

Field Test of Combined Desiccant-Evaporator Cycle Providing Lower Dew Points and Enhanced Dehumidification

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Abstract

Control of humidity in spaces is especially important in hot and humid climates where the latent load can easily be as much as 50% of the AC load. This paper discusses a new application that combines a desiccant wheel and a standard air conditioning unit into a system sometimes referred to as the Cromer cycle. The use of the desiccant provides the AC unit with enhanced moisture removal and a control mechanism whereby the moisture removal of the evaporator coil can be adjusted on the fly down to SHR_s below 50% with little to no increase in energy use. The paper discusses how this cycle works from a thermodynamic and psychrometric perspective. The paper provides results from side by side field testing and the independent testing of a 3 ton commercial rooftop system by an ARI certified test lab, Intertek, at Cortland, N.Y. The independent tests of the unit showed a 40% increase in moisture removal vs. the standard equipment at 50% RH return and a 100% increase at 40% RH return with practically no increase (less than 2%) in unit energy use including fan power. The side by side field test demonstrated over 70% in energy savings over an electric reheat system providing similar humidity control. As of February, 2005 this new technology is available through a major HVAC manufacturer in the US.

Introduction

Today, with higher fresh air specifications born of growing mold and mildew awareness, end-users and designers alike are looking to control humidity in the same way they control temperature. Many existing products control temperature effectively, but the amount of humidity control is only coincidental. Typically, the compressor satisfies the thermostat but has no mechanism to respond to rising humidity in the space. When humidity control is added, the industry normally resorts to a "cold coil" strategy, that is, the air is overcooled by the machine to remove the humidity, and then reheated to get it back into the comfort zone. This process is inefficient, adding extra cooling and heating energy costs and

dramatically reducing overall cooling capacity to gain the dehumidification needed.

In search for an alternative, numerous HVAC industry manufacturers, and specifically those working with desiccant wheels, have recognized a need for a combined desiccant/HVAC products that have the capability to satisfy several building functions: cooling/heating, enhanced dehumidification, and fresh air. It is important that such a product provide improved efficiency (energy savings) and improved indoor comfort and air quality. Also, this product must have first costs similar to existing vapor compression dehumidification products if they are to make a substantial market penetration. Further, if such products could utilize low grade waste heat for desorption of the desiccant, the product would be more marketable and of greater benefit in reducing building and national energy use. A number of products have been developed to meet this set of difficult criteria, some with more success than others.

Combined Cycle with Desiccant and AC Coil

This paper describes the field testing of a novel air conditioning desiccant cycle. This cycle uses a desiccant to move moisture within the air handler system of an air conditioner system. It moves moisture with a desiccant from the saturated air leaving the cooling coil (supply) to the inlet duct (return). This has the thermodynamic effect of reducing the overall energy consumption of the air conditioner and also has the benefit of dramatically increasing the moisture removal capacity of the air conditioner coil.

This is how it works.(Figure 1) The desiccant sucks up moisture from the high relative humidity air leaving the coil, point 3, wetting the desiccant and providing a much dryer duct system and conditioned space when the air leaves the wheel at point 4. The desiccant then transfers its moisture to the air returning from the space, point 1, before it

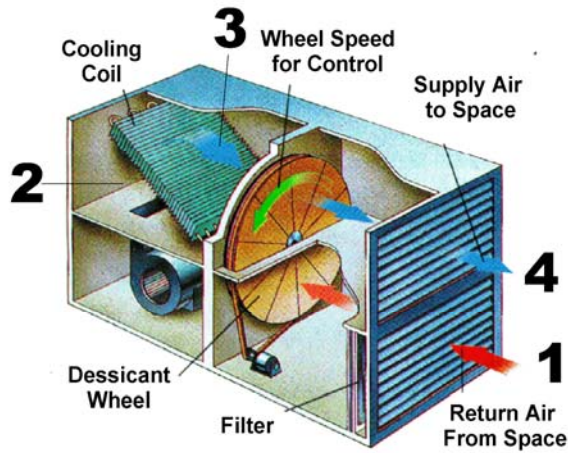


Figure 1. Diagram of Desiccant Wheel and AC Coil

enters the cooling coil, drying the desiccant wheel on the low side. The release of this moisture into the air before the coil makes that air wetter, point 2, which increases the moisture removal of the coil enhancing its dehumidification. This cycle will provide additional drying (shift of sensible to latent work) with very little reduction in coil temperature. With a "colder coil" strategy such as lower air flow, some additional moisture removal is achieved but with a decrease in efficiency and an increase in energy use. For this cycle to operate, a desiccant must be cycled back and forth between: a., the air returning to the air conditioner from the air conditioned space (return air) and b., the air being supplied to the space from the air conditioner (supply air). Any cycling mechanism can be used, however an easy mechanical application of this cycle is a rotating wheel loaded with desiccant.

