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

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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
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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

- Ventilation
- Infiltration
- Envelope
- Internal gains
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

---

**Diagram Notes**
- Infiltration/ventilation
- Moisture generation
- Heat generation
- Adsorption into materials
- Heat transfer into materials
- Sensible heat transfer
- Latent heat transfer

---

**Heat gain through envelope**
Internal Moisture Gains Are Highly Variable and Unknown

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**
  o House model inputs and assumptions
  o Moisture buffering model
  o Air conditioner model
  o Stochastic approach to occupant behavior

• **Brief Q&A**

• **Results and discussion**
  o Sensible and latent cooling loads
  o Humidity sensitivity results
  o Cooling system design and controls impact on humidity

• **Conclusions**

• **Additional Q&A**
Modeling Approach and Assumptions
Infiltration/ventilation
- Window SHGC •
- Wall/roof R-value •
- Blower off delay •
- Sizing •
- Indoor air flow rate •

Level of furnishings •

Air conditioner
- Internal gains •
- Window shading •
- Cooling set point •

Occupants

Envelopes
- Window SHGC •
- Wall/roof R-value •

Infiltration/ventilation •

Moisture generation

Heat generation

Heat gain through envelope

Sensible heat transfer

Latent heat transfer

Heat transfer into materials

Adsorption into materials
**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 ● ●
New construction; single family; 2,500 ft²; 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

<table>
<thead>
<tr>
<th>City</th>
<th>Climate</th>
<th>Wall R-Value</th>
<th>Ceiling R-Value</th>
<th>ACH&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Window U-Value</th>
<th>Window SHGC</th>
<th>Duct Location</th>
<th>Ventilation</th>
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<tbody>
<tr>
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<td>R-30</td>
<td>4.75</td>
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<td>0.30</td>
<td>Attic</td>
<td>Spot vents per GIHM profiles</td>
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<td></td>
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<td>Phoenix, AZ</td>
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<td>R-13+5</td>
<td>R-38</td>
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<td></td>
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<tr>
<td>Las Vegas, NV</td>
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<td>R-49</td>
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<td>Basement</td>
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<td>R-49</td>
<td></td>
<td></td>
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</table>

### IECC 2009 Home

### Low-Load Home

<table>
<thead>
<tr>
<th>City</th>
<th>Climate</th>
<th>Wall R-Value</th>
<th>Ceiling R-Value</th>
<th>ACH&lt;sub&gt;50&lt;/sub&gt;</th>
<th>Window U-Value</th>
<th>Window SHGC</th>
<th>Duct Location</th>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami, FL</td>
<td>1</td>
<td>R-13</td>
<td>R-30</td>
<td>3</td>
<td>0.37</td>
<td>0.25</td>
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<td>ASHRAE 62.2 + Spot vents per GIHM profiles</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>3</td>
<td>R-13+5</td>
<td>R-38</td>
<td>2.5</td>
<td>0.30</td>
<td>0.25</td>
<td>Conditioned Space</td>
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<tr>
<td>Atlanta, GA</td>
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<td>R-38</td>
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<tr>
<td>Nashville, TN</td>
<td>6</td>
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<td>R-49</td>
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<tr>
<td>Albuquerque, NM</td>
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<td>R-13+10</td>
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<tr>
<td>Indianapolis, IN</td>
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<td>R-13+10</td>
<td>R-49</td>
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<tr>
<td>Denver, CO</td>
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<td>R-38</td>
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<td></td>
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</tr>
<tr>
<td>Minneapolis, MN</td>
<td>10</td>
<td>R-13+10</td>
<td>R-49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 generation
Heat generation
Adsorption into materials
Heat transfer into materials

Heat gain through envelope

Sensible heat transfer
Latent heat transfer
Moisture Buffering Field Tests

- Moisture addition (humidifier)
- Moisture removal (dehumidifier)
- Tank
- Scale
- Moisture adsorption & desorption into building materials

Graph:
- X-axis: Time (hr)
- Y-axis: Relative humidity
- Data points showing fluctuations in relative humidity over time.
What Parts of a Home Adsorb Moisture?

