Smart Ventilation Control of Indoor Humidity in High Performance Homes in Humid U.S. Climates

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Background

- Need to develop strategies for humidity control in high performance humid climate homes
- Control/time shift ventilation to optimize for indoor/outdoor humidity differences
- Use equivalence principle to ensure that IAQ standards are met (Appendix C ASHRAE 62.2)
- Use simulations to evaluate potential control strategies

Background – High Performance Homes

- low sensible load leads to little incidental moisture removal by Air Conditioner
  - Need a dehumidifier
- Dehumidifier energy 200-2000 kWh/year, 1000 kWh/year typical

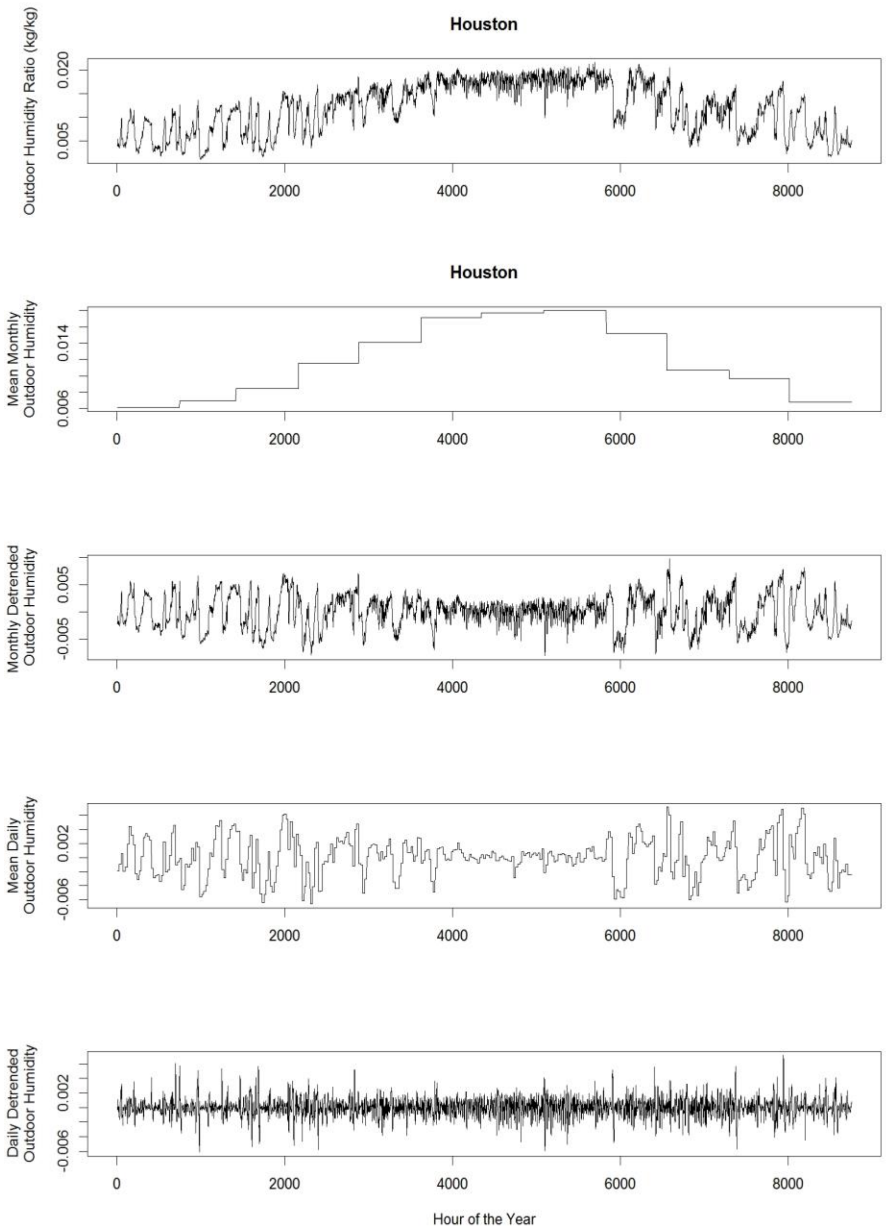
Can this be reduced/eliminated by ventilating smarter?