Drying by a cold coil can be depicted on a psychometric chart and is shown in Figure 2. State point 1 is the air that returns from the space to the system (return air). For a typical air conditioning system, this air at state point 1 enters the cooling coil and leaves at about state point 4' after cooling and drying. State point 4' represents the temperature and moisture content of the air that leaves the unit, about 45 to 50° F and 98%RH. The Cromer cycle is depicted with the dotted line. A desiccant is used to remove moisture from the high humidity air exiting the cooling coil at 3. This sorption of moisture dries the supply air and it follows the line between state point 3 to state point 4. The moisture taken from the supply air by the desiccant, is re-evaporated into the return air prior to it reaching the cooling coil. This is represented by state point 1 to state point 2. The work of the coil is shown by the process from state point 2 to state point 3.

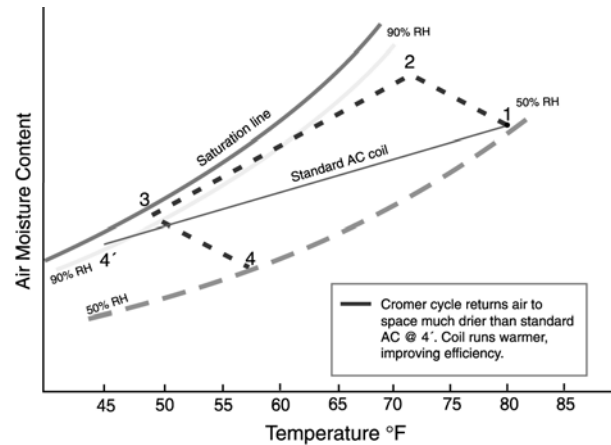


Figure 2. Psychometric Chart of Standard AC Cycle and Cromer Cycle Air Conditioning

By observation of the psychometric process, there are a number of improvements to the air conditioning cycle that should be apparent. First, the end state point 4 for air from the wheel represents a significant latent ratio increase, to about 45% as opposed to the 25% of the typical coil shown. Secondly, the air quality delivered by the cycle is much dryer, i.e. about 55% RH (state point 4) rather than 98% with the standard coil (state point 4'). Third, this is accomplished with a **higher evaporator coil temperature**. This is significant because given a constant condenser temperature, the higher the evaporator coil temperature, the more efficient is the refrigeration cycle and the greater capacity any particular system can deliver. This is how the Cromer cycle saves energy over a typical air conditioner cycle running a "cold coil" strategy for humidity control.

The feature which differentiates the Cromer cycle from other gas fired and heat driven desiccant-assisted cooling systems is there is no high temperature air used to regenerate the desiccant. No gas is burned, no electric heating is used thus the energy performance is similar to the EER of the AC equipment. The regeneration of the desiccant is accomplished by the return air which is very close to the space air condition. The moisture is returned to the cold refrigeration-cycle coil to remove it. This is much more efficient at removing moisture than a stand alone dehumidifier which adds substantial heat to the space.

Selecting the Desiccant

To operate in this cycle, the desiccant is required to absorb moisture from air coming off of the coil that is colder and about 98% RH, and desorb moisture to air that is warmer and at a lower RH. The desiccant is regenerated by the vapor pressure differential inherent in the RH differences rather than heat or temperature difference. Desiccants that have isotherms of the type shown in Figure 3 (Type III), are common. Davison silica gel, grade 59, is of this type. Type III desiccants absorb little moisture below 70% RH but many will take up more than their own weight in water from the air when presented with over 90% RH. The absorption isotherm is very steep between 90 to 100% RH. Desiccants of this type have plenty of potential for the cycling of moisture from the air off of the coil, around 98% RH, to the return air stream, typically around 50% RH.

Where Does the Water Absorbed by the Desiccant Go?

