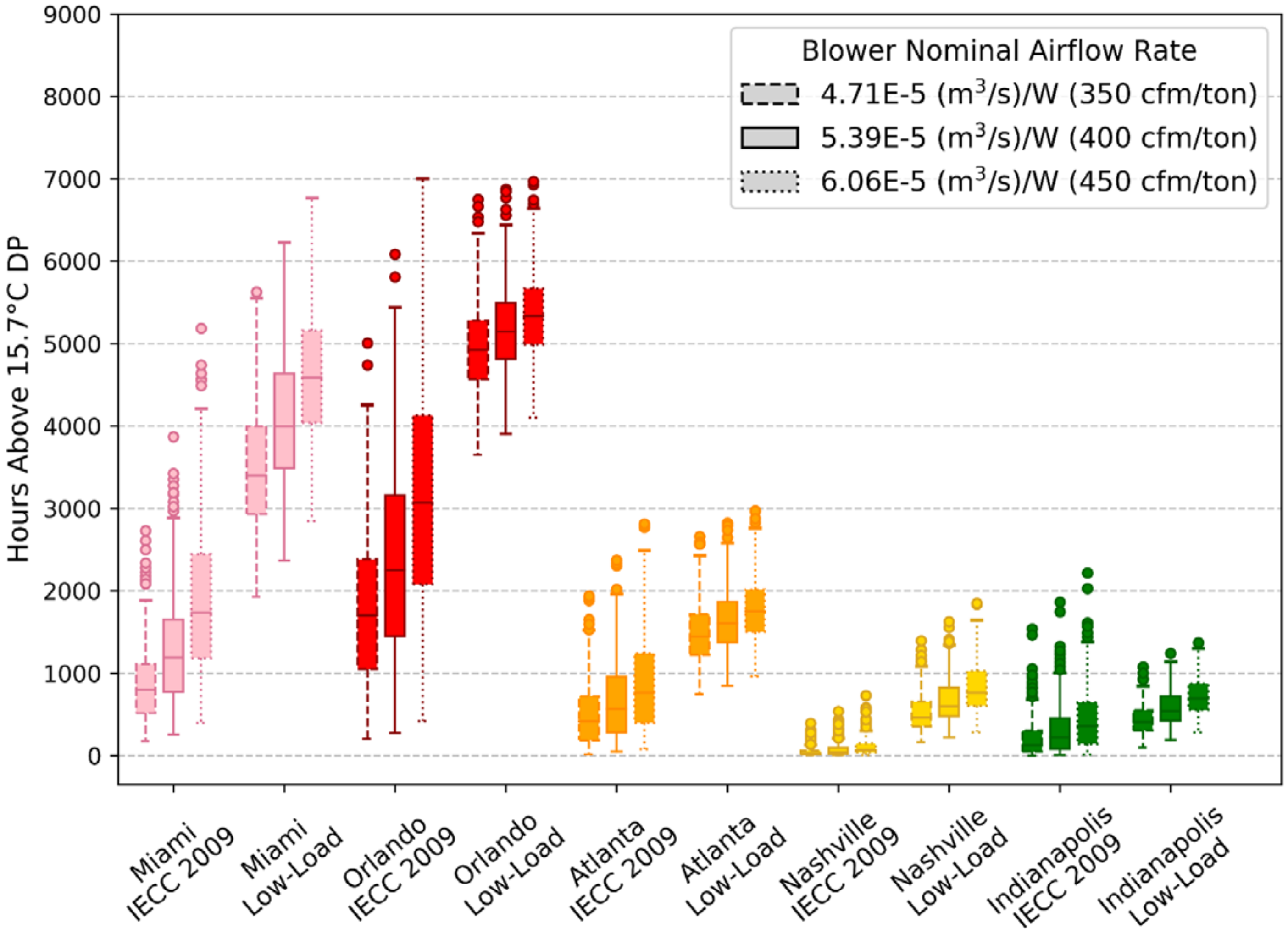


- **Similar trend compared to using DP-based metric**
- **Decrease in hours above 60% RH is less significant due to RH dependence on dry-bulb temperature**
- **Trend reverses in CZ 4 & 5 low-load homes**



