ENHANCE DEHUMIDIFICATION AND SAVE ENERGY.

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Charles J. Cromer, Ph.D. P.E. Program Director, Appliance Laboratory Florida Solar Energy Center Cocoa, FL

ABSTRACT

The Cromer cycle uses a desiccant to move moisture from the saturated air leaving an air conditioning (AC) cooling coil to the air returning to the AC unit from the conditioned space. This has the thermodynamic effect of reducing the overall energy consumption of the AC unit and also has the side benefit of dramatically increasing the moisture removal capacity of the AC coil. Simulations, engineering analysis and laboratory tests have confirmed the technical feasibility of the thermodynamics of the cycle. This work reports on a test at ARI conditions (95 deg. F outside, 80 deg F, 51% RH inside). The test unit (10 year old, 5 ton Bryant Air Conditioner) without the Cromer cycle, averaged an EER of 7.93 at a latent ratio of 26.2 % (SHR = 0.738). With the Cromer cycle added, the same unit averaged a total cooling EER of 11.82 with a water removal latent ratio of 53.4% (SHR= 0.466). The measured 16.4% reduction in energy use and 47.9 improvement in EER is significant for the tests at the 95% confidence level. This technology represents a major improvement in energy performance for the control of humidity conditions.

INTRODUCTION

The problem is the humidity. Water removal results in substantial energy use in residential and commercial air conditioning applications. The engineering terms **"sensible heat ratio"** and **"latent ratio"** are generally used to characterize moisture loads. In cooling a space to reach a comfortable condition, two types of heat energy must be removed, the temperature associated heat or sensible heat, and the moisture associated heat or latent heat. The proportion of the total load that must be removed that is sensible is termed the sensible heat ratio (SHR), and the remaining proportion is the latent ratio (LR).

You've heard, "Its not the heat, its the humidity." Too much water in living, shopping or working spaces is tied hand in hand with indoor air quality (IAQ). "Bring in fresh air" is always the cry when IAQ problems arise. Newly revised ASHRAE standard 62 calls for larger amounts of outside air flow and controlled humidity conditions in spaces. In hot-humid environments, this fresh air brings with it significant levels of moisture, upsetting the temperature moisture balance of the interior and reducing comfort. Indeed, it may even contribute to the IAQ problem associated with excessive interior moisture, rather that solve it. In the residential market, as structures are improved to reduce the sensible air conditioning load, a need has been recognized to better match the latent load, and thus maintain a better balance for health and comfort. The natural response to moisture discomfort (RH is too high), is to reduce the temperature setting of the thermostat. This uses more energy, leads to over cooling, and many times does not solve the problem leading to a "cold-clammy" environment, wet ducts, and mold and mildew growth. The attempt of the home owner or building operator to provide better comfort, leads directly to higher humidities and high energy use. Additional outside air with additional air conditioner run time is energy inefficient and a costly way to solve the problem. The problem is too much moisture in the space, and it must be removed to provide a solution. In residences, the Electric Power Research Institute (EPRI) estimate from their surveys that 30% of their customers use dehumidifiers.[1]

In supermarkets, where much of the sensible cooling is already done by the display cases, wasteful overcooling is done for dehumidification. Page 2 of the Jan/Feb issue of *AGCC Cool Times,* in a report titled "*Desiccant Applications: What's Next after Supermarkets, Ice Arenas and Refrigerated Warehouses?*" by Doug Kosar of the Gas Research Institute (GRI) provides the guideline: "Conventional cooling equipment characteristically matches up well with cooling loads having SHRs of 0.75 or higher." The article further explains that mismatches or inefficiencies occur in typical equipment whenever the SHR falls below 0.75, or a latent ratio from the space above 25%. This is because an air conditioner coil usually does about 25% moisture removal and 75% cooling. If the moisture load is greater than 25%, overcooling is needed to meet it. This cooling is not needed to maintain temperature control in the space and is usually removed by adding heat which requires further energy. It is much more energy efficient to remove the moisture without having to overcool in the first place.

THE CROMER CYCLE

This paper describes the testing of a novel air conditioning desiccant cycle, named the Cromer cycle after its inventor. [2] The Cromer 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 side benefit of dramatically increasing the moisture removal capacity of the air conditioner coil.