When does high humidity occur indoors?

- Daily/Weekly scale: Winter/Shoulder seasons
- Hourly scale: Late Evening/Early morning
- High indoor generation: occupancy/activity related

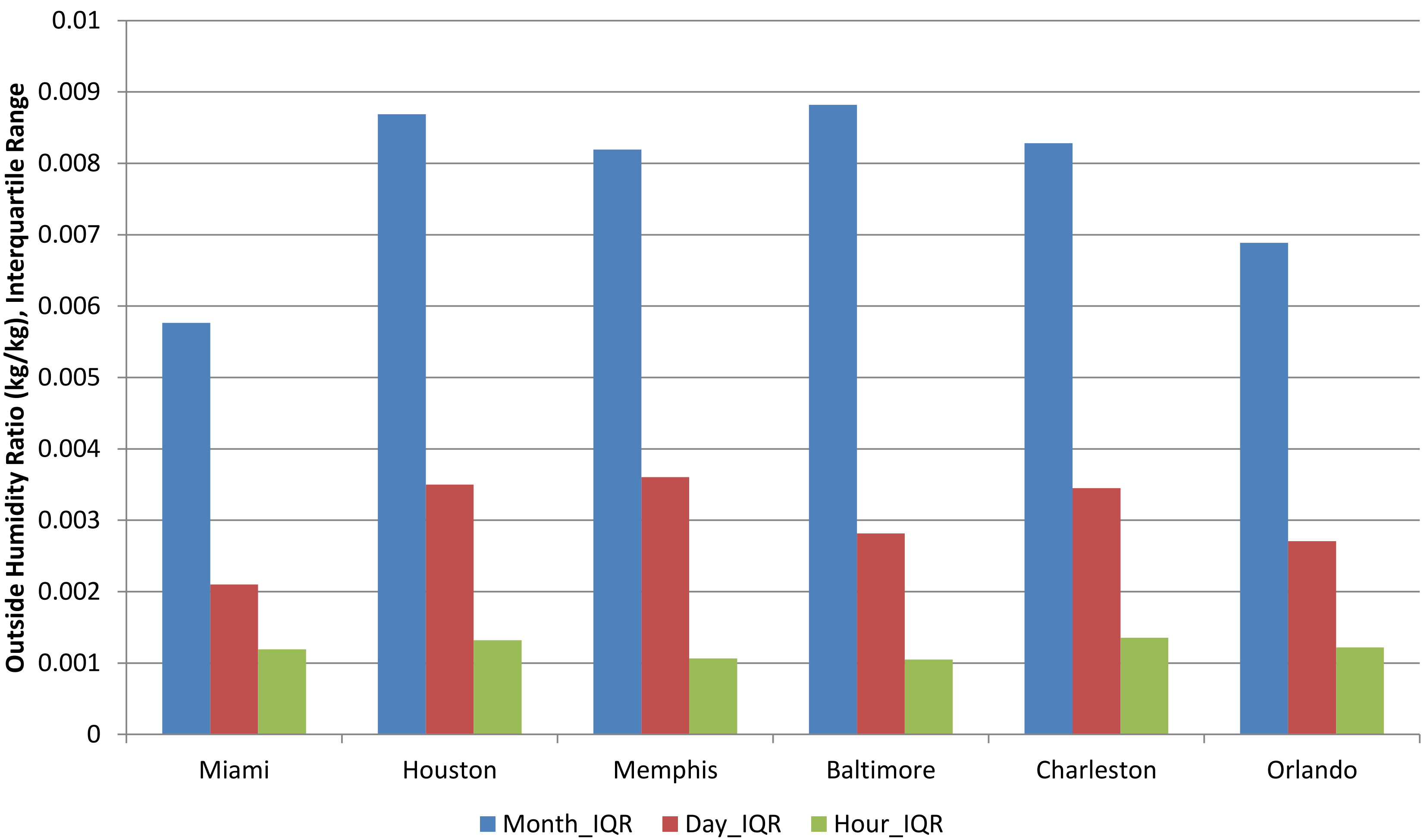
Can time-varying ventilation help?

