Supplemental Dehumidification For Humid Climates

ACI Conference, Denver, May 2, 2013

Armin Rudd

Overview of Results From

- BSC USDOE Building America field studies
- ASHRAE 1449-RP, simulation study, "Energy Efficiency and Cost Assessment of Humidity Control Options for Residential Buildings"

Supported By:

ASHRAE

AHRI

USDOE, Building America Program

Conducted By:

Building Science Corp	CDH Energy Corp
Armin Rudd	Hugh Henderson

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What is Supplemental Dehumidification?

Moisture removal, supplemental to the cooling system, when there is no need for cooling.

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When is it needed?

- Mostly when the house is floating between cooling and heating setpoints
- Spring/Fall swing seasons and summer shoulder months
- Some winter conditions in hot-humid climates
- Some summer nights and rainy periods in hot-humid climates and coastal warm-humid climates

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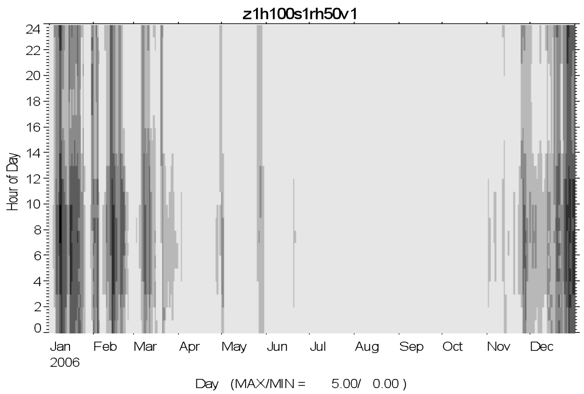
Shade Plot of Humidity Bins



Shades of Gray

0 – below 55%
1 – 55-60%
2 – 60-65%
3 – 65-70%
4 – 75-80%
5 – above 80%

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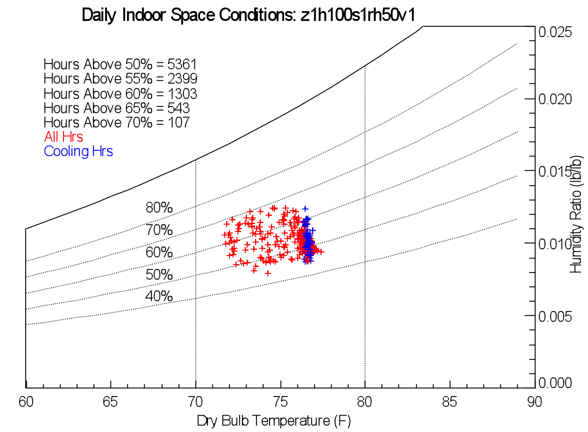
5

Space Conditions

(Miami, HERS100, Conv. Sys, Exhaust vent)



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What is a good metric for determining the need?