Persons familiar with gas fired desiccant systems may have difficulty in first understanding how the cycle works. These other desiccant systems use a desiccant wheel to dry air that is entering the building and use gas heat to evaporate that moisture into air leaving the building. In this cycle, the moisture is captured by the desiccant leaving the coil before it goes down the duct back to the building. The moisture captured by the desiccant is re-evaporated into the air coming from the conditioned space to the AC system. This moisture goes back to the coil, where the coil has another shot at condensing it out as condensate. The air conditioning coil removes the moisture. The desiccant just transfers the moisture from one site in the system to another, but by doing so, substantially increases the moisture removal of the air conditioner coil. To control the amount of moisture removed from the space, when the moisture load is satisfied, the wheel can be rotated more slowly or cycled off. It can then be turned back on if additional moisture removal is needed..

Equipment Development History

In 2002-2003, the Department of Energy through Oak Ridge National Labs provided funding to a U.S. manufacturer to complete two manufactured prototypes. The first prototype was used by them in their own test laboratory to optimize components and configuration. The second prototype, a three ton commercial rooftop system, was tested for performance by an independent, ARI certified test

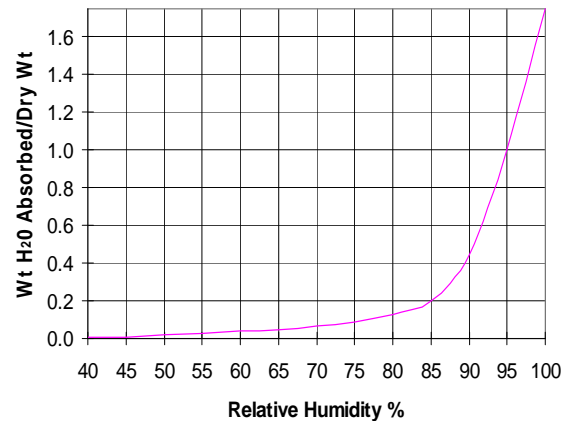


Figure 3. A Type III Desiccant -- Absorption by Weight vs. RH at 72 degrees F (Adapted From ASHRAE 2005 Fundamentals Handbook, Page 22.4)

laboratory, Intertek of Cortland, N.Y. The test was conducted across various RH return values. Test results indicated the desiccant design could lower its SHR to high dehumidification values with practically no increase (less than 2%) in energy use including fan power. As the RH of the return was provided at lower values, the standard unit showed a significant decrease in its moisture removal rate. In contrast, the desiccant enhanced unit continued to show a high level of moisture removal (low SHR). At 40% RH return the desiccant enhanced unit showed a 100% increase in moisture removed over the same unit without the desiccant wheel in place. The unit with the desiccant showed a 40% increase in moisture removal over the standard equipment without the wheel at 50% RH return. In this paper, the desiccant enhanced system will be referred to as “Model C”.

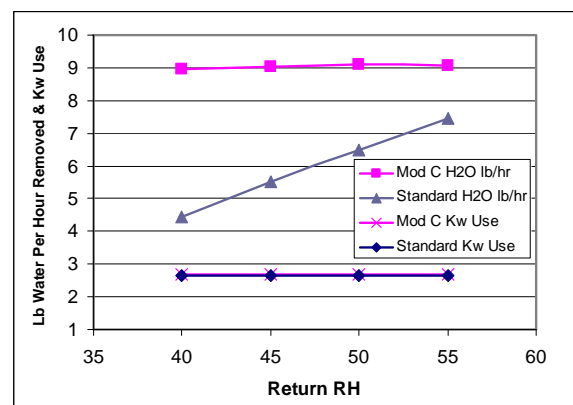


Figure 4. Plot of Intertec Steady State Test Results (unit and fan “on” continuous)

Side by Side Field Test of MODEL C Unit vs. Standard Unit

The University of Central Florida (UCF) located in Orlando, FL operates an extension campus in Cocoa Florida. The Florida Solar Energy Center (FSEC) is a research institute of UCF and is co-located with the extension campus in Cocoa, FL. The high humidity of the Cocoa coastal area makes storage of documents and equipment problematic without humidity control. The humidity control of this pre-manufactured building used for FSEC equipment and document storage was provided by a three ton split system manufactured by Bard of Bryan, Ohio. This standard system design is used as temperature and humidity control of the storage facility. To provide humidity control, a 3360 Watt reheat coil is used in a standard reheat configuration. In this test, this unit is referred to as the “Standard” system.

