FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

AC System Equipment Specification, Installation and Operational Issues that Can Enhance Indoor Humidity Control

Final Report

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Submitted by:
Don Shirey
Rob Vieira
University of Central Florida / Florida Solar Energy Center
1679 Clearlake Road
Cocoa, FL 32922
(321) 638-1000

1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu

A Research Institute of the University of Central Florida

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ABSTRACT:
This report presents summary of research on equipment selection and operation issues with conventional air conditioning equipment that can be employed prior to seeking the added first cost and operating cost of separate dehumidifiers.

INTRODUCTION:
There has been increased concern about maintaining humidity control in homes as energy efficiently as possible. Newer codes and above-code programs encourage energy efficient envelope methods that reduce sensible cooling loads form roofs, windows, floors, walls and doors. Multifamily housing is particularly problematic as many units have only one or two exposed surfaces. Less sensible cooling load form outside means that the latent portion of the cooling load, from infiltration, mechanical ventilation, and internal moisture sources –including people, is a larger portion. During times of humid, but mild temperature conditions when many Floridians are air conditioning the interior humidity levels may become higher than desired in these homes.

There are many products on the market and many strategies that can successfully reduce the incidences of the problem. Some may save energy while most may use more energy in order to further dry the space. This report presents summary of research on equipment selection and operation issues with conventional air conditioning equipment that can be employed prior to seeking the added first cost and operating cost of separate dehumidifiers.

HVAC METHODS:

1) Select AC Systems with Lower Sensible Heat Ratio

There is a wide range of AC equipment in the marketplace, and different equipment combinations (coil, air handler, condensing unit) result in a different Sensible Heat Ratio (e.g., at AHRI Rating conditions of 80F db / 67F wb indoors and 95F outdoors, equipment SHRs may range from 0.67 to 0.8). The air flow rate across the evaporator can vary for this rating test, up to 450 cfm/ton. The data shown in the figure below are for 400 ± 15 cfm/ton.

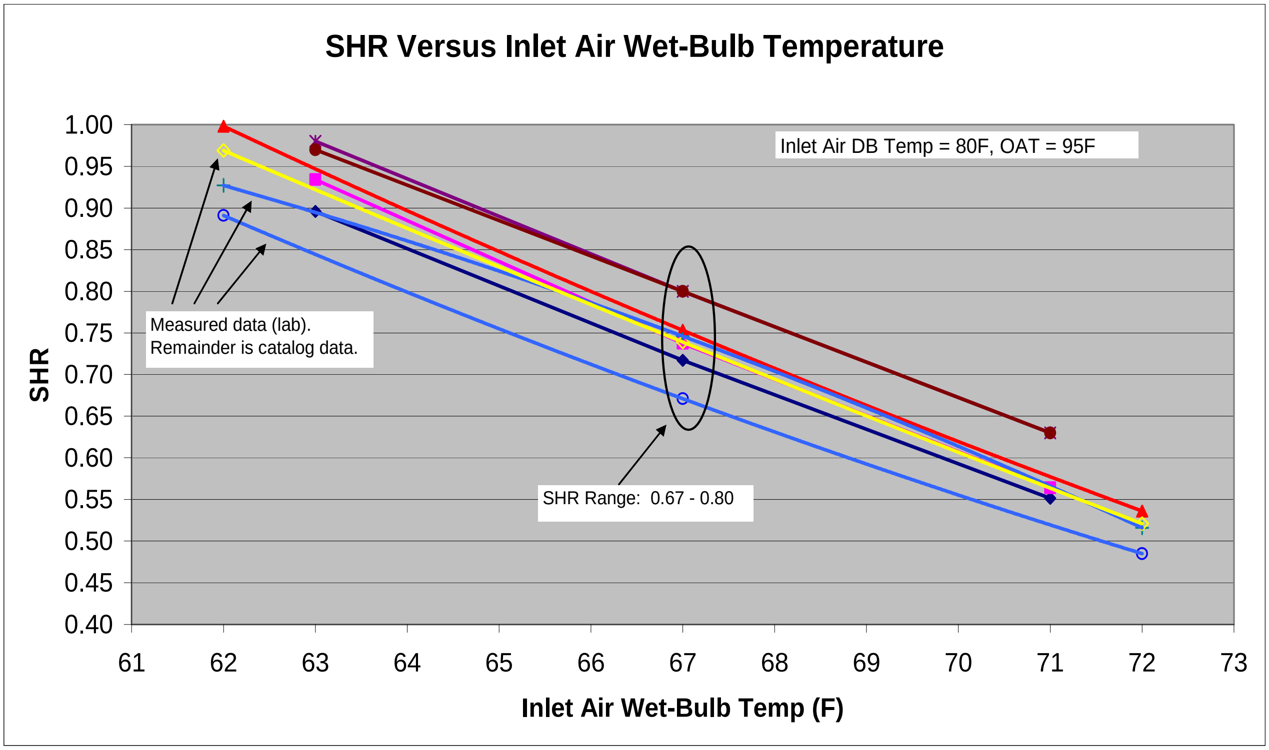

Figure 1

For improved dehumidification, an equipment combination with lower SHR should be specified (e.g., <= 0.73).