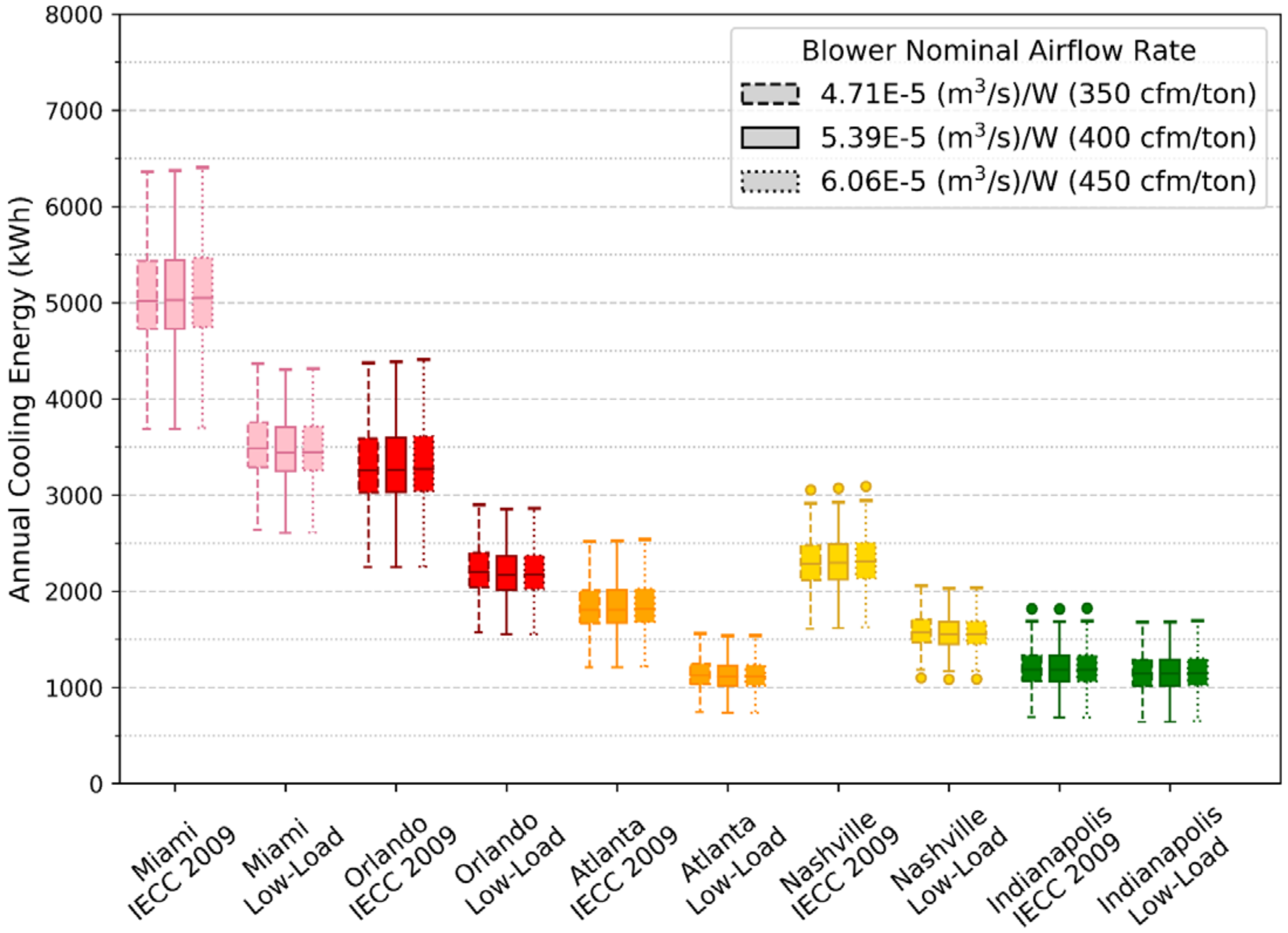
Results – Cooling System Design and Controls

Blower Airflow Rate – Indoor Humidity



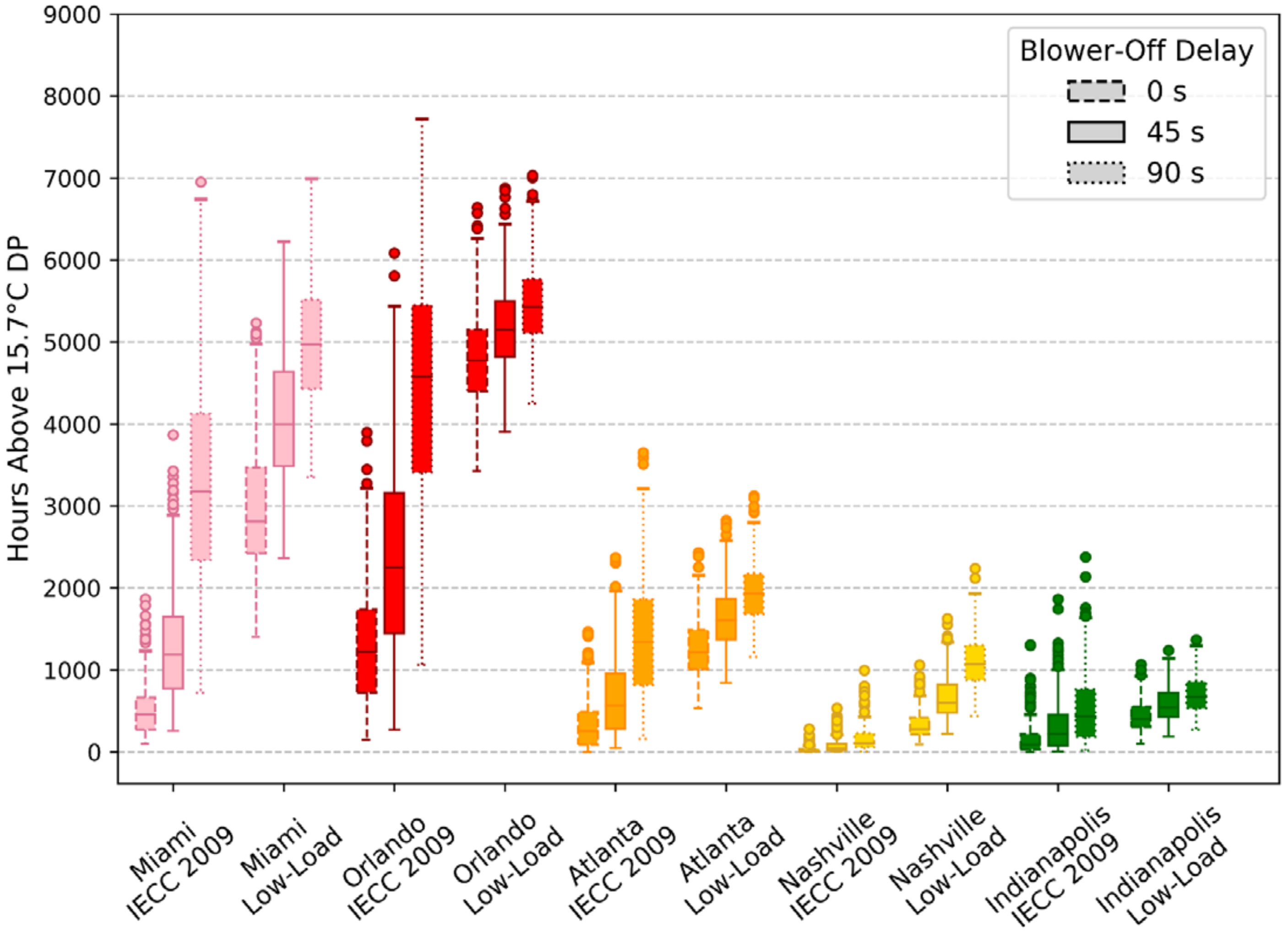
- **Small to moderate impact on indoor humidity**