The alternative desiccant/air-conditioning system was installed on May 27, 2005 to provide air conditioning and moisture control to the space. The AC system is a Precedent Model manufactured by Trane Co. rated at 3 tons, with a desiccant wheel curb attachment for enhanced humidity control. This system will be referred to as “Model C.”

For this comparison test, both units were instrumented such that they could be monitored for performance and energy use. The facility was operated on one system (with the other off and isolated) for two week intervals, then the alternative system was used for two weeks. In this way, direct comparison data on the operation of the two systems was obtained. Prior to testing, both systems were thoroughly cleaned, both evaporator and condenser coils, and charged with R-22 to the optimum charge.

A photo of the Bard system is shown in Figure 5 and a photo of the rooftop unit (installed over the mechanical room) is shown in Figure 6. Both systems were operated throughout the test with the fan on “Auto” control, that is, each units fan would cycle on and off when the compressor cycled on and off. The fans were not run in the “continuous” mode.



Figure 5. Three (3) ton Standard Unit with Reheat



Figure 6. MODEL C Three Ton Rooftop Unit Installed on Storage Building

Figure 7 shows how the two systems were installed to utilize the same duct distribution system by switching a length of flex duct. Figure 8 shows the Campbell Scientific CR-7 data acquisition system. The same return and supply RH and temperature sensors were used for both systems and the single air flow sensor used on both systems was located in the supply main duct after the flex duct segment. Separate Kwh meters were used to monitor total power used by each unit. Fan power, wheel motor power, and heater power were not sub-metered. Standard drawn thermocouple wire (for temperature) and Vaisala HMD40U humidity transmitters (for RH) were calibrated in the FSEC Appliance Lab prior to installation.



Figure 8. Data Acquisition Monitoring System for Side-by-Side Test



Figure 7. The Distribution Plenum Can Be Switched Between the Two Systems

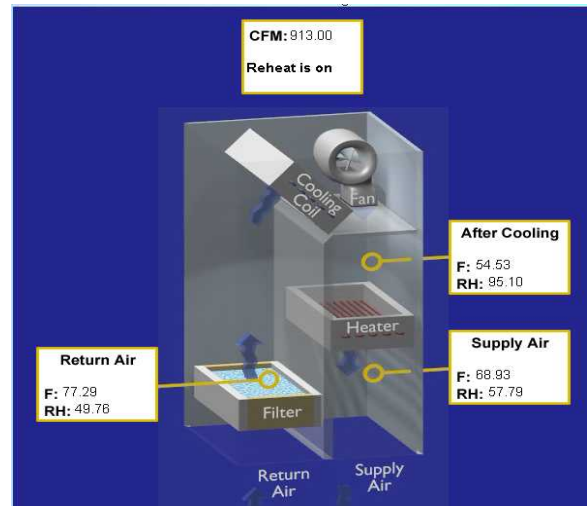


Figure 9. Configuration Diagram of Standard/Reheat Unit

A configuration diagram of the Standard/Reheat unit is shown by Figure 9 and the configuration of the MODEL C unit is shown by Figure 10.

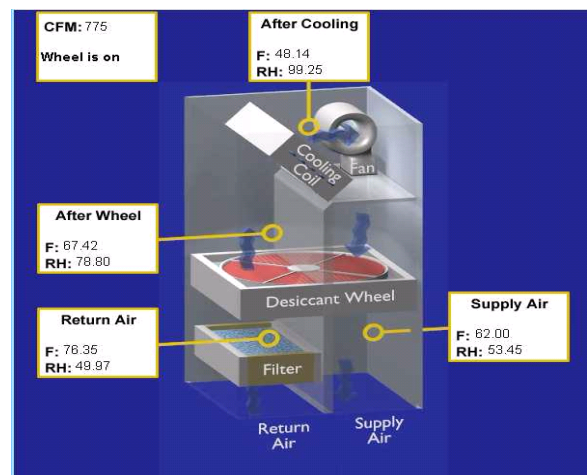


Figure 10. Configuration Diagram of MODEL C Desiccant Wheel Unit

Figure 11 shows typical operational state points of the Standard/Reheat unit and Figure 12 shows typical operational state points of the MODEL C unit.

