Monitored Indoor Moisture and Temperature Conditions in Humid Climate U.S. Residences

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Introduction

- Started looking at humidity control in hot-humid climate homes in the early 90's
- Some Southeast US production builders began routinely installing supplemental dehumidification in the late 90's
- Started an extensive field research project on cost and performance of dehumidification options in early 2001
- Continued gathering indoor temperature and relative humidity data during the course of additional projects involving dehumidification, unvented-cathedralized attics, and cooling system sizing
- Questions from some industry members about the extent of the humidity control problem prompted analysis of the combined data from all of these projects

Humidity control goals

1. Comfort and IEQ
    - Control indoor humidity year-around, just like we do temperature
2. Durability
    - Reduce builder risk and warranty/service callbacks

Humidity control challenges

1. In humid cooling climates, there will always be times of the year when there is little sensible cooling load to create thermostat demand but humidity remains high
   - Cooling systems that modify operation based on humidity can help but are still limited in how much they can over-cool to
2. More energy efficient homes have lower sensible heat gain to drive thermostat demand but the latent gain remains mostly the same
   - Low glazing heat gain
   - Ducts in conditioned space
   - More and better-installed insulation
   - Less heat gain from energy efficient appliances and fluorescent lighting

Humidity control challenges

4. More energy efficient cooling equipment often has a higher evaporator coil temperature yielding less moisture removal
    - Larger evaporator coil by manufacturer design, or up-sized air handler unit or air flow by installer choice
5. Conventional over-sizing to cover for lack of confidence in building enclosure or conditioning system performance causes short-cycling yielding less moisture removal

System engineering trade-offs

- Start with high-performance building enclosure
  - Decreased energy consumption
  - Increased occupant comfort
  - Reduced cooling system size
    - Helps pay for the enclosure improvements
    - More compact duct system
      - lowers cost and helps get the ducts inside
  - Overall building performance more predictable
    - Gives confidence for right-sizing equipment
      - No short-cycling: Better moisture removal, Higher average efficiency, Better spatial mixing
    - Controlled ventilation instead of random infiltration
  - Improves the more permanent features of a home which has longer-term sustainability benefits

Introduction

- Data set
  - 43 homes, each with 1-4 T/RH space measurements
  - Data recorded at 60-minute intervals
  - 27 homes <u>also</u> had equipment runtime measurements (cool, heat, fan, dehumidifier)








House energy performance level

- Standard-performance (standard builder practice)
- Medium-performance (Energy Star+)
  - Improved thermal performance
  - Mechanical whole-house ventilation
- High-performance (Building America)
  - Low SHGC windows (0.33)
  - Ducts in conditioned space
  - At least 50% tighter building envelope than Standard-performance
  - Mechanical whole-house ventilation
  - Pressure balanced interior zones

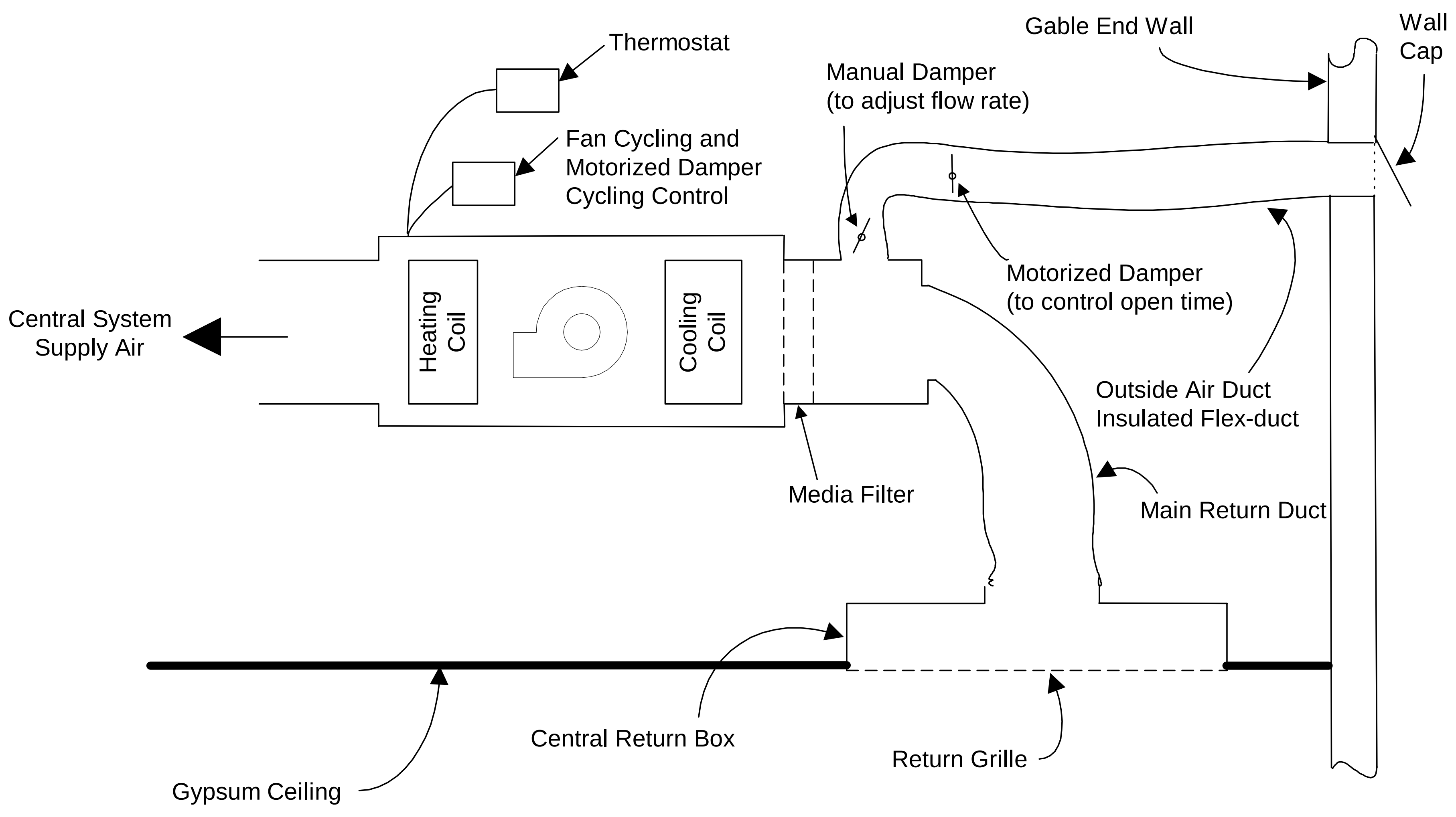
HVAC Systems

- Standard AC
- Enhanced AC (variable speed blower, intermittent low blower speed, 3 degrees over-cooling, two-stage compressor)
- Infiltration only or Whole-house Ventilation
  - Central Fan Integrated Supply ventilation (CFIS)
  - Energy Recovery Ventilation (ERV)
- Dehumidifier (unducted: interior closet, unvented-attic; ducted independent of central system; ducted into central system)

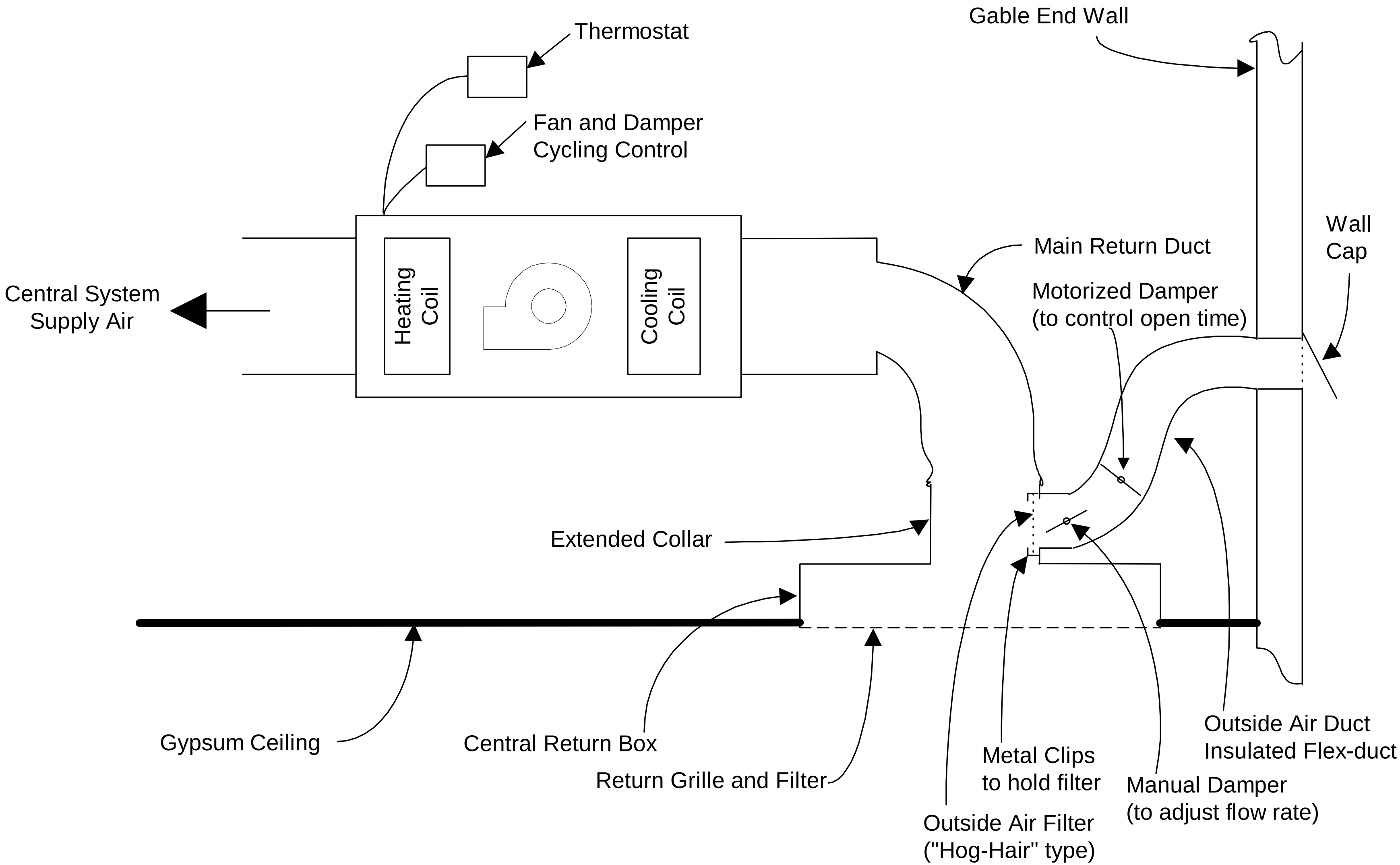
Residential ventilation

- Spot exhaust for pollutant removal
  - Kitchen (duct to outside, no recirculation)
  - Bath (excess moisture is a top pollutant)
  - Laundry
- Whole-house for pollutant dilution
  - Supply, exhaust, balanced
  - Single-point, multi-point, integrated with central system