Blower Airflow Rate – Cooling Energy



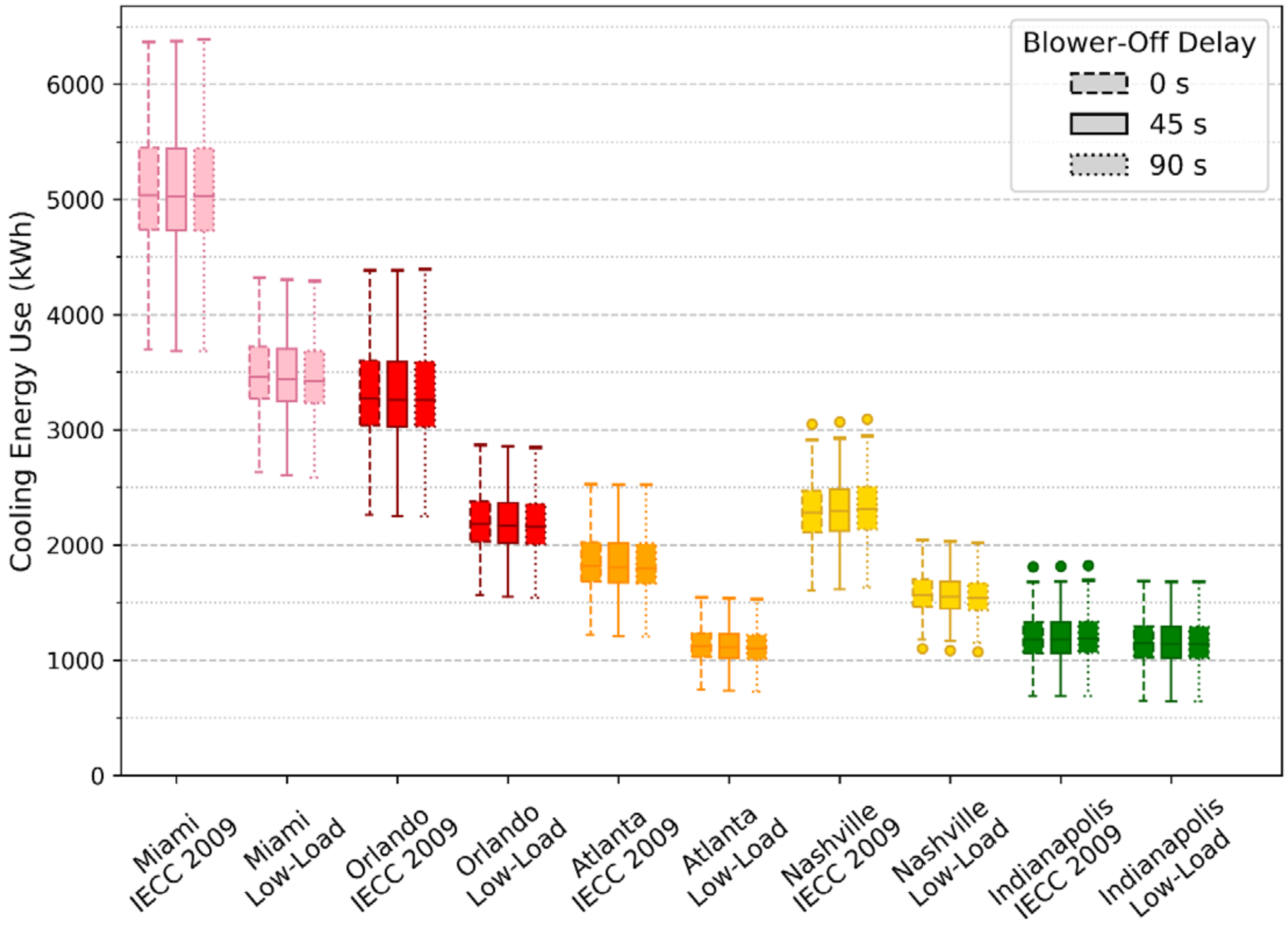
- **< 1.5% change in cooling energy use**
- **As airflow increases, compressor power decreases, and blower power increases**