The desiccant sucks up moisture from the high relative humidity air leaving the coil, wetting the desiccant and providing a much dryer duct system and conditioned space. The desiccant then transfers its moisture to the air returning from the space before it enters the cooling coil, drying the desiccant. The release of this moisture into the air before the coil 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 heat pipes, or lower air flow, some additional moisture removal is achieved but with a decrease in efficiency and an increase in energy use. For the Cromer 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. Figure 1 provides a diagram of just such a wheel type system operating as a space conditioning roof top device with fresh air intake.

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 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 1to state point 2. The work of the coil is shown by the process from state point 2 to state point 3.

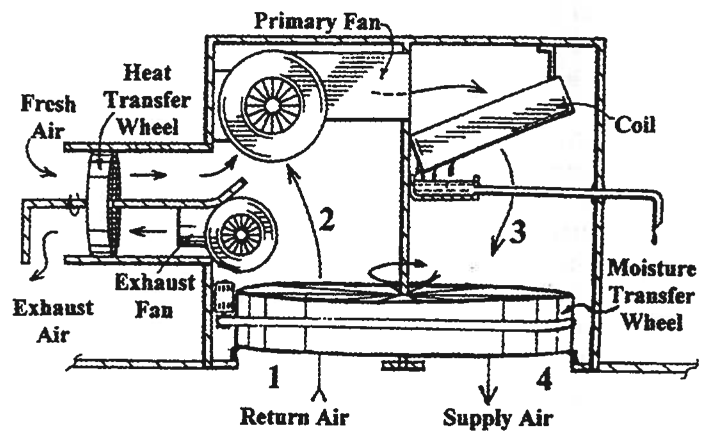

Figure 1. Diagram of a Desiccant Wheel Cromer Cycle as Rooftop Unit with Fresh Air.

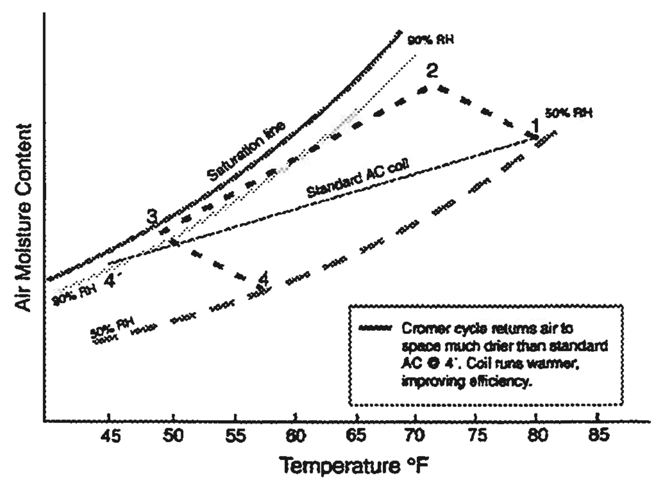

Figure 2. Psychometric Chart of Standard AC Cycle and Cromer Cycle Air Conditioning

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 Cromer 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. The psychometric charts demonstrate this win-win situation. The Cromer cycle delivers increased dehumidification, higher EER, and greater capacity than any of the alternative strategies to control humidity such as low air flow over the coil or heat pipes.

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 superior. 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. 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 Cromer 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 the Cromer 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. Some of this moisture leaves the building with the exhaust air, but most of it 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 Cromer cycle desiccant just transfers the moisture from one site in the system to another, but by doing so, substantially improves the energy efficiency and moisture removal potential of the air conditioner coil which provides operational savings and substantially improved control over the space humidity.

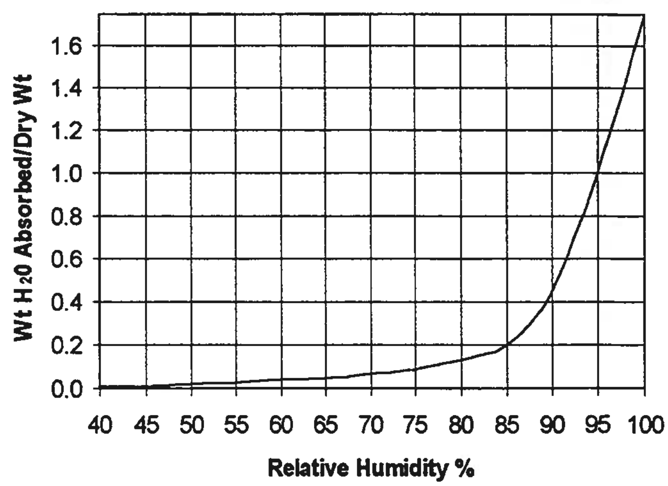

Figure 3. A Type III Desiccant -- Absorption by Weight vs. RH at 72 degrees F (Adapted From ASHRAE 1993 Fundamentals Handbook, Page 19.4)

