ORNL/SUB/94-SV044/3Report

FIELD DEMONSTRATION OF ACTIVE DESICCANT-BASED OUTDOOR AIR PRECONDITIONING SYSTEMS

Final Report: Phase 3

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ABSTRACT

This report summarizes an investigation of the performance of two active desiccant cooling systems that were installed as pilot systems in two locations—a college dormitory and a research laboratory—during the fall of 1999. The laboratory system was assembled in the field from commercially available Trane air-handling modules combined with a standard total energy recovery module and a customized active desiccant wheel, both produced by SEMCO. The dormitory system was a factory-built, integrated system produced by SEMCO that included both active desiccant and sensible-only recovery wheels, a direct-fired gas regeneration section, and a pre-piped Trane heat pump condensing section.

Both systems were equipped with direct digital control systems, complete with full instrumentation and remote monitoring capabilities. This report includes detailed descriptions of these two systems, installation details, samples of actual performance, and estimations of the energy savings realized. These pilot sites represent a continuation of previous active desiccant product development research (Fischer, Hallstrom, and Sand 2000; Fischer 2000).

Both systems performed as anticipated, were reliable, and required minimal maintenance. The dehumidification/total-energy-recovery hybrid approach was particularly effective in all respects. System performance showed remarkable improvement in latent load handling capability and operating efficiency compared with the original conventional cooling system and with the conventional system that remained in another, identical wing of the facility.

The dehumidification capacity of the pilot systems was very high, the cost of operation was very low, and the system was cost-effective, offering a simple payback for these retrofit installations of approximately 5 to 6 years. Most important, the dormitory system resolved numerous indoor air quality problems in the dormitory by providing effective humidity control and increased, continuous ventilation air.

1. INTRODUCTION: ACTIVE DESICCANT SYSTEMS PILOT SITE INVESTIGATION

This report summarizes an investigation of the performance of two active desiccant cooling systems that were installed as pilot systems in two locations—a college dormitory and a research laboratory—during the fall of 1999. The laboratory system was assembled in the field from commercially available Trane air-handling modules combined with a standard total energy recovery module and a customized active desiccant wheel, both produced by SEMCO. The dormitory system was a factory-built, integrated system produced by SEMCO that included both active desiccant and sensible-only recovery wheels, a direct-fired gas regeneration section, and a pre-piped Trane heat pump condensing section.

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Phase 1 work, summarized in the ORNL/SUB/94-SV004/1 (Fischer, Hallstrom, and Sand 2000), is a desiccant work report analysis. These market studies concluded, among other findings, that a significant market opportunity exists for active desiccant systems in certain target markets, such as research laboratories and dormitory facilities.

Phase 2 work is summarized in ORNL/SUB/94-SV044/2 (Fischer 2000). It concludes that most opportunities for active desiccant systems could be effectively met with three system designs: desiccant-based cooling (DBC), dehumidification/total recovery hybrid, and dehumidification only (a subset of the dehumidification/total energy recovery hybrid approach).

The Phase 2 report also concluded that cost-effective active desiccant systems could be produced from readily available standardized modules currently produced by the major manufacturers of heating, ventilating, and air-conditioning (HVAC) systems, such as the Climate Changer® modules marketed by the Trane Company. To do so would require some modifications to the existing product offerings and some customized modules, such as the desiccant wheels and regeneration options.

As a logical continuation of this earlier work, two pilot sites were selected for field testing of prototype active desiccant systems based upon the DBC and dehumidification/total energy recovery hybrid designs. Part of the latter system included the dehumidification-only module. These sites involved a research laboratory and a college dormitory. The college dormitory project was completed using the dehumidification/total energy recovery hybrid system approach, and a DBC system was installed in the research laboratory.

The dormitory selected is located on the campus of Berry College in Rome, Georgia. This project involved installing the desiccant hybrid system in the basement area of a three-story building. Core drilling of 20-in. concrete slabs was necessary to provide ductwork for outdoor air distribution to several first- and second-story dormitory rooms. Standard Climate Changer modules, a standard SEMCO total energy recovery module, and a customized active desiccant wheel module manufactured by SEMCO were used for this project. A customized DDC package was provided to control all of the components provided with the system and provide continuous, remote monitoring and data acquisition for the site.

The research laboratory selected is on the campus of Georgia Tech University in downtown Atlanta. The project involved installing an integrated DBC system complete with active desiccant dehumidification and sensible-recovery wheels, a factory-installed heat pump section, a direct-fired gas regeneration section with full gas piping, and a controls/instrumentation package. The integrated system and all components were manufactured by SEMCO, with the exception of the Trane heat pump condensing unit. Since this system was roof-mounted and direct-fired gas regeneration was required, the Climate Changer modules were not an option for this site.

2. BACKGROUND: PILOT SITE AND DESICCANT SYSTEM DESCRIPTION

2.1 PILOT SITES SELECTED

College Dormitory—East Mary Hall

Mary Hall is a large dormitory situated on the campus of Berry College in Rome, Georgia (Fig. 1). This historic stone building was constructed in the 1920s and, until recently, had no air-conditioning. The way the building was constructed allowed it to stay reasonably cool during hot weather: stone walls several feet thick with few windows to allow a solar load provided an effective "passive" thermal storage facility. However, the construction did not mitigate moisture infiltration. The result was high humidity and an uncomfortable indoor environment, especially during humid outdoor conditions. When the building was renovated in 1992, a cooling system was installed, consisting of a central chiller that fed fan coil units installed in each dormitory room and the adjacent hallways. However, because the building had a low sensible-to-latent load ratio, the installed cooling system exacerbated numerous humidity control problems. It reduced the sensible load dramatically and quickly, but it left the latent load uncontrolled.

Fig.1. East Mary Hall at Berry College in Rome, Georgia.

The college attempted to improve conditions inside Mary Hall by dehumidifying the hallways with large electrical dehumidification units placed throughout the dormitory. Humidity control improved somewhat [from a typical 90% relative humidity (RH) without the dehumidification units to approximately 65% RH]. The dehumidifiers were noisy, creating a new set of complaints, and the cost of operating them 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 outdoor air was delivered to the facility. Students would open the windows in an attempt to improve the indoor air quality, creating serious humidity problems, including condensation on cool building surfaces, on humid days. If the windows were closed, which was 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, a mirror image of East Mary, connects to it via a central foyer. The existing chiller/fan coil air-conditioning system was left in place in West Mary. This arrangement provided an excellent opportunity to quantify the impact of the desiccant hybrid system installed in East Mary, since East and West Mary are identical with regard to size, occupancy, layout and HVAC design. Note that during the installation of the desiccant hybrid system and a ventilation air distribution system in East Mary, the industrial dehumidifiers were removed. The dehumidifiers remained in West Mary.

The active desiccant/total energy recovery hybrid system was installed in the basement of East Mary Hall. It combined a standard total energy recovery (FV-5000) module produced by SEMCO, a custom active desiccant wheel module also produced by SEMCO, and standard Climate Changer modules purchased from the Trane Company.

Research Laboratory—Baker Building, Georgia Tech Research Institute

The Baker Research Building houses the Georgia Tech Environmental Monitoring Branch, one of the most respected indoor air quality research groups in the country. This building was originally designed with a ventilation system that supplied approximately 50% outdoor air to make up for exhaust from the many laboratory fume hoods in the facility. The remaining airflow was returned through a common grill located at the end of each hallway in this four-story building. As a result, indoor contaminants from individual labs could be mixed together by the central air-handling unit and distributed to every other laboratory. Because of the sophisticated instrumentation (highly sensitive mass spectrometers) used for indoor air quality research, a clean environment free from external contaminants, with effective temperature and humidity control, was desired for the labs served by the pilot/prototype system.

To isolate the indoor air quality laboratory from the contaminants present in other parts of the building, it would be necessary for that laboratory to have its own outdoor air system and to be pressurized relative to the rest of the building. Since the outdoor air preconditioning system would have to be located on the roof of the building, another problem arose. Approximately 30 fume hood exhaust fans are located on the roof of the building. This arrangement, which is very common for chemical research facilities, would add to the concentration of contaminants re-entrained into the outdoor air feeding the laboratory.

Therefore, this application needed a system to provide 100% outdoor air to the laboratory while controlling temperature and humidity. It also needed to effectively filter particulates from the outdoor air and, ideally, to reduce the level of airborne gaseous contaminants as well. No suitable exhaust air path existed at this facility to allow for energy recovery, so the cost of preconditioning the outdoor air required by this facility for 24 hours per day would be high. The chilled water cooling equipment serving the current central system was fully utilized.

To meet these needs, a system was designed for the Baker Building that used a DBC configuration, combining an active desiccant wheel to dehumidify the ventilation air with an epoxy-coated sensible-only energy wheel to both cool the air leaving the desiccant wheel and preheat the outdoor air used for regeneration (Fig. 2). The outdoor air inlet for this system was isolated as much as possible from the potential sources of contamination that exhaust to the roof. The system included an integral heat pump condensing section to provide the final post-cooling. It also provided heating during the heating season. The system did not use an evaporative cooling section because of maintenance concerns.

