Active Desiccant, Total Energy Recovery Hybrid System Optimizes Humidity Control, IAQ, and Energy Efficiency in an Existing Dormitory Facility

John C. Fischer
Member ASHRAE

James R. Sand, Ph.D.
Member ASHRAE

Ben Elkin, P.E.
Member ASHRAE

Kirk Mescher, P.E.
Associate Member ASHRAE

ABSTRACT

This paper summarizes the investigation of an active desiccant, total energy recovery hybrid system pilot site installed during the fall of 1999. The hybrid system was assembled from a combination of commercially available air-handling modules, a standard total energy recovery module, and a customized active desiccant wheel cassette designed to integrate with these standard components. Significant performance advantages were recognized as a result of the combination of both "passive" and "active" desiccant technologies.

The dehumidification capacity of the hybrid system was shown to be very high, the cost of operation very low, and the overall system cost-effective. After two years of operation, the system has performed reliably and as anticipated. Most importantly, the system resolved numerous IAQ problems plaguing the dormitory facility by providing effective humidity control and increased, continuous ventilation air in accordance with ASHRAE Standard 62 recommendations.

The system was equipped with a direct digital control system, including full instrumentation, data trending, and remote monitoring capabilities. A detailed description of the system, installation details, samples of actual performance data, and documented energy savings are presented. The performance of the hybrid approach is compared with that of the original conventional cooling system serving an identical, opposite wing of the same facility.

INTRODUCTION

Mary Hall is a large dormitory situated on the campus of Berry College in Rome, Georgia. This historic stone building was constructed in the 1920s and, until recently, was operated without any air-conditioning. This was possible over the years due to the construction of the facility. Stone walls several feet thick and few windows to allow solar load provided an effective "passive" thermal storage facility. The building design did not, however, mitigate moisture infiltration. This resulted in high space humidity and an uncomfortable indoor environment, especially during humid outdoor conditions. When the building was renovated in 1992, cooling was added to the dormitory by way of central chiller feeding fan coil units installed in each dormitory room and the adjacent hallways. Because the building load profile had a low sensible to latent load ratio, the installed cooling system actually exacerbated further humidity control problems. It reduced the sensible load dramatically and quickly but left the latent load uncontrolled.

For several years, the college attempted to improve the conditions inside Mary Hall by dehumidifying the hallways with large electrical dehumidification units placed throughout the dormitory. Humidity control improved somewhat (from

Figure 1 *Photo of East Mary Hall, Berry College, Rome, Georgia.*

John Fischer is a technology consultant, SEMCO Inc., Columbia, Mo. **James R. Sand** is a research engineer, Oak Ridge National Laboratory, Oak Ridge, Tenn. **B. Elkin** is physical plant director, Berry College, Rome, Ga. **Kirk Mescher** is principal of CM Engineering, Columbia, Mo.

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80% to 90% relative humidity without the dehumidification units to 65% to 70%). This proved an ineffective solution since the dehumidification systems were noisy, creating a new set of complaints, and the cost of operation was extremely high.

An additional problem resulting from the age of the facility was that the original design did not provide for mechanical exhaust from the dormitory. Bathrooms located at the end of each hallway depended upon natural ventilation through airshafts vented at the roof of the building. No provisions for the delivery of outdoor air to the facility existed. Students would open the windows in an attempt to improve the indoor air quality. On humid days, this would create serious humidity problems, including condensation on cool building surfaces. With the windows closed, often the case during the heating season, the indoor air quality was very poor.

In September 1999, an active desiccant, total energy recovery hybrid system was installed to serve East Mary Hall. West Mary Hall, the mirror image of East Mary was connected to West Mary via a central foyer. This provided an excellent opportunity to quantify the impact of the desiccant hybrid system since both wings were identical with regard to size, occupancy, layout, and HVAC design. The only exception would be the installation of the desiccant hybrid system, ventilation air, and the removal of the industrial dehumidifiers from East Mary (the dehumidifiers remained in West Mary).

INSTALLATION DESCRIPTION

The total energy recovery module (Figure 2), standard air-handling unit modules, and the active desiccant wheel cassette (Figure 3) all needed to fit through a double-man door in the basement of the dormitory. The ventilation air supplied by the active desiccant, total energy recovery hybrid system was delivered to each individual dormitory room via a dedicated ductwork system, which involved drilling numerous holes through 20 in. of stone and concrete.

A chase that had previously served as a "natural ventilation" shaft serving the bathrooms located at the end of the hallway on each floor was capped at the roof and connected to the return air side of the total energy recovery module. This exhaust airstream allowed for preconditioning of the outdoor air prior to its delivery to the cooling coil and active desiccant wheel (Figure 4).