PREVIOUS STUDIES

Three independent simulations have been conducted to determine if the Cromer cycle concept is scientifically valid. The first, conducted by the inventor, used a wheel simulation model developed by Kirk Collier (DCSSMX1) which incorporates the finite difference algorithms for moisture adsorption and desorption developed by Ian McClaire-Cross in

Australia (MOSHMIX) into the DESSIM wheel model developed at NREL (then SERI). The simulation data provided the state points of air before and after the wheel. The air response through the coil and performance data were provided by a set of equations developed from measured data on a 3.5 ton split system AC unit. Two desiccant types, three wheel sizes, and three wheel thicknesses were simulated. All showed excellent moisture transfer and increase of the AC system moisture removal. Significant latent ratios were predicted -- up to 50%. All three parameters, desiccant selection, wheel size, and wheel thickness, had an effect on optimal rotation speed. The simulations provided that at a LR of 40% the Cromer cycle would save 68%, 39% and 5% in energy over the alternatives: electric reheat, hot gas bypass reheat, and heat pipes respectively, with a 66% increase in capacity above the reheat options. [3]

The second set of simulations were completed by Dr. Bruce Nimmo at the Florida Solar Energy Center (FSEC) in 1993 and published in *ASHRAE Transactions*. [4] Dr. Nimmo's simulations found the Cromer cycle to provide better moisture removal capability than the alternatives simulated, and at a LR of 52%, showed an improvement in EER from 10.1 to 11.1 over the heat pipe application, a 10% energy savings. Simultaneously, the Cromer cycle increased capacity from 30.8 kBtu/hr to 34.0 kBtu/hr, a 10% increase in capacity over the state-of-the-art heat pipe system. Dr. Nimmo used an upgraded version of the Collier-Cross simulation developed by Hugh Henderson while he was at FSEC, and the HVAC response was simulated by DOE-2. A Type III silica gel was used as the desiccant in the simulation. He writes in his conclusion, "The parametric study and the seasonal simulation results indicate that the DEAC (Cromer cycle) process is feasible and holds promise for maintaining a healthy and comfortable environment at a lower cost for residential and fast food restaurant applications. In addition, the (Cromer cycle) can save energy compared to current high-efficiency air conditioners if both systems are required to maintain the ASHRAE recommended comfort levels."[5]

The third set of simulations were conducted by Dr. Chant and Dr. Jeter while Dr. Chant was at the Georgia Institute of Technology, Atlanta and also published by ASHRAE. [6] Dr. Chant used a simulation developed at Georgia Tech. in 1991 using a parabolic concentration profile model (PCP) to model the desiccant moisture and sensible exchange. Chant's model predicted that the Cromer cycle, when providing excellent moisture removal, i.e. a LR of 52%, would improve on the heat pipe system by providing an energy savings (increase in COP) of 2.58 to 2.68 (4%) and also an improvement in total cooling capacity from 9.23 Kw with the heat pipe to 10.39 Kw with the Cromer cycle (12.6% improvement). It should be noted that Dr. Chant assumed the desiccant wheel would have a greater pressure drop than the double coil heat pipe system and consequently the simulation added a large fan energy penalty to the Cromer cycle (which was called DEC).

Dr. Chant writes, "The DEC (Cromer cycle) system uses mass transfer in a similar way that a heat pipe system uses heat transfer to enhance the latent capabilities of a cooling coil. The simulations found that the DEC system experiences a dramatic rise in latent capacity compared with a vapor compression (VC) unit alone. Heat pipes are currently considered the state of the art technology for controlling the latent load of a conditioned space. The DEC (Cromer cycle) system compared favorably to the heat pipe system. A desiccant wheel installation is hardly more complicated than an auxiliary heat pipe heat exchanger but promises a higher coefficient of performance (COP) and increased capacity for a given sensible heat ratio."[7]