Since the equipment needed to be mounted on the roof, and external static pressure requirements were high, Climate Changer modules could not be used. SEMCO produced the entire system for this installation, including the integration of a Trane heat pump, all electrical components, and controls.

2.2 ACTIVE DESICCANT SYSTEMS SELECTED FOR FIELD INVESTIGATION

The Phase 2 report (Fischer 2000) completed as part of the work that preceded this pilot site investigation, concluded that the needs of the most attractive markets for active desiccant systems could be met with three system configurations: (1) traditional DBC systems, (2) desiccant dehumidification/total energy recovery hybrid systems, and (3) dehumidification-only systems (a subset of hybrid desiccant dehumidification systems).

The pilot sites described in Sect. 2.1 were selected to demonstrate the advantages of each of these technologies. Since the "back half" of the desiccant dehumidification/total energy recovery

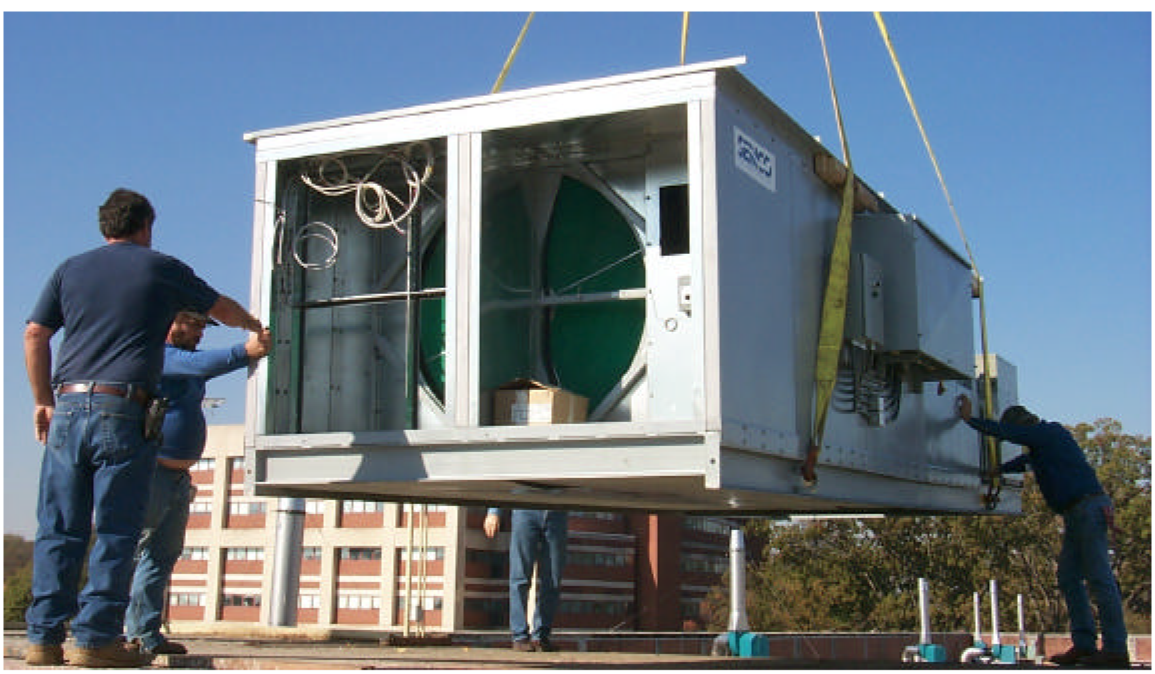

Fig. 2. The roof of the Baker Research Building and the active desiccant system.

hybrid system is identical to the dehumidification-only system, all three approaches were highlighted in the systems at the two pilot sites.

The Berry College dormitory, East Mary Hall, required very dry air to handle the significant internal latent load with a limited supply of outdoor air. This project also provided an exhaust air stream from each of the bathroom areas, allowing for effective total energy recovery. As a result, this site was adequately and effectively served by a desiccant dehumidification/total energy recovery hybrid system.

The Georgia Tech research facility, the Baker Building, did not allow access to an exhaust air path for total energy recovery; therefore, the traditional DBC system was applied along with conventional post-cooling provided by a heat pump condensing section integral to the DBC system. The heat pump section was used to provide post-cooling of air coming from the active desiccant section and preheating of the outdoor air during winter operation.

A complete description follows of each of these system approaches.

Active Desiccant-Based Cooling System

The DBC system uses an active desiccant dehumidification wheel that produces warm, dry air. A sensible-only energy recovery wheel (or a plate-type or heat-pipe exchanger) cools the dehumidified outdoor air. The temperature prior to post-cooling is often about the same as the temperature of the outdoor air. In many cases, this system approach will also use an indirect evaporative cooling section positioned in the regeneration inlet air stream to help reduce the post-cooling load (see Fig. 3).

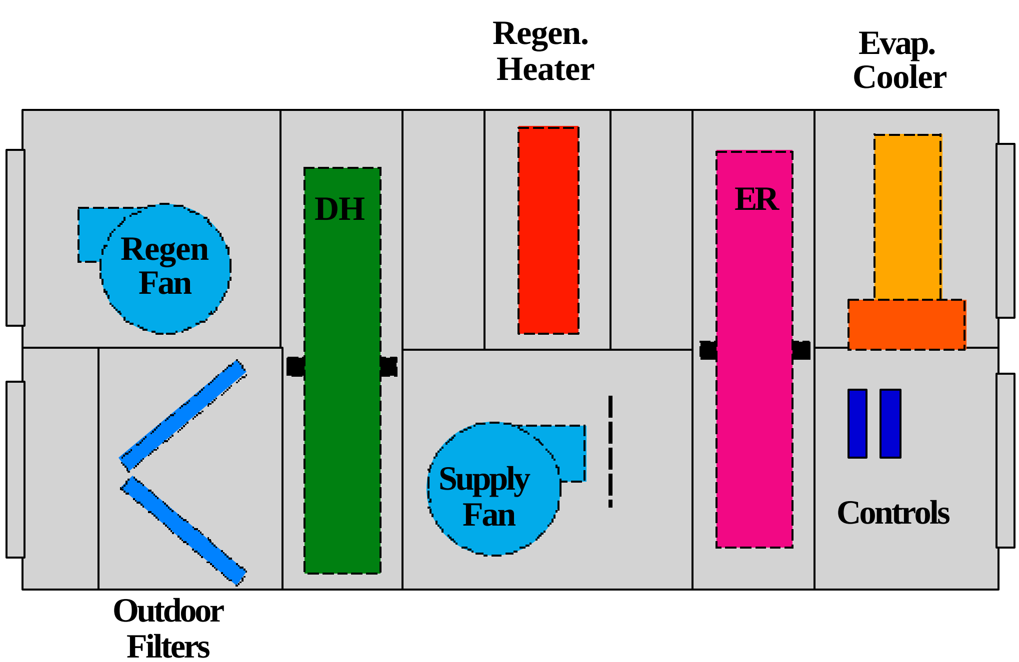

Fig. 3. Typical desiccant-based cooling system approach.

This approach is best suited for applications where an exhaust air path is not available for total energy recovery. If an exhaust air path is available, the desiccant dehumidification/total energy recovery approach or other passive energy recovery options will likely be far more efficient and often less costly. As a result, during the heating season, a DBC unit is generally deactivated, although sensible recovery is an option if an exhaust air path is used for regeneration.

Active Dehumidification/Total Energy Recovery Hybrid System

The active desiccant/total energy recovery system combines an active desiccant dehumidification wheel and a passive total energy recovery wheel to provide much lower humidity levels more efficiently than is possible with the traditional DBC approach (see Fig. 4). This approach requires a return air path (building exhaust) for the total energy recovery wheel, while the traditional DBC approach is typically applied without the need for a return air path.