Central-fan-integrated supply ventilation
Attic AHU, media/electronic filter



CFIS, Attic AHU, ceiling filter grille, extended collar

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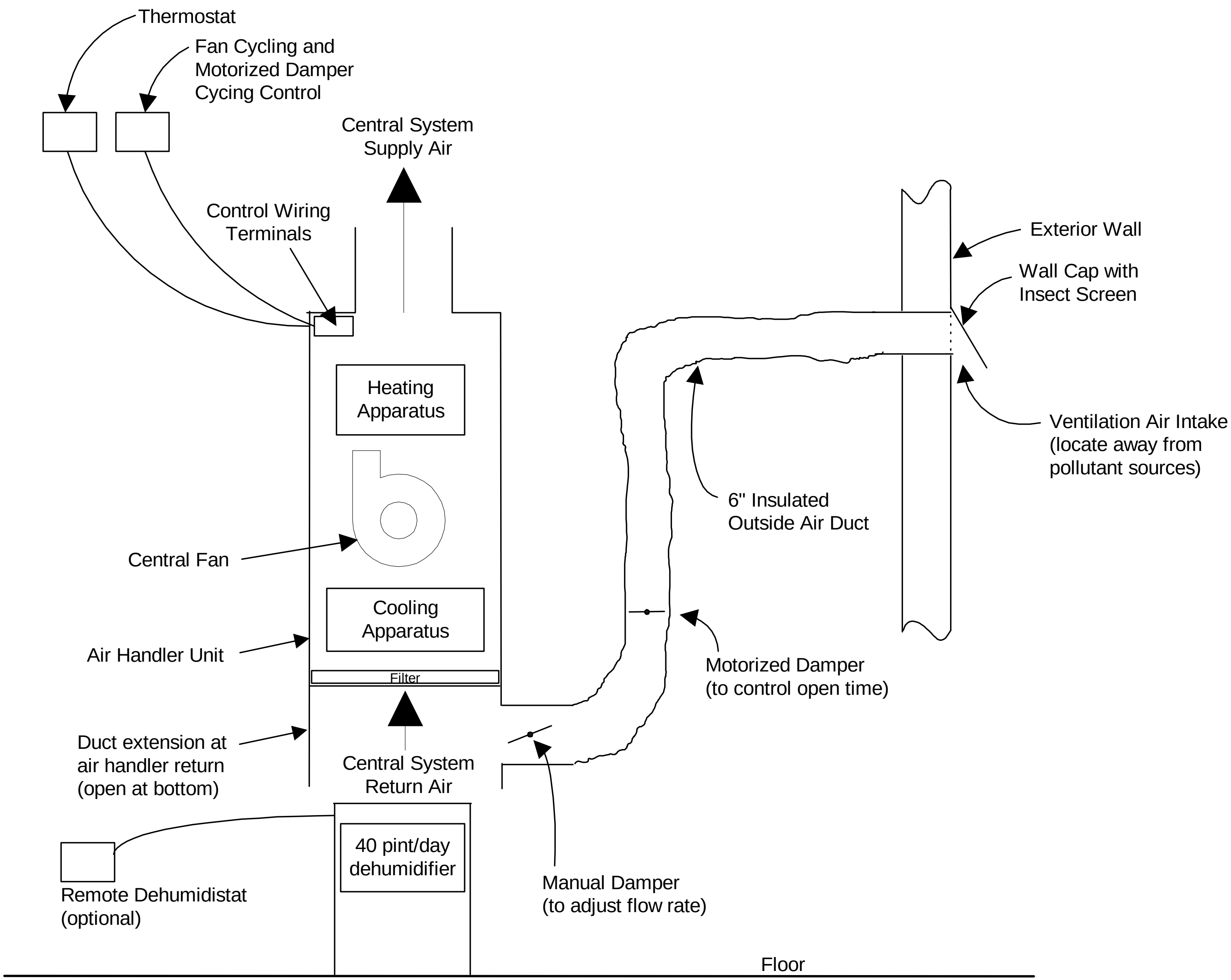
CFIS with dehumidification separate from cooling hot-humid climate, interior mechanical closet configuration

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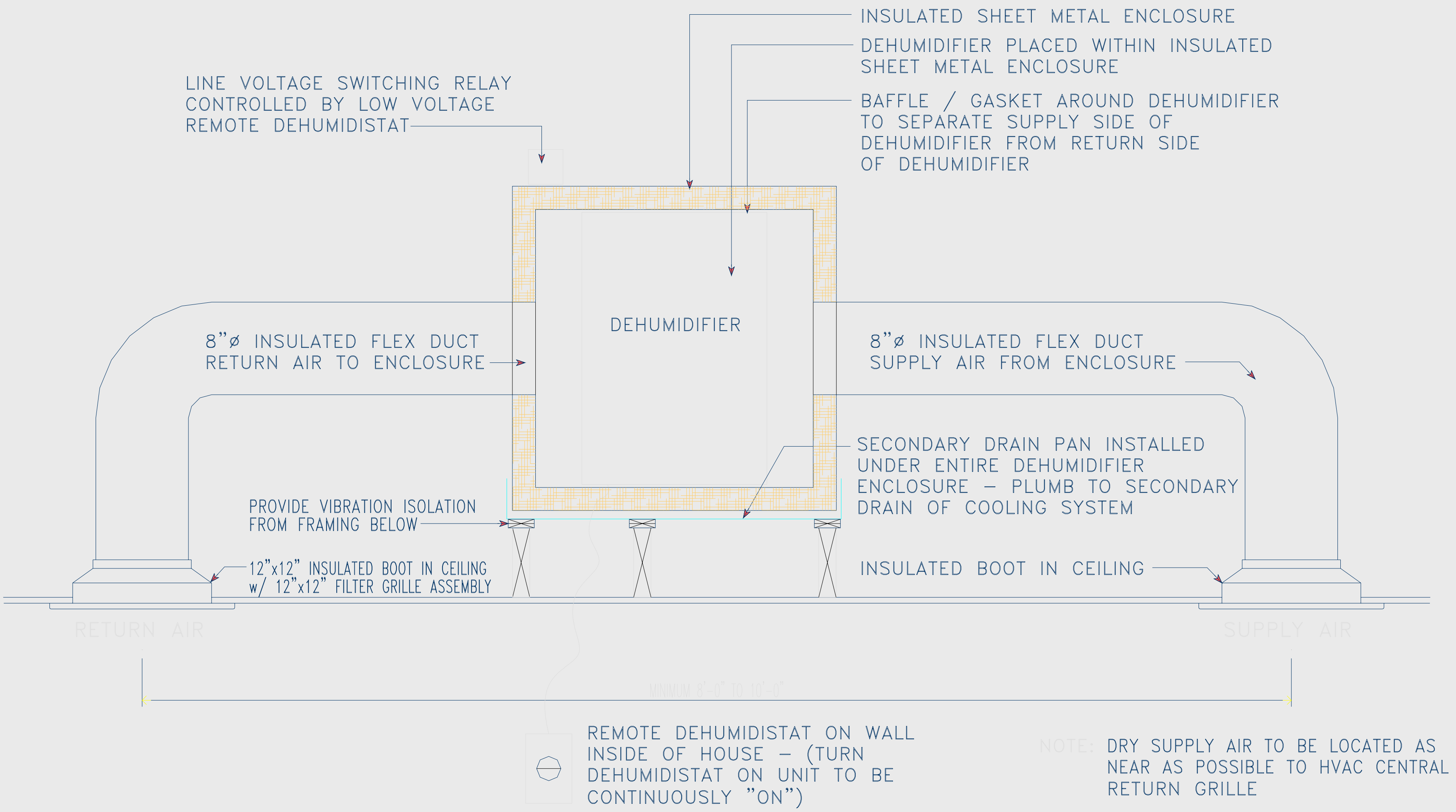
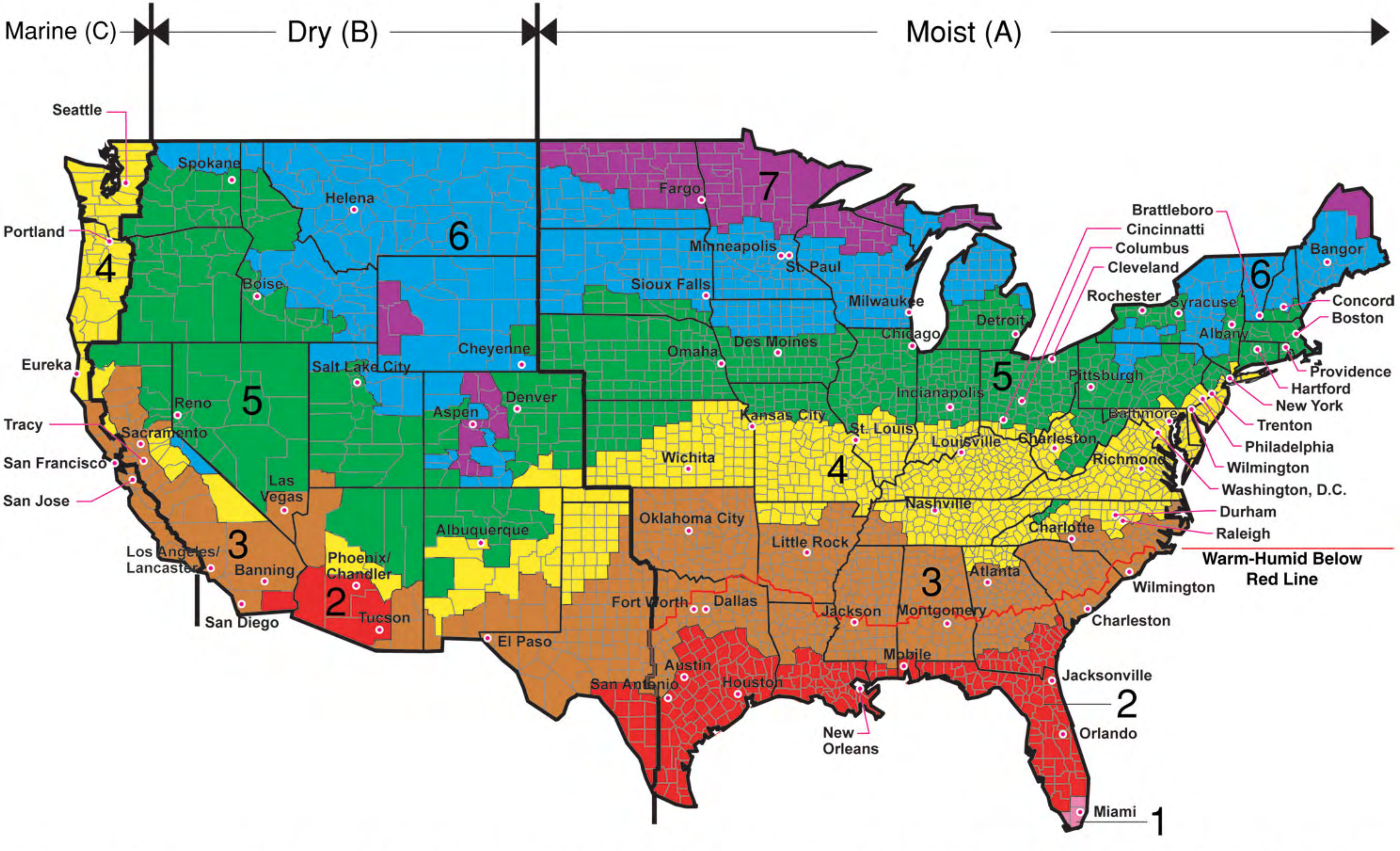
Site-configured dehumidifier system not integrated with central system



Manufactured dehumidifier integrated with central system

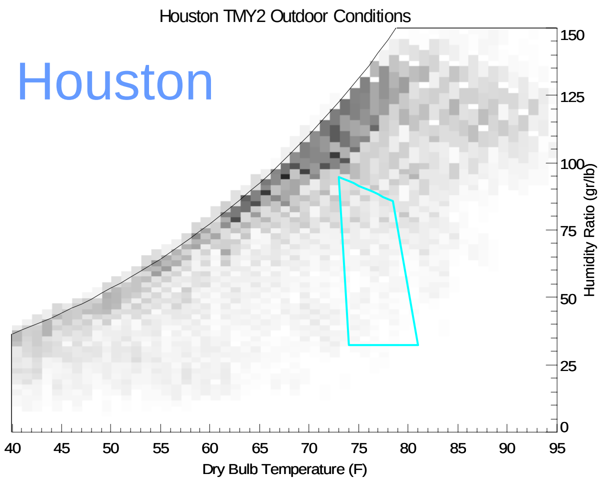
Houston (29), Austin (3), Dallas (3), Jacksonville (2), Ft. Myers (2), Orlando (1), OK City (3)