For 2-stage cooling equipment, you must be careful to check the SHR at high speed (e.g., AHRI Rating Conditions of 80F db / 67F wb indoors and 95F db outdoors) and at low speed (e.g., at 80F db/ 67F wb indoors and 82F db outdoors). Sometimes due to mismatches between the ratio of cooling capacity at high and low compressor speed versus the supply air fan speed ratio at high and low speed, you can end up with a system that has a good SHR at high speed (e.g., 0.73 at 350 cfm/ton) and a poor SHR at low speed (e.g., 0.8 at 450 cfm/ton). In this example, the fan speed wasn't reduced in the proper proportion to match the reduction in compressor capacity when going from high speed to low speed. As a result, you end up with a high SHR (less dehumidification) at the low operating speed, which is the speed where the system operates most often. For Florida's hot/humid climate, the SHR at low speed operation should be less than the SHR at high speed operation (e.g., <0.73).

2) Configure the AC System Fan to Operate at a Lower Air Flow Rate

Reducing the supply air flow rate through a cooling system will increase its dehumidification performance. It will typically result in a small increase in energy use, but it may be negligible in some cases (depends on supply air fan and compressor characteristics). Operating at too low of a supply air flow rate could cause coil icing and/or sweating ductwork. Placing ductwork and the air handler in conditioned space or increasing duct insulation levels can help alleviate the sweating ductwork issue, but the potential for coil icing remains so a lower limit on supply air flow rate is required.

It is recommended to set the supply air flow rate near 350 cfm/ton if the air handling unit (AHU) and/or supply air ductwork is located outside of the conditioned space. If the AHU and supply air ductwork are located within the conditioned space, then there may be the opportunity to reduce air flows even lower (e.g., 300-320 cfm/ton). Only operate the supply air flow as low as is needed for adequate dehumidification.

COOLING CAPACITY - XP15-036 with

Entering Wet Bulb Tempera-ture	Total Air Volume		Outdoor Air Temperatur												
			85°F (29°C)						95°F (35°C)						
			Total Cooling Capacity		Comp Motor kW Input	Sensible To Total Ratio (S/T) Dry Bulb			Total Cooling Capacity		Comp Motor kW Input	Sensible To Total Ratio (S/T) Dry Bulb		
	cfm	L/s	kBtuh	kW		75°F 24°C	80°F 27°C	85°F 29°C	kBtuh	kW		75°F 24°C	80°F 27°C	85°F 29°C
63°F (17°C)	1090	515	34.6	10.1	2.29	.76	.90	1.00	32.8	9.6	2.61	.77	.93	1.00
	1225	580	35.4	10.4	2.29	.78	.94	1.00	33.6	9.8	2.62	.80	.97	1.00
	1380	650	36.2	10.6	2.30	.81	.98	1.00	34.4	10.1	2.62	.84	.99	1.00
67°F (19°C)	1090	515	36.6	10.7	2.31	.60	.73	.87	34.8	10.2	2.62	.60	.75	.89
	1225	580	37.6	11.0	2.31	.61	.76	.90	35.6	10.4	2.63	.62	.78	.93
	1380	650	38.5	11.3	2.31	.63	.79	.95	36.4	10.7	2.63	.64	.81	.97
71°F (22°C)	1090	515	38.5	11.3	2.32	.45	.58	.71	36.8	10.8	2.62	.45	.59	.72
	1225	580	39.5	11.6	2.32	.46	.60	.74	37.6	11.0	2.64	.46	.61	.76
	1380	650	40.5	11.9	2.33	.46	.62	.77	38.5	11.3	2.64	.47	.63	.79

The following information is taken from the table above:

> Point 1: 1225 cfm, 35.6 kBtuh = 413 cfm/ton. Sensible capacity = 35.6 x **0.78** = 27.77 kBtuh
> Point 2: 1090 cfm, 34.8 kBtuh = 376 cfm/ton. Sensible capacity = 34.8 x **0.75** = 26.1 kBtuh

Reducing the air flow rate across the cooling coil lowers the sensible heat ratio (SHR, or S/T in the table above) of the cooling equipment, and the lower SHR means the unit will remove more moisture from the air when it operates. In addition, the lower sensible capacity means the system will run a little longer to achieve the same dry-bulb set point temperature resulting in additional dehumidification.