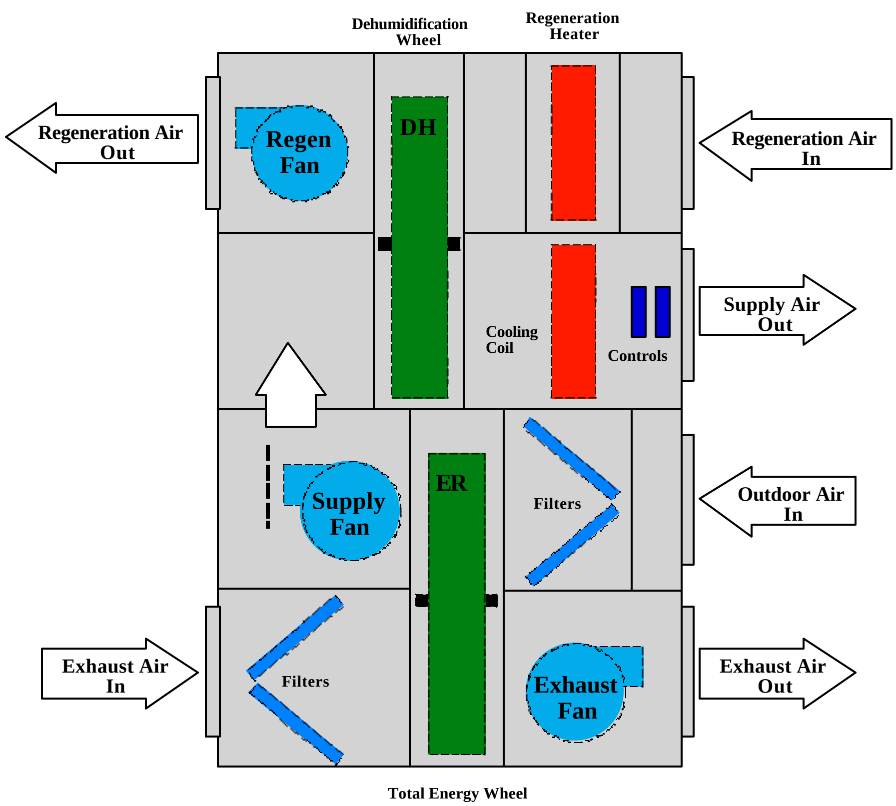

Fig. 4. Active dehumidification/total energy recovery hybrid system approach.

A significant benefit of the active dehumidification/total recovery hybrid approach is that it provides total energy recovery during the heating season, which significantly reduces the payback period. It also eliminates the need for the evaporative cooler that is used in the traditional DBC approach. Evaporative cooling is often viewed as a negative because of the maintenance the coolers require and because of the microbial activity and odors sometimes linked to these devices.

The total energy wheel used in the active desiccant/total energy recovery hybrid system approach effectively reduces the humidity level entering the active desiccant wheel. Three significant performance advantages result from that arrangement. First, much drier air can be delivered to the space. Second, a much smaller active desiccant wheel can be used because a portion of the supply air can be bypassed around the wheel. Finally, since there is typically less load on the active desiccant wheel, far more moderate regeneration temperatures can be used than with other active desiccant system approaches.

3. RESULTS: EAST MARY HALL DORMITORY INVESTIGATION

3.1 INSTALLATION DESCRIPTION

The SEMCO FV total energy recovery module (Fig. 5), the active desiccant wheel module (Fig. 6), and the individual Climate Changer modules (Fig. 7) all needed to fit through a normal double door in the basement of the dormitory. The ventilation air supplied by the active desiccant/total energy recovery hybrid system is delivered to each individual dormitory room via a dedicated ductwork system, an arrangement that involved drilling numerous holes through 20 in. of stone and concrete.

A chase that had served as a "natural ventilation" shaft was capped at the roof of the building and connected to the return air side of the total energy recovery module. This air stream preconditions the outdoor air prior to its delivery to the cooling coil and active desiccant wheel and is then exhausted from the basement area.

Outdoor air is also used for the regeneration air stream, which is heated as necessary by a hot water boiler also installed on site as part of this pilot installation. A DDC system modulates all system components to maintain the desired space conditions. It allows remote monitoring of performance, since the data acquisition portion is accessible via modem. SEMCO provided a central control panel including the DDC, motor starters, and variable-speed frequency inverter for the desiccant wheel.

Fig. 5. The SEMCO FV total energy recovery module installation. Note active desiccant system with Climate Changer modules is shown to the right of the FV unit.

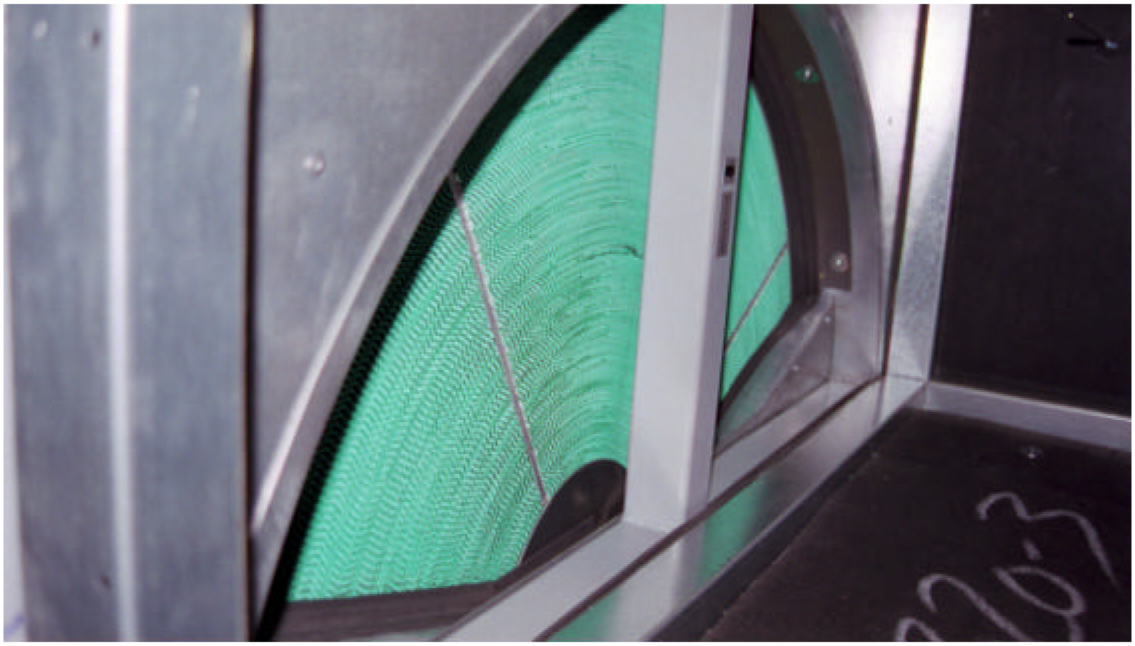

Fig. 6. SEMCO active desiccant wheel designed for the Climate Changer modules.

Fig. 7. Active desiccant system in the basement of Mary Hall showing standard Climate Changer modules attached to the SEMCO active desiccant wheel cassette.

3.2 SYSTEM DESCRIPTION AND SCHEMATIC

A schematic of the hybrid system installed in the dormitory at Berry College is shown in Fig. 8. Energy is first recovered from the air exhausted from the bathroom areas by the total energy recovery wheel module. This module precools and pre-dehumidifies the outdoor air during the cooling season and preheats and pre-humidifies 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 provide conditions easily attainable with a conventional chilled water system. Part of this outdoor air is then passed through an active desiccant wheel that is regenerated by a separate outdoor air stream heated, as necessary, with a hot water coil served by a low-pressure boiler.

The remainder of the outdoor air leaving the cooling coil bypasses the active desiccant wheel and remixes with the very dry, hot air leaving the desiccant wheel. The air is then supplied directly to the individual dormitory rooms by the hybrid system.

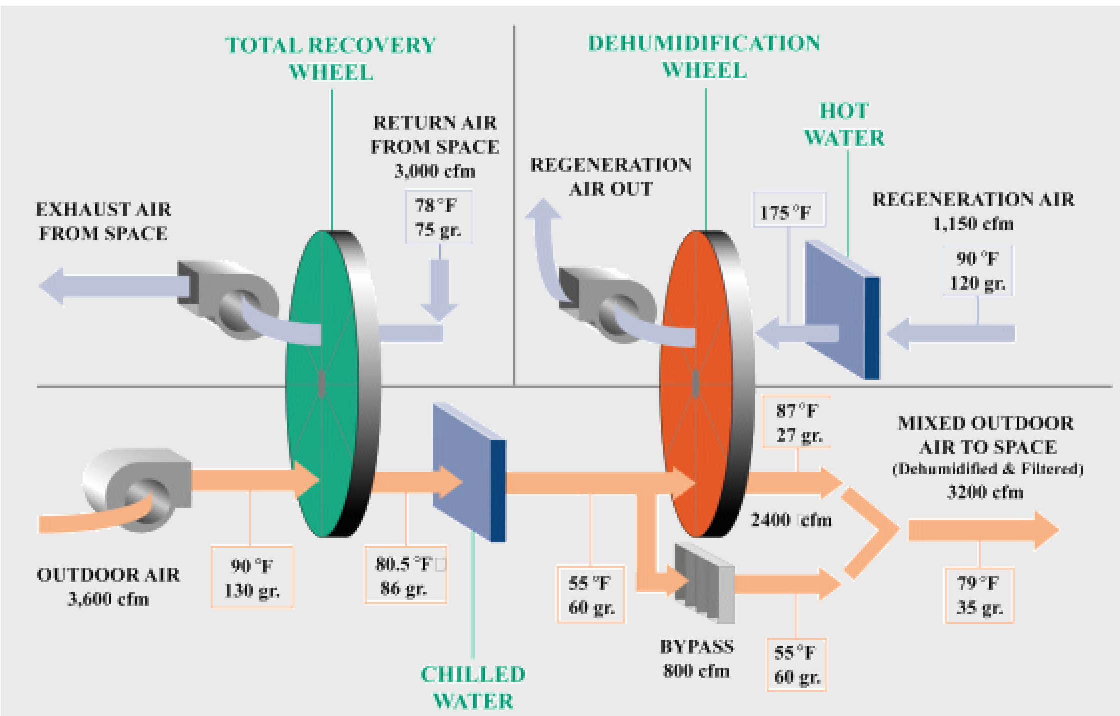

Fig. 8. Schematic of the active desiccant/total energy recovery hybrid system installed in the dormitory at Berry College at peak load and conditions.