Hours above 60% relative humidity

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7

1449-RP Conventional Cooling System

		Hours Above 60% RH	AC Runtime (hrs)	AC EER (Btu/Wh)	AC Energy (kWh)	Htg Energy (kWh)	AHU Fan Energy (kWh)	Exh Fan Energy (kWh)	Total Electric w/o HT (kWh)	Total Costs w Furnace ($)
Orlando	HERS 50	1,011	3,266	21.3	1,869	633	140	203	2,211	$ 265
	HERS 70	575	3,491	21.0	2,615	673	217	203	3,036	$ 354
	HERS 85	1,121	2,039	16.6	3,611	2,247	700	203	4,514	$ 614
	HERS 100	1,645	1,860	15.4	4,302	5,642	1,179	203	5,684	$ 980
	HERS 130	1,361	2,127	11.7	6,629	6,876	1,358	203	8,190	$ 1,352
Miami	HERS 50	822	4,378	21.0	2,516	38	173	203	2,893	$ 295
	HERS 70	382	5,303	20.0	3,629	42	360	203	4,192	$ 426
	HERS 85	756	2,859	16.5	5,064	420	947	203	6,214	$ 657
	HERS 100	1,303	2,700	15.3	6,232	1,513	1,572	203	8,007	$ 917
	HERS 130	1,313	3,054	11.6	9,505	1,944	1,786	203	11,495	$ 1,309
Houston	HERS 50	380	3,252	20.4	1,963	1,758	181	203	2,347	$ 269
	HERS 70	191	3,844	19.3	2,856	2,034	350	203	3,410	$ 376
	HERS 85	228	2,185	16.3	3,876	3,047	759	203	4,838	$ 540
	HERS 100	628	1,966	15.0	4,572	7,687	1,286	203	6,061	$ 849
	HERS 130	942	2,170	11.4	6,823	14,261	1,555	203	8,581	$ 1,386
Atlanta	HERS 50	40	2,054	21.1	1,149	3,370	135	203	1,488	$ 341
	HERS 70	15	2,604	19.7	1,815	4,594	271	203	2,289	$ 510
	HERS 85	20	1,703	16.6	2,364	6,228	515	203	3,082	$ 689
	HERS 100	291	1,338	15.2	2,546	13,004	881	203	3,631	$ 1,168
	HERS 130	426	1,726	11.7	3,530	18,387	935	203	4,668	$ 1,673
Nashville	HERS 50	-	2,184	21.0	1,248	4,254	160	203	1,611	$ 320
	HERS 70	-	2,641	19.7	1,859	5,975	299	203	2,361	$ 475
	HERS 85	-	1,705	16.6	2,379	8,000	535	203	3,118	$ 632
	HERS 100	4	1,555	15.4	2,938	10,150	928	203	4,069	$ 823
	HERS 130	119	1,658	11.6	4,246	18,838	1,145	203	5,594	$ 1,387
Indianapolis	HERS 50	-	1,457	21.5	812	8,523	198	203	1,213	$ 364
	HERS 70	-	1,828	20.5	1,206	12,390	327	203	1,736	$ 553
	HERS 85	-	1,154	17.0	1,582	13,605	452	203	2,238	$ 634
	HERS 100	-	1,057	15.8	1,960	18,145	850	203	3,013	$ 862
	HERS 130	7	1,240	12.0	3,090	22,902	1,029	203	4,322	$ 1,177

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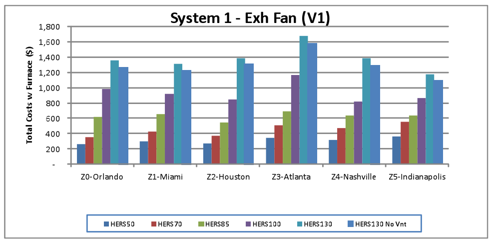
8

1449-RP Conventional Cooling System

Table 1. Comparing Relative Annual Costs for each HERS Level and Climate

	HERS50	HERS70	HERS85	HERS100	HERS130	HERS130 No Vnt
Z0-Orlando	27%	36%	63%	100%	138%	129%
Z1-Miami	32%	46%	72%	100%	143%	134%
Z2-Houston	32%	44%	64%	100%	163%	154%
Z3-Atlanta	29%	44%	59%	100%	143%	135%
Z4-Nashville	39%	58%	77%	100%	169%	157%
Z5-Indianapolis	42%	64%	74%	100%	137%	126%



Conventional Cooling System Runtime

2-spd systems for HERS 70 and 50

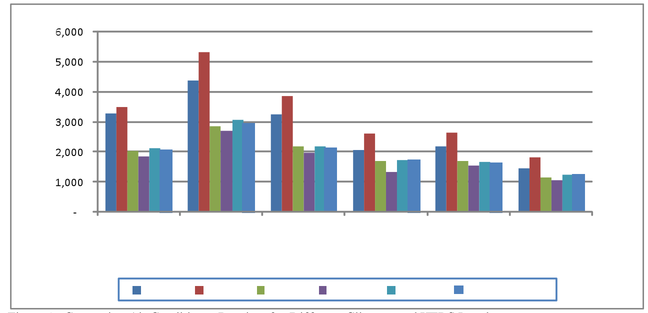
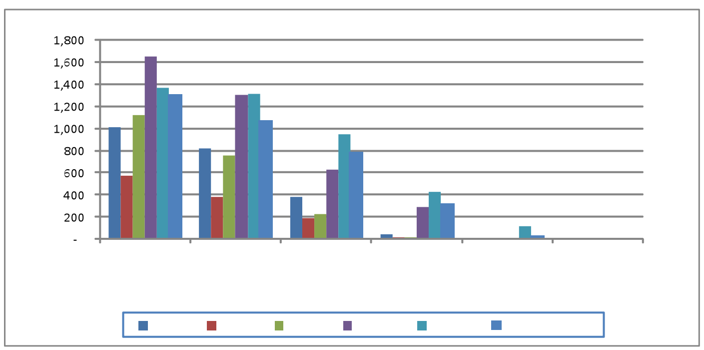