Blower-Off Delay – Indoor Humidity



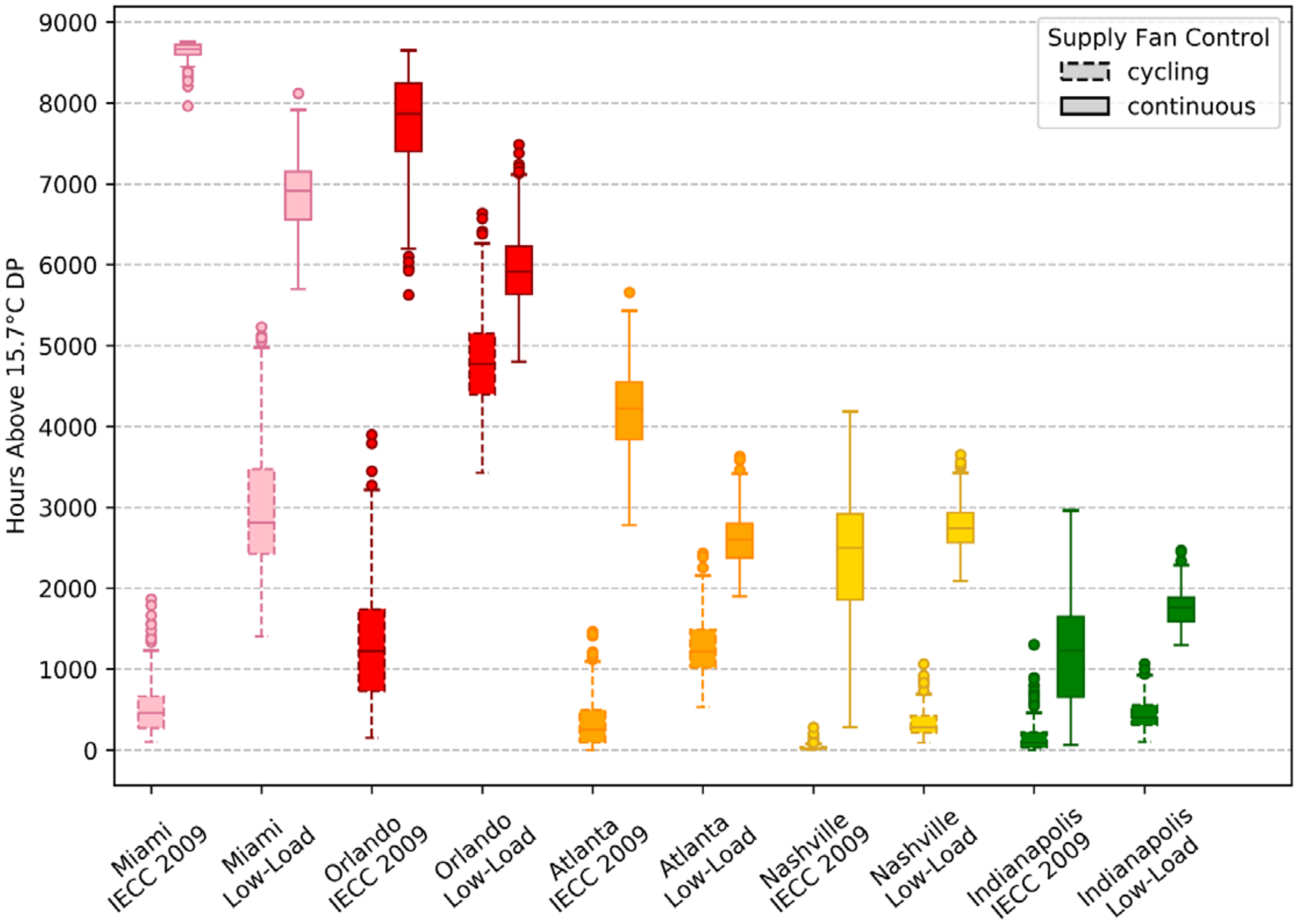
- **Blower-off delay had a larger impact on indoor humidity than blower airflow rate**

Blower-Off delay – Cooling Energy



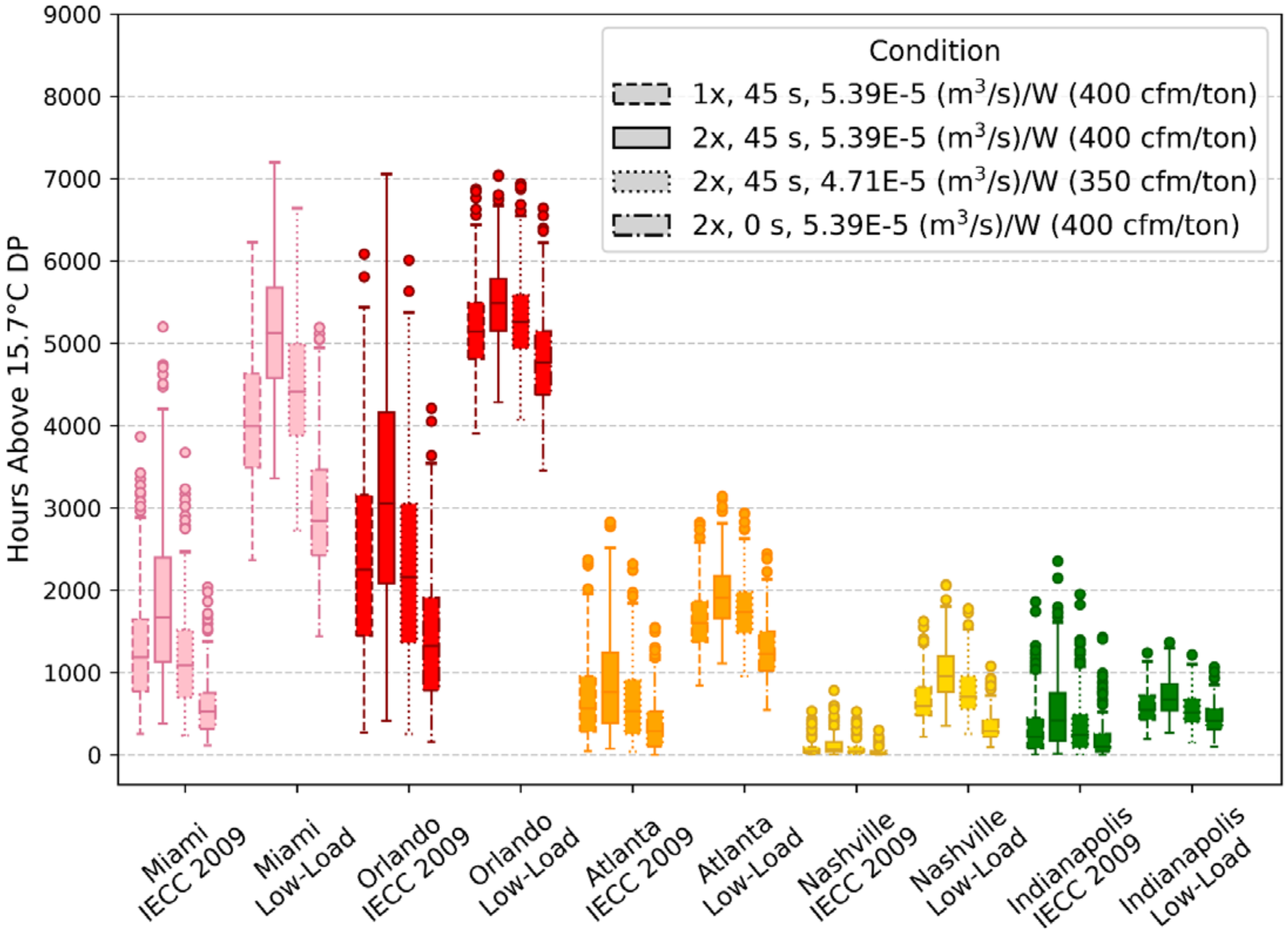
- **Cooling energy use variation between +1% and -2% for all cities**
- **Models did not account for thermal mass of ductwork or air handler**