When is impact of ventilation biggest?



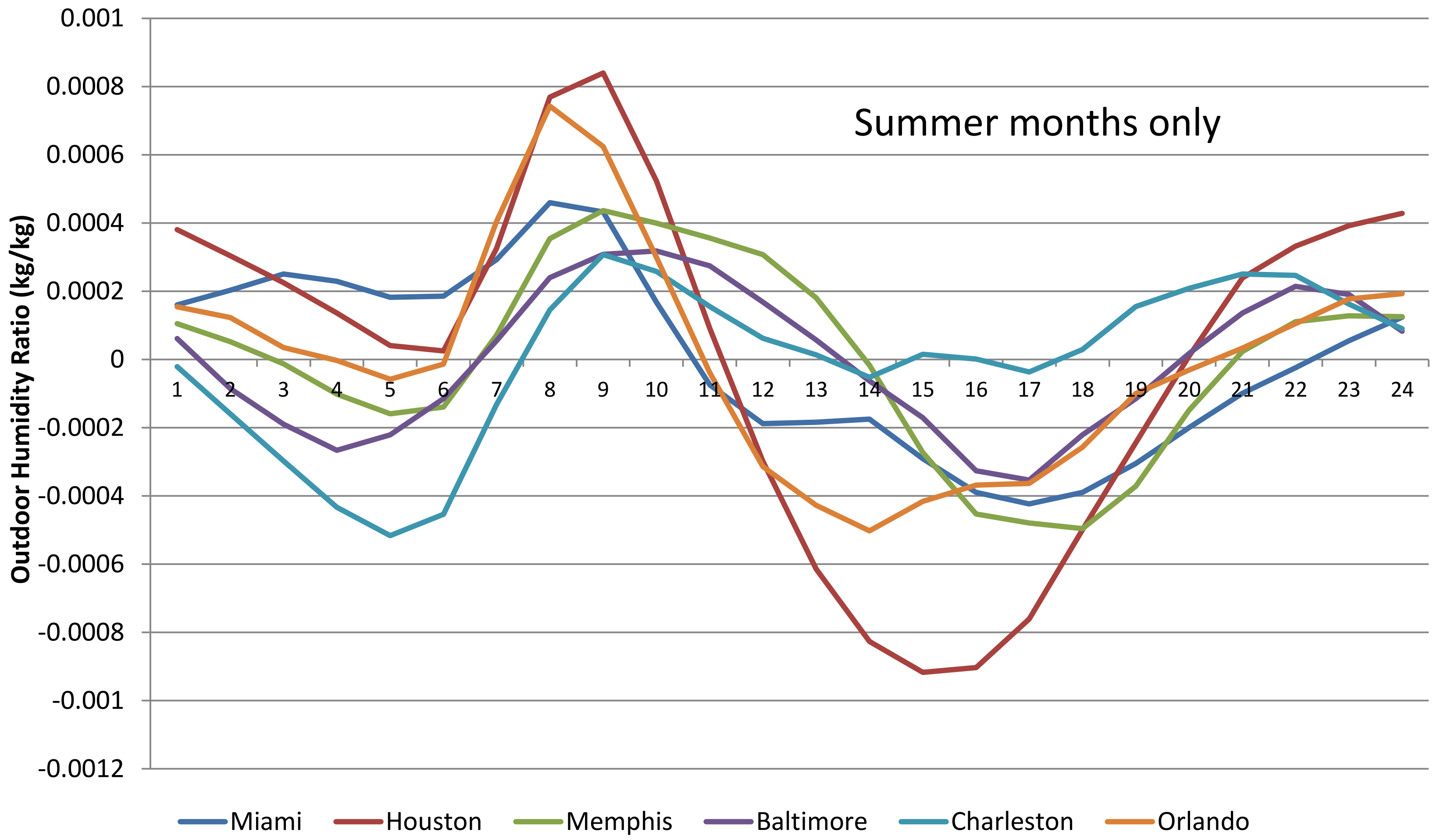
For outdoor humidity:
Big differences are
seasonal,
not daily or hourly