Figure 1. Comparing Air Conditioner Runtime for Different Climates and HERS Levels

Hours > 60% RH by HERS Index and Climate

Conventional Cooling System and Mechanical Ventilation



Duration of Events > 60% RH

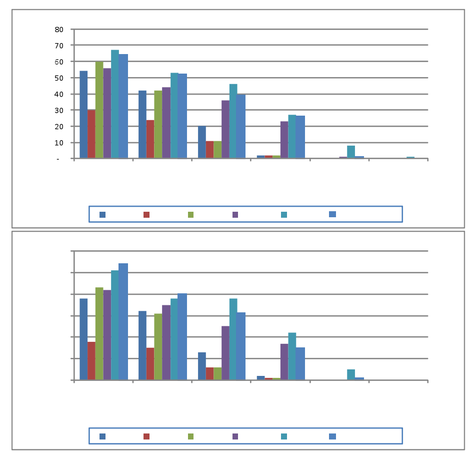
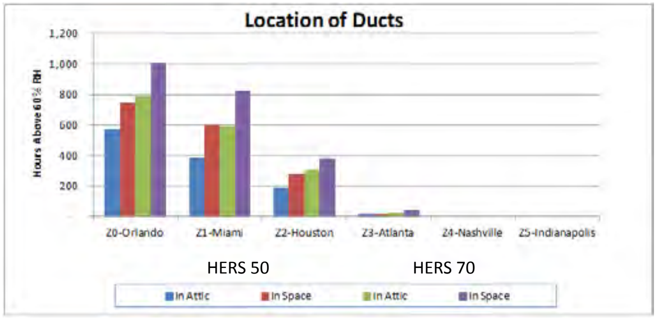


Figure 1. Comparing Number of High Humidity Events (exceeding 60% RH) for Different Climates and HERS Levels

Impact of Duct Location



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Impact of Duct Location

Elevated Indoor Relative Humidity
Impact of Moving Ducts from Attic to the Conditioned Space
(due to sensible cooling load reduction)

	Hours >60% RH		% Diff. wrt
	Ducts inside	Ducts in attic[1]	ducts in attic
HERS 50			
Orlando	770	580	33%
Miami	600	390	54%
Houston	290	190	53%
HERS 70			
Orlando	1000	790	27%
Miami	820	600	37%
Houston	380	300	27%

[1] ducts in attic have 5% leakage (3% supply, 2% return)

Total Space Conditioning Cost Reduction Impact of Moving Ducts from Attic to the Conditioned Space

	Total HVAC Annual Cost Reduction	
	HERS 70	HERS 50
Orlando	22%	26%
Miami	27%	28%
Houston	26%	26%
Atlanta	24%	24%

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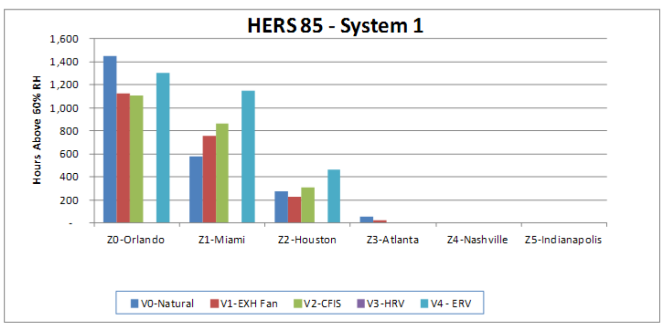
Comparing High Humidity Levels with Different Ventilation Options



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Effect of Enhanced Cooling Strategy

Low airflow (200 cfm/ton) and Overcooling (2ºF)