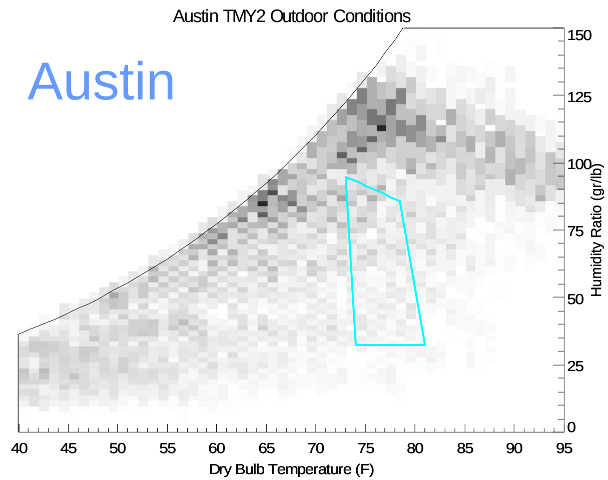


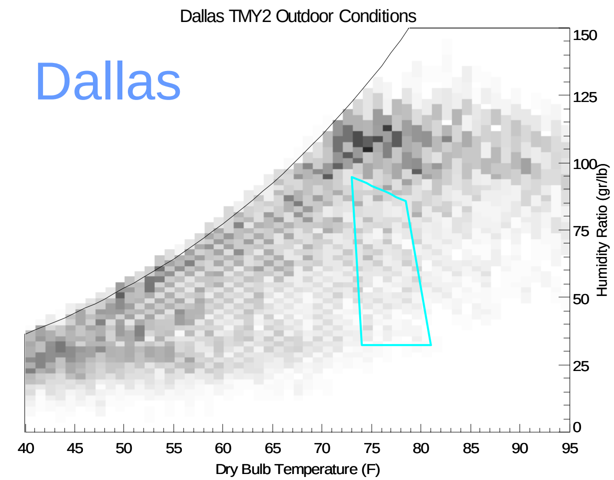
All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

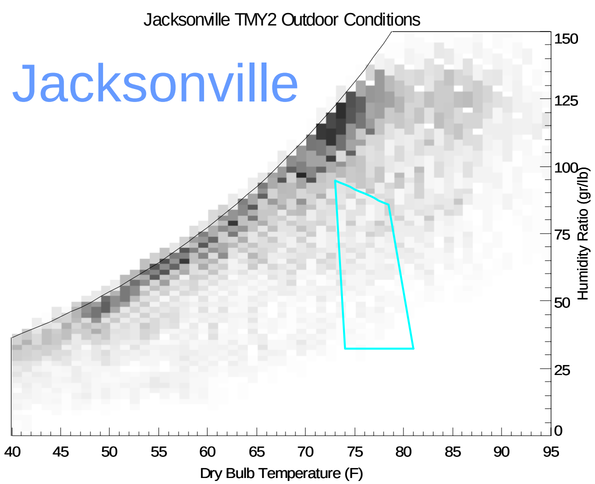
Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

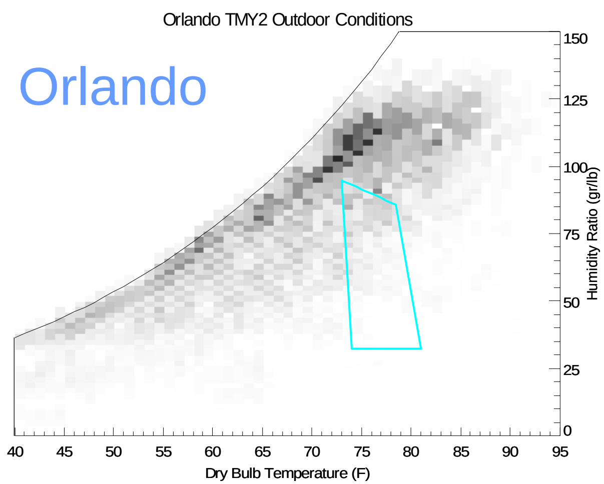
Outdoor conditions

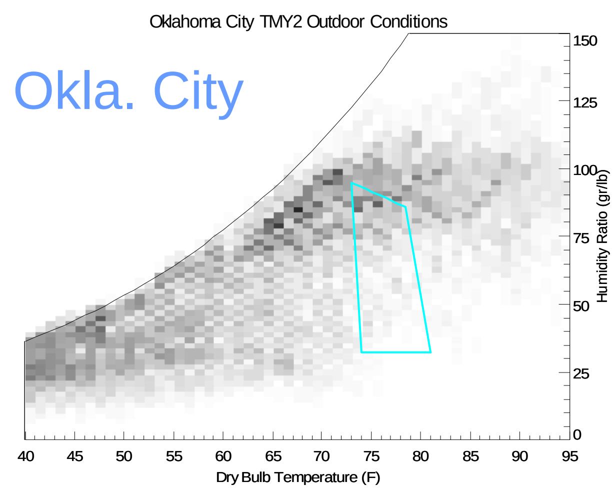












Standard performance houses: space humidity

							Number of events longer than 4 hrs		Number of events longer than 8 hrs		Avg temperature (F)	
Site #	System	City	Month/Yr	Hours of Data	% hours over 60%	% hours over 65%	>60%	>65%	>60%	>65%	over 60%	over 65%
Standard houses without ventilation												
20	STD	Houston	Mar-02	744	19%	3%	11	1	6	1	72	72
27	STD	Houston	Mar-03	744	20%	1%	13	0	6	0	70	70
25	STD	Houston	May-04	744	48%	26%	23	13	18	9	75	75
19	STD	Houston	Apr-02	720	57%	22%	11	10	11	5	74	74
18	STD	Houston	Nov-01	335	67%	5%	12	2	11	0	74	73
Standard houses with ventilation												
36	STD-CFI	Austin	Jan-03	396	0%	0%	0	0	0	0		
34	STD-CFI	Austin	May-03	744	5%	0%	1	0	0	0	74	
39	STD-CFI	Dallas	May-03	744	24%	3%	11	0	3	0	74	75
37	STD-CFI	Dallas	Jun-03	717	38%	6%	12	2	5	0	76	76
38	STD-CFI	Dallas	May-03	744	51%	16%	22	10	12	4	76	76
35	STD-CFI	Austin	May-03	744	66%	15%	9	7	7	4	77	77
Standard houses with ventilation and supplemental dehumidification												
26	STD-CFI-DH-D	Houston	Nov-02	720	0%	0%	0	0	0	0	73	
33	STD-CFI-APR	Houston	Apr-04	720	5%	1%	1	0	0	0	72	73
32	STD-CFI-APR	Houston	Mar-04	744	9%	3%	2	1	1	1	71	71
28	STD-CFI-DH-D	Houston	Nov-02	720	18%	0%	5	0	4	0	72	72
40	STD-CFI-APR	Orlando	Sep-04	720	25%	5%	10	1	6	1	77	78

Medium-performance houses: space humidity

							Number of events longer than 4 hrs		Number of events longer than 8 hrs		Avg temperature (F)	
Site #	System	City	Month/Yr	Hours of Data	% hours over 60%	% hours over 65%	>60%	>65%	>60%	>65%	over 60%	over 65%
Medium performance houses with ventilation												
43	ES-CFI	OK City	Nov-03	720	24%	13%	5	6	4	4	72	72
42	ES-CFI	OK City	Jun-03	720	100%	82%	1	22	1	16	79	79
41	ES-CFI	OK City	Jun-03	720	100%	94%	2	17	2	16	73	73

High-performance houses: space humidity

					Number of events		Number of events			
			% hours	% hours	longer than 4 hrs		longer than 8 hrs		Average temperature (F)	
Site #	System	Month/Yr	over 60%	over 65%	>60%	>65%	>60%	>65%	over 60%	over 65%
	High performance houses with ventilation									
17	BA-CFI	Apr-02	82%	34%	21	21	19	13	75	76
15	BA-CFI	Feb-01	95%	68%	4	8	4	8	71	73
16	BA-CFI	Feb-01	99%	90%	1	2	1	2	68	68
	High performance houses with energy recovery ventilation									
13	BA-ERV	Apr-02	56%	18%	30	12	22	1	74	74
12	BA-ERV	Apr-02	85%	52%	3	23	3	10	78	78
11	BA-ERV	Apr-02	98%	53%	8	30	8	20	75	75
	High performance house with ventilation and cooling system enhancement									
14	BA-CFI-ECM	Apr-02	88%	29%	14	15	11	9	71	71
	High performance houses with ventilation and supplemental dehumidification									
10	BA-FV	Oct-02	13%	4%	1	0	0	0	75	75
5	BA-UA	Oct-01	23%	2%	4	0	0	0	73	73
2	BA-CFI-DH-C	Oct-01	45%	17%	16	7	10	1	74	74

Results

- There was little clear difference in space humidity between Standard houses with and without ventilation
  - However, the Standard houses with ventilation were located in the somewhat drier climate of Austin versus Houston
- Two of the three Medium-Performance houses with ventilation showed a marked increase in space humidity compared to Standard houses with ventilation, in spite of the drier climate of Oklahoma City versus Austin.
- All High-Performance houses with ventilation, showed a marked increase in space humidity compared to Standard houses with ventilation.
- All three High-Performance houses with energy recovery ventilation showed a marked increase in humidity compared with Standard houses, but slightly lower humidity than High-Performance houses with ventilation.
  - The effect of reducing the latent ventilation load through energy recovery was insufficient to avoid high humidity at part-load (sensible) and no-load conditions.

Results, cont.

- There was no definitive impact of adding cooling system dehumidification enhancements for Standard houses with ventilation.
- Cooling system enhancements showed little effect on space humidity for High-Performance houses with ventilation
- Three of the five Standard houses with ventilation and supplemental dehumidification exhibited superior humidity control throughout the year.
- Some High-Performance houses with ventilation and supplemental dehumidification controlled space humidity mostly below 60% RH and some did not due to occupant manipulation of the humidistat setpoint.
- The average cooling set points were generally several degrees lower than the commonly assumed value of 78°F. The data provided no clear indication that either lower or higher cooling set points caused high humidity events.

Figure 2. Standard House without ventilation; temperature and RH measured in four conditioned space zones from June 2001 to October 2002