Continuous Fan – Indoor Humidity



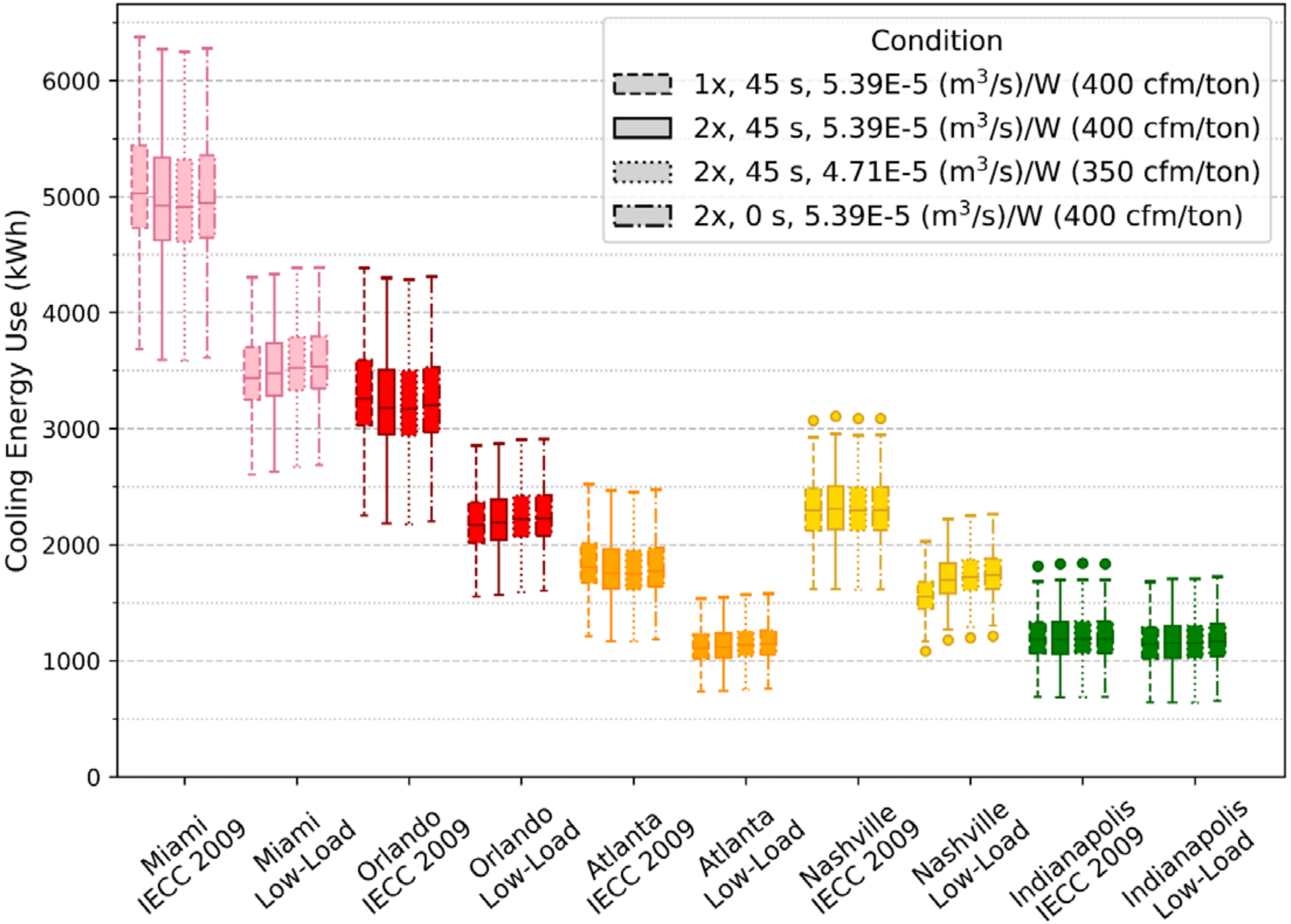
<u>Don't run continuous fan!</u>

Oversizing – Indoor Humidity



- **2x oversize affects indoor humidity similar to running at 450 cfm/ton**
- **Reduced airflow rates and no blower-off delay can mitigate comfort effects of oversizing**

Oversizing – Cooling Energy



- **Cooling energy is only slightly affected**

Conclusions

- **Cooling load SHRs below 0.6 for much of the year for low-load homes in humid climates**
  - Typical air conditioner SHR of 0.7 – 0.8
  - Supplemental dehumidification needed
  - Research into separate sensible and latent cooling technologies may be advantageous

Conclusions

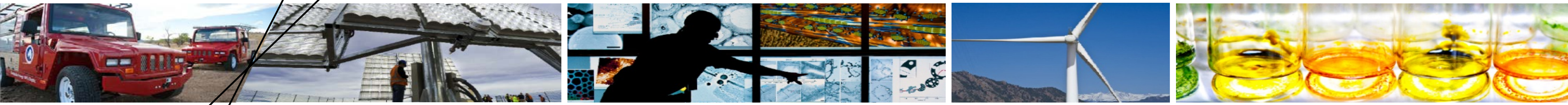
- **Internal loads can have a significant impact on indoor humidity**
- **Lowering the cooling set point by 3.0°F (1.7 °C) nearly eliminated high humidity conditions in all homes**
  - Increases cooling energy use significantly
  - Potential for uncomfortably cool temperatures in order to reduce humidity
  - Increases risk of condensation on building surfaces and in wall structures