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 much drier air than was possible with either conventional cooling or the traditional DBC approach, and significantly reduced the amount of energy required to condition the dormitory.

Some of these performance advantages have already been discussed in Sect. 2.2. The more important advantages offered by the hybrid approach are summarized in the following paragraphs.

Given that the total energy wheel removes a significant amount of moisture from the outdoor air before it enters the active desiccant wheel, the active wheel is used in the way it is most effective: delivering drier air than is possible with conventional cooling. Because much of the latent load is removed from the active wheel, the size of the active wheel can be reduced and it can process air at a higher velocity, making it possible to reduce the size and cost of the overall system.

The chilled water coil shown in Fig. 8 ensures that the air entering the active dehumidification wheel is near saturation during dehumidification mode. This arrangement enhances the performance of the active desiccant wheel. It allows the use of more moderate regeneration temperatures, so the problematic evaporative cooling section is not needed.

The total energy wheel and the cooling coil deliver outdoor air to the active desiccant wheel that is already cool and dehumidified. Thus the hybrid system produces dehumidified outdoor air that is much drier, and delivers it more efficiently, than other active desiccant system approaches (i.e., DBC).

Because the regeneration temperature used by the hybrid approach is moderate, because the active wheel processes fewer pounds of moisture, and because the air temperature entering the active desiccant wheel is low, the temperature of the air leaving the desiccant wheel is moderate even at peak dehumidification conditions. Cool air can bypass the active wheel and deliver post-cooling in lieu of an additional cooling coil. This arrangement further reduces the cost and size of the hybrid system.

The system provides a high degree of total energy recovery during the heating season. It effectively preheats and pre-humidifies the ventilation air, improving space comfort and significantly decreasing annual energy costs.

The use of the commercially available total energy recovery and air handling modules allowed flexibility of installation for this Berry retrofit because the system could be built up on the site from individual pieces. The competitive pricing of these components reduced the initial cost of the installation.

A DDC system (which also served as the data acquisition system for this investigation) modulates the chilled-water valve and hot-water regeneration valve to maintain the supply air conditions from this hybrid system at below 80EF and at 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 an RH setpoint of 50%. Since the dehumidified air was delivered directly to the dormitory rooms and not to the hallways, the humidity level in the rooms was lower than that in the hallways. It was determined that maintaining the space humidity in the hallways at the 50% RH level would allow the individual fan coil units, served by chilled water and located in each dormitory room, to operate without condensation in most cases. The 50% RH level was maintained easily with the ventilation air pretreatment system, resolving numerous indoor air quality problems that had previously plagued this facility.

Actual performance data recorded for this project showed that this facility required very dry air to maintain the humidity level desired in the hallway areas (Figs. 9–11). This situation was due, in part, to significant infiltration into the facility. Because the entire latent load was being handled by a relatively small volumetric flow rate of outdoor air, and because high humidity levels are common in the north Georgia climate, the equipment had to dehumidify the ventilation air to very low levels. These characteristics made this facility an excellent site for demonstrating the advantages offered by an active desiccant/total energy recovery hybrid system.

3.3 CONTROLS, INSTRUMENTATION AND DATA ACQUISITION

Controls

In this pilot installation, the DDC system was developed to control the active desiccant/total enthalpy hybrid system. One of most innovative (and best) decisions made in this project was also to use the DDC system to acquire remote, real-time data and monitor energy utilization. In short, the monitoring 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 RTD temperature sensors, eight highly accurate RH sensors, and various control valves and start/stop signal inputs and outputs. The direct digital controller was driven by a custom program module developed by SEMCO 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.

The custom program is built from a combination of standard control blocks and custom-built macros. A sample portion of the control program screen used for Mary Hall is shown in Fig. 12. The programmable microblock symbols shown in Fig. 12 represent devices commonly used in conventional control systems. The programmer can drag and drop graphical microblocks to create a sequence of control operations and system output values for the equipment via a programmable microprocessor that is part of the DDC package from this vendor. This graphical programming eliminates the need for complex programming or cryptic line-by-line computer code. A powerful library of color-coded microblocks is available that provides the flexibility to develop simple yet sophisticated control sequences with full simulation capability.

The upper section shown in Fig. 12 controls the space dewpoint setpoint to 55EF by activating and deactivating the desiccant wheel, controlling the hot water flow that reactivates the desiccant wheel (reactivation temperature), and controlling the flow rate of chilled water to the cooling coil. Note that all of these controls work to keep the temperature of the supply air to the space below 80EF.

Calculation blocks for converting dry bulb temperatures and relative humidity readings to absolute humidity values are shown in the lower section of Fig. 12.

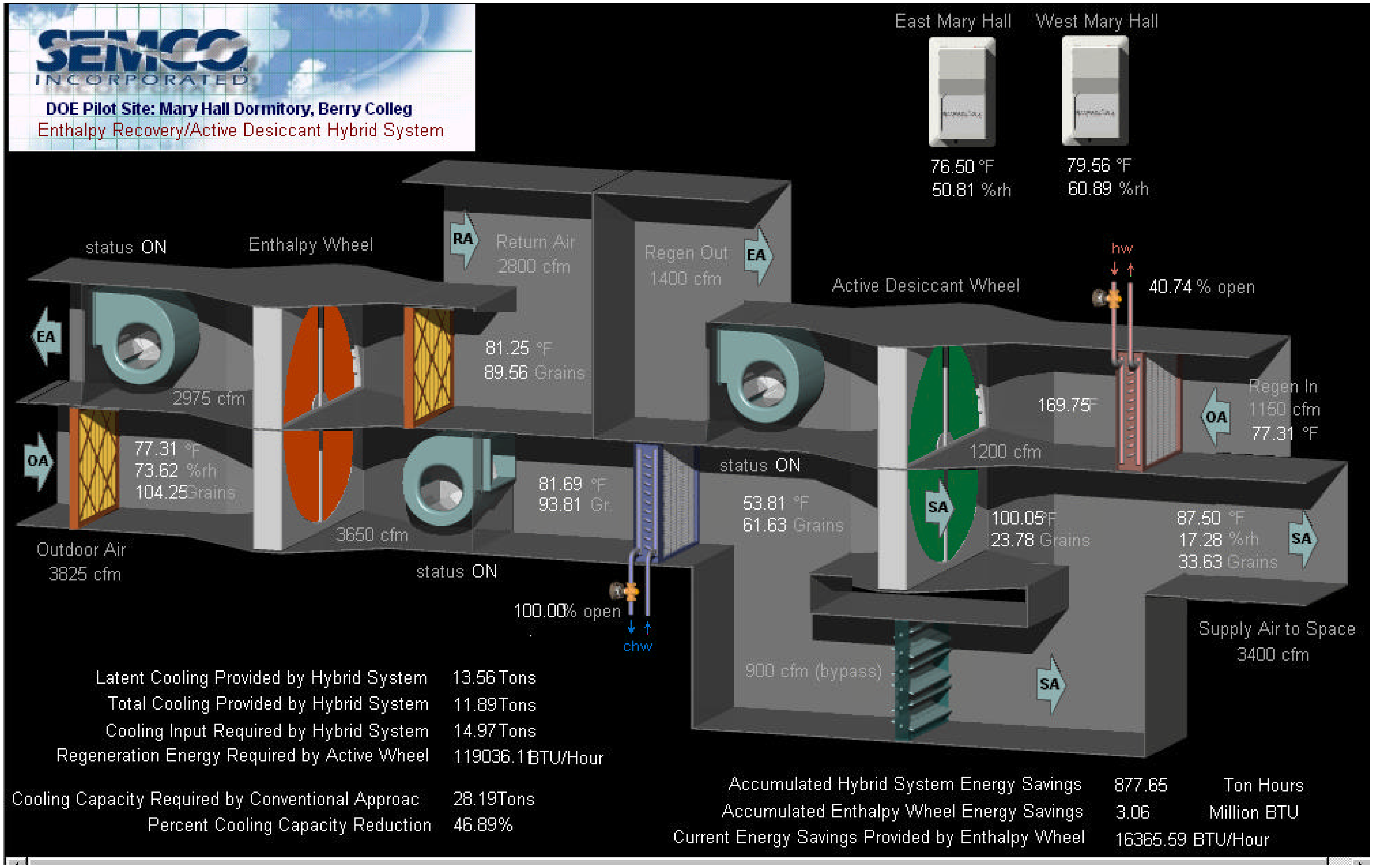

Fig. 9. Sample window showing the graphic flow schematic developed by SEMCO and used for the Berry pilot project. The flow schematic provides real-time conditions throughout the system and space, with real-time and accumulated energy savings reporting at typical, off-peak condition.