The table below shows computer simulation results for the impacts of reduced supply air flow rate on indoor humidity levels (annual hours above 60% RH) and energy use. For the simulations, it was assumed that the ductwork size and duct air leakage decreased with the lower supply air flow rate. However, the unit's nominal cooling capacity and the fan power rate (Watts for cfm of air flow) remained the same.

Impact of Lower Supply Air Flow on High Indoor Humidity and AC Energy Use (Henderson et al. 2007)

Miami		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	400 cfm/ton	724	2075.9	100%	1,641	1911.0	100%
	300 cfm/ton	533	2015.2	100%	1,306	1876.1	101%
Constant Infiltration	400 cfm/ton	1,583	2166.2	100%	3,909	2170.4	100%
	300 cfm/ton	1,116	2104.6	100%	2,861	2128.7	101%

Notes: Supply air flow, fan power, ductwork size and duct air leakage all decrease at 300 cfm/ton.
Unit size remains the same. Fan power is maintained at 0.35 W/cfm. Cooling set point temperature is 75°F.

In reality, the normalized fan power (W per cfm) increases slightly when the supply airflow rate is decreased from 400 to 300 cfm per ton. The example above assumed that the supply fan power decreased in proportion with the air flow at 300 cfm/ton (i.e., the normalized fan power remained constant at 0.35 W/cfm). If the fan power is assumed to be 0.4 W/cfm at 300 cfm/ton, this is more representative of "riding the fan curve" with a forward-curve centrifugal fan. With this assumption the hours above 60% RH do not change significantly from those shown in the table above; however, the relative energy use for the 300 cfm/ton scenario increases to 102-103%.

3) Disable Supply Air Fan Overrun

Most air handlers have the ability to operate the supply air fan for a brief period after the compressor shuts off (a.k.a. Supply Air Fan Overrun). This control method provides some additional cooling, which can increase the Seasonal Energy Efficiency Ratio (SEER) rating somewhat (typical increase <= 0.5 SEER point). However, the additional "cooling" comes primarily from evaporating moisture from the wet cooling coil at the end of the compressor operation cycle and sending that moisture back into the conditioned space. This would be fine for systems installed in dry climates -- sending the extra moisture back into the conditioned space would be a benefit. But in hot/humid climates like Florida, this supply air fan strategy increases indoor humidity levels.

Air handlers are normally shipped with supply air fan overrun "enabled". However, the installation guide typically provides instructions on how to disable this feature. It is recommended that Florida AC contractors disable the "Supply Air Fan Overrun" feature on every new system installation.

The table below summarizes computer simulation results showing the impacts of supply air fan overrun. With a conventional 90-second fan overrun, the indoor humidity levels increase significantly. For this particular simulation, the hours above 60% RH rose by 80% (1,583 hrs => 2,854 hrs). The difference in energy use was minor.

Impact of Fan Delays on Dehumidification Performance (Henderson et al. 2007)

Miami		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Base Case	AUTO Fan	1,583	2,166	5,201	859	6,411	100%
Fan Overrun (1s)	AUTO Fan	1,587	2,165	5,199	860	6,409	100%
Fan Overrun (30 s)	AUTO Fan	1,894	2,143	5,159	890	6,398	100%
Fan Overrun (90 s)	AUTO Fan	2,854	2,096	5,075	948	6,373	99%

The figure below shows the impact of a supply air fan overrun strategy that keeps the fan on at the same airflow rate for a fixed length of time after the compressor on cycle. The overrun delays shown on the plot are for 0.5, 1.5, and 3 minutes. In each case the thicker line is for a simple model that added a fan delay (and assumes no evaporation for the remainder of the off-cycle when the fan is off). The thinner lines associated with each time delay use the two off-cycle interval model and assume that the 2nd interval in the off-cycle when the fan is off has a very small airflow (10^2, 10^3, and 10^4 times less are shown on the plot). As expected the two models converge at very small off-cycle flow rates.