Conclusions

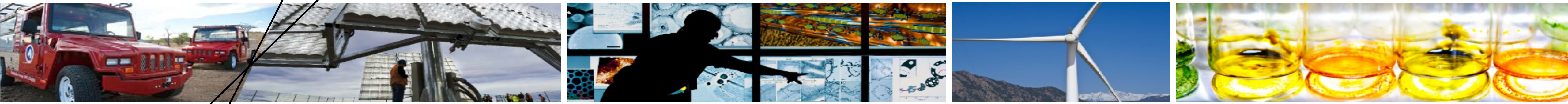
- **Reducing cooling supply airflow rate and eliminating the cooling blower-off delay were both shown to reduce indoor humidity**
  - Small impact on cooling energy use (<2% individually)
  - Typically easy to adjust (changing speed taps, dip switches, jumpers)
  - Can mitigate humidity effects of an oversized system

Future Work

- **Need a metric for assessing comfort based on temperature and humidity that reflects residential occupant expectations**
  - ASHRAE 55 analytical method does not seem sensitive enough to indoor humidity (large fluctuations have little effect on percent dissatisfied)
- **Need a method for distilling hourly measurements into simple value representing annual comfort**



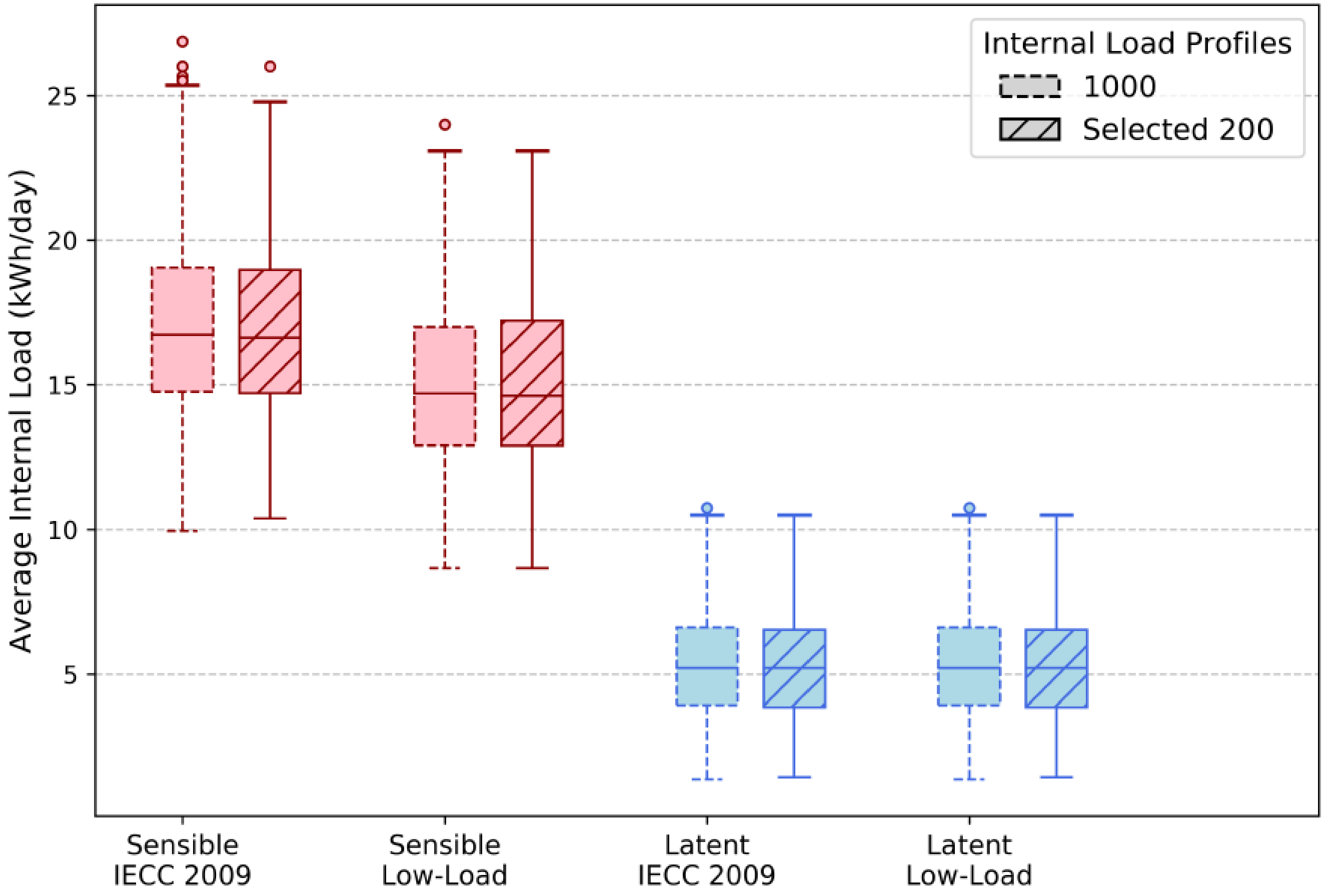
Questions



Supplemental Material

Number of GIHM Profiles