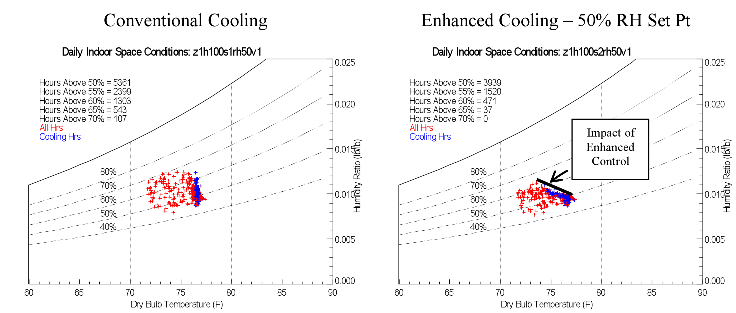

Figure 1. Psychrometric Plots Showing Impact of Enhanced Control in Miami, HERS 100 House

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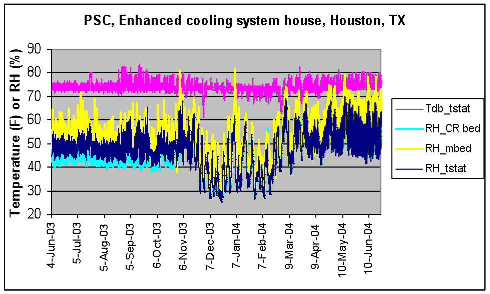
However, it has its limitations



Mode 1: "normal cooling" 350 cfm/ton
Mode 2: "cool to dehumidify" 280 cfm/ton only with a call for cooling
Mode 3: "super dehumidify" 210 cfm/ton for 10 minutes on / 10 minutes off limited to 3°F overcooling

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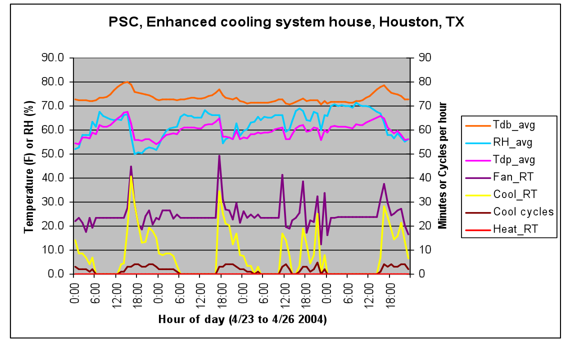
17



Mode 1: "normal cooling" 350 cfm/ton
Mode 2: "cool to dehumidify" 280 cfm/ton only with a call for cooling
Mode 3: "super dehumidify" 210 cfm/ton for 10 minutes on / 10 minutes off limited to 3°F overcooling

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18

How much supplemental dehumidification is needed?

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19

Houston Field Study

Table 1. Monitoring results for Stand-alone dehumidifier system and the Ducted dehumidifier system in the Houston study

	Stand-alone Dehumidifier	Ducted Dehumidifier
Monitoring period	10/4/2001 - 7/31/2002	10/17/2001 - 8/1/2002
Total days with data	300	288
House dry bulb temperature (avg of 3 points)		
min	67	63
max	80	80
avg	73	72
std dev	2	3
House relative humidity (avg of 3 points)		
min	26	25
max	70	69
avg	50	51
std dev	8	7
House dew point temperature (avg of 3 points)		
min	35	32
max	64	66
avg	53	53
std dev	5	6
Hours above 60% RH	7%	4%
Supplemental dehumidification energy consumption (kWh)	209	463