4818 Cottage, Houston

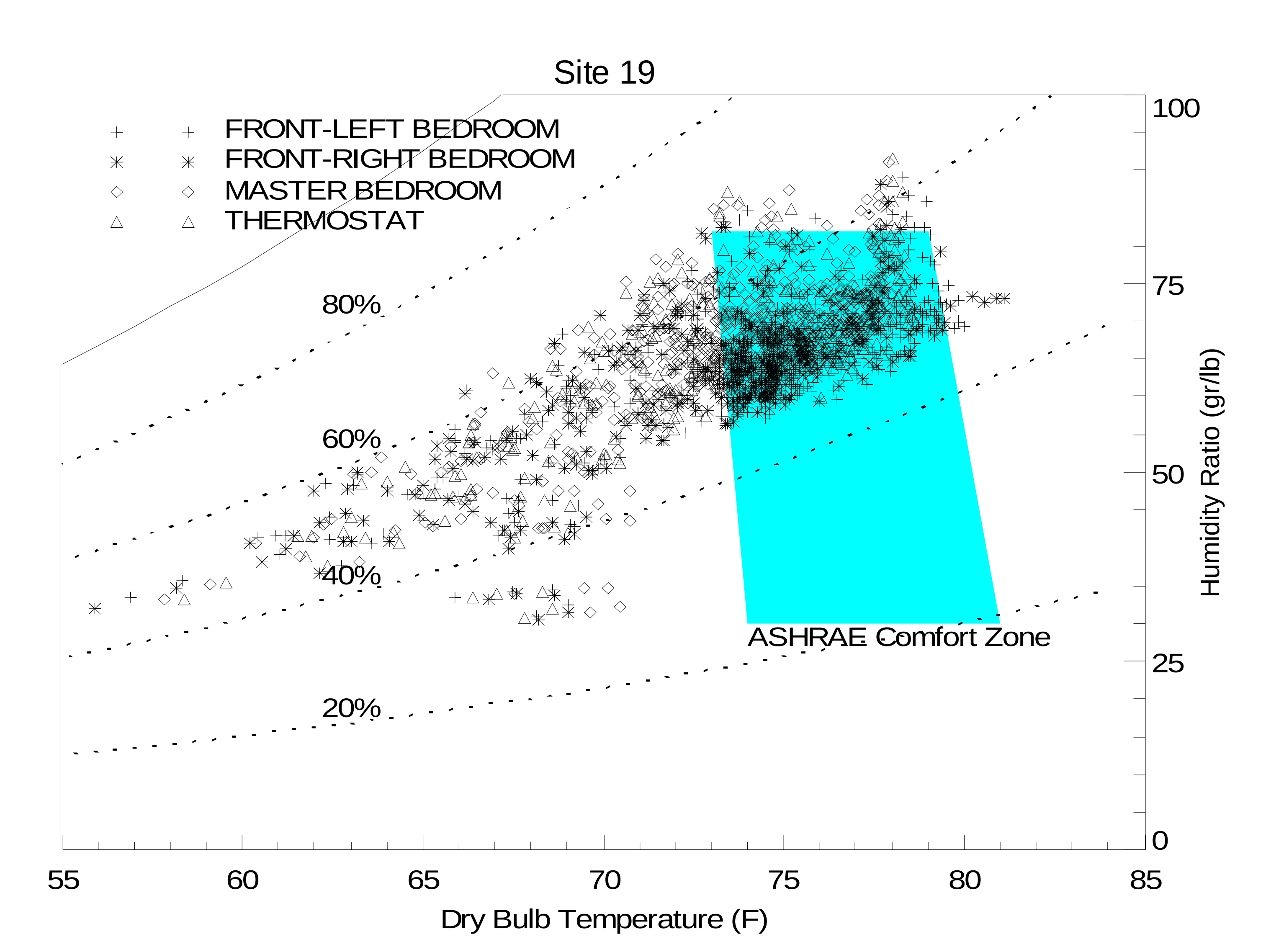


Figure 3. High humidity month (April) compared to typical summer month (August) for Standard House without ventilation

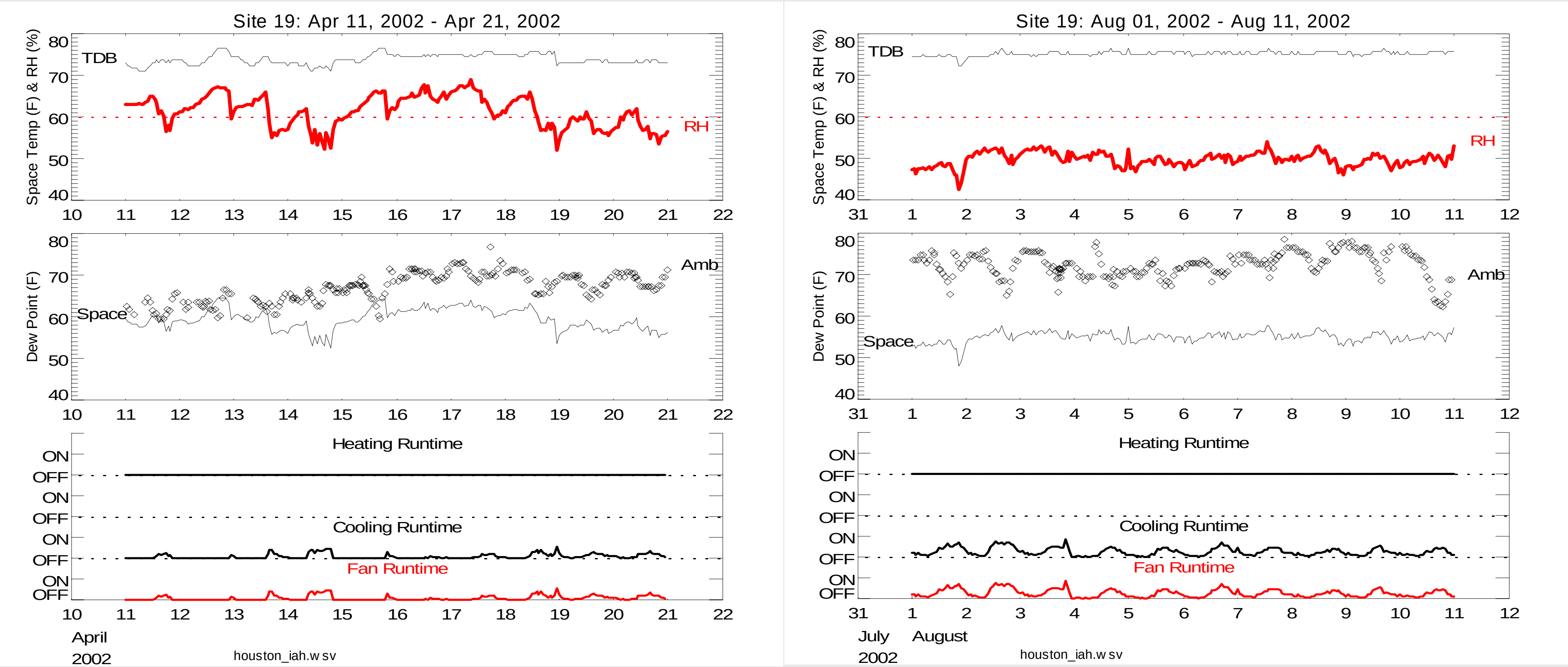


Figure 4. Standard House with Ventilation; temperature and RH measured in three zones from January 2003 to June 2003

6905 Twilight, Austin

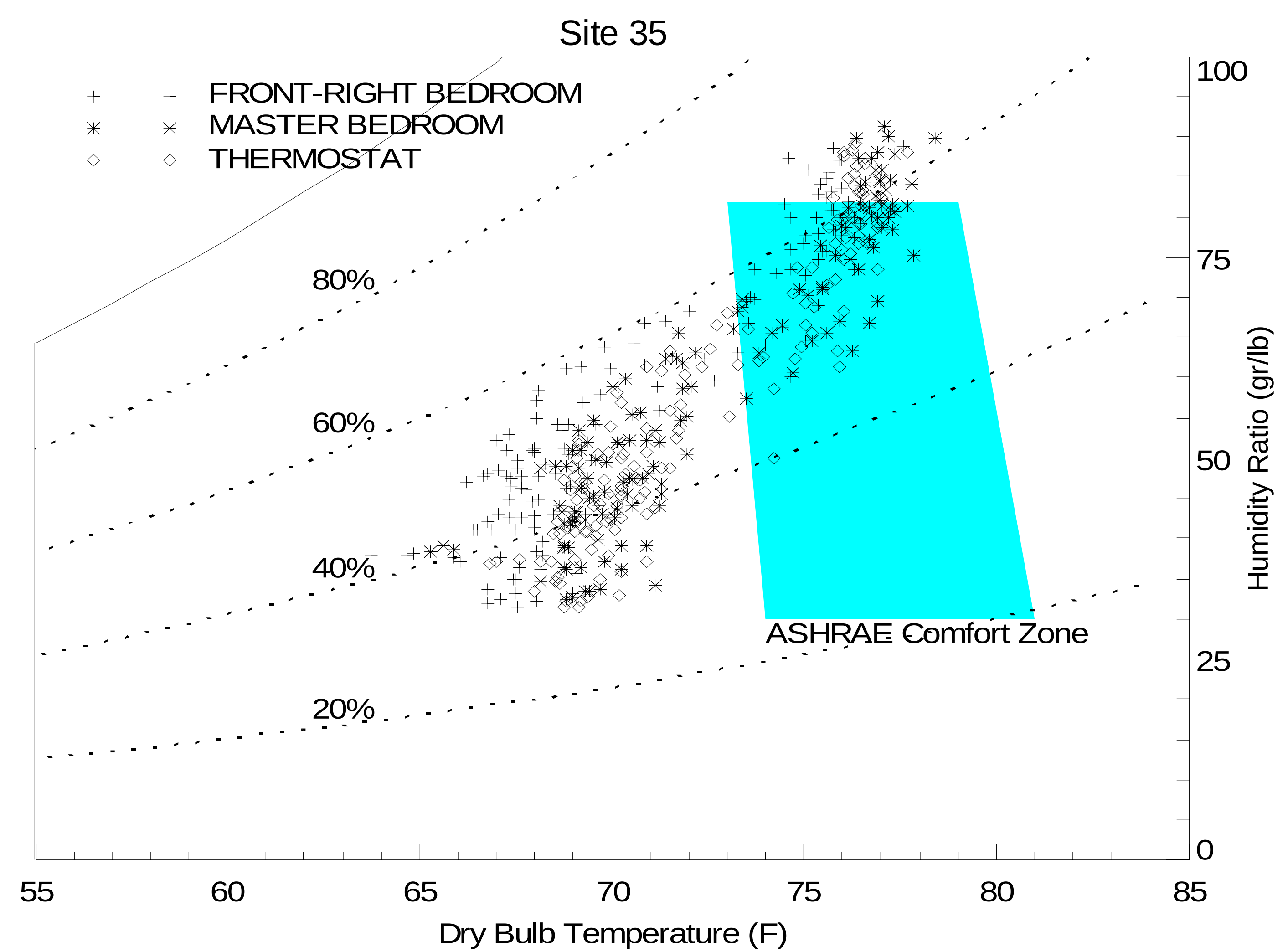
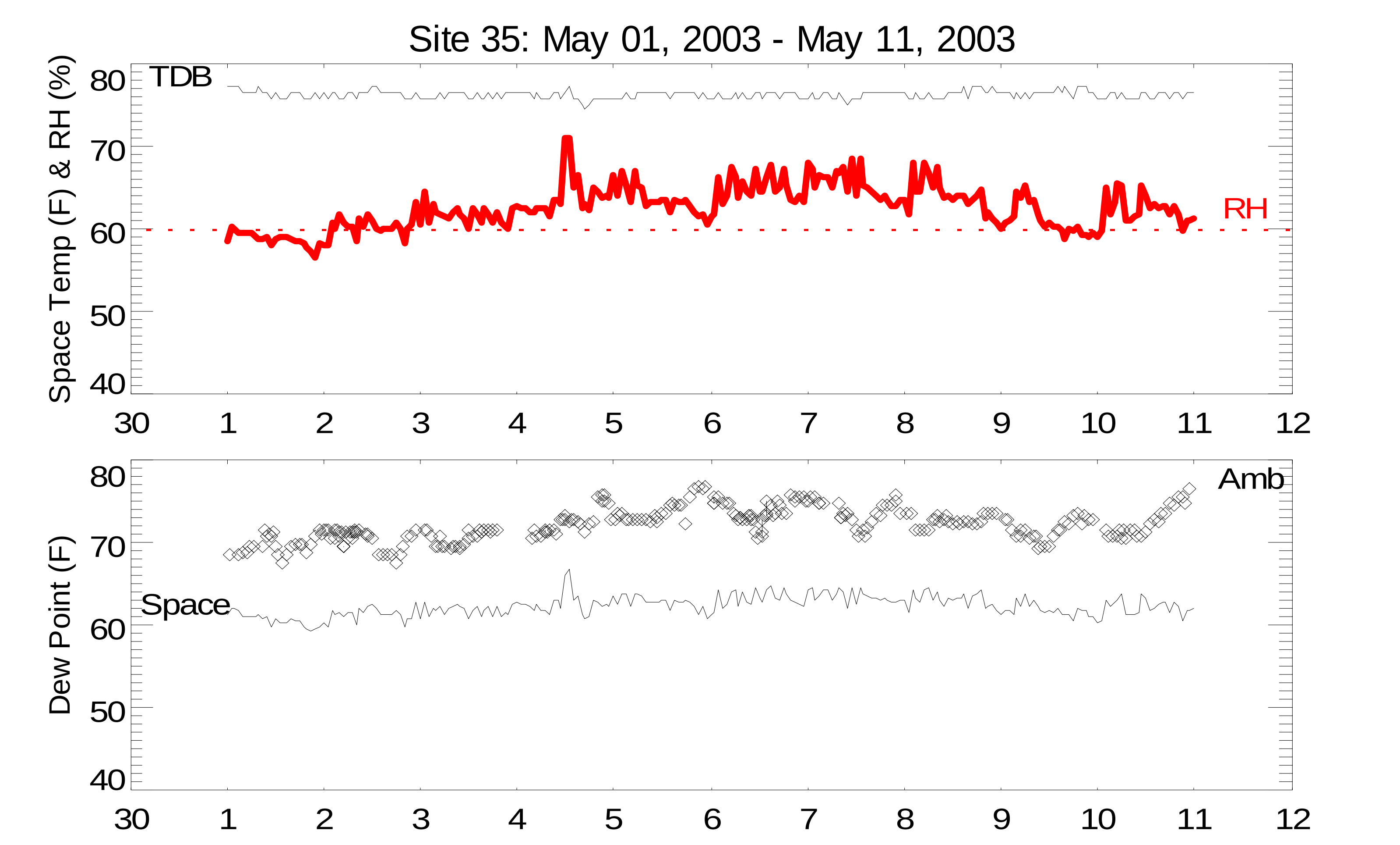