METHOD OF TEST

The tests were completed in the Appliance Laboratory environmental control chambers at the Florida Solar Energy Center. The method of test utilized is defined by the Air Conditioning and Refrigeration Institute (ARI) and the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) for testing the performance characteristics of unitary air conditioning equipment. The ARI Standard 210/240 [8] references the ASHRAE Method of Testing for Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps, ANSI/ASHRAE 116-1983. [9] The test set-up was configured to use the Tunnel Air Enthalpy Test Method Arrangement of Standard 116 (section 6.1.1), with the addition of chamber bypass as a suitable means for maintaining tight control of chamber temperature and moisture. Control was provided by a pair of Magic-Aire air handlers (Model 24BVW), fed by a Copeland 5 h.p. R-502 condensing unit, which conditioned the rooms to the tolerances prescribed in Standard 116 for the tests. For all test runs,the indoor chamber was maintained at 80 degrees F and 51% RH and the outdoor chamber was maintained at 95 degrees F.

TEST PROCEDURE

The desiccant wheel used (silica gel), 2' x 2' x 1", was designed and sold for energy recovery by AirXChange, Rockland, MA. The wheel and its cassette were installed on a Bryant 5 ton air conditioner for test. A test run consisted of one hour of stabilization operation and then one hour of operation for data collection. Three runs of the air conditioner without the wheel installed were first completed as a "pre-test" to provide a check on the instrumentation, calibration, chamber control programs, and the data acquisition programs and to establish a baseline for the AC system. The desiccant wheel was slid into the duct system and a test run completed. The wheel was then removed from the system, the ducts resealed, and an additional test run completed. By this alternation method, three runs with the wheel on the AC system and three runs with the wheel removed were obtained as the test data. At the completion of the test of the wheel, three "post-test" runs of data with the wheel removed were completed. The experimental system included the instrumentation required to monitor the performance of the Bryant unit, along with the data acquisition system that was employed to obtain the test data. The laboratory chamber and duct set-up is depicted in Figure 4.

TEST RESULTS

Data obtained on indoor and outdoor chamber temperature and humidity demonstrate that all the tests were conducted within the control limits established by ARI. The three data sets from the "before" test runs were averaged and the three data sets from the "after" runs were averaged to provide values for return temperature, return RH, supply temperature, supply RH, and watts used by the AC unit (fan power included) for the pre and post tests. T- tests of means were conducted on the "before" and "after" test variables with Ho: The "before" variable was equal to the "after" variable, and Ha: the "before" and "after" variables were not equal. All tests passed with a confidence (p value) greater than .98. This showed that it was highly unlikely that the AC system or the monitoring equipment drifted during the test period. This was also verified by the evaluation of residuals across the full test sequence, i.e. the residuals across the test sequence remained normally distributed and with uniform variance. The results of the test are provided in Table 1.