When is impact of ventilation biggest?



Big differences are **month to month**, not daily or hourly

When is impact of ventilation biggest?



Some climates (Houston) might respond to hourly controls in the summer

Maintaining IAQ: Equivalence

1. Have a time-varying ventilation rate have the same dilution of indoor pollutants as a continuous rate
2. Calculate the dose & exposure for time-varying ventilation relative to constant ventilation
3. Have annual average dose be the same for time-varying ventilation relative to constant ventilation

Calculating Equivalence – Stepwise Approach

At each time step:

Turnover Time, τ, depends on air change rate, A_i, timestep, Δt, and previous turnover time

$$e_i = A_{eq} t_i$$

Relative Exposure, ε, depends on turnover time and the target continuous ventilation rate, A_{eq}

Relative dose, d, depends on turnover time and the target continuous ventilation rate and previous relative dose

Controlling a ventilation system

- Force system to be off, or at a reduced rate at some times
- Operate system at higher air flow rate to make up for this
- Use calculated dose and exposure to control the system
- Different control strategies used to determine these “on” and “off” times

Strategies Evaluated

Schedule: Control ventilation based on time of year or time of day

Sensors: Measure humidity indoors, outdoors or both – can be simple on/off or proportional

Cooling system tie-in: ventilate more when cooling system operating – introduce ventilation air before cooling coil to maximise dehumidification

Relative Dose Targets: Allow relative dose targets to vary during the year – but still meet annual equivalence

A total of 13 strategies were evaluated

Control Strategy Summary

ID	Control Name	Schedule	Sensors	Rel Dose Target	Cooling Tie -In
1	Cooling system tie-in	N	0	Fixed	Y
6	**Monthly seasonal**	**Y**	**0**	**Variable**	**N**
8	Monthly seasonal + Hourly	Y	0	Variable	N
12	Monthly seasonal + Cooling system tie-in	Y	0	Variable	Y
10	Fixed outdoor HR cutoff	N	1	Fixed	N
13	**Annual medians**	**N**	**1**	**Variable**	**N**
14	**Monthly quartiles**	**N**	**1**	**Variable**	**N**
2	**Fixed sensor**	**N**	**2**	**Fixed**	**N**
3	**Fixed sensor + Cooling system tie-in**	**N**	**2**	**Fixed**	**Y**
4	Proportional sensor	N	2	Fixed	N
5	Proportional sensor + Cooling system tie-in	N	2	Fixed	Y
9	**Fixed sensor + Variable dose target**	**N**	**2**	**Variable**	**N**
7	**Fixed sensor + Cooling system tie-in + Variable dose target**	**N**	**2**	**Variable**	**Y**

Simulation Description

- REGCAP simulation tool: combined heat, mass and moisture transport and allows complex ventilation controls and HVAC integration
- One Minute time step – allows for HVAC cooling system dynamics
- TMY 3 weather data for: Miami, Orlando, Houston, Charleston, Memphis & Baltimore
- Home meets DOE Zero Net Energy Ready requirements
- Three house sizes: 100, 200 and 300 m^2
- Three internal moisture generation rates: 3, 6.5 and 11.8 kg/day
- Ventilation provided by Central Forced Air integrated supply (CFIS) sized to have three times ASHRAE 62.2-2013 minimum air flow rate and operated 20 minutes per hour
- 3 ACH50: Miami, Orlando, Houston
- 2.5 ACH50: Charleston, Memphis & Baltimore

What is “acceptable” indoor humidity?