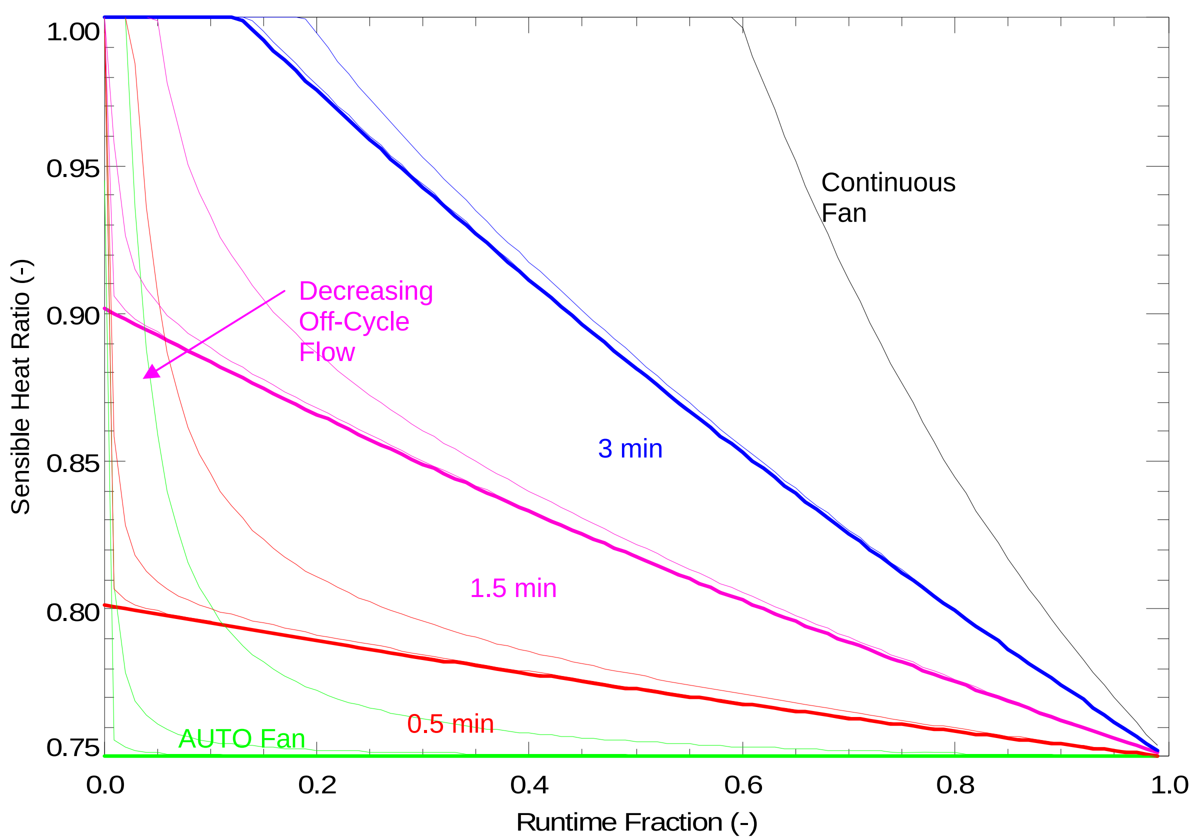

Figure 2. Predicting Latent Degradation with Fan Overrun Delay (Shirey et al. 2006)

Some manufacturers implement fan delays that maintain 50% of full flow for a brief period. The figure below shows the impact of reducing airflow during the fan delay. The reduced air flow during the fan delay does, in part, mitigate the latent degradation. However, any supply air fan overrun negatively impacts the dehumidification performance of the system and is therefore not recommended.