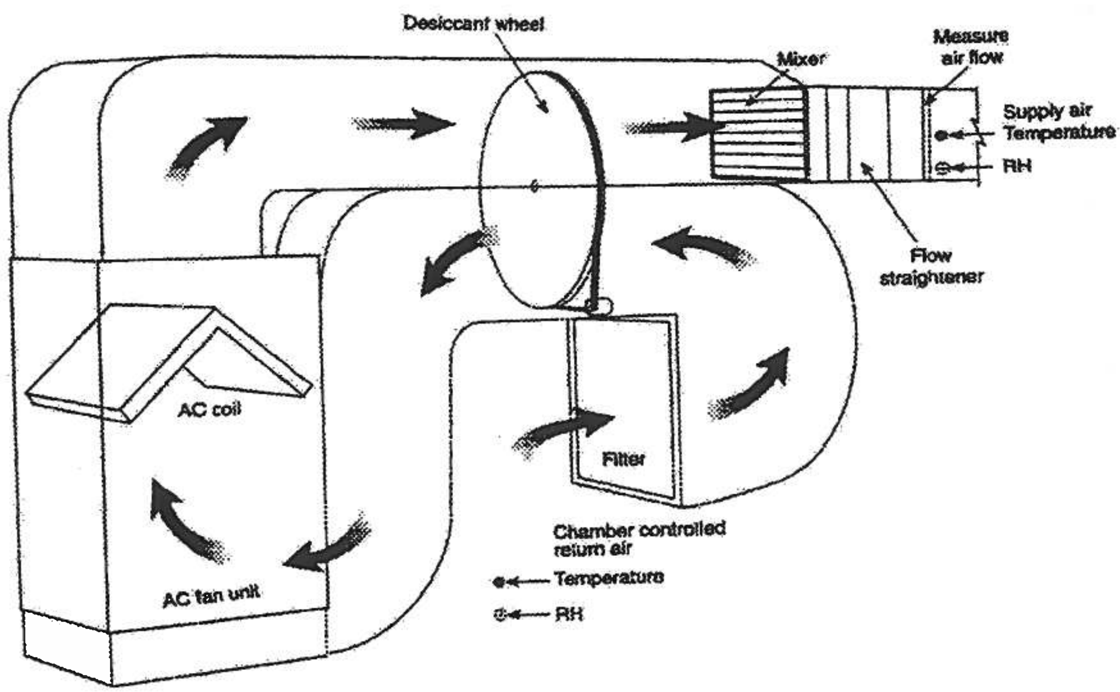

Figure 4. Diagram of Ducting and Control Chamber Setup for Performance Testing

Table 1. Test Results (three run averages) from Lab Test (80 F, 51% RH Indoor, 95 F outdoor).

	Standard AC	Cromer Cycle
Return Air, F degrees	81.7	80.3
Return Air, % RH	51.0	50.8
Supply Air, F degrees	58.2	58.3
Supply Air, % RH	96.2	51.4
Condenser Air, F degrees	96.2	94.7
Air Flow, CFM	1524	1081
Watts (over test hour)	6709	5610

The three data sets of run data taken for the Cromer cycle, i.e. with the wheel in place, were averaged and the three data sets without the desiccant wheel in place were averaged in a like manner. The variability of the data was such that the averages are statistically significant at the 95% level. The state point data of the comparison test were analyzed using psychometric analysis software, PsyChart, version 3.1. [9] A comparison of the two psychometric cycles is provided in Table 2. The Cromer cycle more than doubled the water removal rate, the latent ratio was doubled, and the state points of dry air sent to the space down the supply ducts, i.e. 58 degrees F at 51 % RH, are all similar to those predicted by previous simulations.

Table 2. Comparison of Psychometric Cycles from ARI Lab Test.

	Standard AC	Cromer Cycle	% Change
Capacity, Btu/hr	53,590	66,328	+ 23.8
Capacity, Tons	4.467	5.527	+ 23.8
Latent Cooling, Btu/hr	14,017	35,425	+ 152.7
Latent Ratio, %	26.2	53.4	+ 103.8
Water removal, gal/hr	1.56	3.93	+ 153.2
Watts (over test hour)	6709	5610	- 16.4
EER	7.99	11.82	+ 47.9

The Bryant unit without the Cromer cycle averaged an EER of 7.99 at a latent ratio of 26.2 % (SHR = 0.738). With the Cromer cycle added, the same unit under similar conditions averaged a total cooling EER of 11.82 with a water removal latent ratio of 53.4% (SHR= 0.466). These measured improvements in capacity (24%) and EER (48%) are much higher than simulation predictions, probably because all the simulations added a major fan energy penalty to the Cromer cycle. In the prototype equipment, no change was made to the fan. This resulted in a reduced air flow rate when the wheel was in place, but the penalty from reduced air flow on total cooling delivered to the space and the system performance was far smaller than suggested by the simulations.

The test data of the prototype unit showed that: (1) the Cromer cycle works, i.e. it is scientifically feasible, (2) when compared to published performances of alternatives, it has the potential to provide greater moisture removal than alternative "cold coil" technologies, i.e. heat pipes, run around coils, plenum heat exchangers, low speed fans, and variable speed compressors, (3) it has significant potential for saving energy and operation costs over standard air conditioning systems- even those with moisture removal or balancing alternatives, i.e. "cold coil" technologies, electric reheat, hot gas bypass, sub-cooling with supply air, unitized dehumidifiers and make-up air dehumidifiers -- gas or vapor compression, and (4) due to increased capacity, the Cromer cycle has the potential for reduced first costs.