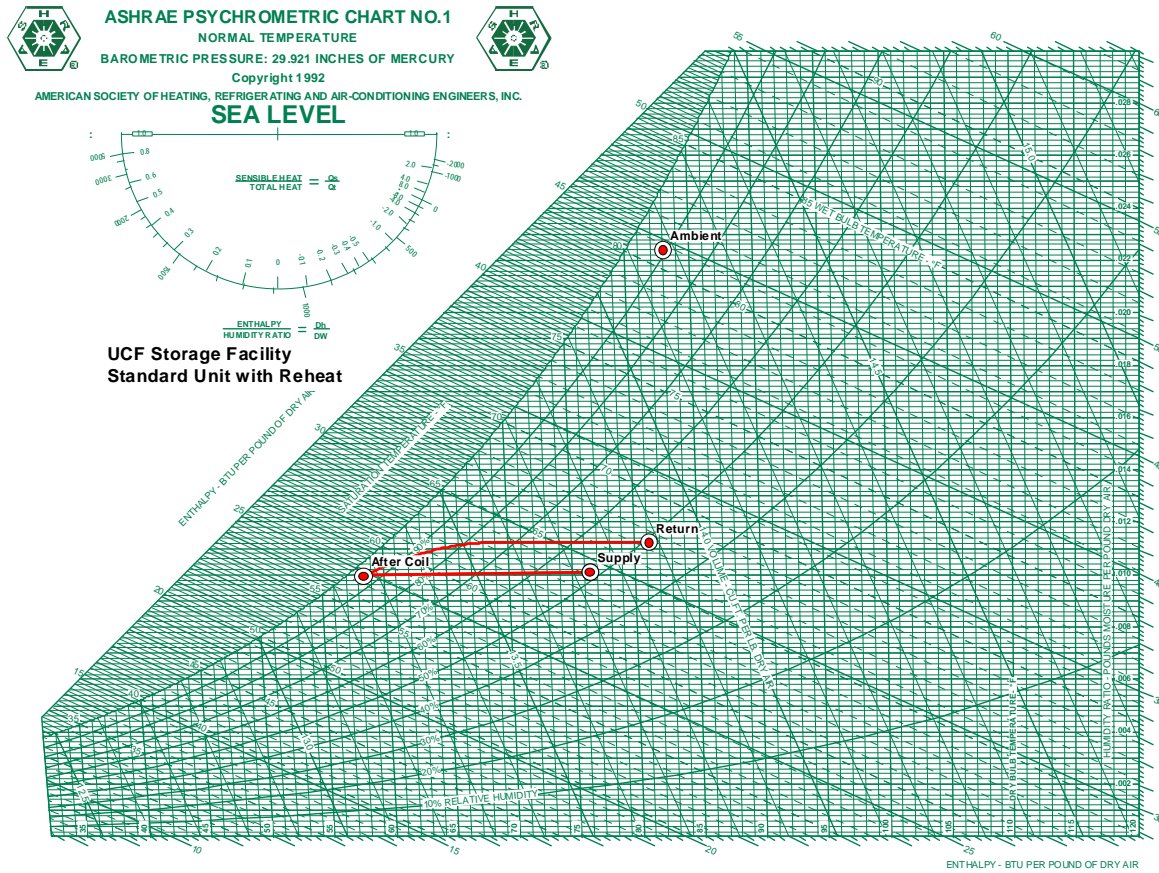


Figure 11. Typical Operational State Points for UCF Storage Facility Standard Unit with Reheat Activated.