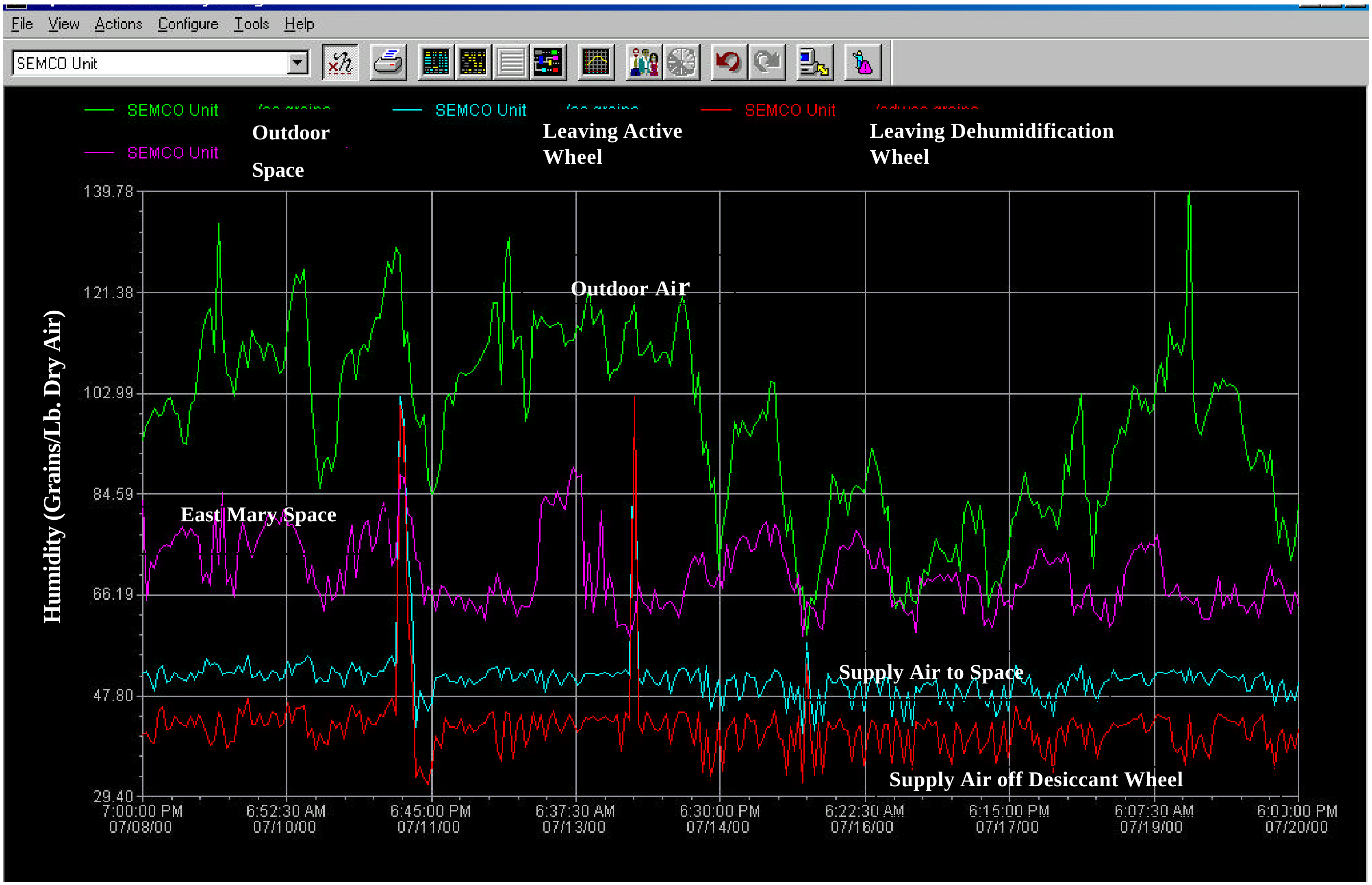

Fig. 10. Sample window showing the data acquisition and trending files set up by SEMCO and used for the Berry pilot project. Here the absolute humidity (grains) in the outdoor air—leaving the active wheel, hybrid system, and occupied space—are trended.

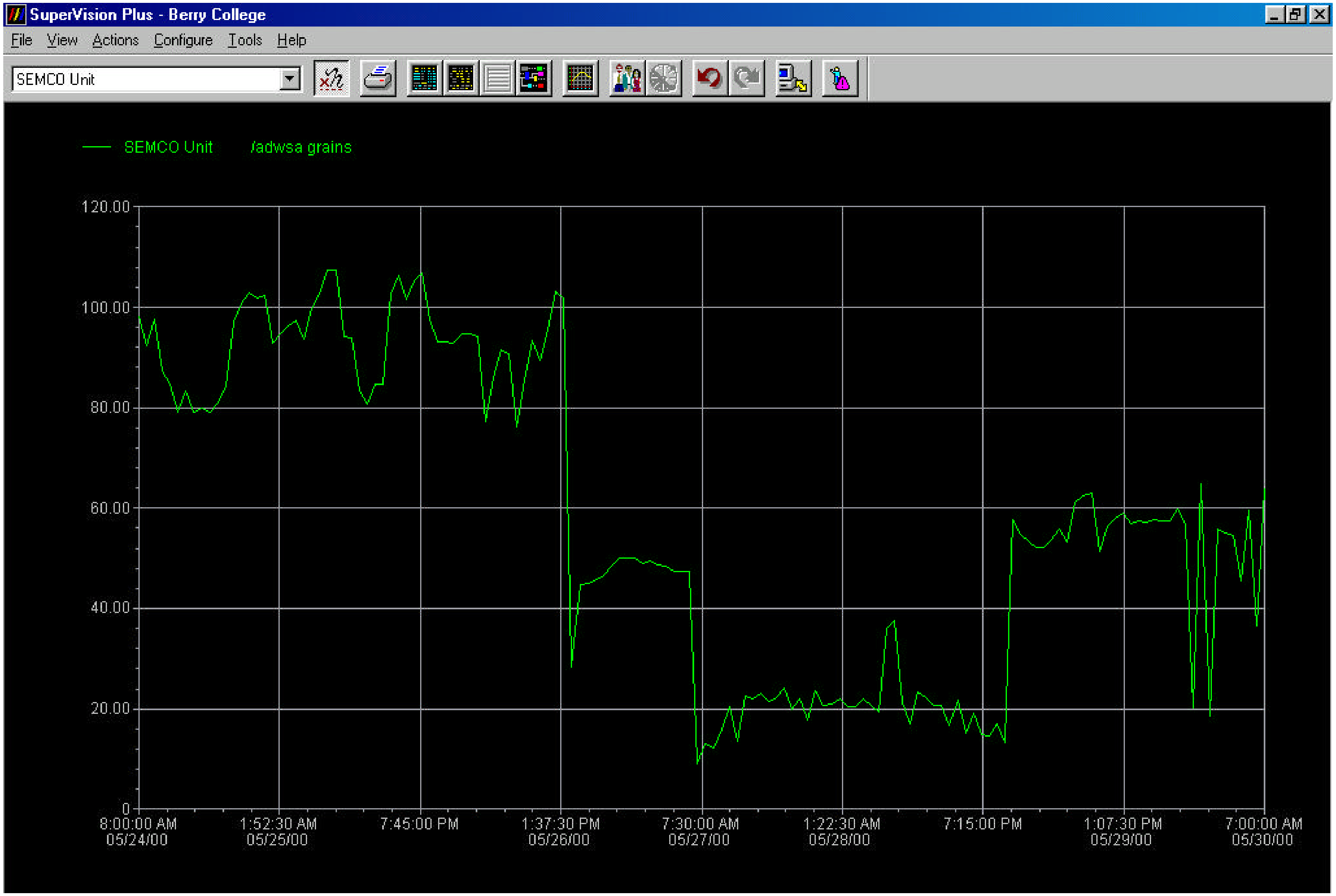

Fig. 11. Absolute humidity level delivered by the desiccant hybrid system at the time of initial startup, showing "building dry-out" cycle and normal control modulation once the building humidity level is obtained.