- **Selected 200 of the 1,000 profiles to run in the study simulations**



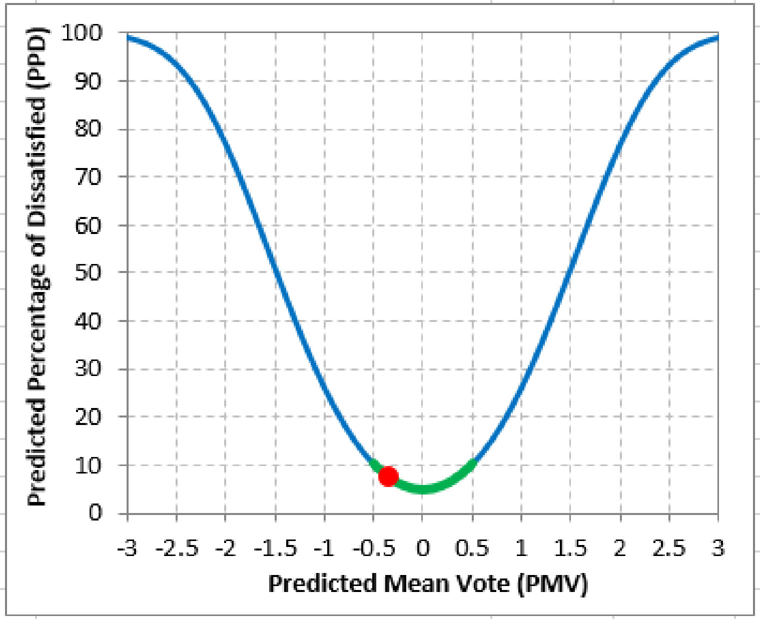
Sensitivity to Building Inputs

Atlanta, Low-Load Home w/ BA HSP Internal Gains	Hours above 60% RH
70 Htg SP, 75 Clg SP, A62.2 2013, 400 cfm/ton	1316
72 Htg SP, 78 Clg SP, A62.2 2010, 375 cfm/ton	926
Removed neighbors	725
BA Benchmark lighting	572
RP-1449 window inputs	401
Added ceiling fans	375
RP-1449 ACH50 & attic insulation	409
RP-1449 slab insulation & BA Benchmark carpet	183
No window shading	91

ASHRAE 55-2013 Analytical Comfort Zone Method

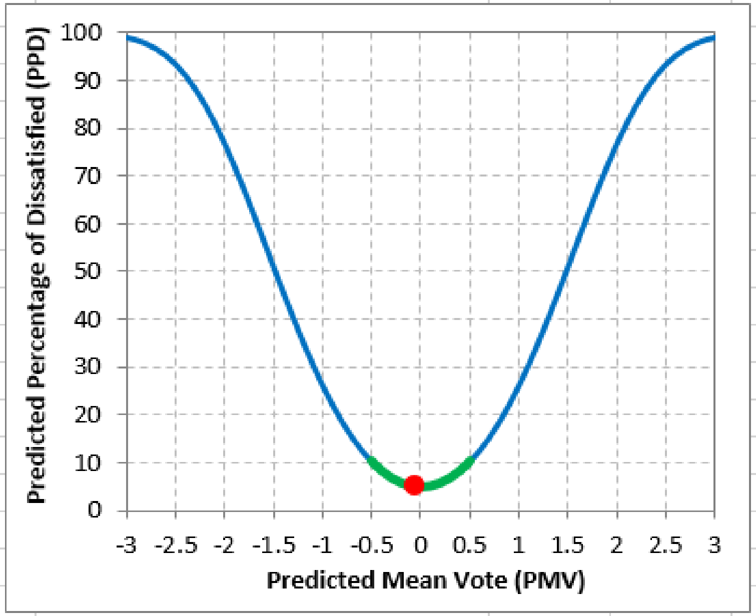
INPUTS		
Air Temperature (°C)	*TA*	23.89
Mean Radiant Temperature (°C)	*TR*	23.89
Relative Humidity (%)	*RH*	60
Relative Air Velocity (m/s)	*VEL*	0.08
Clothing (clo)	*CLO*	0.5
Metabolic Rate (met)	*MET*	1.1
External Work (met)	*WME*	0