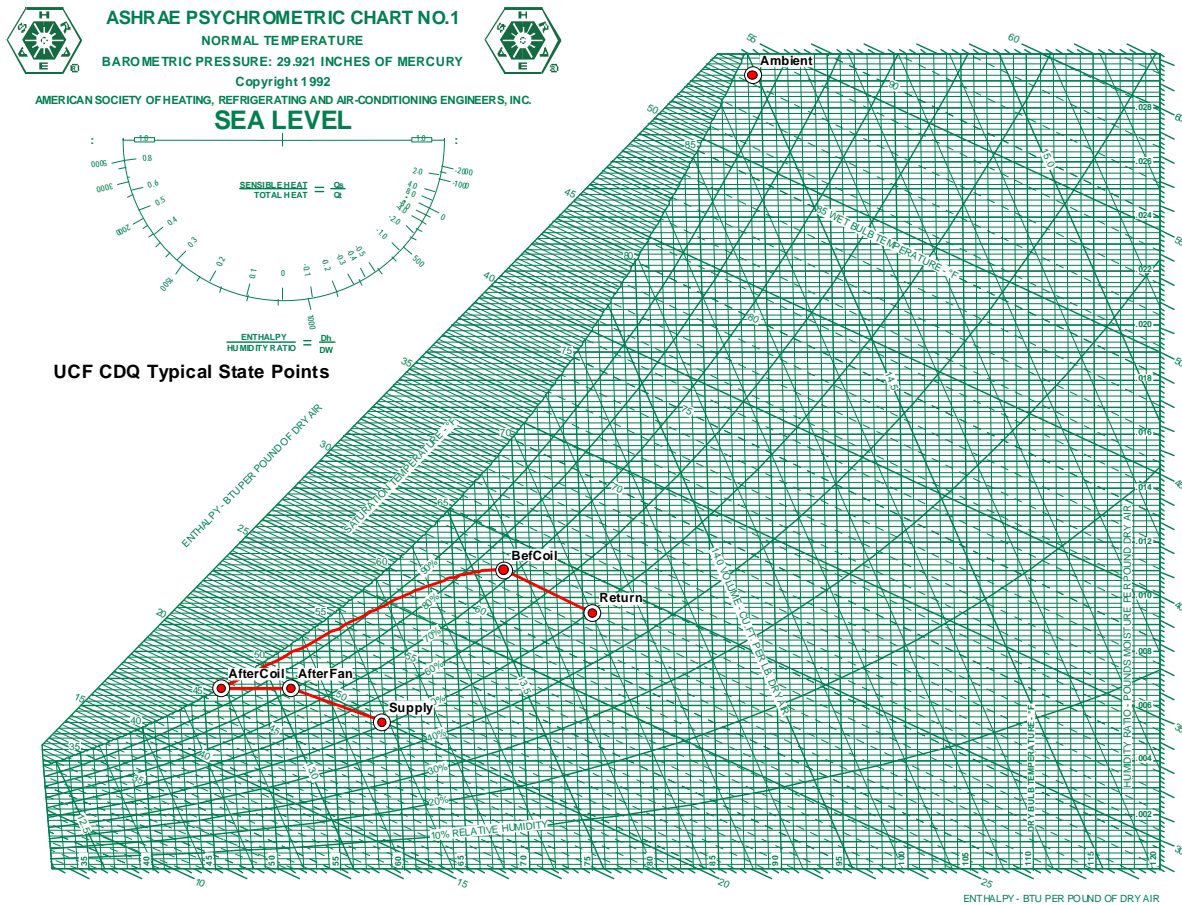


Figure 12. Typical Operational State Points of the MODEL C Unit

Data Results

The data plots of Figures 13 and 14 show the accumulated data on the two systems. Figure 13 shows the MODEL C data first, as it was the first two week set to be accrued. Prior to the test, the standard unit set points for the thermostat was 76 degrees F,

and 50% RH for the humidity control. Because the test is about controlling humidity, the RH set point was moved to 45% RH, for both the units, a more difficult specification. However, the standard unit could not maintain that set point, so the setting for the standard unit was set back to control on the original 50% RH about half way through the test.