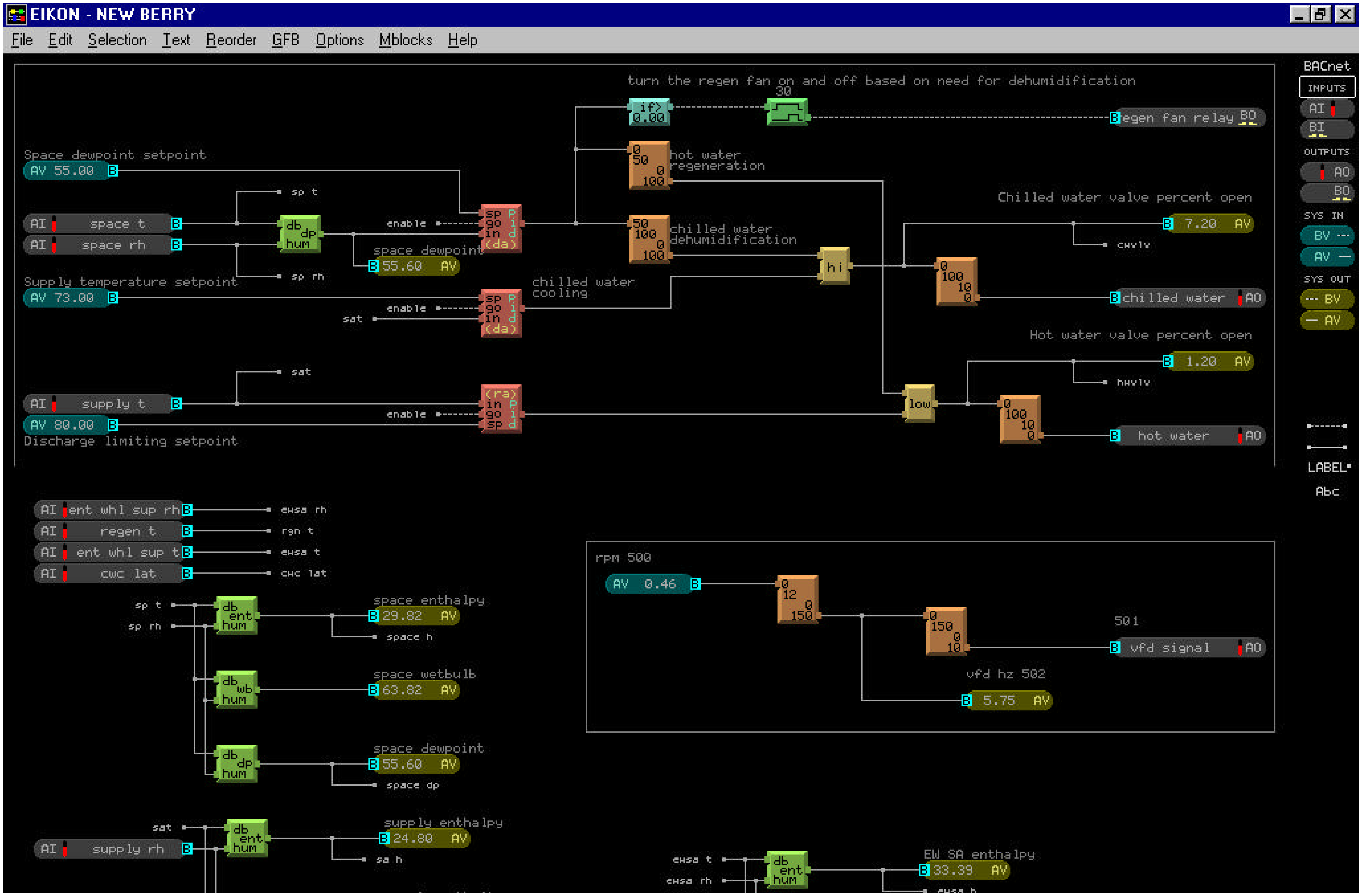

Fig. 12. Sample window showing a portion of the programming logic developed by SEMCO and used for the Berry pilot project. Control was the primary function of this DDC system, but it also provided the data acquisition and remote monitoring capability.

Instrumentation

Eighteen different sensors were used to monitor 10 different state points within the East Mary hybrid system and the two spaces monitored (Fig. 9). For this retrofit project, the hybrid system was built up on site using the SEMCO FV energy recovery module, the custom active desiccant wheel, and standard Trane Climate Changer modules. Once the system was assembled, all of the instrumentation was installed and connected to the main DDC panel by SEMCO.

The RTD and RH sensors performed very well with respect to reliability and accuracy over the 1-year monitoring period. One advantage of the DDC software used is that the sensors could be easily recalibrated, remotely if necessary. Another significant advantage of the DDC system with remote monitoring is the graphics capabilities. Figure 9 shows a custom schematic diagram developed by SEMCO to show the function of the hybrid system. Customer feedback was extremely positive for this feature because this complex hybrid system, which was difficult to explain verbally or with sales literature, was easily understood by simply viewing this graphical presentation during actual operating conditions.

A real-time energy comparison between the hybrid system and a more conventional system was calculated and reported (Fig. 9), in addition to accumulated energy savings. This comparison clearly shows the user instantaneous system benefits. Better understanding of the system resulted in better maintenance and more overall interest in the technology than otherwise would have existed.

An important point to understand is that the instrumentation required for performance monitoring for this project was clearly more than would normally be affordable for a typical end user. However, effective system performance monitoring can be accomplished with only 10 of the 18 sensors. Given that approximately six to eight sensors are required to control the system effectively, and that the DDC system costs approximately the same as a more conventional control system approach when numerous sensors are required, the additional first cost required to remotely monitor system performance is very small. The benefit provided, however, based upon the experience gained from these two pilot sites, is quite significant.

Data Acquisition

The performance data for the systems monitored were collected in three modes. Instantaneous data were recorded by downloading the system schematic showing live data (Fig. 9). The data for all of the selected state points were recorded and saved in the control module memory over an approximate 1-month period (depending upon the frequency of sample collection). The third and most effective option, used for preparation of this report, is the ability to trend the stored performance data (shown graphically in Fig. 10). Stored data also can be tabulated in a spreadsheet format for any subsequent analysis.

3.4 SYSTEM PERFORMANCE DATA

During the engineering phase of the East Mary pilot project, the performance analysis of the system was completed and presented in a schematic format, and is included in this report as Fig. 8. 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 13 summarizes the performance advantage offered by the hybrid system over a conventional cooling system, based upon the design data shown in Fig. 8. For this simple analysis it is assumed that the conventional system is operated to cool the outdoor air to 50EF (the lower limit possible with the 45EF chilled water available at Mary Hall) and then reheated to 70EF to avoid over-cooling the individual dormitory rooms.

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 (a 25EF dewpoint vs a 50EF dewpoint) (Fig. 13). This advantage is important for this application because the plan was to handle the entire space latent load with the relatively small volumetric flow rate.

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. Since the drier air offered by the desiccant hybrid system allowed for the space latent load to be handled with less air flow, smaller ducts and lower static pressure losses resulted.

The system and building were monitored for more than one year. These data made it clear that both the internal latent load of the building and the latent load for dehumidifying outdoor ventilation air supplied to the building exceeded those used to design and size the hybrid system that was installed. It was 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 ventilation on a continuous basis in accordance with ASHRAE 62. The only outdoor air available for West Mary was through infiltration or opened windows.

	Details—hybrid system	**Details—conventional system** (over-cool and reheat)
Total cooling provided (BTU/h)	**244,736**	**238,848**
Latent cooling provided (BTU/h)	**206,720**	**169,728**
Sensible cooling provided (BTU/h)	**38,016**	**69,120**
Cooling energy required (BTU/h)	**136,800**	**302,400**
Reheat energy required (BTU/h)	**N/A**	**138,000**
Regeneration energy required (BTU/h	**105,550**	**N/A**
Supply dew point used for analysis	**39EF**	**50EF**
Supply low dew point obtainable	**25EF**	**50EF**
Mechanical cooling required (tons)	**11.4**	**38[a]**
Dehumidification capacity (Lb/h)	**195**	**160[b]**

[a] Cooling tons required to deliver 195 lb/hour of dehumidification capacity at an increased air flow rate.
[b] Capacity obtained by 28 tons of conventional cooling at comparable air flow rates.

Fig. 13. Initial performance comparison between the conventional and hybrid system.

Figure 9 shows a snapshot of system performance during a typical off-peak cooling season day. The performance monitored agrees well with that projected for this pilot project. Figure 10 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 and a low occupancy period. Note that the outdoor air humidity content was as high as 140 grains/lb of moisture. Also note that the outdoor air volume needed to be dehumidified to as low as 35 grains/lb to reach the desired control range of 50–55% RH.

In viewing the data provided by Fig. 10, it is important to note that although the control sensor was located in the hallway outside 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 to the showers in the common bathroom areas.

Figure 11 shows the hybrid system performance during startup and highlights several 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/lb could be delivered with the 43E 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/lb could be delivered.

A second interesting finding was the amount of time required for an initial dry-out of the East Mary facility. Figure 11 indicates that the system had to provide outdoor air dehumidified to 20 grains/lb for about 2 days to bring humidity in the space under control. Once under control, the supply air humidity content modulated between a high of 60 grains/lb and a low of 20 grains/lb to maintain the space humidity setpoint condition.

Figure 14 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 pre-humidifies the outdoor air during the heating season.

Comparing Space Conditions at East Mary and West Mary

Figures 15 and 16 highlight the performance advantages offered by the desiccant hybrid system preconditioning compared with the conventional chilled water and fan coil system (the original HVAC design for the East and West Mary facilities). Figure 15 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/lb (50% RH) on the more humid days, while the humidity level in West Mary averaged approximately 90 grains/lb and often exceeded 100 grains/lb (70% RH). A simple setpoint change made between 6/30 and 7/2 shows that even lower humidity levels could be easily maintained by the hybrid system.