Variation in occupant behaviors impacting internal generation has a big impact

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20

Supplemental DH Results – HERS 85, 60% setpt

HERS 85, 60% RH Set Pt		Hours Above 61.5%	Hours Above 51.5%	AC Runtime (hrs)	AC EER (Btu/Wh)	AC Energy (kWh)	Htg Energy (kWh)	AHU Fan Energy (kWh)	DH Energy (kWh)	DH Fan Energy (kWh)	Total Electric w/o HT (kWh)	Total Costs w Furnace ($)	
Orlando	S3 - 2-Spd	1,116	5,775	3,461	20.1	2,898	2,253	324	-	-	3,425	504	100%
	S2 - AC low flw	802	4,552	2,041	16.6	3,615	2,268	716	-	-	4,534	617	122%
	S8 - Partial SC/RH	507	4,467	2,072	16.4	3,693	2,286	723	-	-	4,619	627	124%
	S9 - Full RH	1	4,117	2,124	16.5	3,717	2,299	825	-	-	4,745	641	127%
	S5 - DH Unit	127	4,551	2,046	16.6	3,627	2,169	849	183	-	4,862	643	128%
	S6 - Ducted DH	89	4,539	2,046	16.6	3,626	2,166	848	142	28	4,847	642	127%
	S14 - Cond DES	-	4,357	2,039	16.6	3,614	2,229	847	145	22	4,832	645	128%
Miami	S3 - 2-Spd	740	4,118	4,825	19.9	4,069	412	401	-	-	4,673	501	100%
	S2 - AC low flw	506	3,025	2,863	16.5	5,070	420	946	-	-	6,219	658	131%
	S8 - Partial SC/RH	182	2,980	2,892	16.3	5,150	421	953	-	-	6,306	667	133%
	S9 - Full RH	2	2,799	2,923	16.4	5,148	427	1,092	-	-	6,443	681	136%
	S5 - DH Unit	83	3,148	2,865	16.5	5,077	349	1,039	131	-	6,451	676	135%
	S6 - Ducted DH	57	3,138	2,864	16.5	5,076	354	1,039	100	19	6,438	675	135%
	S14 - Cond DES	-	2,998	2,856	16.5	5,061	376	1,038	107	16	6,425	675	135%
Houston	S3 - 2-Spd	217	2,527	3,576	19.3	3,203	3,030	380	-	-	3,787	450	100%
	S2 - AC low flw	143	1,828	2,185	16.3	3,877	3,047	758	-	-	4,838	540	120%
	S8 - Partial SC/RH	55	1,727	2,195	16.2	3,901	3,059	761	-	-	4,865	543	121%
	S9 - Full RH	-	1,598	2,214	16.3	3,917	3,060	868	-	-	4,988	554	123%
	S5 - DH Unit	35	1,858	2,183	16.3	3,876	3,052	882	47	-	5,009	555	123%
	S6 - Ducted DH	32	1,844	2,183	16.3	3,876	3,056	882	37	7	5,006	555	123%
	S14 - Cond DES	-	1,780	2,181	16.3	3,873	3,063	882	37	6	5,001	555	123%
Atlanta	S3 - 2-Spd	20	810	2,655	19.3	1,998	6,211	307	-	-	2,508	629	100%
	S2 - AC low flw	11	631	1,703	16.6	2,364	6,228	515	-	-	3,082	689	110%
	S8 - Partial SC/RH	11	631	1,703	16.6	2,364	6,228	515	-	-	3,082	689	110%
	S9 - Full RH	6	618	1,715	16.6	2,379	6,228	583	-	-	3,165	697	111%
	S5 - DH Unit	-	530	1,695	16.6	2,354	6,289	670	-	-	3,227	707	113%
	S6 - Ducted DH	-	530	1,695	16.6	2,354	6,289	670	-	-	3,227	707	113%
	S14 - Cond DES	-	530	1,695	16.6	2,354	6,289	670	-	-	3,227	707	113%