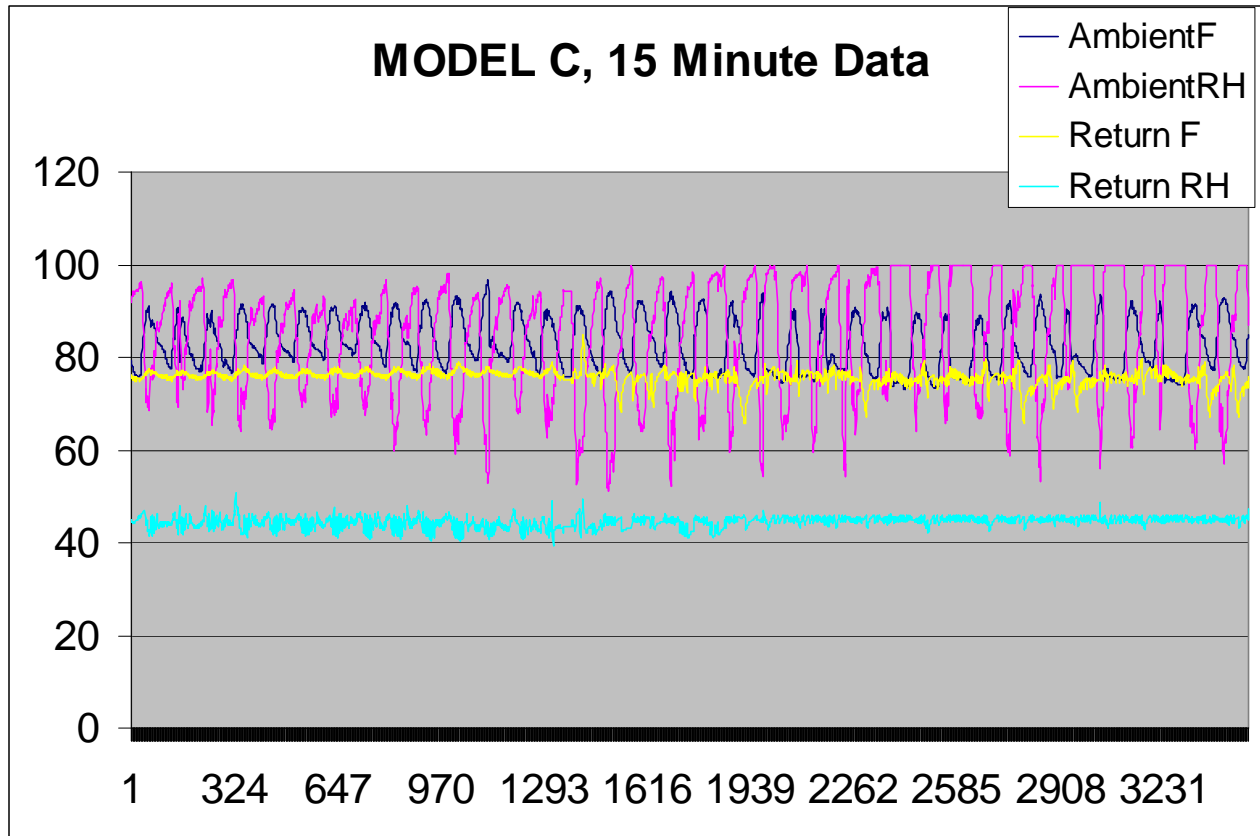


Figure 11. One Month MODEL C Operational Data. Set Points Are 76 F and 45 % RH. Each Data Point Represents A 15 Minute Average. The Fan Is Set on “Auto”, That Is, It Cycles On and Off with the Compressor.

On about 1418 the probe measuring the return temperature and RH was moved from the site of the thermostat, (on the wall about 2 feet over and 4 feet up from the return plenum) to the return plenum air flow. Thus the data shows more variation in the return temperature with the probe located directly in the return air flow. On about 1921, the humidistat control was changed from a Honeywell unit (about 6%RH swing) to a Visalia unit (about 2%RH swing). Humidity control was tighter with the better humidistat.

The MODEL C unit provided excellent humidity control at the 45% RH set point, with occasional overcooling at night of several degrees (when the building is unoccupied). No reheat was used. For control, the unit was cycled “on”, if either the temperature or the humidity set point were not satisfied in the space condition. If the humidity set point was not satisfied, the wheel was rotated. If the humidity set point was satisfied, the wheel was switched off and not rotated.