Figure 5. High humidity month (May) shows long periods with RH between 60% and 70% for Standard House with ventilation



Standard house with Ventilation and ducted Dehumidification; very good humidity control, measured in three zones

12942 Oakwood, Houston

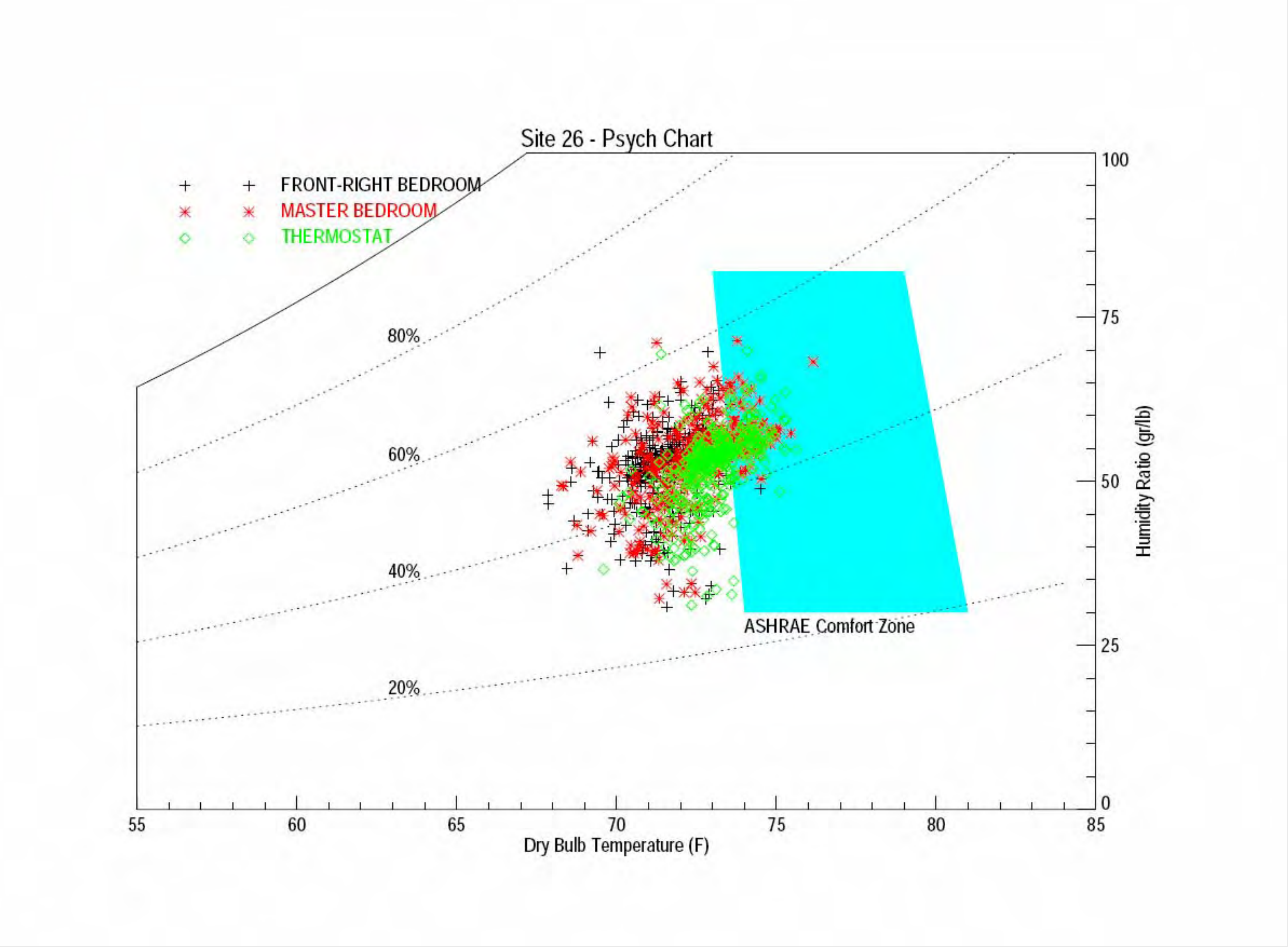


Figure 6. High-Performance House with Ventilation; temperature and RH measured in four zones from July 2001 to October 2002

19906 Ashland, Houston

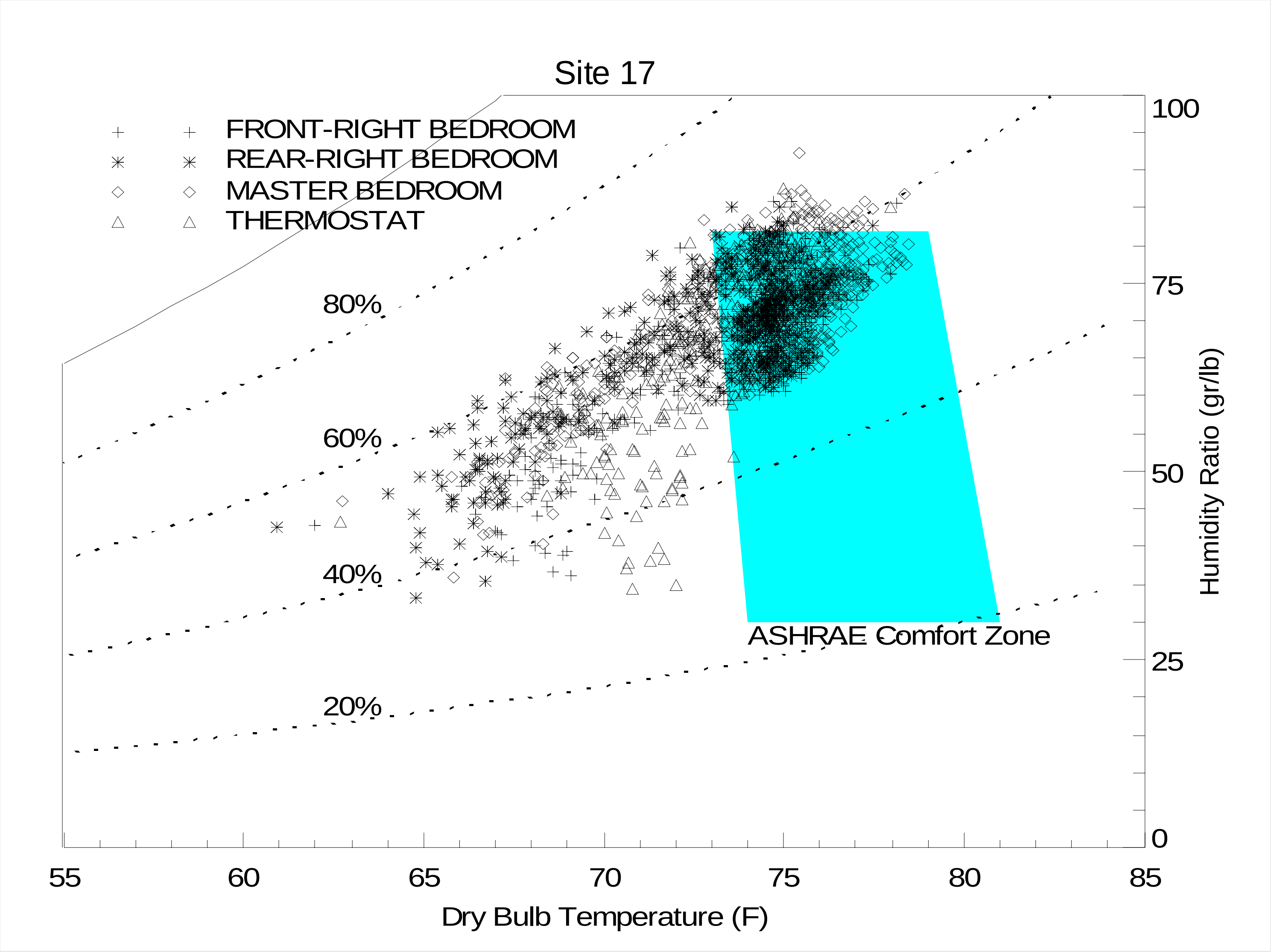
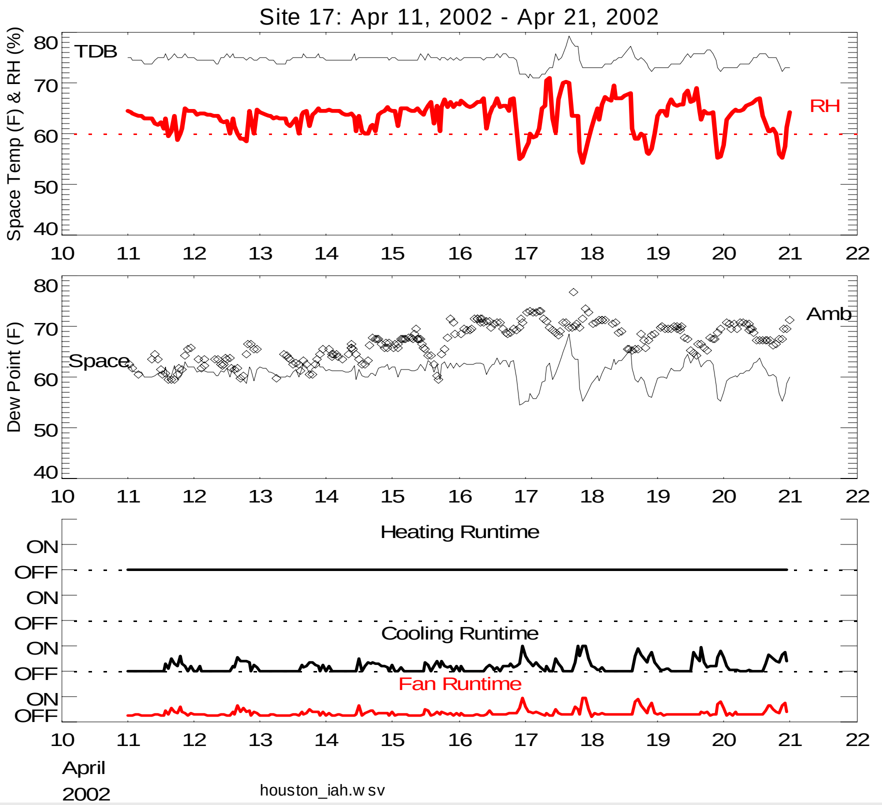


Figure 7. High humidity month (April) compared to typical summer month (July) for High-Performance House with Ventilation