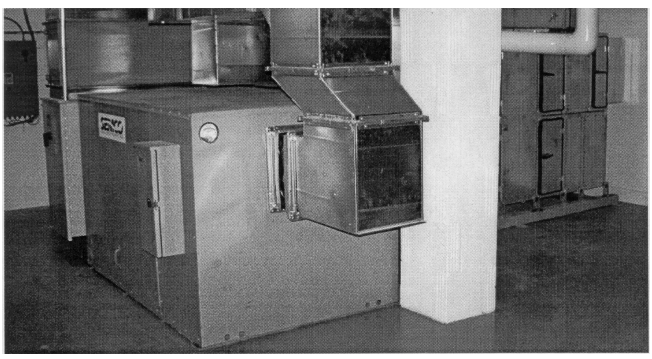

Figure 2 *Total energy recovery module installation with air-handling modules to the right of the column.*

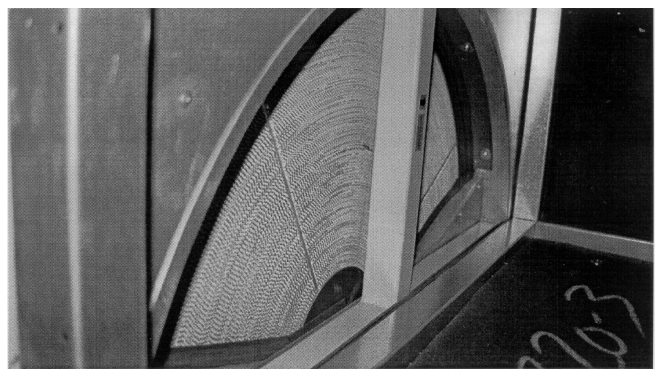

Figure 3 *Active desiccant wheel cassette designed to match the standard air-handling module dimensions.*

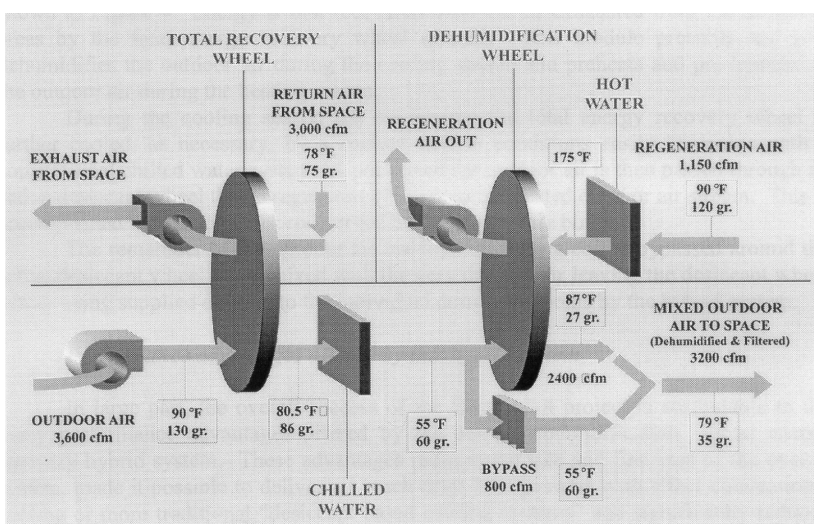

Figure 4 *Schematic of the active desiccant—total energy recovery hybrid system installed in East Mary.*

Raw outdoor air was used for the regeneration airstream, which was heated as necessary by a small hot water boiler installed on site as part of this project. A direct digital control package modulated all system components to maintain the desired space conditions while also serving a performance monitoring function since the data acquisition portion was accessible via modem.

SYSTEM DESCRIPTION AND SCHEMATIC

A schematic of the hybrid system installed in the dormitory at Berry College is shown in Figure 4. Energy is first recovered from the air exhausted from the bathroom areas by the total energy recovery wheel module. This module precools and predehumidifies the outdoor air during the cooling season and preheats and prehumidifies the outdoor air during the heating season.

During the cooling season the air leaving the total energy recovery wheel is further cooled, as necessary, by a cooling coil to conditions easily attainable with a conventional chilled water system. A portion of the outdoor air is then passed through an active desiccant wheel that is regenerated by a separate heated outdoor airstream. This is accomplished with a hot water coil served by a low-pressure boiler.

The remainder of the outdoor air leaving the cooling coil is bypassed around the active desiccant wheel and remixed with the very dry, hot air leaving the desiccant wheel before being supplied directly to the individual dormitory rooms by the hybrid system.

Performance Advantages Offered by this Hybrid System

In large part, the overall success of the Berry pilot project is attributable to the many performance advantages offered by the active dehumidification, total energy recovery hybrid system. These advantages reduced the size and first cost of the overall system, made it possible to deliver air much drier than possible with either conventional cooling or more traditional desiccant-based cooling systems, and significantly reduced the energy required to condition the dormitory facility.