- Never above 50/60/70% RH at any time?
- Above a limit less than X hours?
- Above a limit less than X consecutive hours?
- Seasonal variations?
- We used:
  - annual fraction above 60%
  - maximum duration above 60%
  - annual fraction above 70%
  - maximum duration above 70%

Baseline (no controls) results

Average over house size and moisture generation rate

	Indoor Relative Humidity (%)			Annual Fraction		Maximum Duration (days)	
Climate Zone	**Mean**	**75th**	**Max**	**>60% RH**	**>70% RH**	**>60% RH**	**>70% RH**
Miami	51	55	87	10%	1%	1.2	0.5
Orlando	49	53	77	8%	1%	2.5	0.6
Houston	49	54	77	9%	1%	2.0	0.3
Charleston	48	54	71	8%	0%	1.7	0.2
Memphis	42	49	63	2%	0%	0.2	0.0
Baltimore	38	46	62	1%	0%	0.2	0.0

- High annual humidity issues most significant for small home, high generation rate.
- Some locations had high indoor humidity all year (Miami and Orlando), whereas others experienced it only during summer months (Memphis and Baltimore).
- Shoulder seasons had the highest humidity, due to low sensible cooling loads and similar indoor and outdoor absolute humidity.
- Few high humidity hours occurred during either heating or cooling system operation (<10%).

Control Strategy Results

- All smart controls increased HVAC energy use, but they also decreased hours of high humidity and shifted overall indoor humidity distributions downward
- More energy used in colder climates due to seasonal ventilation shifting
- For small homes with high moisture generation rates, between 20 and 25% of annual hours remained >60% in the most humid locations. Mechanical dehumidification still required in these homes.

Control Strategy Results

- Sensor-based strategies outperformed schedule-based approaches.
- Two sensors were generally better than one, as they were able to respond to real-time changes in indoor and outdoor humidity.
- The cooling tie-in generally led to better performance with a small energy penalty (roughly 450 kWh in small homes and 580 kWh in medium homes).
- Controls using variable dose targets were more effective, but fixed dose approaches worked well in locations with substantial heating demand.
- Control Strategy 7 combined these and had best performance