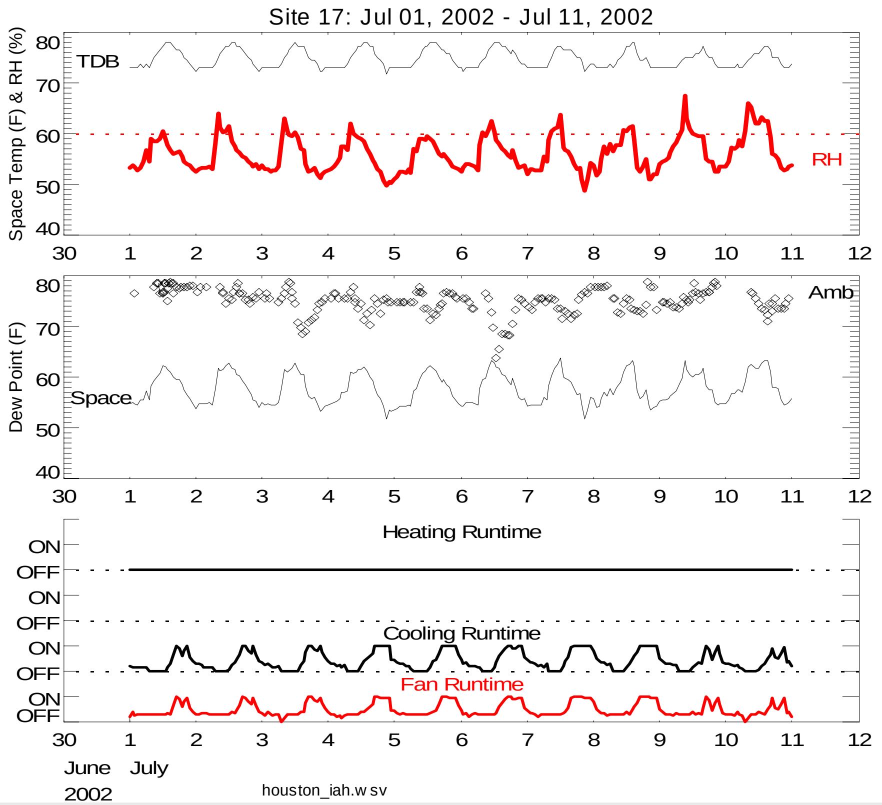
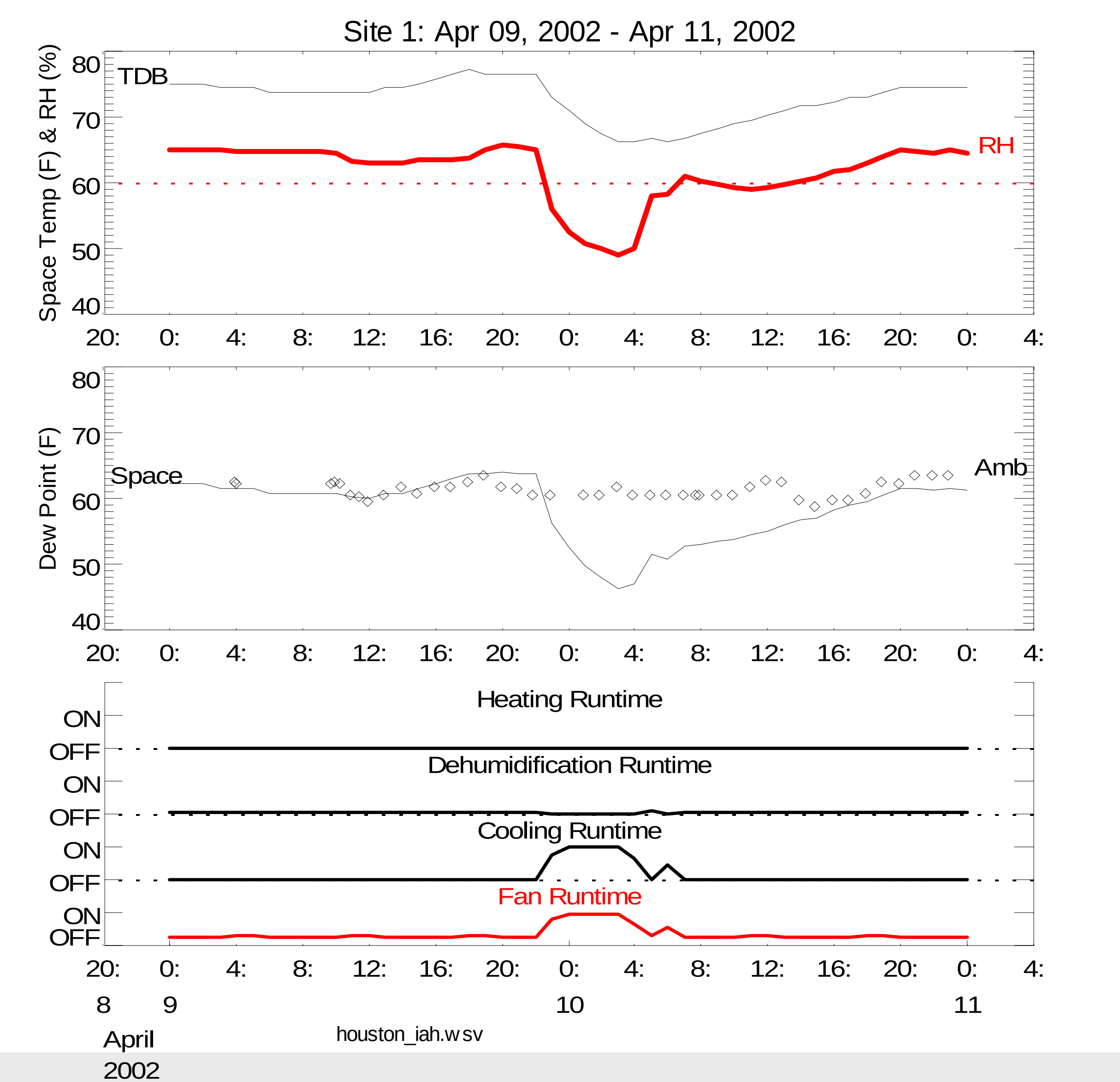
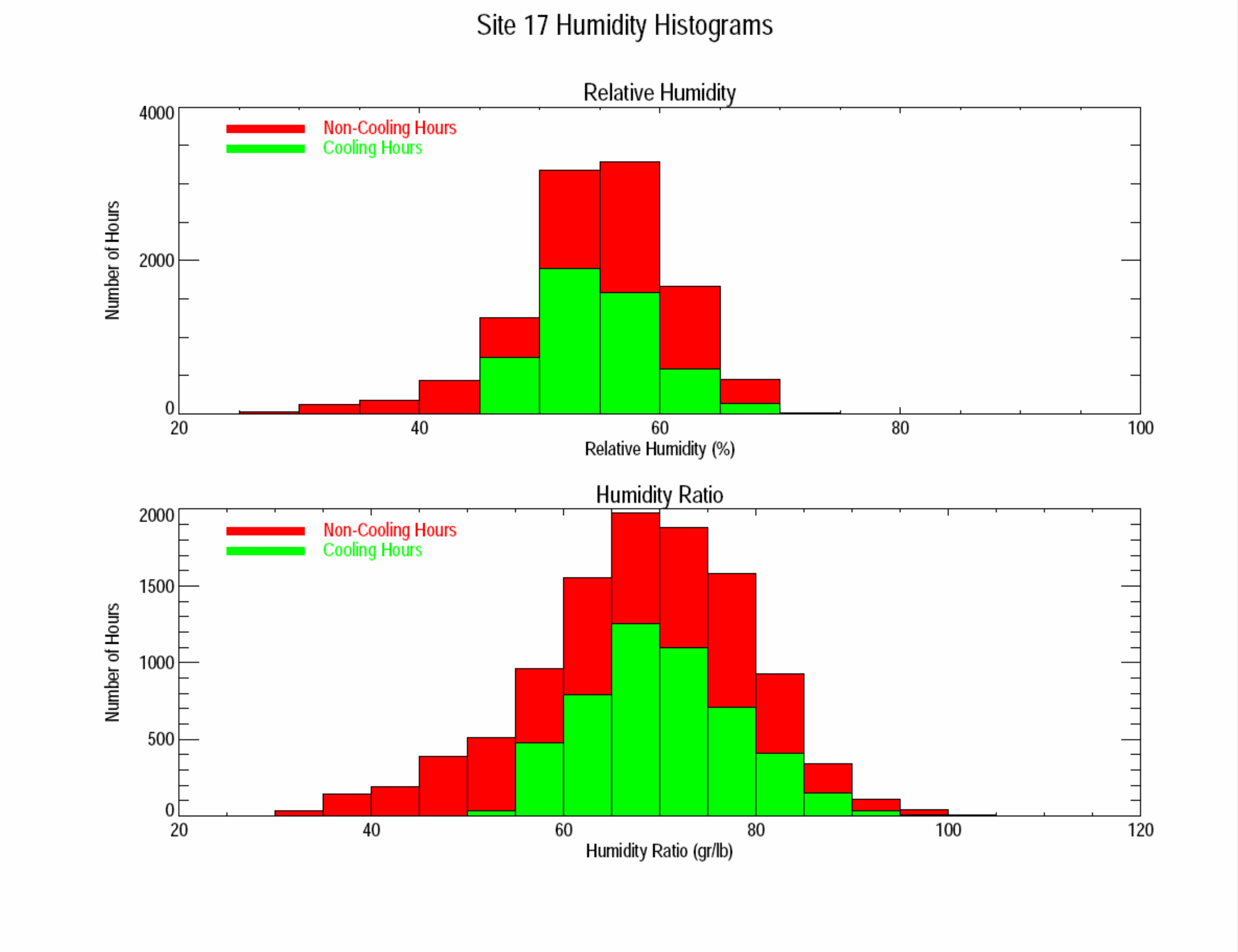


Figure 8. High-performance house with Ventilation; steady increase of indoor humidity driven by continuous ventilation and internal generation during non-cooling hours



High-Performance house with Ventilation; most hours of high humidity are during non-cooling hours



High-Performance house with Ventilation; most hours of high humidity are during non-cooling hours