Some of the more important advantages offered by the active desiccant, total energy recovery hybrid approach are summarized below.

a. Given that the total energy wheel removes a very significant amount of moisture from the outdoor air prior to the active desiccant wheel, the active wheel is utilized where it is most effective, delivering air drier than possible with conventional cooling. By removing this latent load from the active wheel, the wheel size can be reduced and it can process air at a higher velocity. This reduces the size and cost of the overall system.

b. Since the air entering the active dehumidification wheel is near saturation during the dehumidification mode, the performance of the active desiccant wheel is enhanced. This allows for the use of more moderate regeneration temperatures and allows for the omission of the problematic evaporative cooling section.

c. Since the total energy wheel and cooling coil deliver outdoor air to the active desiccant wheel that is cool and dehumidified, the hybrid system can deliver dehumidified outdoor air much drier and more efficiently than other active desiccant system approaches that do not incorporate the total recovery module.

d. Since the regeneration temperature used by the hybrid approach is moderate, since the active wheel processes fewer pounds of moisture, and since the air temperature entering the active desiccant wheel is low, the air temperature leaving the desiccant wheel is moderate even at peak dehumidification conditions. This allows the use of cool bypass air, around the active wheel, to deliver postcooling in lieu of an additional cooling coil. This further reduces the cost and size of the hybrid system.

e. The system provides a high degree of total energy recovery during the heating season (effectively preheating and prehumidifying the ventilation air), improving space comfort and significantly decreasing annual energy costs.

f. The use of the commercially available total energy recovery and air-handling modules allowed flexibility of installation, essential for this retrofit since it could be built up "on site" from individual pieces. It reduced the initial cost of the installation due to the competitive pricing associated with these components.

A direct digital control system modulates the chilled water valve and hot water regeneration valve to maintain the supply air conditions delivered by this hybrid system below 80 degrees and to whatever absolute humidity level is necessary to satisfy the specified space control setpoint.

A space relative humidity sensor and temperature sensor located in the hallway on the second floor of East Mary Hall was given a relative humidity setpoint of 50%. Since the dehumidified air was delivered directly to the individual dormitory rooms, the resulting absolute humidity level in the dormitory rooms was lower than that maintained in the hallways. By controlling the space humidity in the hallways at this level, the individual fan coil units, served by chilled water and located in each dormitory room, operated without condensation in most cases. By improving the humidity control in the occupied space and simplifying condensate management, numerous indoor air quality problems that had previously plagued this facility were eliminated. Past problems included mold, musty odors, damp walls and carpeting, and a general dissatisfaction with the perceived quality of the indoor air.

As shown by the actual performance data recorded for this project (see Figures 5, 6, and 8), this facility required very dry

air to maintain the humidity level desired in the hallway areas. This was due, in part, to significant infiltration into the facility, the fact that the entire latent load was being handled by a relatively small outdoor air volume, and that high humidity often exists in north Georgia.

As a result, this facility provided an excellent site for both highlighting and demonstrating the many advantages offered by an active desiccant, total energy recovery hybrid system preconditioning design approach.

CONTROLS, INSTRUMANTAION, AND DATA ACQUISITION

Controls

One of most innovative (and best) decisions made with regard to this pilot installation was to utilize the direct digital control system, developed to control the active desiccant, total enthalpy hybrid system and to also provide remote, real-time data acquisition and energy utilization monitoring. In short, it provided a "virtual laboratory" for observing and recording the overall performance of the desiccant hybrid system serving the East Mary wing of the dormitory. It also recorded conditions maintained within the West Mary wing served by the original conventional system and large industrial dehumidifiers, installed by Berry in an attempt to mitigate space humidity problems.

The hybrid system and two dormitories were fitted with approximately ten high-end RTD temperature sensors, eight high-end relative humidity sensors and various control valves, and start/stop signal inputs and outputs. The DDC controller was driven by a custom program module developed by the equipment supplier to monitor the building temperature and humidity, compare it against a user-specified input, then adjust modulating valves at the cooling coil and regeneration coil accordingly to reach setpoint.

Instrumentation

As shown by Figure 5, eighteen different sensors were utilized to monitor ten different state points within the East Mary Hybrid system and the two spaces monitored. The sensors used high-end RTD (±0.2°F) and resistance type relative humidity sensors (±2% RH) that performed very well with respect to reliability and accuracy over the two-plus years of operation. One advantage of the DDC software utilized is that the sensors were routinely compared against one another and a separate, well-calibrated instrument. The sensors could also be easily recalibrated remotely if necessary.

The airstream leaving the active desiccant wheel cannot be measured with a single-point sensor since a wide temperature and moisture gradient exists. To obtain accurate readings, the mixed supply airstream leaving the system (see Figure 5) was monitored in the duct downstream of a booster fan (not shown in Figure 5). Since the bypass air volume around and through the desiccant wheel is fixed, the average temperature and humidity conditions leaving the desiccant wheel were easily calculated using airflow ratios and the temperatures and humidities leaving the cooling coil and the mixed supply airstream. System airflow quantities were initially adjusted using a duct traverse, then monitored overtime by airflow stations integrated into the energy recovery module.