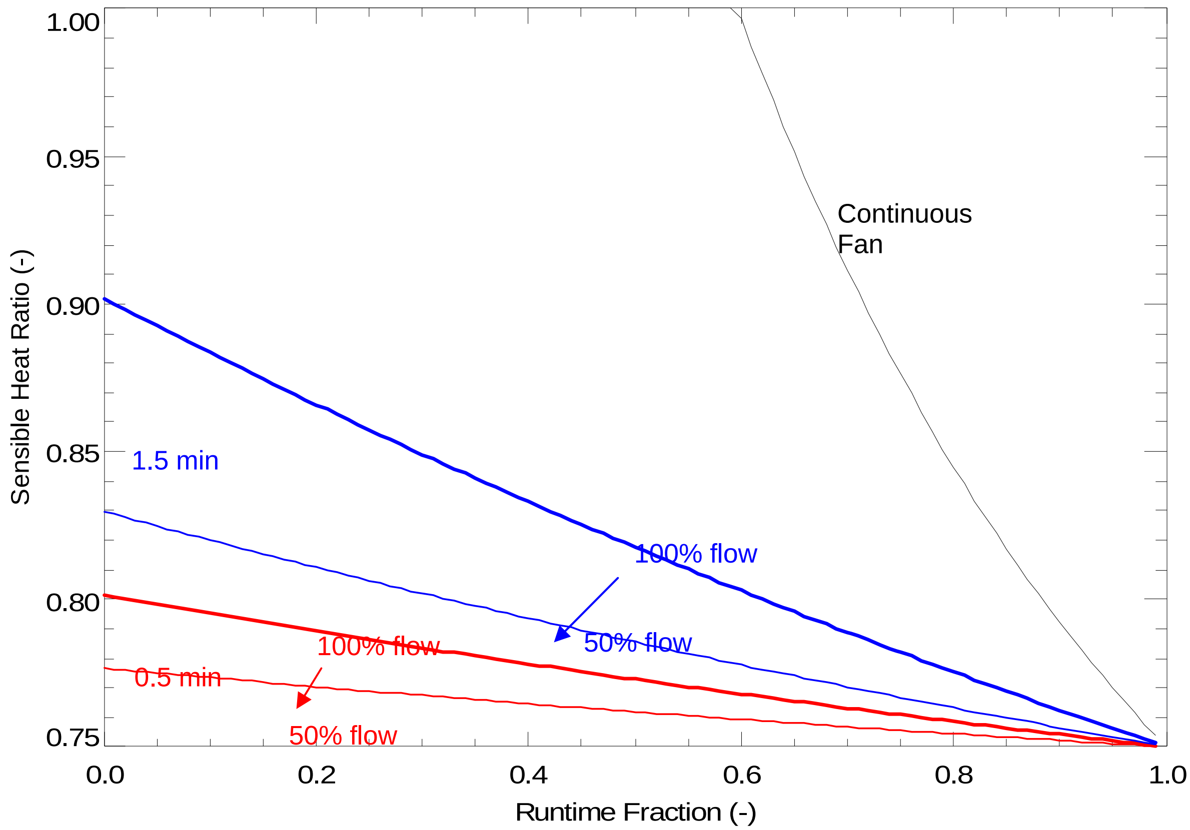

Figure 3. Predicting Latent Degradation with a Fan Overrun Delay and Reduced Off-Cycle Airflow (Shirey et al. 2006)

4) Operate the Supply Air Fan in AUTO Mode

Most thermostats allow the supply air fan of the system to operate in AUTO mode (i.e., supply air fan cycles on and off in tandem with the compressor) or the ON mode (i.e., supply air fan operates continuously while the compressor cycles on and off to meet the cooling set point). Operating the supply air fan when the compressor is off (i.e., ON mode) causes moisture from the wet cooling coil to be evaporated into the airstream and sent back into the conditioned zone, thereby increasing indoor humidity levels.

For Florida residential application, it is recommended that the system be operated in the AUTO mode (with no supply air fan overrun, see section 3 above).

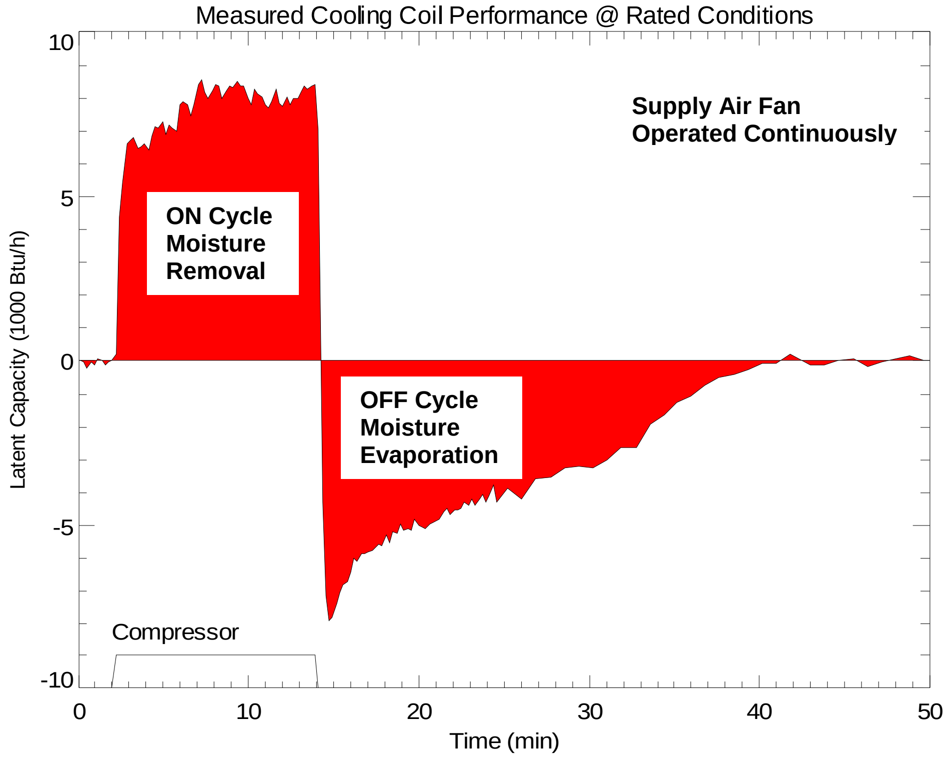

Figure 4. On-Cycle Condensation and Off-Cycle Evaporation of Moisture from a Cooling Coil (Henderson 1990)