- Interior walls (+ furniture & carpet)
- Furniture (+ carpet)
- Carpet
- Slab
- Empty
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

<table>
<thead>
<tr>
<th>Buffering model input</th>
<th>Low</th>
<th>Baseline</th>
<th>High</th>
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<tbody>
<tr>
<td>Drywall to finished floor area multiplier (m²/m²)</td>
<td>2.04</td>
<td>2.92</td>
<td>3.80</td>
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<tr>
<td>Floor carpet fraction</td>
<td>0.3</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Furniture to finished floor area multiplier (m²/m²)</td>
<td>0.25</td>
<td>0.75</td>
<td>2.25</td>
</tr>
<tr>
<td>Wood to finished floor area multiplier (m²/m²)</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
</tbody>
</table>
Envelopes
- 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 generation
Heat generation
Heat gain through envelope

AC

Sensible heat transfer
Latent heat transfer

Adsorption into materials
Heat transfer into materials

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 ● ●
Space Conditioning Equipment Type

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

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

• Evaluate the impact of 3 design/setup parameters
  o Equipment sizing
  o Blower airflow rate
  o Blower-off delay
Air Conditioner Sizing

• Based on ACCA Manual J
• 2x

• Effects of oversized equipment
  o Increased cycling
    – Reduced efficiency
    – Increased latent degradation associated with blower-off delay
  o Reduced runtime
    – Decreased duct conduction losses
Air Conditioner Blower Air Flow Rate

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

Increase in cfm/ton results in:
- Decrease in latent capacity
- Increase in sensible capacity
- Increase in sensible heat ratio (SHR)

Manufacturer’s Performance Data
Air Conditioner Blower-Off Delay

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

During the blower-off delay:
- Evaporative cooling due to condensate evaporation
- Sensible cooling
- Negative latent cooling

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
**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 ● ●

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**Moisture generation**

**Heat generation**

**Heat gain through envelope**

**Sensible heat transfer**

**Latent heat transfer**
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
  o Developed to evaluate envelope moisture durability risks
  o 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

- House size
  - # bed/baths

- # of occupants

- Occupant age and gender
  - Metabolic Rate Multipliers

- Employment, work/school schedule
  - Average sensible and latent gains for activity

- Sleep schedule
  - Home/Away/Sleep Schedule

- Activities while at home
  - Hourly occupant sensible and latent gains

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

Input Distributions

8760 hour sensible and latent loads
Internal Gain Profiles

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

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

- 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

- **Median**: 50% of the data is greater than this value; middle of the data set
- **Lower quartile (Q1)**: 25% of the data is less than this value
- **Upper quartile (Q3)**: 25% of the data is greater than this value
- **Interquartile range (IQR)**: Q3 - Q1
- **Minimum**: Least value, excluding outliers
- **Maximum**: Maximum value, excluding outliers
- **Outliers**
  - Less than Q1 - 1.5IQR
  - Greater than Q3 + 1.5IQR
Occupant Internal Gains

Load Type
- IECC 2009 Sensible
- Low-Load Sensible
- Latent

Average Daily Internal Load (kWh/day)

Bathing  Bathing  Evaporation  Bathrooms  Cooking  Dishes  Laundry  Mopping  Humans  Pets  Plants  Lighting  Refrigerator  MELS  Total
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
  o 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)
  o 23.9°C (75°F)
    – Baseline value based on ACCA Manual J
  o 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

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**

<table>
<thead>
<tr>
<th>Building Characteristic</th>
<th>Low</th>
<th>Baseline</th>
<th>High</th>
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<tr>
<td>Internal gains</td>
<td>200 stochastic simulations</td>
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<tr>
<td>Interior window shading</td>
<td>200 stochastic simulations</td>
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<tr>
<td>Moisture buffering</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
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<tr>
<td>Cooling set point (°C)</td>
<td>22.2</td>
<td>23.9</td>
<td>25.6</td>
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<tr>
<td>Equipment sizing</td>
<td>Manual J</td>
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<td>2x</td>
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<tr>
<td>Blower air flow rate (cfm/ton)</td>
<td>350</td>
<td>400</td>
<td>450</td>
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<tr>
<td>Blower-off delay (s)</td>
<td>0</td>
<td>45</td>
<td>90</td>
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</tbody>
</table>
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
  o Cooling set point = 23.9°C (75°F)
  o Relative humidity set point = 55% RH