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21

Supplemental DH Results – HERS 85, 50% setpt

HERS 85, 50% RH Set Pt		Hours Above 61.5%	Hours Above 51.5%	AC Runtime (hrs)	AC EER (Btu/Wh)	AC Energy (kWh)	Htg Energy (kWh)	AHU Fan Energy (kWh)	DH Energy (kWh)	DH Fan Energy (kWh)	Total Electric w/o HT (kWh)	Total Costs w Furnace ($)	
Orlando	S3 - 2-Spd	1,116	5,775	3,461	20.1	2,898	2,253	324	-	-	3,425	504	100%
	S2 - AC low flw	352	3,143	2,185	16.5	3,777	2,323	662	-	-	4,642	632	125%
	S8 - Partial SC/RH	46	1,504	2,413	13.8	4,546	2,346	784	-	-	5,533	724	144%
	S9 - Full RH	-	18	2,495	15.3	4,139	2,389	860	-	-	5,203	693	138%
	S5 - DH Unit	-	870	2,159	16.6	3,802	1,917	875	1,219	-	6,099	751	149%
	S6 - Ducted DH	-	792	2,144	16.6	3,775	1,942	871	922	191	5,962	739	147%
	S14 - Cond DES	-	4	2,003	16.5	3,528	2,144	834	1,113	169	5,847	741	147%
Miami	S3 - 2-Spd	740	4,118	4,825	19.9	4,069	412	401	-	-	4,673	501	100%
	S2 - AC low flw	75	2,017	2,996	16.4	5,225	441	900	-	-	6,328	670	134%
	S8 - Partial SC/RH	-	531	3,185	14.6	5,885	440	1,004	-	-	7,092	747	149%
	S9 - Full RH	-	4	3,207	15.7	5,485	438	1,118	-	-	6,805	718	143%
	S5 - DH Unit	-	498	2,969	16.5	5,238	282	1,065	912	-	7,419	769	154%
	S6 - Ducted DH	-	428	2,956	16.5	5,216	290	1,062	694	142	7,317	759	152%
	S14 - Cond DES	-	2	2,831	16.5	5,000	346	1,028	815	124	7,169	748	149%
Houston	S3 - 2-Spd	217	2,527	3,576	19.3	3,203	3,030	380	-	-	3,787	450	100%
	S2 - AC low flw	31	1,269	2,238	16.3	3,936	3,071	739	-	-	4,879	545	121%
	S8 - Partial SC/RH	-	378	2,346	15.0	4,285	3,068	787	-	-	5,276	578	128%
	S9 - Full RH	-	2	2,368	15.8	4,086	3,091	882	-	-	5,172	571	127%
	S5 - DH Unit	-	248	2,230	16.3	3,948	2,973	893	470	-	5,514	595	132%
	S6 - Ducted DH	-	222	2,224	16.3	3,937	2,986	892	356	73	5,461	591	131%
	S14 - Cond DES	-	4	2,170	16.3	3,846	3,029	878	395	60	5,383	586	130%
Atlanta	S3 - 2-Spd	20	810	2,655	19.3	1,998	6,211	307	-	-	2,508	629	100%
	S2 - AC low flw	9	591	1,711	16.6	2,370	6,229	514	-	-	3,087	689	110%
	S8 - Partial SC/RH	-	323	1,750	16.1	2,459	6,232	522	-	-	3,185	700	111%
	S9 - Full RH	-	148	1,769	16.4	2,425	6,230	587	-	-	3,215	703	112%
	S5 - DH Unit	-	61	1,704	16.6	2,365	6,255	671	122	-	3,361	719	114%
	S6 - Ducted DH	-	54	1,703	16.6	2,363	6,255	671	96	20	3,354	718	114%
	S14 - Cond DES	-	-	1,694	16.6	2,351	6,277	669	96	15	3,334	718	114%

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22

Supplemental Dehumidification Energy and Cost

		Exhaust Ventilation				CFIS Ventilation				ERV Ventilation			
	RH Setpoint:	60%	60%	50%	50%	60%	60%	50%	50%	60%	60%	50%	50%
HERS 85		Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)	Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)	Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)	Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)	Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)	Dehumification Energy over Conv. System (kWh)	Dehumification Cost over Conv. System ($)
Orlando	Conv or 2-spd[1]	--	--	--	--	--	--	--	--	--	--	--	--
	Low flow+overcool[2]	19	3	127	18	17	3	105	17	8	1	102	18
	Subcool Reheat[2]	104	13	1019	110	141	16	943	102	139	16	1007	109
	Full Cond Reheat[4]	230	27	688	79	232	28	564	68	227	29	604	77
	Standalone DH[3]	347	30	1585	137	221	14	1316	105	216	13	1268	104
	Ducted DH[4]	333	28	1448	125	203	12	1212	97				
	Cond Desiccant[4]	317	31	1332	127	194	16	1122	103				
Miami	Conv or 2-spd[1]	--	--	--	--	--	--	--	--	--	--	--	--
	Low flow+overcool[2]	6	1	114	13	9	1	104	14	13	1	116	17
	Subcool Reheat[2]	93	9	879	90	136	15	855	89	177	20	1017	106
	Full Cond Reheat[4]	230	24	592	61	242	26	516	55	255	28	590	64
	Standalone DH[3]	238	19	1205	112	164	12	1064	98	200	15	1186	109
	Ducted DH[4]	224	18	1103	102	154	11	968	89				
	Cond Desiccant[4]	212	18	956	91	141	12	869	84				
Houston	Conv or 2-spd[1]	--	--	--	--	--	--	--	--	--	--	--	--
	Low flow+overcool[2]	0	0	41	4	2	0	48	6	6	1	53	7
	Subcool Reheat[2]	27	3	438	38	54	5	503	44	63	6	561	49
	Full Cond Reheat[4]	150	13	334	30	163	14	328	30	162	14	365	33
	Standalone DH[3]	171	15	676	54	67	4	588	45	76	5	647	48
	Ducted DH[4]	168	15	622	50	60	3	537	41				
	Cond Desiccant[4]	163	15	545	46	53	4	473	39				
Atlanta	Conv or 2-spd[1]	--	--	--	--	--	--	--	--	--	--	--	--
	Low flow+overcool[2]	0	0	5	1	0	0	4	0	0	0	1	0
	Subcool Reheat[2]	0	0	103	11	0	0	107	11	0	0	64	6
	Full Cond Reheat[4]	83	8	132	14	81	8	125	13	78	8	110	11
	Standalone DH[3]	145	19	279	30	0	0	142	13	0	0	78	7
	Ducted DH[4]	145	19	271	30	0	0	132	11				
	Cond Desiccant[4]	145	19	252	29	0	0	120	12				