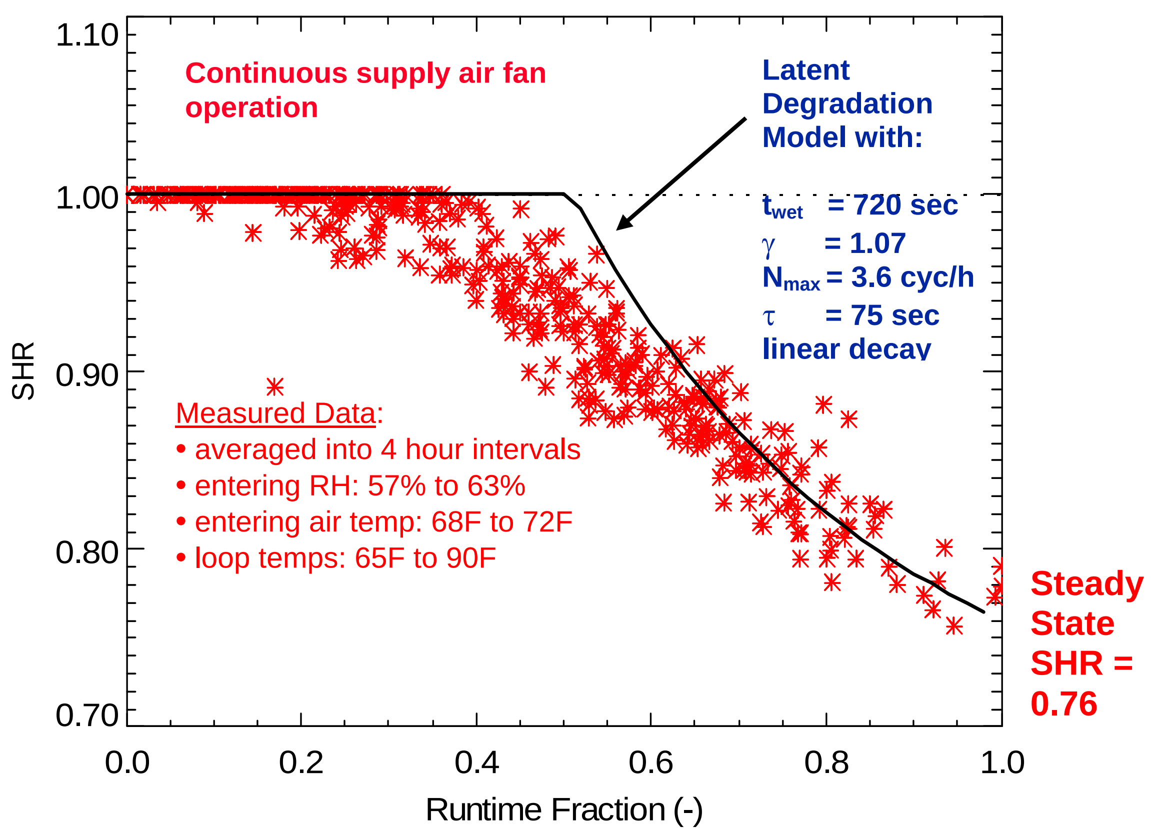

Figure 5. Comparison of Measured SHR with First-generation Latent Degradation Model (Henderson 1998)

The figure below shows measured indoor humidity levels in a Florida house. Clearly, operating the supply air fan continuously (fan ON mode) results in significantly higher indoor humidity levels.