Figure 16 shows the impact on a conventional cooling system when the building latent load is removed. It is clear that the chilled water/fan coil cooling system located in West Mary cycles far more often in an attempt to hold the setpoint than does the same system in the dehumidified East

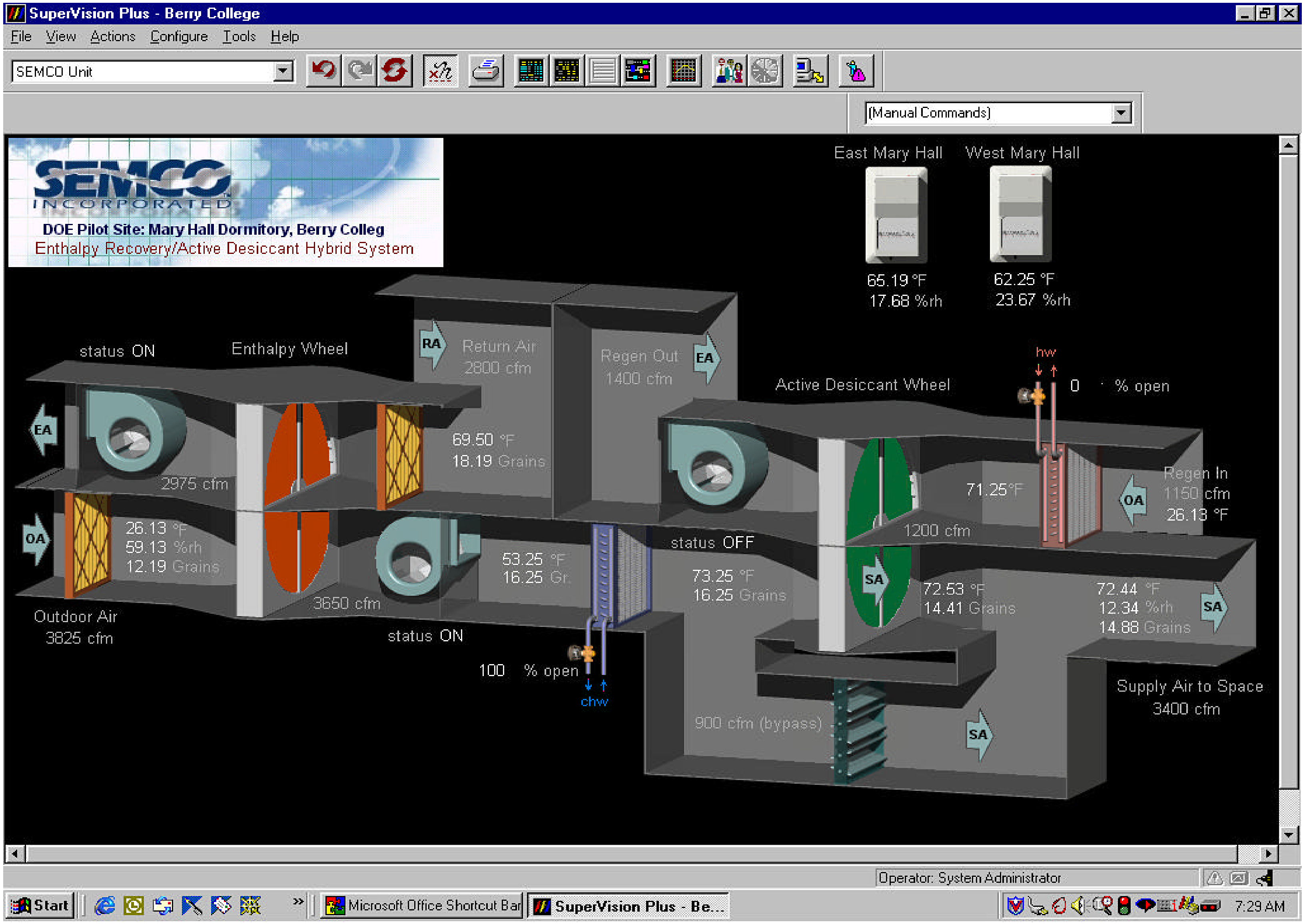

Fig. 14. Typical performance of desiccant hybrid system during the heating season. The system is a year-around technology (unlike the traditional DBC approach) since the total energy wheel preheats and pre-humidifies the outdoor air.

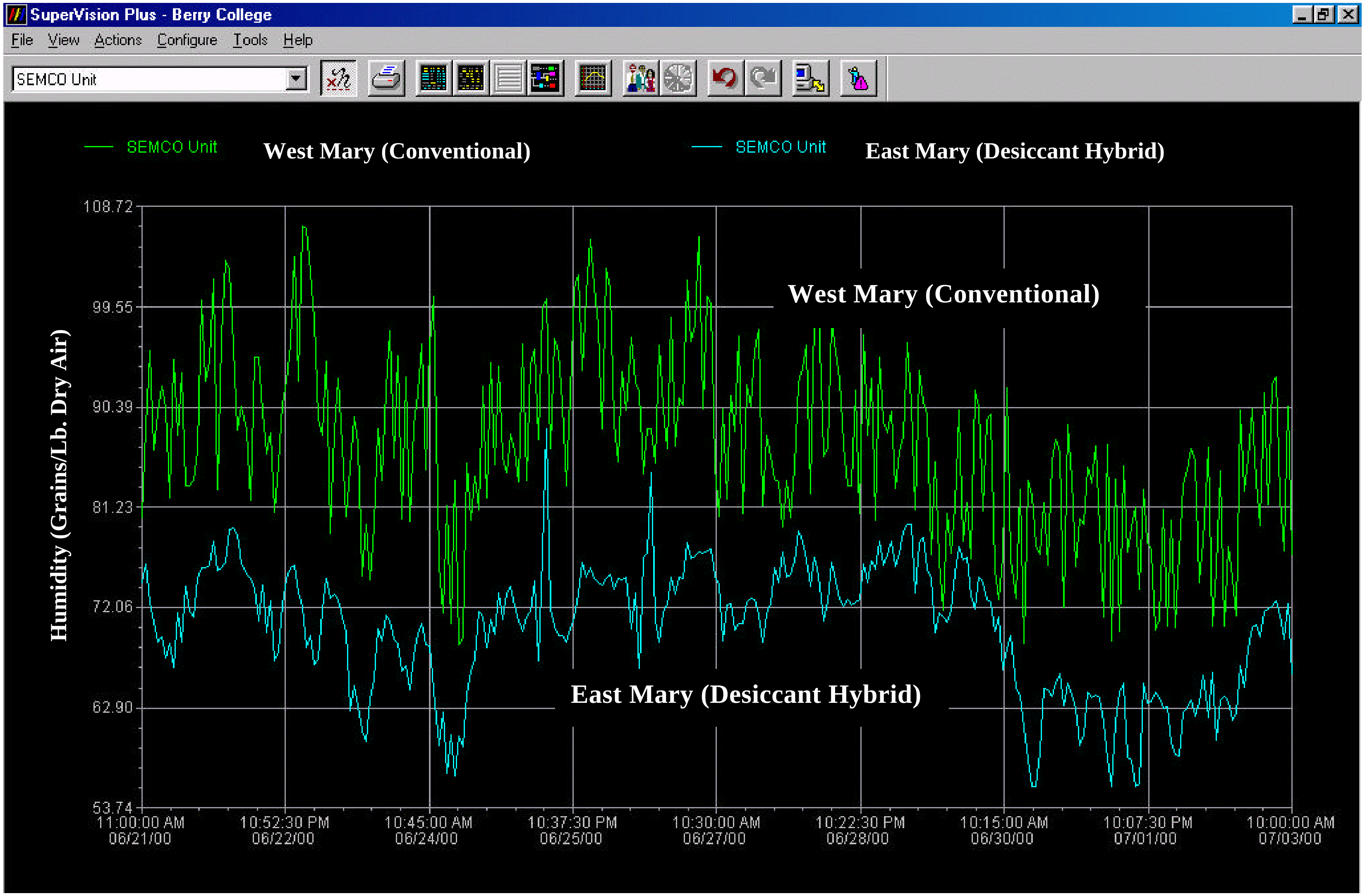

Fig. 15. Humidity data (grains) for East Mary (space 1) and West Mary (space 2). East Mary with desiccant hybrid/continuous ventilation, West Mary with conventional cooling/no ventilation. On 6/29/00, the East Mary setpoint was lowered from 60 to 50% RH.