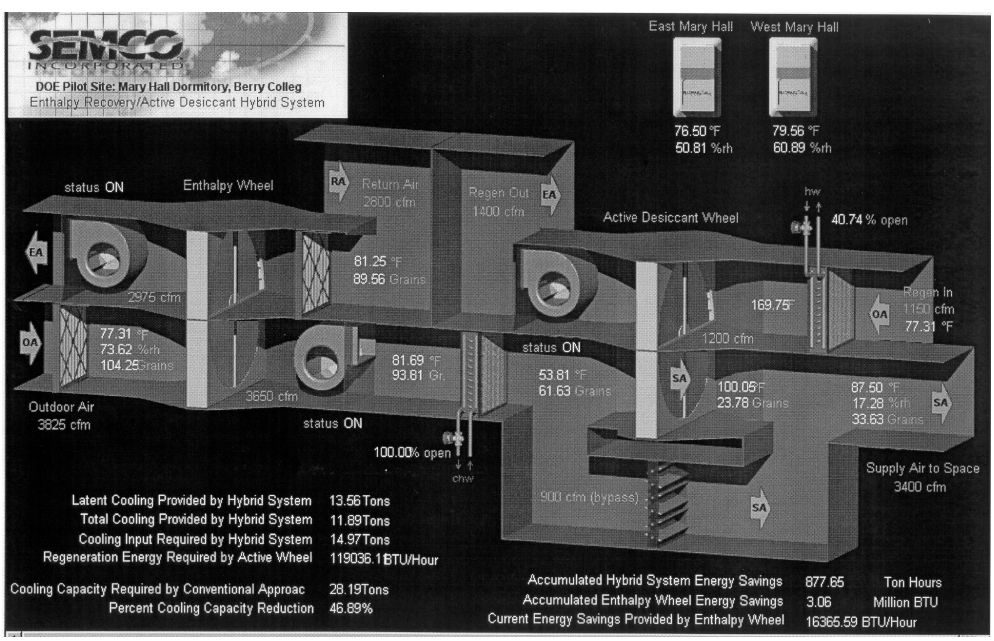

Figure 5 *Sample window showing the graphic flow schematic developed and used for the Berry pilot project. The flow schematic provides real-time conditions throughout the system and space, with real-time and accumulated energy savings reporting.*

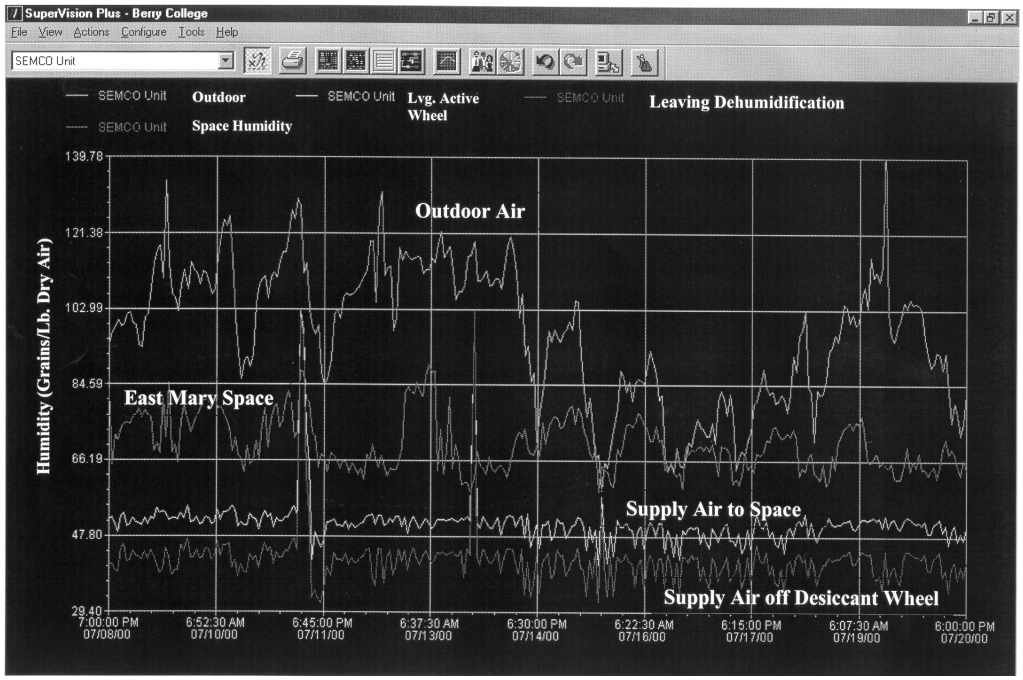

Figure 6 *Sample window showing the data acquisition and trending files set up and used for the Berry pilot project. Here the absolute humidity (grains) in the outdoor air leaving the active wheel, hybrid system, and occupied space are trended.*

Another significant advantage of the DDC system with remote monitoring is the graphics capabilities. Figure 5 shows a custom schematic diagram that was developed by the equipment supplier to show the function of the hybrid system. Customer feedback was extremely positive for this feature since this complex hybrid system, which was difficult to explain verbally or with sales literature, was easily understood by simply viewing this graphic presentation during actual operating conditions.