Description of Control 7

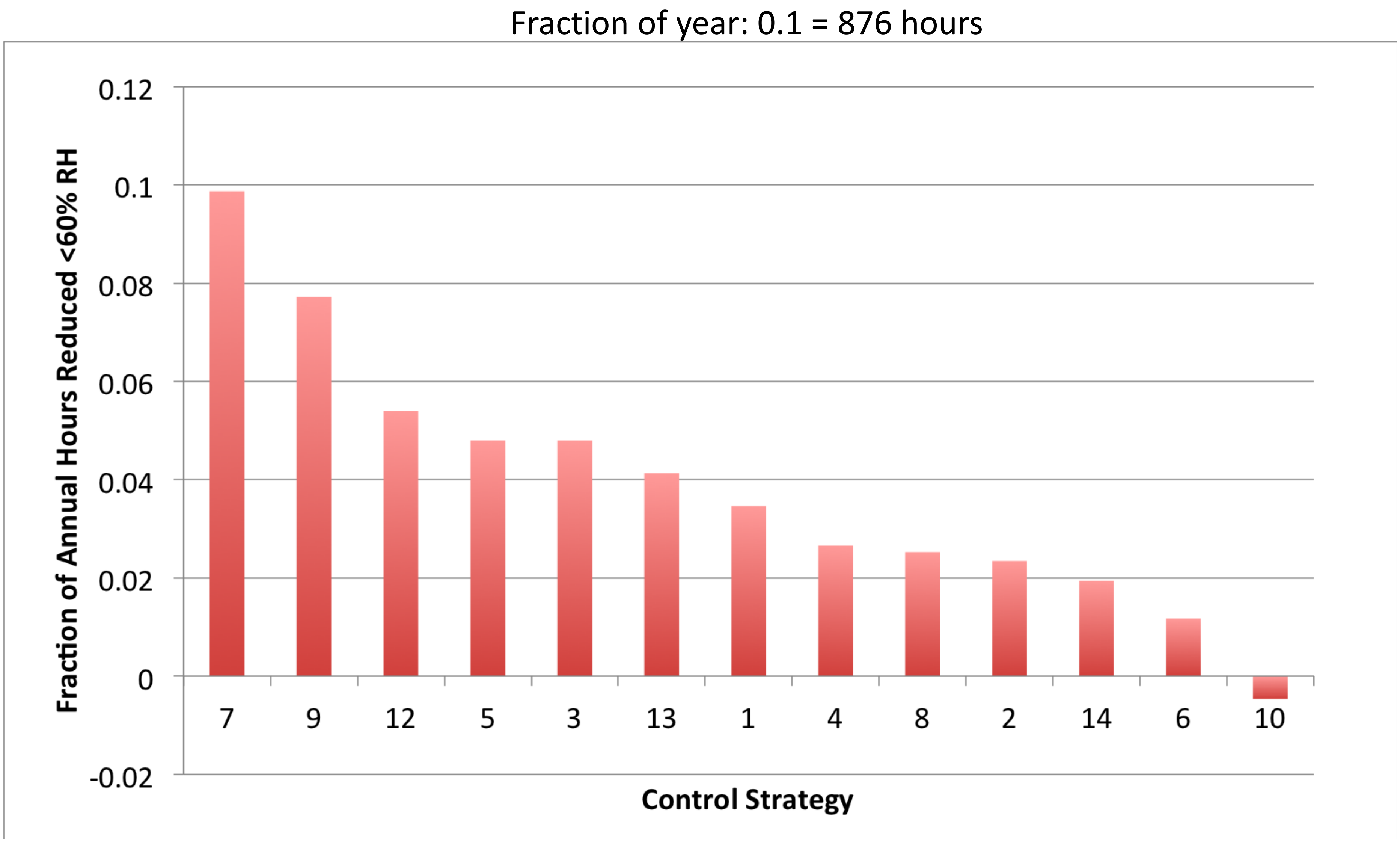
- Tied-in to cooling system
- Changes dose target during the year
- Measures both inside and outside humidity ratio, W

Condition	**Ventilation ON**
$W_{out} >= W_{in}$	Cooling system ON OR Exposure >= 2.5 OR Dose > *HighDoseTarget*
$W_{out} < W_{in}$	Dose > *LowDoseTarget*