[1] This system does not control to a RH setpoint
[2] These systems will attempt to control to an RH setpoint but will not always meet the setpoint due to a limit on overcooling
[3] This system will control to a RH setpoint but may not have the capacity to always meet the setpoint, especially without whole-house mixing
[4] These systems will control to a RH setpoint and will meet the setpoint

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23

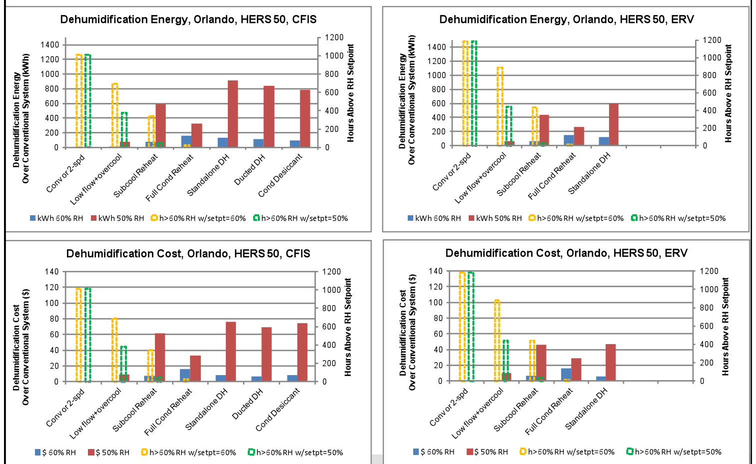
Supplemental DH Energy, HERS 85 - Min/Max/Avg

Tier 1, **60% RH setpoint**, Miami, Orlando, Houston (full condensing reheat, DH, ducted DH, condenser regen. desiccant)				
min	53	kWh		
max	347	kWh		
avg	195	kWh		
Tier 2, 60% RH setpoint, Miami, Orlando, Houston (sub-cool reheat)				
min	27	kWh		
max	141	kWh		
avg	93	kWh		
Tier 3, 60% RH setpoint, Miami, Orlando, Houston (low airflow, overcooling)				
min	0	kWh		
max	19	kWh		
avg	9	kWh		
Tier 1, **50% RH setpoint**, Miami, Orlando, Houston (full condensing reheat, DH, ducted DH, condenser regen. desiccant)				
min	328	kWh	6	times more than 60% RH setpoint
max	1,585	kWh	5	times more than 60% RH setpoint
avg	860	kWh	4	times more than 60% RH setpoint
Tier 2, 50%, Miami, Orlando, Houston (sub-cool reheat)				
min	438	kWh	16	times more than 60% RH setpoint
max	1,019	kWh	7	times more than 60% RH setpoint
avg	773	kWh	8	times more than 60% RH setpoint
Tier 3, 50%, Miami, Orlando, Houston (low airflow, overcooling)				
min	104	kWh	4577	times more than 60% RH setpoint
max	127	kWh	7	times more than 60% RH setpoint
avg	90	kWh	10	times more than 60% RH setpoint

ACI Conference – Supplemental Dehumidification
2 May 2013, Denver

24

Supplemental DH Energy and Cost – HERS 50



Lessons Learned

- Periods of high relative humidity mostly occur at mild conditions in the winter and swing seasons when there is little or no need for sensible cooling. Humidity is rarely out of control during the main summer periods.
- The number of hours above a certain humidity threshold (say 60% RH) is good metric for comparing the humidity control performance of different systems. A similar result is found when analyzing the duration of high humidity events.
- Moving ducts from the attic to the conditioned space saves energy but increases space humidity levels in hot-humid climates. The reduction in sensible heat gains is greater than the reduction in latent loads, resulting in a mix of sensible and latent loads that increases space humidity levels in homes with conventional air conditioning systems.