An energy comparison between the hybrid and a more conventional system was calculated and reported (see Figure 5) in addition to accumulated energy savings. This shows the user clear, instantaneous system benefits.

Data Acquisition

The performance data could be collected in three fashions. Instantaneous data could be recorded by downloading the system schematic showing live data (see Figure 5). The data for all of the selected state points were recorded and saved in the control module memory over an approximate one-month period (depending upon the frequency of sample collection). The third, and most effective, option used for this report preparation is the ability to trend the stored performance data (see Figure 6).

SYSTEM PERFORMANCE DATA

During the engineering phase of the East Mary pilot project, a performance analysis of the hybrid system was completed and presented in a schematic format, and it is included in this report as Figure 4. This schematic reflects the peak latent load within the East Mary facility, the peak outdoor air conditions for Rome, Georgia, along with the projected performance of the components within the desiccant hybrid system.

Figure 7 summarizes the performance advantage offered by the hybrid system over a conventional cooling system, based upon the initial design data shown in Figure 4. For this simple analysis it is assumed that the conventional system is operated to cool the outdoor air to 50°F (the lower limit possible with the 45°F chilled water available at Mary Hall) and then reheated to 70°F to avoid overcooling the individual dormitory rooms.

As shown in Figure 7, the primary advantage offered by the desiccant hybrid system is that it is capable of providing much drier outdoor ventilation air than is possible with the conventional approach (25°F dew point vs. a 50°F dew point). This is important for this application since the desire was to handle the entire space latent load with the relatively small outdoor airflow volume.

The other advantages offered by the hybrid system were greatly reduced chiller capacity requirements (11.4 vs. 38 tons), greater dehumidification capacity, reduced energy costs, and heating season preheat and free humidification. The drier air offered by the desiccant hybrid system allowed for the space latent load to be handled with less airflow, smaller ducts, and lower static pressure losses resulted.

After monitoring the system for more than two years it is clear that both the space latent load estimates and the outdoor air latent design conditions were often exceeded during actual operation. It is also clear from the monitored data that the desiccant hybrid system performed extremely well and that the conditions maintained in East Mary (served by the hybrid system) were much better than the conditions that existed in West Mary (served by the original conventional system), even with the hybrid system providing outdoor air on a continuous basis in accordance with ASHRAE Standard 62. The only outdoor air available for West Mary was through infiltration or opened windows.

Figure 5 shows a snapshot of hybrid system performance during a typical cooling season day. The performance monitored agrees well with that projected during the design phase of this pilot project.

Figure 6 summarizes the performance of the desiccant hybrid system over a period of two weeks during the most challenging humidity control period, during the summer months with a low occupancy period. Note that the outdoor air humidity content was as high as 140 grains of moisture per pound of dry air. Also note that the outdoor air volume needed to be dehumidified as low as 35 grains of moisture per pound of dry air in order to reach the desired control range of 50% to 55% relative humidity.

When viewing the data provided by Figure 6 it is important to note that while the control sensor was located in the hallway outside of the dormitory rooms, the dehumidified outdoor air was provided directly to the rooms. As a result the room humidity level was typically much lower than that maintained in the hallways. Also, the high humidity peaks recorded at times in the hallways, despite the very dry air delivered to the rooms, can be linked to windows and doors being left open by the building occupants and maintenance personnel and high shower activity in the common bathroom areas.

Figure 8 shows the hybrid system performance during start-up and highlights several very interesting findings. First, note the difference in humidity level made possible by the addition of the active desiccant portion of the hybrid system. With the cooling coil energized, air at a humidity level of approximately 50 grains could be delivered with the 43 degree chilled water available and the total energy wheel in operation. However, when the active desiccant wheel was operated for maximum dehumidification, supply air as dry as 20 grains of moisture per pound of dry air could be delivered.

Figure 9 shows actual performance data collected for the desiccant hybrid system during a typical heating season condition. As previously discussed, the desiccant hybrid system is a year-round technology (unlike the traditional DBC approach using outdoor air for regeneration) since the total energy wheel preheats and prehumidifies the outdoor air during the heating season.

A second interesting finding was the amount of time required for an initial dry-out of the East Mary facility. Figure 9 indicates that outdoor air provided at the 20 grain of moisture per pound of dry air level for approximately two days was required before the space could be brought under control. Once under control, the supply air humidity content was modulated between a high of 60 grains and a low of 20 grains of moisture per pound of dry air in order to maintain the space humidity setpoint condition.