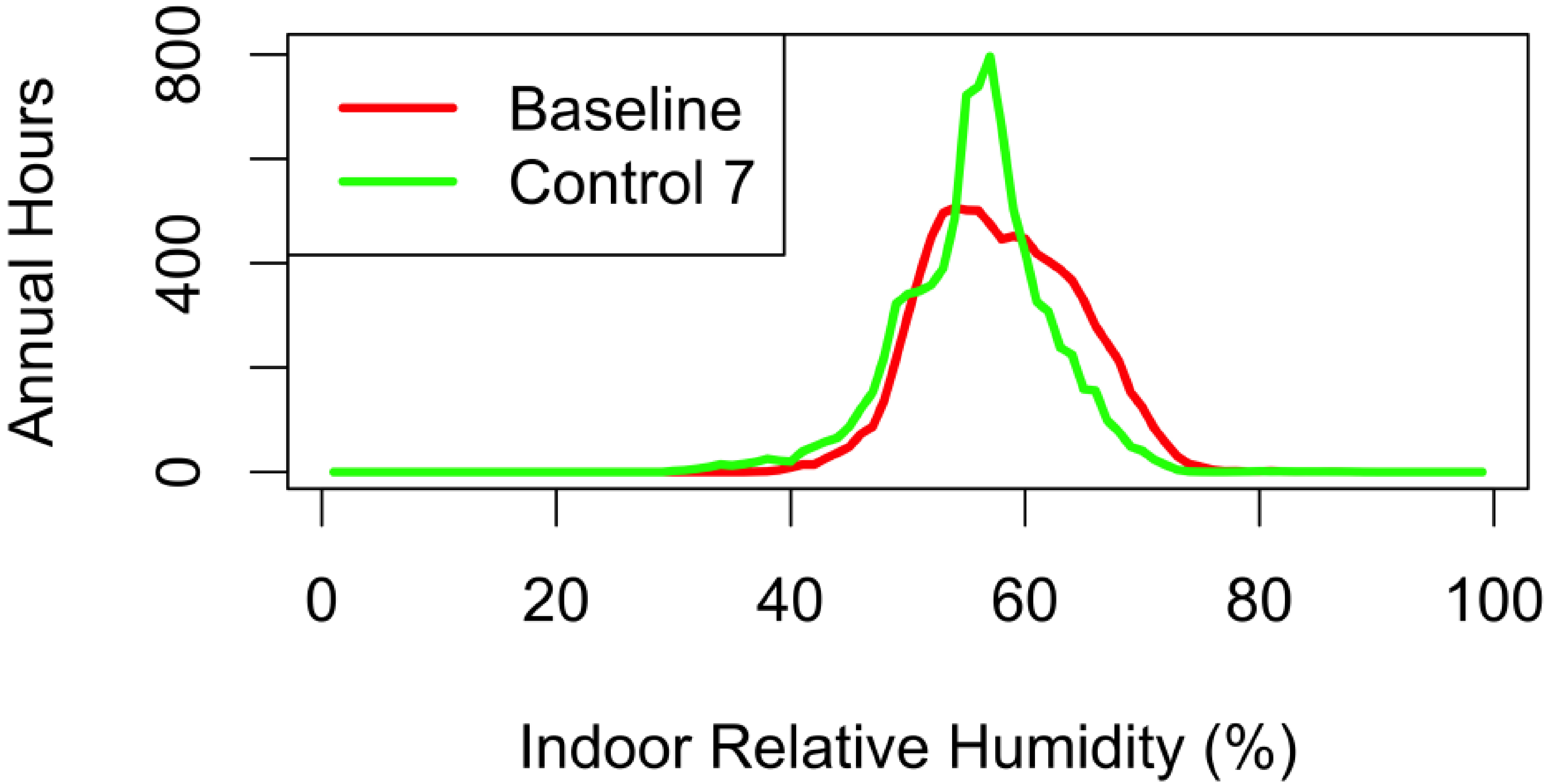
High/Low dose targets determined iteratively to ensure annual dose and exposure <= 1
Depend on climate (W_{out})

	HighDoseTarget	LowDoseTarget
Miami	1.1	0.38
Orlando	1.2	0.36
Houston	1.2	0.36
Charleston	1.2	0.47
Memphis	1.2	0.64
Baltimore	1.3	0.66