2802 Sunbird, Houston

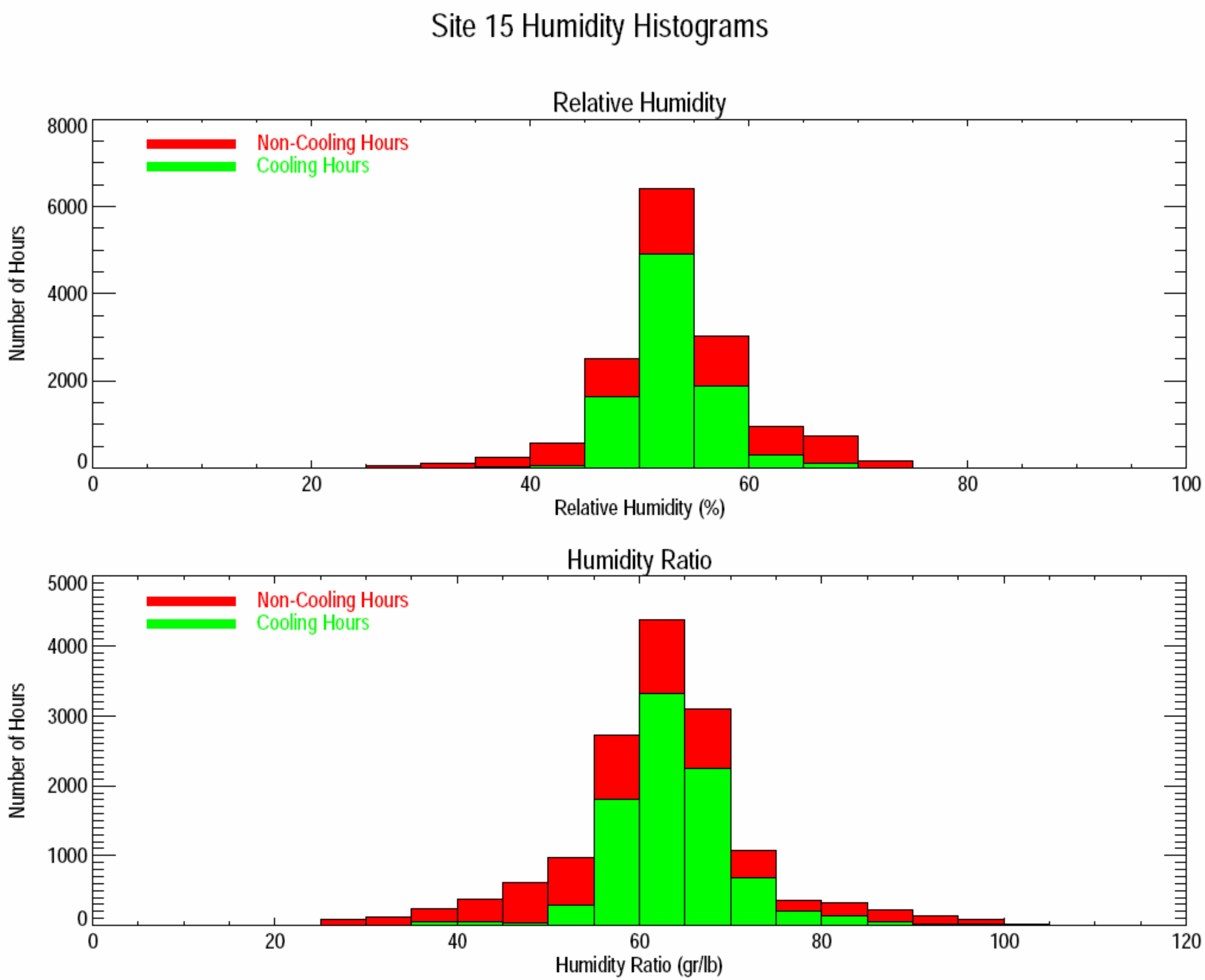
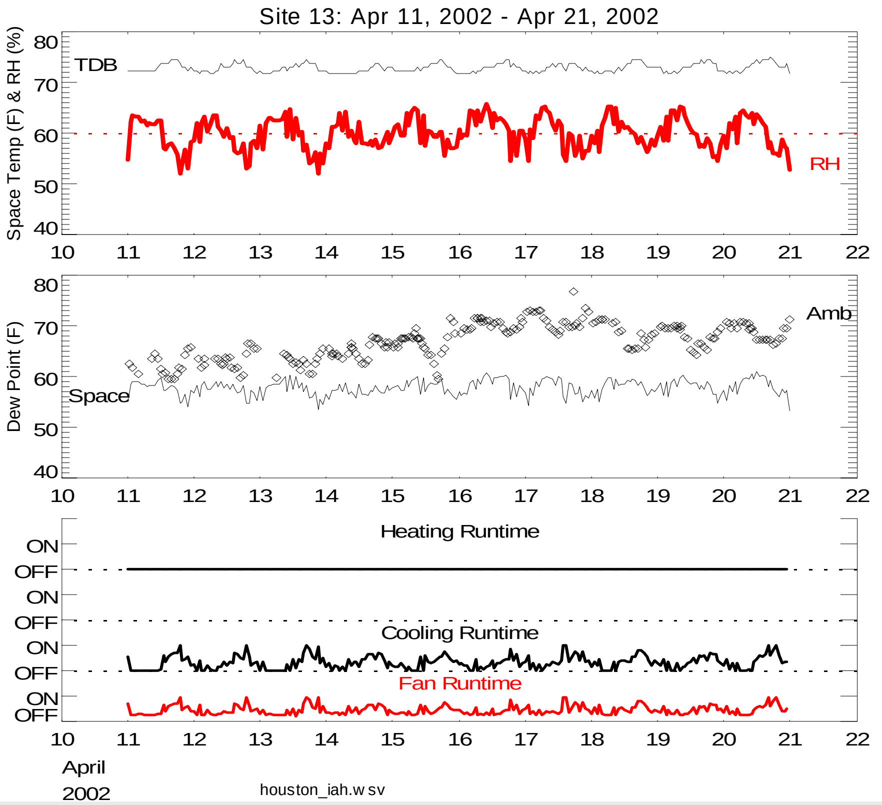


Figure 9. High humidity month (April) compared to typical summer month (July) for High-Performance House with Energy Recovery Ventilator (ERV)



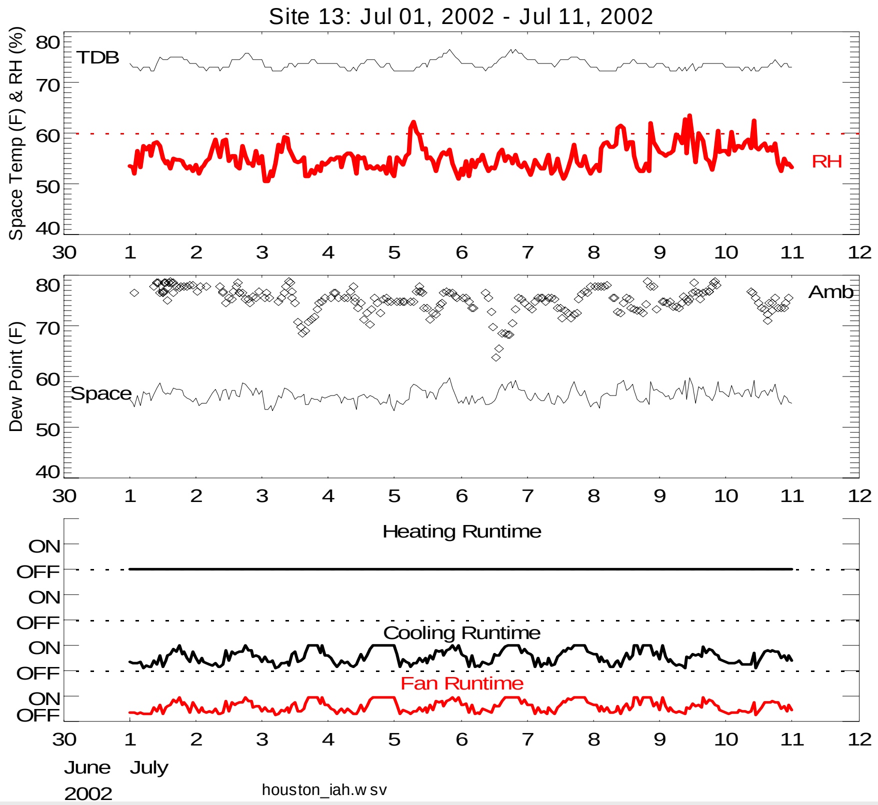


Figure 10. High humidity month (April) compared to typical summer month (July) for High-Performance House with Ventilation and Enhanced Cooling

19422 Colony, Houston

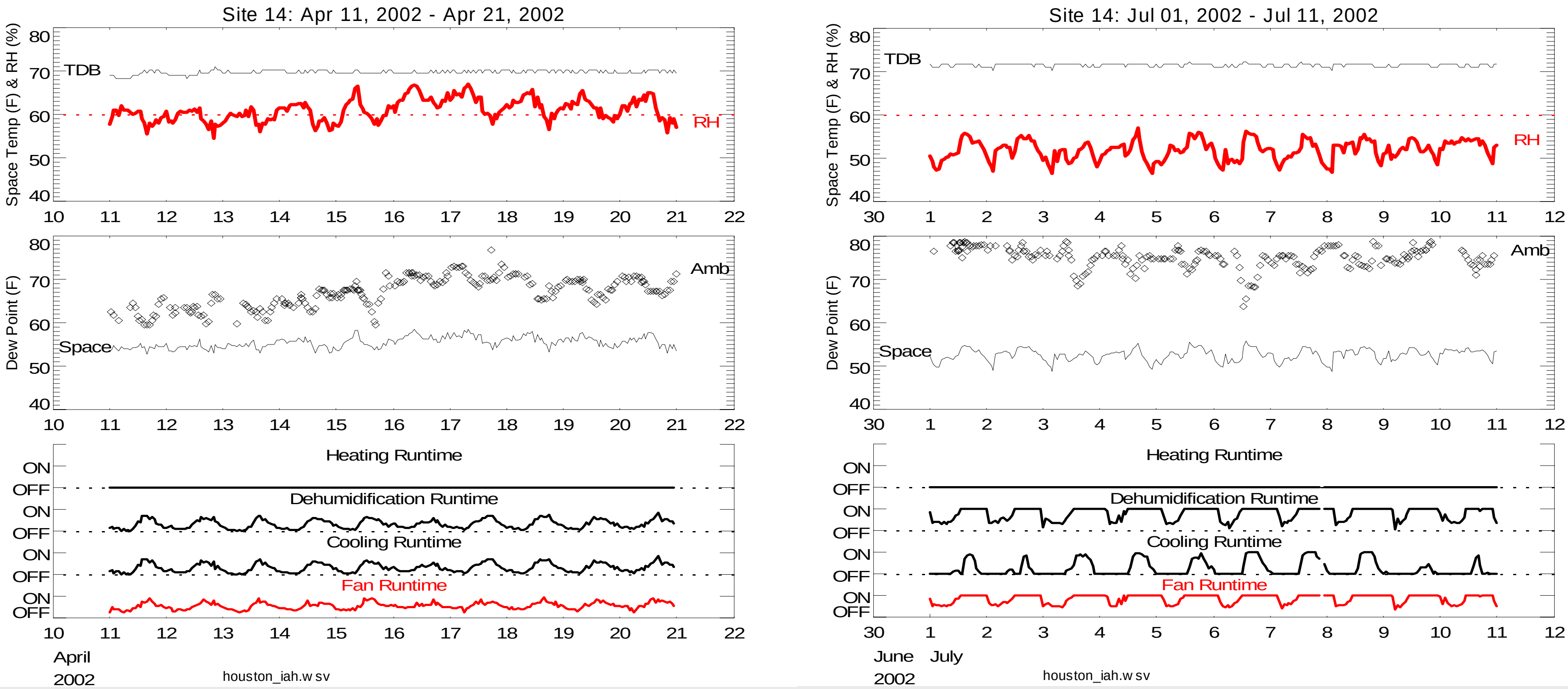


Figure 11. High-Performance House with Ventilation and ducted Dehumidification; temperature and RH measured in four zones from October 2001 to October 2002