COMPARING SPACE CONDITIONS AT EAST AND WEST MARY

Figures 10 and 11 highlight the performance advantages offered by the desiccant hybrid system preconditioning when compared to the conventional chilled water, fan coil system (original HVAC design for the East and West Mary facilities). Figure 10 shows the space humidity conditions that existed in the separate wings of Mary Hall during the low occupancy, humid summer semester. Note that the absolute humidity level in East Mary averaged approximately 70 grains (50% RH) on the more humid days while the humidity level in West Mary averaged approximately 90 grains and often exceeded 100

	Details Hybrid System	Details Conventional System (over-cool and reheat)
Total Cooling Provided (BTU/Hr)	244,736	238,848
Latent Cooling Provided (BTU/Hr)	206,720	169,728
Sensible Cooling Provided (BTU/Hr)	38,016	69,120
Cooling Energy Required (BTU/Hr)	136,800	302,400
Reheat Energy Required (BTU/Hr)	N/A	138,000
Regeneration Energy Rqd. (BTU/Hr)	105,550	N/A
Supply Dew Point Used for Analysis	39 Degrees F	50 degree F
Supply Low Dew Point Obtainable	25 Degrees F	50 degree F
Mechanical Cooling Required (Tons)	11.4	38*
Dehumidification Capacity (Lbs./Hr.)	195	160

Figure 7 *Initial performance comparison between the conventional and hybrid system. * Cooling tons required to deliver 195 pounds per hour of dehumidification capacity.*

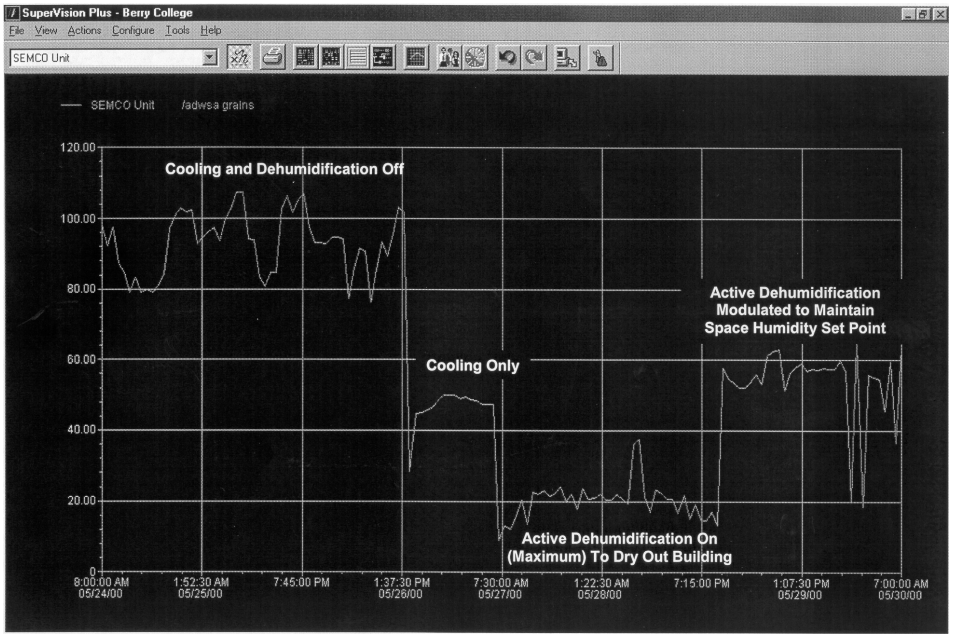

Figure 8 *Absolute humidity level delivered by the desiccant hybrid system at the time of initial start-up showing "building dry out" cycle and normal control modulation once building humidity level was obtained.*