OBSERVATIONS

It should be noted that potential clogging of the desiccant wheel is solved by filtering the air before it reaches the wheel. Such filtering is already a component of standard air conditioning units to keep the evaporator coil clean. The air channels of the desiccant wheel can be made larger than the channels of the evaporator coils, thus the filtering used in these systems is sufficient to prevent the desiccant wheel from becoming clogged over time. If the desiccant wheel does become clogged, with proper wheel design, it is possible to remove and wash and clean the wheel with a spray of water or blow of air without damage to the wheel. It may be possible to construct a wheel that is so inexpensive that it operates as the air filter itself and is simply replaced when it becomes dirty.

By rotating the desiccant wheel at various speeds, the amount of moisture removed by the air conditioner coil can be controlled. This was verified by tests subsequent to the ARI tests. A step change in rotation speed produced a step change in SHR and LR from the equipment. Thus, a separate humidity control could be provided to the operator such that they could dial in the humidity they want – perhaps on a dial reading from 40% to 60% RH. There is no competing product that provides such a capability with an energy savings. Also, the higher the moisture load of the space, the greater is the comparative energy savings.

As mentioned earlier, EPRI estimates that 30% of their residential customers use stand alone dehumidifiers.[1] With the doubled moisture removal capacity of their Cromer cycle air conditioner, these separate dehumidifiers would not be needed. The moisture could be handled by the air conditioner alone, and at much higher efficiency with a resulting energy saving.

Because desiccants attach and draw water from the air or anything that touches them, by their rapid wetting and drying, they have the property to kill bacteria and spores that get through the filter. Thus, the additional health benefit of some air disinfecting is provided.

The desiccant in the desiccant wheel does not wear out. There would typically be no maintenance required on the desiccant wheel for the life of the air conditioner system if filters are properly changed as needed. However, if a unit becomes clogged, it could be easily removed, blown clean or washed, and replaced without damage. The application is so simple, that training for HVAC professionals in installation and O & M of such equipment would be minimal.

When combined with a simple heat wheel working on make-up air as depicted in Figure 1, the Cromer cycle has the potential to meet the IAQ fresh air make-up air requirements of ASHRAE 62, while easily meeting the energy use guidelines of ASHRAE 90.1. By taking the return air designed to be expunged from the building from after the desiccant wheel as shown, in the cooling mode, the Cromer cycle effectively pumps moisture from the building at no additional energy cost. Because the air being expunged is cooler than the indoor condition (moisture evaporated into it), it provides greater heat transfer capacity to pre-cool the incoming fresh air than direct heat exchange with expunged return air. In the Cromer cycle application, the fresh air and expunged air heat transfer is best accomplished with a heat wheel - not an enthalpy wheel. In the Cromer cycle, the moisture content of the expunged air is high, almost always above that of the fresh air - even for hot humid climates. An enthalpy wheel used for this heat transfer function has the tendency to bring moisture that would have been expunged, back into the building. A simple heat transfer wheel is best in this use.

In an evaluation of the system provided in Figure 1, it should also be considered, that in winter under the heating mode, with the coil operating as a heating coil, the moisture transfer desiccant wheel of the Cromer cycle moves moisture in the opposite direction - from the return air to the supply air. It acts to reclaim moisture that would have been expunged but is now needed within the building for comfort conditions. The heat wheel of the application also improves efficiency by preheating fresh air with heat that would have been expunged.

The benefits of the Cromer cycle AC system are:

- Provides major moisture removal capacity increases for control of humidity and an improved healthy environment,
- Dry ducts - no more wet ducts and duct mold/mildew growth,
- Provides some air disinfecting,
- Reduces the need for additional stand-alone dehumidifiers,
- Saves a minimum of 10% on air conditioner energy use up to 40%,
- The higher the moisture load, the more energy is saved in the cooling mode,
- The technology is inexpensive with a typical, residential unit adding less than 10% to the cost,
- The application is simple requiring minimal training for HVAC professionals,
- With proper filter maintenance, no maintenance of the wheel is required.

CONCLUSION

Residential air conditioners use more than half of the electrical energy consumed by residences in the US and the air conditioning costs to commercial customers represents a large portion of their energy costs. A novel air conditioning cycle has been shown under laboratory conditions to double the moisture removal capacity and save over 16% in energy use. While in actual field installations, if this technology could save a target of 12% of air conditioning energy consumption while providing the same cooling, the customer would save significant energy costs with the additional benefit of dryer duct systems, less mold and mildew growth, and total independent control of the space humidity.

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