• Hourly load calculations
  \[
  \dot{Q}_{\text{bldg,sens}} = \dot{Q}_{\text{AC,sens}} - \dot{Q}_{\text{dehum,heat,added}} - \dot{P}_{\text{blower}}
  \]
  \[
  \dot{Q}_{\text{bldg,lat}} = \dot{Q}_{\text{AC,lat}} + \dot{Q}_{\text{dehum,lat}}
  \]

• Monthly output calculations
  o Average daily peak load
  o 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

<table>
<thead>
<tr>
<th>Year</th>
<th>DP Temperature</th>
<th>RH</th>
<th>WB Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>16.8°C (62.2°F)</td>
<td>60%</td>
<td>20.0°C (68.0°F)</td>
</tr>
<tr>
<td>1992</td>
<td>16.8°C (62.2°F)</td>
<td>60%</td>
<td>20.0°C (68.0°F)</td>
</tr>
<tr>
<td>1995</td>
<td>16.8°C (62.2°F)</td>
<td>60%</td>
<td>20.0°C (68.0°F)</td>
</tr>
<tr>
<td>2010</td>
<td>16.8°C (62.2°F)</td>
<td>60%</td>
<td>20.0°C (68.0°F)</td>
</tr>
</tbody>
</table>

- 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 below dew point comfort limit
  - Higher buffering reduces hours above the dew point limit

- Mean humidity is 2°C above 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

Don’t run continuous fan!
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
  o Typical air conditioner SHR of 0.7 – 0.8
  o Supplemental dehumidification needed
  o 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
  o Increases cooling energy use significantly
  o Potential for uncomfortably cool temperatures in order to reduce humidity
  o 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
  o Small impact on cooling energy use (<2% individually)
  o Typically easy to adjust (changing speed taps, dip switches, jumpers)
  o 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
  o 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
Number of GIHM Profiles

• Selected 200 of the 1,000 profiles to run in the study simulations
# Sensitivity to Building Inputs

<table>
<thead>
<tr>
<th>Atlanta, Low-Load Home w/ BA HSP Internal Gains</th>
<th>Hours above 60% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 Htg SP, 75 Clg SP, A62.2 2013, 400 cfm/ton</td>
<td>1316</td>
</tr>
<tr>
<td>72 Htg SP, 78 Clg SP, A62.2 2010, 375 cfm/ton</td>
<td>926</td>
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<tr>
<td>Removed neighbors</td>
<td>725</td>
</tr>
<tr>
<td>BA Benchmark lighting</td>
<td>572</td>
</tr>
<tr>
<td>RP-1449 window inputs</td>
<td>401</td>
</tr>
<tr>
<td>Added ceiling fans</td>
<td>375</td>
</tr>
<tr>
<td>RP-1449 ACH50 &amp; attic insulation</td>
<td>409</td>
</tr>
<tr>
<td>RP-1449 slab insulation &amp; BA Benchmark carpet</td>
<td>183</td>
</tr>
<tr>
<td>No window shading</td>
<td>91</td>
</tr>
</tbody>
</table>
ASHRAE 55-2013 Analytical Comfort Zone Method

**Inputs**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
<td>TA</td>
<td>23.89</td>
</tr>
<tr>
<td>Mean Radiant Temperature (°C)</td>
<td>TR</td>
<td>23.89</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>RH</td>
<td>60</td>
</tr>
<tr>
<td>Relative Air Velocity (m/s)</td>
<td>VEL</td>
<td>0.08</td>
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<tr>
<td>Clothing (clo)</td>
<td>CLO</td>
<td>0.5</td>
</tr>
<tr>
<td>Metabolic Rate (met)</td>
<td>MET</td>
<td>1.1</td>
</tr>
<tr>
<td>External Work (met)</td>
<td>WME</td>
<td>0</td>
</tr>
</tbody>
</table>

| PMV          | -0.356 |
| PPD          | 7.633  |

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<td>Relative Humidity (%)</td>
<td>RH</td>
<td>100</td>
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<td>Relative Air Velocity (m/s)</td>
<td>VEL</td>
<td>0.08</td>
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<tr>
<td>Metabolic Rate (met)</td>
<td>MET</td>
<td>1.1</td>
</tr>
<tr>
<td>External Work (met)</td>
<td>WME</td>
<td>0</td>
</tr>
</tbody>
</table>

| PMV          | -0.870 |
| PPD          | 5.101  |

Lower PPD = large percentage of people are comfortable.
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
Question?

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