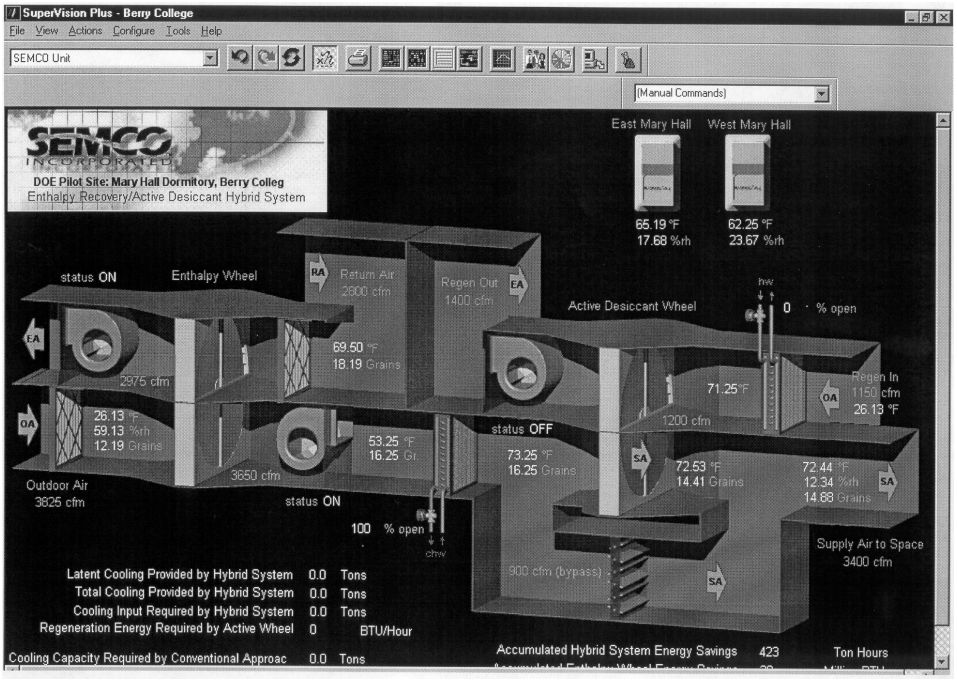

Figure 9 *Typical performance of desiccant hybrid system during the heating season. The system is a year-round technology (unlike the traditional DBC approach) since the total energy wheel preheats and prehumidifies the outdoor air.*

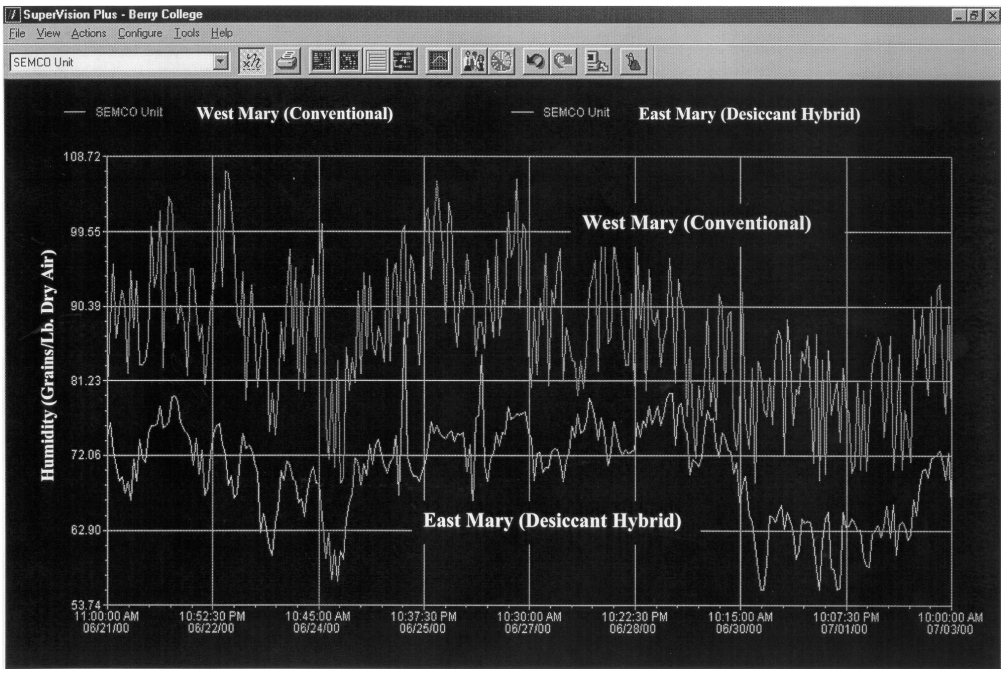

Figure 10 *Humidity data (grains) for East Mary (space 1) and West Mary (space 2). East Mary with desiccant hybrid/ continuous ventilation, West Mary with conventional cooling/no ventilation. On 6/29/00 East Mary was lowered from 60% to 50% RH.*

grains of moisture per pound of dry air (75% RH). As shown, a simple setpoint change made between June 30 and July 2 shows how even lower humidity levels could be easily maintained by the hybrid system.

Figure 11 shows the impact on the conventional cooling system when the building latent load is removed. It is clearly shown that the same chilled water/fan coil cooling system located in West Mary cycles far more often in an attempt to reach setpoint than does the same system in the dehumidified East Mary wing. This decreases the comfort level of the West Mary wing occupants and increases energy consumption.

Given that the latent load is removed from the fan coil units in East Mary, cooler air can be delivered, which not only reduces cycle time but also results in a more comfortable space temperature without the wide temperature swings evident in West Mary that are shown in Figure 11. Once again, it is important to point out that the comparisons presented in these figures were all based on the East Mary facility being well ventilated, on a continuous basis, while the West Mary facility was operated without any mechanical ventilation.

One of the most valuable benefits recognized from decoupling the latent load from the fan coil units is that condensate produced at the individual fan coil units is virtually eliminated from the East Mary wing. Managing the condensate over the years has caused numerous, significant maintenance and housekeeping problems.

The improved humidity control, temperature control, and increased, continuous ventilation significantly enhanced the indoor air quality at East Mary Hall. For example, the Director of facilities for Berry College commented that before the retrofit with the hybrid system, "Mary Hall was plagued with odors associated with mold and mildew." He later commented that "after the retrofit we finally gained control of the humidity in East Mary. During setup, we drove the dew-point down to 26°F. The odors are gone and humidity spikes no longer affect the building's comfort zone."