PMV		**-0.356**
PPD		**7.633**

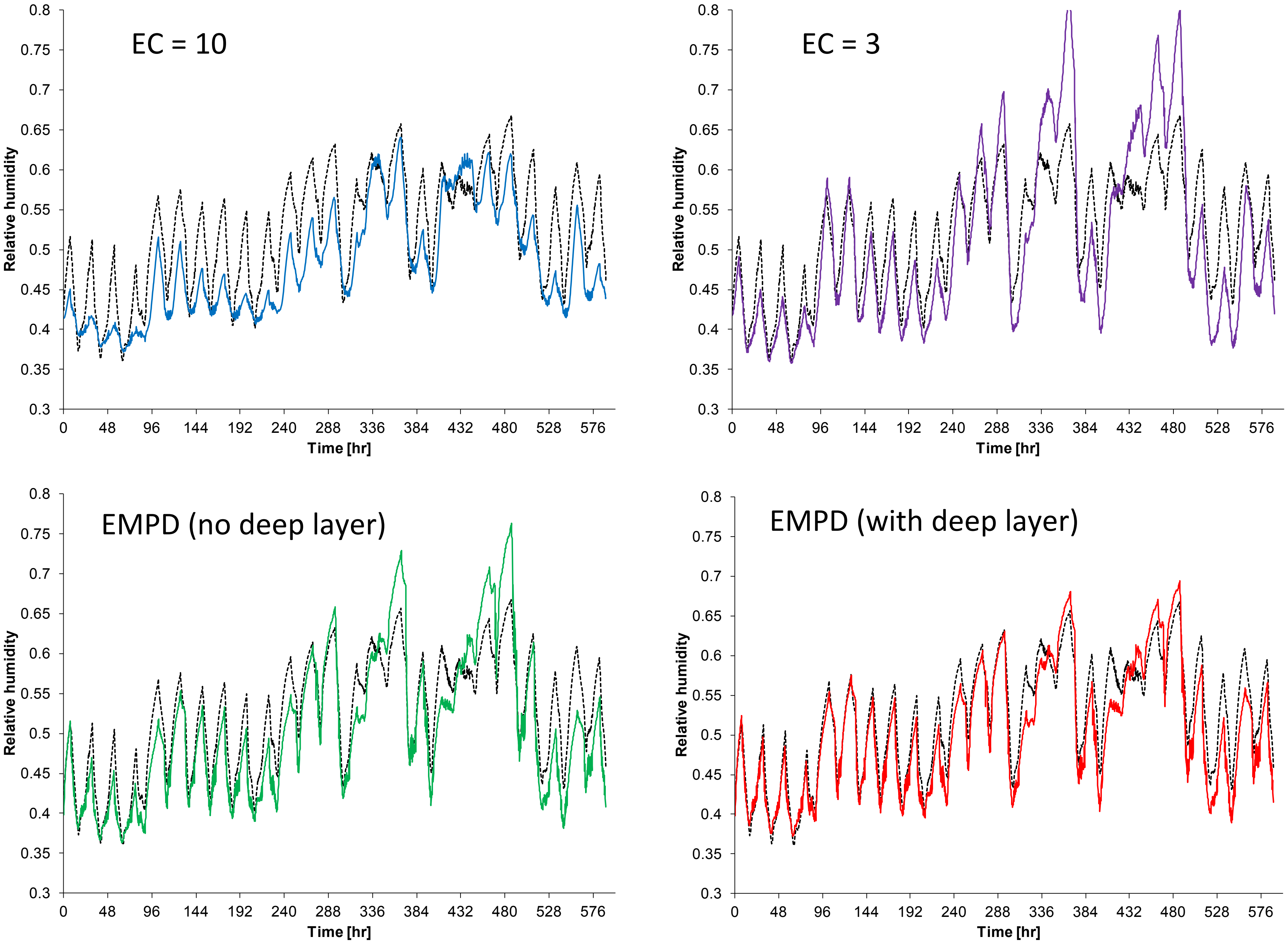


INPUTS		
Air Temperature (°C)	*TA*	23.89
Mean Radiant Temperature (°C)	*TR*	23.89
Relative Humidity (%)	*RH*	100
Relative Air Velocity (m/s)	*VEL*	0.08
Clothing (clo)	*CLO*	0.5
Metabolic Rate (met)	*MET*	1.1
External Work (met)	*WME*	0

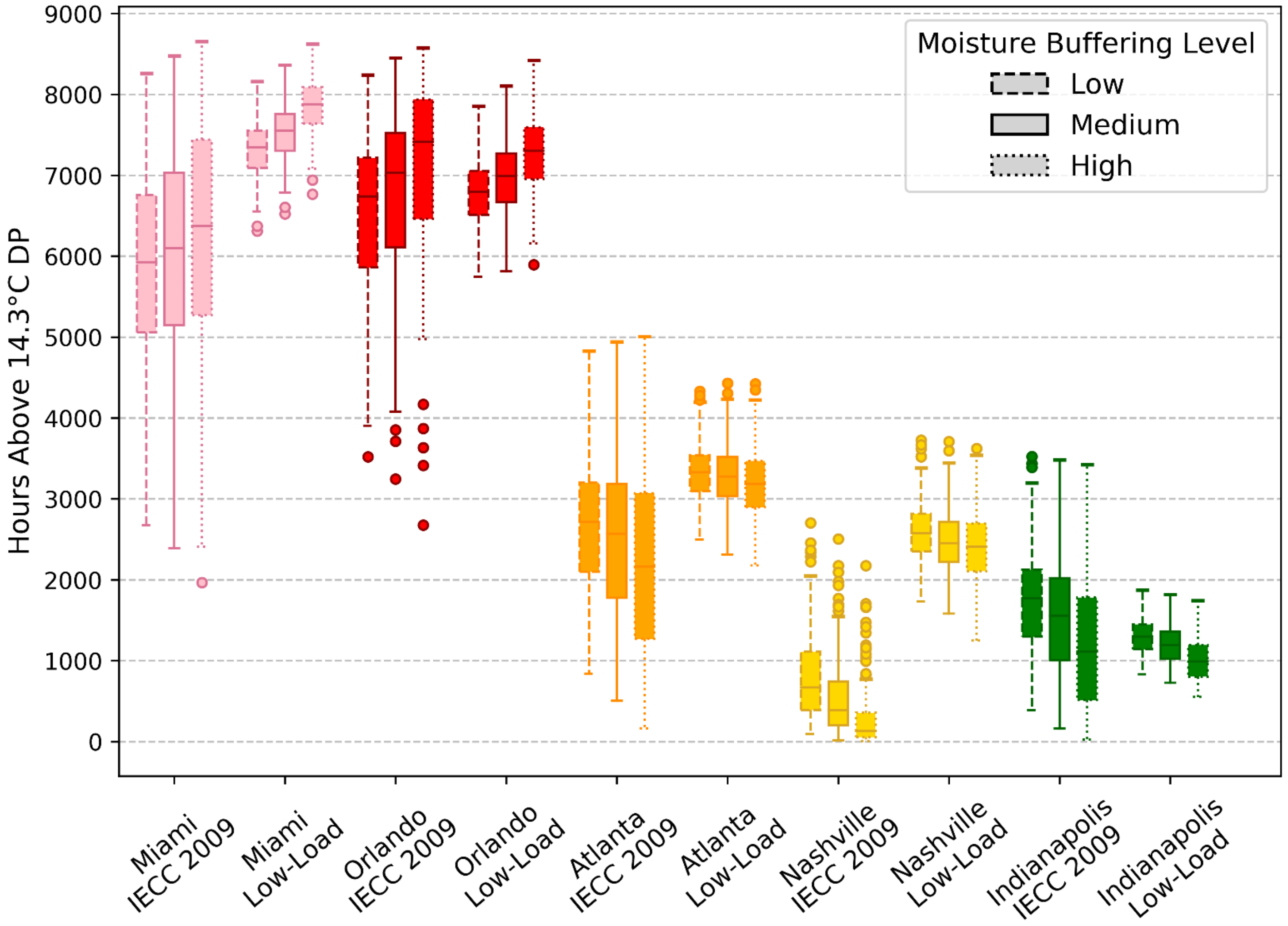
PMV		**-0.070**
PPD		**5.101**



Lower PPD = large percentage of people are comfortable


EC = 10
EC = 3
EMPD (no deep layer)
EMPD (with deep layer)
Relative humidity
Time [hr]
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0
48
96
144
192
240
288
336
384
432
480
528
576

Moisture Buffering



- **Decreasing the DP threshold reverses the trend in Miami and Orlando**
- **If mean indoor humidity is below threshold, additional buffering improves comfort**
- **If mean indoor humidity is above threshold, additional buffering worsens comfort**

Q&A Session

Question?

Select the 'questions' pane on your screen and type in your question.

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