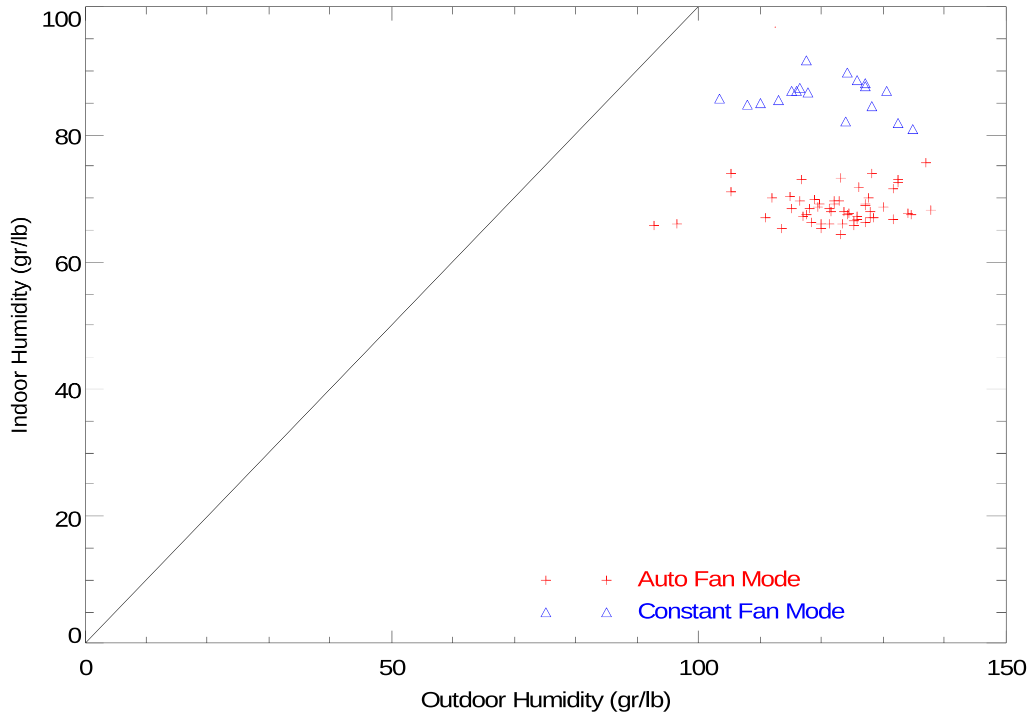

Figure 6. Daily Humidity Ratios for AUTO vs Constant Fan Modes at Site 2 (Shirey et al. 2006)

The tables below summarize computer simulation results showing the impacts of supply air fan operating mode on indoor humidity levels and energy use. Continuous supply air fan mode increases indoor humidity levels tremendously, and also results in a very large increase in energy use (due to increased supply air fan energy and fan heat, and increased duct air leakage).

Impact of Supply Air Fan Operating Mode on Indoor Humidity Levels and Energy Use

HERS Reference House		**Hours above 60% RH (hrs)**	**AC Runtime (hrs)**	**AC Electric Use (kWh)**	**Supply Fan Electric Use (kWh)**	**Total HVAC Electric Use[1] (kWh)**	**Relative Energy Use (%)**
Miami	AUTO Fan	1,583	2,166	5,201	859	6,411	100%
	CONST Fan	7,283	2,089	5,165	3,434	8,598	134%
Jacksonville	AUTO Fan	1,391	1,333	3,460	641	4,451	100%
	CONST Fan	5,579	1,298	3,476	3,679	7,155	161%

High Efficiency House		**Hours above 60% RH (hrs)**	**AC Runtime (hrs)**	**AC Electric Use (kWh)**	**Supply Fan Electric Use (kWh)**	**Total HVAC Electric Use[1] (kWh)**	**Relative Energy Use (%)**
Miami	AUTO Fan	3,909	2,170	3,187	520	4,057	100%
	CONST Fan	7,971	2,102	3,180	2,085	5,265	130%
Jacksonville	AUTO Fan	2,833	1,333	2,310	418	3,078	100%
	CONST Fan	5,903	1,315	2,350	2,453	4,803	156%

Notes: 1 - AUTO Fan case includes additional 40 Watts of power for mechanical exhaust fan that runs continuously year-round to exhaust 57.5 cfm (350 kWh/yr)

Cooling set point temperature is 75ºF.

5) Install Airtight Ductwork

Duct air leakage can have significant negative impacts on indoor humidity levels, energy consumption and indoor air quality. The Florida Energy Code currently encourages installing airtight ductwork by providing an energy credit for tight tested ductwork (via Compliance Method A). It is recommended that this energy code credit continue. In addition, investigate additional training opportunities to address this very important issue.

6) AC Equipment Sizing

The Florida Energy Code contains provisions to limit AC equipment oversizing (<= 115% Manual J), and these provisions should be retained. Methods for additional checking of Manual J input assumptions and verification of the calculation results should be investigated and implemented to the extent possible.

In a field study of more than 300 Florida homes conducted in the early 1990s, AC systems sized 20% larger than the Manual J value consumed 3.7% more cooling energy (James et al. 1997). In this same study, systems sized 50% larger than the Manual J value consumed 9.3% more cooling energy. A recent computer simulation study (Henderson et al. 2007) indicates a slightly smaller impact on energy use, due mainly to recent data which implies that cycling degradation for cooling equipment (i.e., inefficiencies due to on/off cycling) seems to be improving over past levels. Regardless, proper system sizing remains important in terms of system first costs, electric peak demand and indoor humidity levels.