Lessons Learned

- In a multi-home field study in Houston, TX, measured supplemental dehumidification energy consumption from two mechanically ventilated homes was 209 kWh/yr for a representative home with a stand-alone dehumidifier and 463 kWh/yr for another representative home with a ducted dehumidifier.
- The ducted dehumidifier was more efficient, and the homes had similar temperature and relative humidity control, but variability in occupant behaviors has a strong impact on internal moisture generation which has a strong impact on supplemental dehumidification requirements.

Lessons Learned (cont.)

- Detailed simulations showed that a number of humidity control solutions can be effective in hot-humid climates.
- The most effective solutions, having relatively low operating cost and essentially eliminating indoor humidity above 60% RH, were:
  - full condensing modulating reheat integrated with the central cooling system
  - ducted dehumidifier
  - stand-alone dehumidifier with central system mixing
  - condenser regenerated desiccant dehumidifier
- About 170 kWh/yr could be expected for a HERS 50 house (having ducts inside conditioned space) with a 60% RH setpoint.
- About five times that, and more, could be expected with a 50% RH setpoint.

Lessons Learned (cont.)

- A close second was central cooling system with subcooling reheat but it showed more elevated RH hours.
- A more distant third place was enhanced cooling controls for 2ºF over-cooling and lower airflow (200 cfm/ton) activated at 50% RH and above.
- Two-speed and variable speed systems did little to reduce hours of elevated relative humidity in hot-humid climates unless coupled with the enhanced cooling methods listed above.
- An Energy Recovery Ventilators by itself increased hours above 60% RH in hot-humid climates, however, when coupled with supplemental dehumidification having a 50% RH setpoint an ERV reduced supplemental dehumidification energy needed

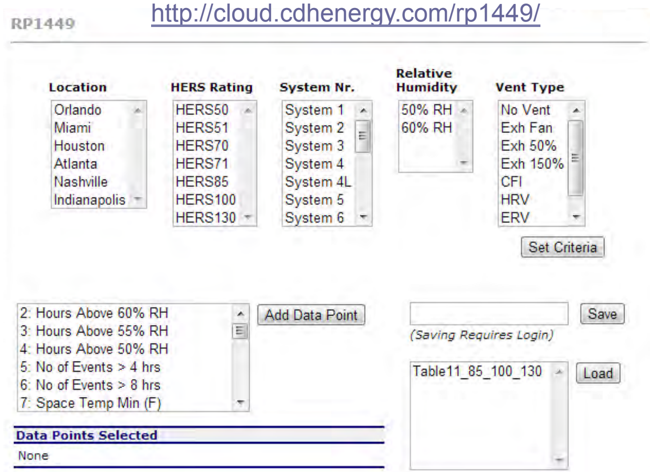
Lessons Learned (cont.)

- When controlling to 60% relative humidity, the required capacity for supplemental dehumidification in average homes in hot-humid climates is not large – about 1.5 lb/h, or that of a typical 40 to 50 pint/day unit.
- Expected cost to operate such a unit at 60% RH is less than $50 yr depending on house efficiency level
- Expected cost to operate such a unit at 50% RH is less than $175/yr depending on house efficiency level

- Finally, supplemental dehumidification, in and of itself, does not save energy, rather, it is justified by enabling the energy savings from dramatically reduced sensible cooling loads in high-performance homes in hot-humid climates.

Web Access to 1449-RP Results

http://cloud.cdhenergy.com/rp1449/



Web Access to 1449-RP Results

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Download Data

Location	HERS Rating	System Nr.	Relative Humidity	Vent Type	Hours Above 60% RH	
Miami	HERS100	System 1	50% RH	Exh Fan	1303	PDF
Miami	HERS130	System 1	50% RH	Exh Fan	1313	PDF
Miami	HERS50	System 1	50% RH	Exh Fan	777	PDF
Miami	HERS70	System 1	50% RH	Exh Fan	433	PDF
Miami	HERS85	System 1	50% RH	Exh Fan	756	PDF

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