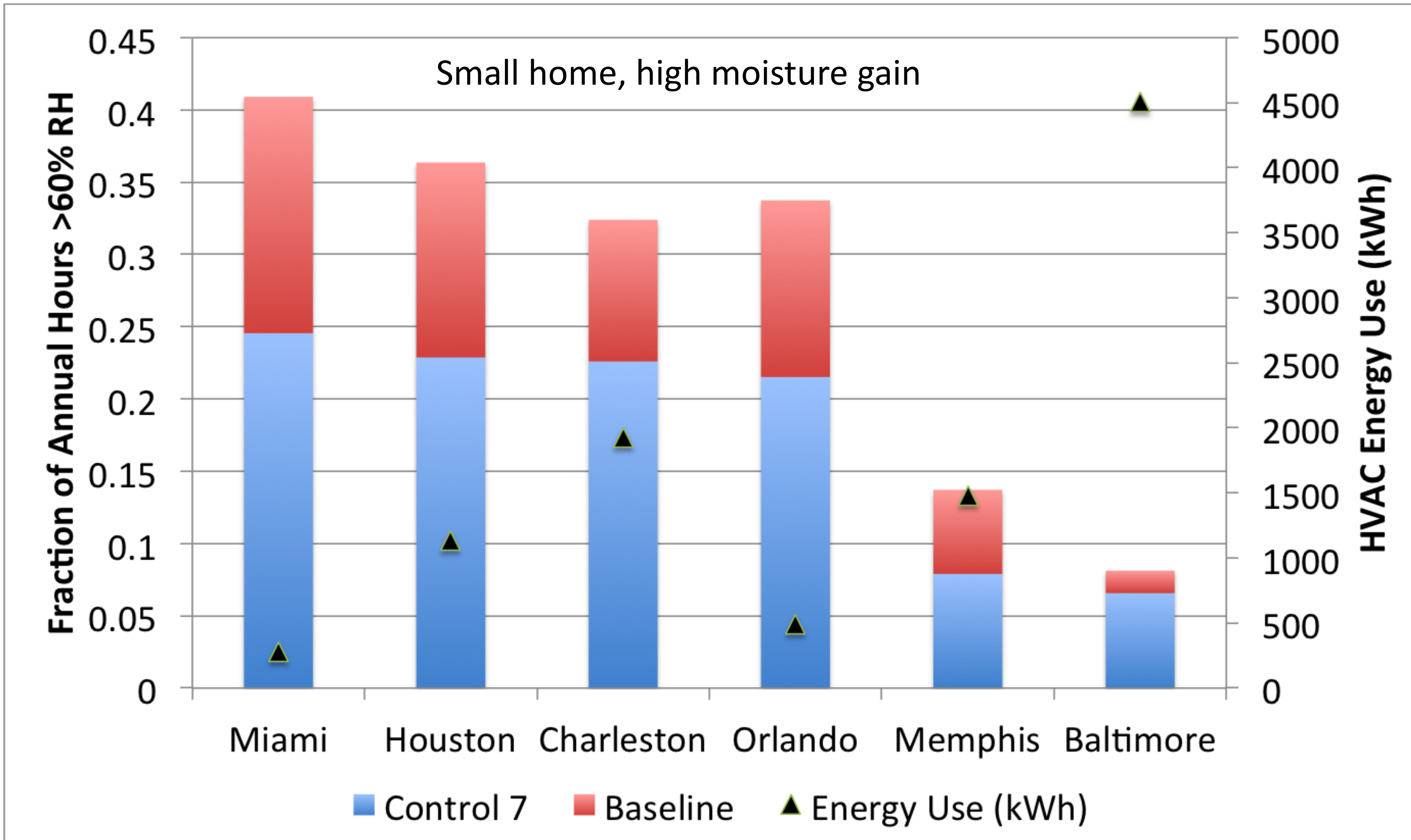
Controls compared to baseline averaged over all climates



Humidity Distribution



Control 7 Results



Summary

- High indoor humidity was not an issue in many combinations of location, house size and moisture gains. The most problematic cases were small homes with high moisture gains, where between 5 and 40% of annual hours were >60% RH.
- Smart ventilation controls were effective at reducing indoor humidity levels, and they maintained air quality equivalent to or better than a continuous fan sized to 62.2-2013.
- The best performing strategy was Control 7 that used both indoor and outdoor sensors and a cooling system tie-in. It was able to reduce 16% of annual hours <60% RH in a small Miami home using under 300 kWh.
- In the most challenging cases, indoor humidity remained >60% for 20 to 25% of annual hours. Supplemental dehumidification in humid climates may be necessary to achieve acceptable levels in these high performance homes.
- Next steps are to evaluate how smart ventilation controls interact with and compare to a supplemental mechanical dehumidification strategy.