ENERGY SAVINGS

The direct digital control and instrumentation package installed on this project offered an additional benefit – the ability to measure instantaneous energy savings compared to a more conventional overcooling and reheat approach.

Approximately 90,000 ton-hours were saved by the hybrid system over a one-year time frame, when compared to a conventional cooling system that would have to deliver approximately 40% more air to reach a similar level of dehumidification (pounds of moisture removal). The total energy wheel saved approximately 360,000,000 Btu of heating and humidification energy during the heating season. The energy required for regeneration of the active dehumidification wheel was offset by the energy that would have been required to reheat the air leaving the cooling coil of the conventional approach (since this air is delivered directly to the occupied space).

Using the energy costs typical for the Atlanta area, Berry College recognized approximately $7,000 in energy savings due to the 3,400 scfm hybrid system. This does not take into account the additional savings that result from the reduction in

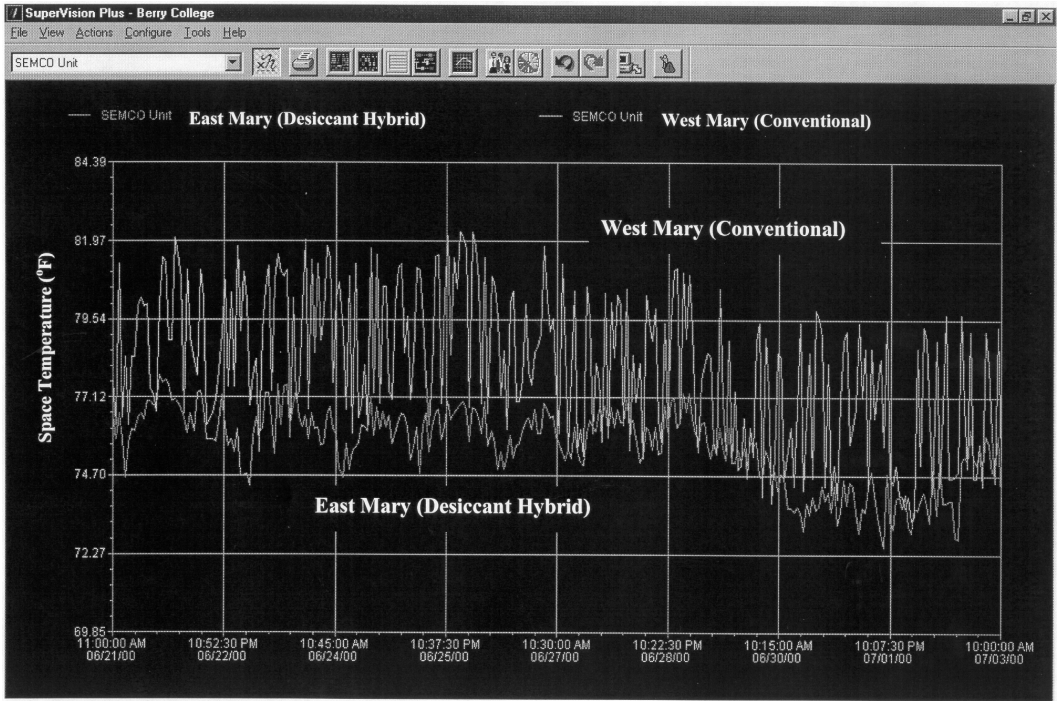

Figure 11 *Temperature data for East Mary and West Mary Dormitory. East Mary with desiccant hybrid/continuous ventilation, West Mary with conventional cooling/no ventilation. Note advantages of hybrid system, reduced run time, better temperature control.*

chilled water used by the individual fan coil units located throughout East Mary. This energy consumption was not measured but is conservatively estimated at an additional $3,000 per year. Based on these energy savings estimates, the payback for the retrofit installation at East Mary would be approximately five years.

However, the most significant benefits provided to the facility, according to the Director of Facilities, are not related to energy savings. The effective reductions in space humidity and the associated odor, maintenance, and indoor air quality problems have more than justified the desiccant hybrid retrofit.

CONCLUSIONS

The pilot installation at the East Mary Hall has been extremely successful. The performance has been as desired and the reliability has been excellent. The addition of the hybrid system has significantly reduced the chilled water consumption while, at the same time, providing mechanical ventilation to the occupied space for the first time. The system also allowed the removal of eight large, electrically driven industrial dehumidifiers from East Mary while simultaneously improving the humidity control within the space.

Both the monitored performance and feedback from the building occupants have confirmed that the benefits offered by the new active desiccant, total energy recovery hybrid system have been significant. The indoor air quality complaints once commonplace are now gone. Space comfort has improved and energy consumption has been reduced. Maintenance costs have also been impacted significantly with benefits ranging from fewer plugged and leaking drain pains to fewer hours required for interior painting.

An unexpected benefit associated with the installation was that enough chilled water demand was removed from the East Mary wing by the hybrid system to allow the chiller serving Mary Hall facility to condition a second large facility as well.