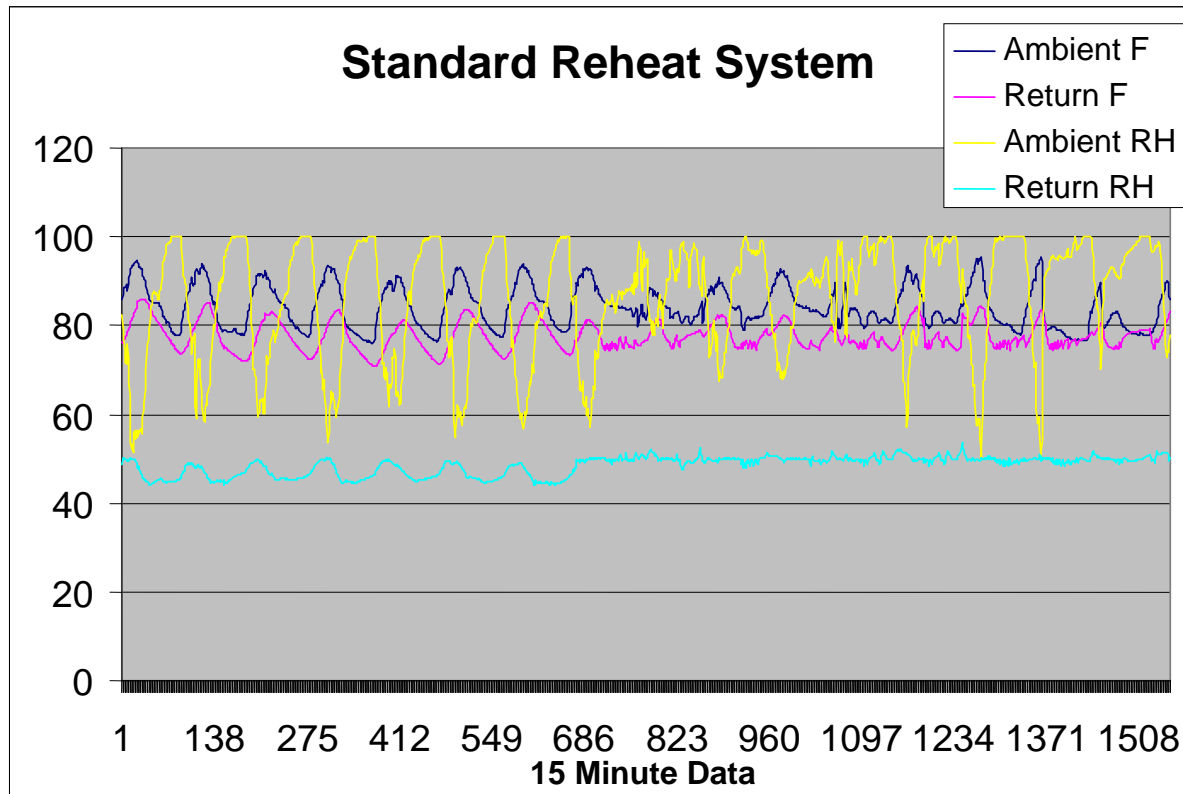


Figure 13. One Month Data, Standard Unit with Reheat. Fan on “Auto” Mode.

Prior to point 683, set points for the reheat unit were set the same as the MODEL C™ unit, i.e. 45% RH and 76 F. The reheat unit could not maintain either temperature or humidity during the heat/humidity load of the afternoon. The 45% RH, 76 F set points were beyond this unit’s capacity, though these state points were met easily by the MODEL C unit of the same tonnage.

After point 683, the RH set point was moved up to 50% RH (the old setting prior to the test) and the reheat unit was able to stabilize the humidity at 50 %

RH. However, interior temperatures continued to go out of spec, rising to over 80 degrees F on some afternoons.

The control of the standard reheat system was the same as the control used for the MODEL C system. The unit was cycled “on”, if either the temperature or the humidity set point were not satisfied in the space condition. If the humidity set point was not satisfied, the reheat element was energized. If the humidity set point was satisfied, the reheat element was switched off.

Data Analysis

The averaged operational data for the two systems operated side-by-side and sequenced every 14 days, is provided in Table 1.

Table 1. Summary of Side by Side Data. Both Fan Units operated in “Auto” mode.

	<u>MODEL C</u>	<u>Standard</u>
Total Time	36 days	32 days
Ave Outdoor F	82.8	84.2
Ave Outdoor RH	84.9	86.1
Set Point F	76.0	76.0
Ave Return F	75.7	77.7
Ave Set Point RH	45.0	47.8
Ave Return RH	44.5	48.5
Kwh/day	35.6	146.5

Energy Savings of MODEL C: 110.9 Kwh/day (75.7%)

Conclusion

This study provides a side by side comparison of a standard reheat humidity control system with one that incorporates active desiccant wheel components into a hybrid HVAC air handler system referred to as the MODEL C. The tested MODEL C system, demonstrated the ability to deliver greater cooling and dehumidification capacity per ton, and substantial higher energy efficiency than an AC cold coil system with reheat - the most commonly used alternative for humidity control. Under almost identical conditions, the MODEL C unit was able to deliver a stable 45% RH space at 76 Degrees F where the Standard unit could not. Even when delivering lower RH and more stable interior space conditions, the MODEL C unit saved over 75% of the energy used by the Standard alternative with electric reheat.

Acknowledgements

Support for this study was provided in major part through DOE, Office of Distributed Energy, Office of Energy Efficiency and Renewable Energy, Oak Ridge National Laboratory, Dr. Jim Sand, technical monitor. Thanks also to Trane, Inc., Lexington, KY, Arthur Hallstrom and Ronnie Moffitt for technical installation support.