19915 Ashland - Houston

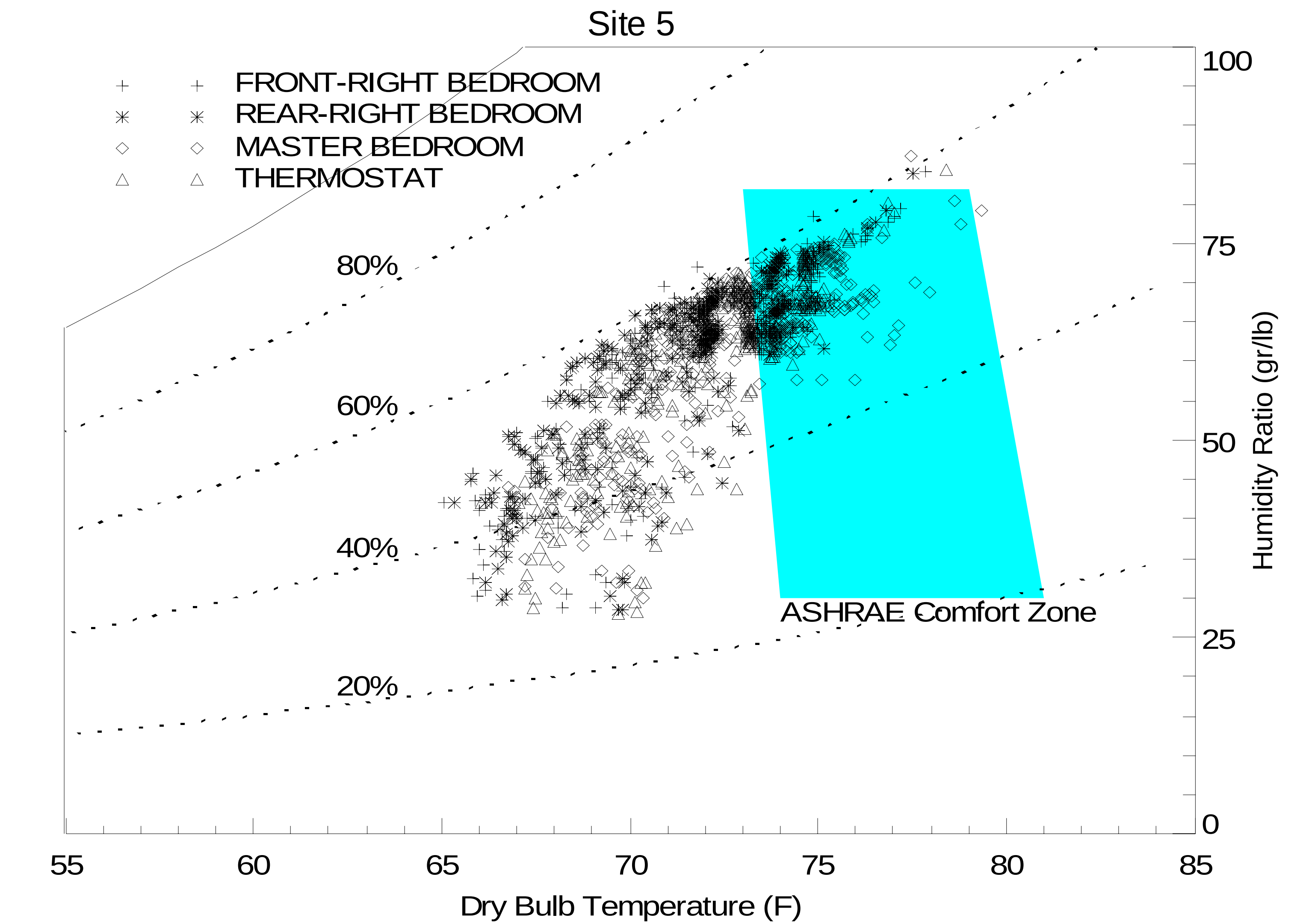
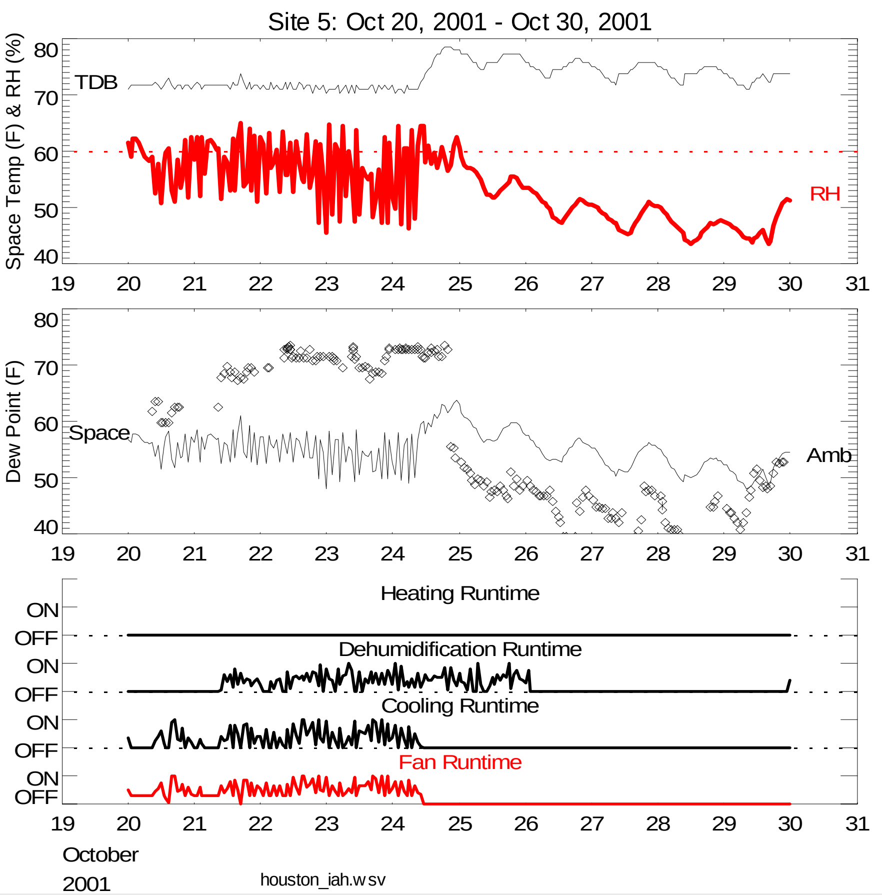
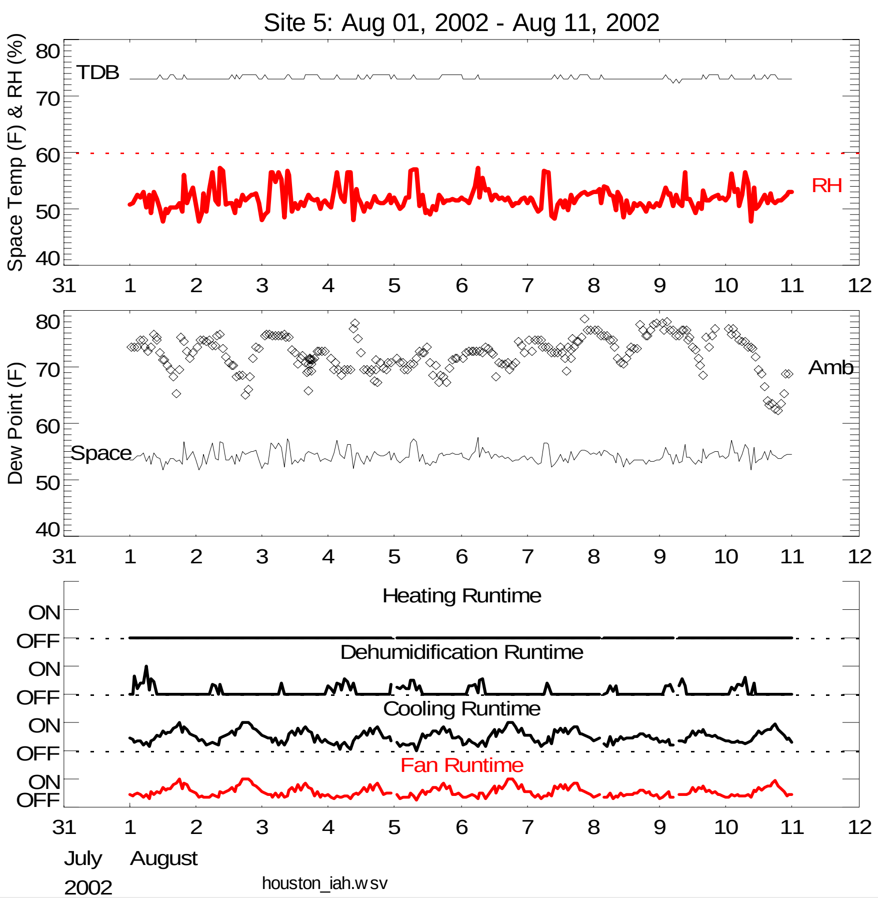


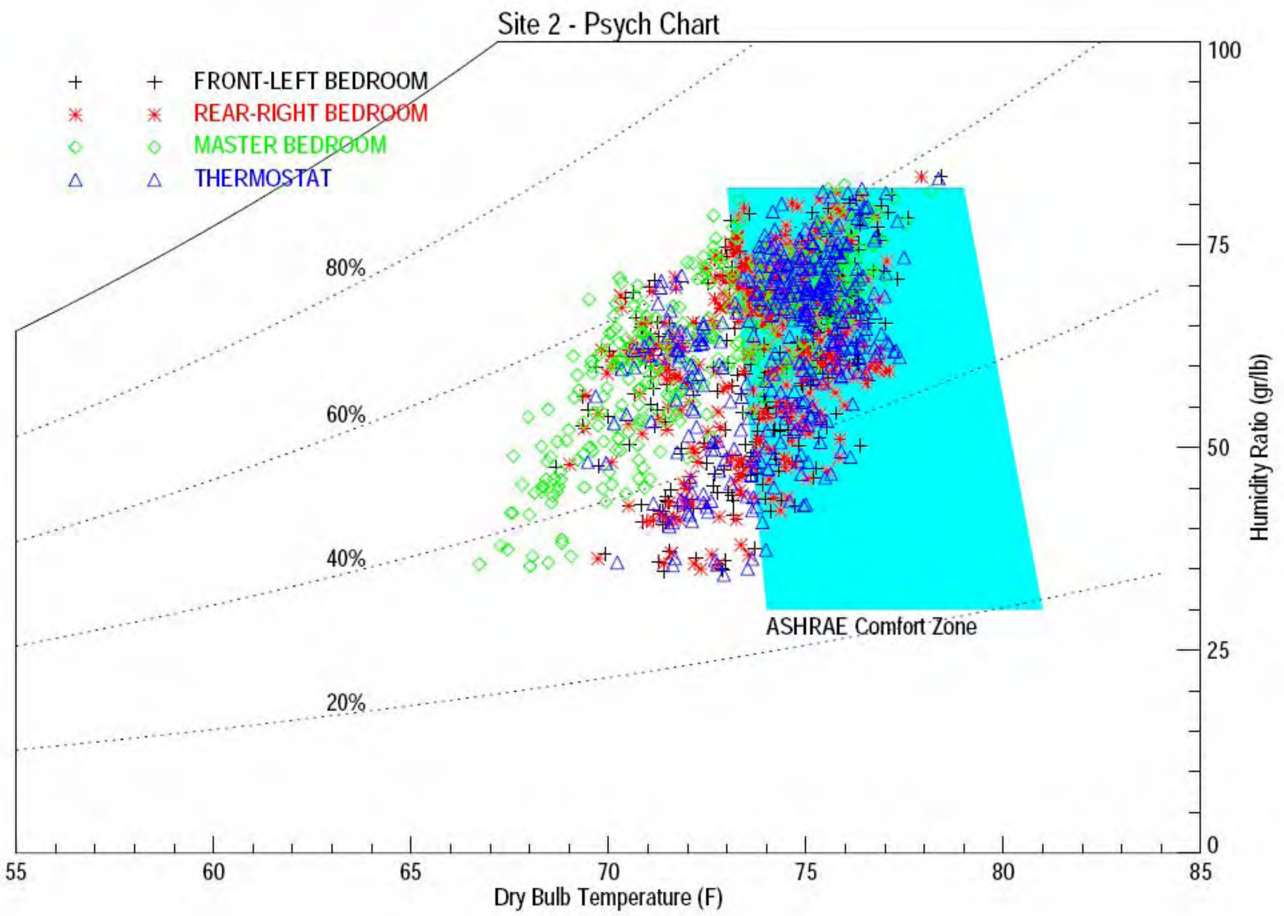
Figure 12. High humidity month (October) compared to typical summer month (August) for High-Performance House with Ventilation and Dehumidification





High-performance house with Ventilation and non-ducted Dehumidifier (hall closet with louvered door near main return)

19902 Ashland - Houston



Conclusions for Standard houses

- Conventional cooling systems in Standard houses usually provide reasonable humidity control (i.e., below 60% RH)
- Some space humidity excursions above 60% RH occur during the spring and fall, and summer nights, when sensible cooling loads are modest or non-existent.
- The effect of adding mechanical ventilation to Standard houses in humid climates was not a consistently clear or strong signal
  - Space humidity better maintained in swing seasons by occasional cooling operation driven by higher sensible gain in Standard houses
  - Differences in occupancy and occupant behavior seem to have a larger impact (i.e. large houses with few occupants, thermostat setup and manual manipulation, extreme temperature setpoints).

Conclusions for High-Performance houses

- The combination of High-Performance, low sensible heat gain buildings and mechanical ventilation significantly increases the number of hours that require dehumidification without sensible cooling.
  - Higher cooling balance point temperature than for conventional Standard houses
  - High space humidity occurs mostly during spring and fall swing seasons and summer nights
- Humidity loads in High-Performance homes cannot always be met by conventional or enhanced cooling systems, but instead require separate dehumidification.
- The addition of supplemental dehumidification to High-Performance homes enables the energy savings of efficiency improvements that significantly reduce cooling demand while alleviating elevated indoor humidity.