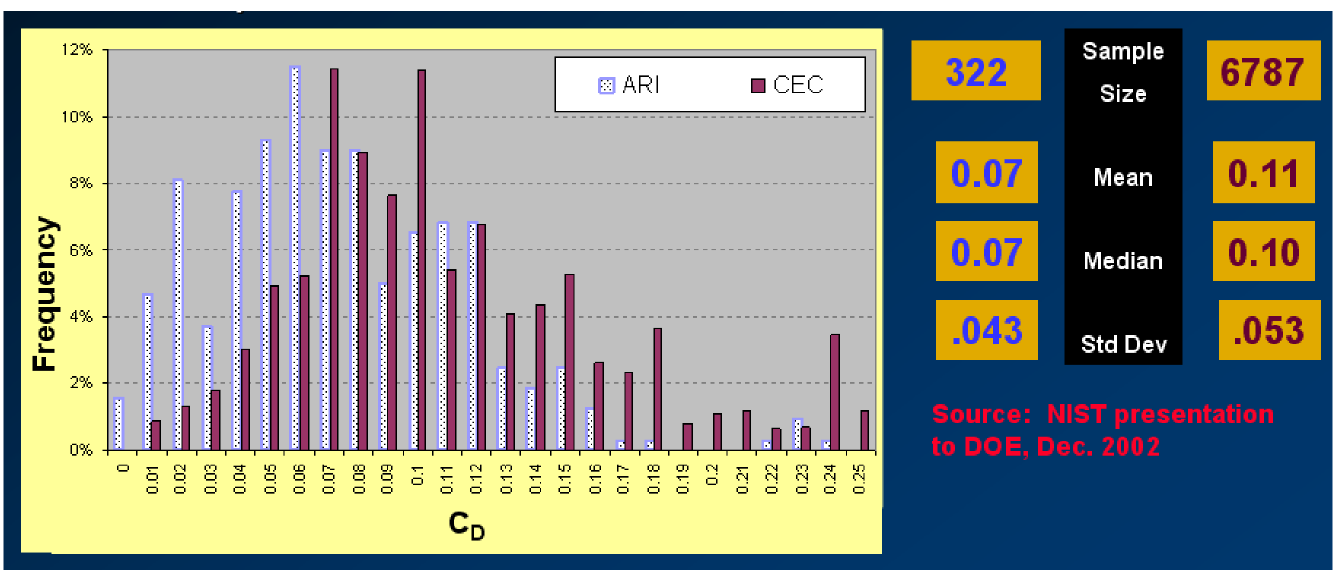

Figure 7.

7) Refrigerant Expansion Device: Fixed Orifice versus TXV

Air-conditioning systems include a refrigerant metering device which separates the high pressure and low pressure sides of the system. There are 2 common types of metering devices: fixed orifice (e.g., capillary tube or short tube restrictor) and thermostatic expansion valves (TXVs). Fixed orifice expansion devices are inexpensive and reliable, but tend to yield lower system efficiencies. TXVs are more expensive and have some moving parts which might impact reliability, but use of these metering devices typically produces higher efficiency units due to its ability to meter the refrigerant flow rate over a wide range of cooling loads. Good TXV operation must include proper location and attachment of the sensing bulb, so installation of TXVs (at the factory or in the field) needs to be completed with care.

Hard-shutoff TXVs do a better job at maintaining high/low refrigerant pressures during compressor off period, which leads to lower start-up losses when the compressor restarts. The compressor must be able to handle the higher starting torque requirements.

References

Henderson, H.I., D. Shirey and R. Raustad. 2007. Closing the Gap: Getting Full Performance from Residential Central Air Conditioners – Develop New Climate-Sensitive Air Conditioner: Simulation Results and Cost Benefit Analysis. FSEC-CR-CR-1716-07. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1716-07.pdf

Shirey, D.B., H.I. Henderson and R. Raustad. 2006. Understanding the Dehumidification Performance of Air-Conditioning Equipment at Part-Load Conditions. Final Report, FSEC-CR-1537-05. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1537-05.pdf

Henderson, H.I. 1990. An Experimental Investigation of the Effects of Wet and Dry Coil Conditions on Cyclic Performance in the SEER Procedure, Proceedings of USNC/IIR Refrigeration Conference at Purdue University, July 1990, West Lafayette, IN.

Henderson, H.I. 1998. The Impact of Part-Load Air-Conditioner Operation on Dehumidification Performance: Validating a Latent Capacity Degradation Model. Proceedings of ASHRAE IAQ & Energy 98, pp. 115-122.

James, P., J.E. Cummings, J. Sonne, R. Vieira, J. Klongerbo . The Effect of Residential Equipment Capacity on Energy Use, Demand, and Run-Time. FSEC-PF-328-97. http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-328-97/index.htm