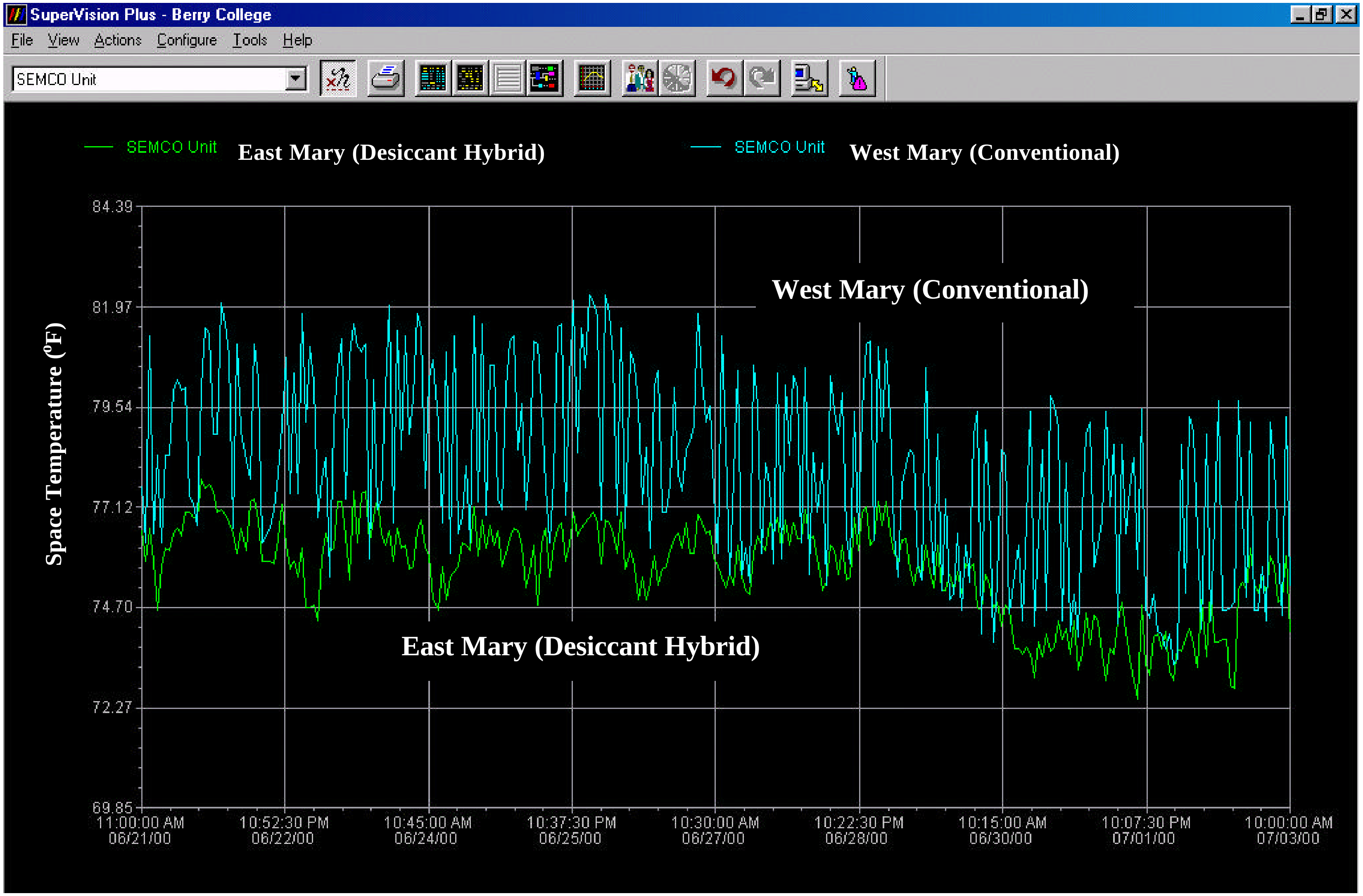

Fig. 16. Temperature data for East Mary and West Mary Dormitories. East Mary with desiccant hybrid/continuous ventilation, West Mary with conventional cooling/no ventilation. Note the advantages of the hybrid system—reduced run time and better temperature control.

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, reducing cycle time and resulting in a more comfortable space temperature without the wide temperature swings evident in West Mary.

One of the most valuable benefits of 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.

Improved humidity control, temperature control, and increased, continuous ventilation significantly improved indoor air quality at East Mary Hall. Although the effect is hard to quantify, in an article published in the American Gas Cooling Center's *Cool Times* [AGCC 2000, (Appendix A)], the Berry facilities manager describes his satisfaction with the improvement in indoor air quality and other benefits provided by the desiccant hybrid system retrofit.

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.

3.5 ENERGY SAVINGS

The DDC and instrumentation package installed on this project offered an additional benefit—the ability to measure instantaneous energy savings compared with a more conventional over-cooling and reheat approach.

The only technical difficulty that made this capability less than ideal was that the accumulated energy savings values were lost each time a new version of the software was downloaded. Because this was the first site to be controlled in this fashion, downloads were quite common; as a result, the accumulated savings needed to be recorded manually.

Nevertheless, approximately 90,000 ton-hours were saved by the hybrid system over a year, compared with a conventional system processing approximately 40% more air to reach a similar level of dehumidification. The total energy wheel saved approximately 360 million 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 with the conventional approach (since this air is delivered directly to the occupied space).

Based on energy rates typical for the Atlanta area, Berry College recognized approximately $7000 in energy savings due to the hybrid system. This amount does not take into account the additional savings that result from the reduction in chilled water used by the individual fan coil units located throughout East Mary. Their energy consumption was not measured, but it is conservatively estimated at an additional $3000 per year.

Based on these energy savings estimates, the simple payback for the retrofit installation at East Mary would be approximately 5 to 6 years.

However, the most significant benefits provided to the facility, according to the Berry College head of facilities, are not related to energy savings. The effective reductions in space humidity and the associated reductions in odor, maintenance, and indoor air quality problems have more than justified the desiccant hybrid retrofit. (More details regarding the owner's perspective are included in Appendix A in the *Cool Times* draft article.)

3.6 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 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 improving the humidity control within the space.

Both the monitored performance and feedback from the building occupants (see Appendix A) has confirmed that the benefits offered by the new active desiccant/total energy recovery hybrid system have been significant. An unexpected benefit associated with the installation was that a large block of chilled water capacity was removed from the East Mary wing. The chiller previously allocated to serve only the Mary Hall facility was then able to condition a second large facility as well.

4. RESULTS: BAKER RESEARCH BUILDING INVESTIGATION

4.1 INSTALLATION DESCRIPTION

The Baker Research Building at Georgia Tech Research Institute is a four-story brick structure housing laboratories and small offices for the researchers and staff. The active desiccant equipment installed in the building was roof-mounted on an existing housekeeping pad previously used to support an atmospheric observation trailer. The active desiccant system, built by SEMCO, was an integrated system that included a pre-piped Trane heat pump condenser section and a complete electrical and DDC/instrumentation package (see Figs. 17, 18, and 19).

The preconditioned outdoor air is delivered to two adjacent laboratory areas, located on the first floor of the facility, via dual-wall insulated spiral ductwork and fittings, also provided by SEMCO. The total laboratory area served, approximately 2500 ft^2, encompasses two laboratory spaces and eight smaller offices/storage rooms.

Two significant challenges were encountered during the installation. First, there was insufficient hot water and chiller water capacity at the Baker Building, despite assurances by Georgia Tech staff. Initially, the plan was to use hot water to regenerate the active desiccant wheel and chilled water for post-cooling. Just before the installation, it was determined that the capacity of the on-site chiller was already inadequate to the needs of the building. At the same time, it became evident that the hot water distribution piping at the roof level was too small to support the regeneration of the DBC system. A new hot water distribution line would be needed from the roof to the main header on the lower floor of the facility. The cost of such a modification was determined to be prohibitive.

Fig. 17. The integrated SEMCO active desiccant system being installed at the Baker Building.

Fig. 18. The desiccant system rigged on existing pad. Gas piping/control panel shown.

Fig. 19. The full electrical package, including the DDCs and communication software, factory-mounted as part of the integrated system. Note that high-efficiency filters were provided with the system to enhance the quality of the lab environment.

To overcome these obstacles, the DBC system was redesigned to use an integrated heat pump unit for summer (post–desiccant wheel) cooling and winter season preheating, and a direct-fired gas burner section for the regeneration of the active desiccant wheel. These additions increased the cost of the active desiccant system but significantly decreased the installation cost, allowing the pilot site to be completed within the original budget allocated.

Another obstacle was the installation of a large electrical signal conditioner in one of the laboratories just before the installation of the DBC system. This signal conditioner, needed for a large mass spectrometer, emitted a significant amount of heat. The heat could not be accommodated by the existing cooling system and was not considered in sizing the cooling capacity to be provided by the new active desiccant system. The net result was that the temperature and humidity sensor controlling the active desiccant system had to be installed in this space with a high sensible load. As a result, cooling, not dehumidification, became the primary controlling factor for this project.

Since the space with the high sensible load called for cooling even on days when the outdoor air was cool (e.g., 58EF), and the system would normally be able to cool the space with unconditioned outdoor air (economizer mode), a hot-gas bypass had to be retrofitted to the heat pump system to avoid frosting the coil at these off-load conditions. Frosting occurs because the refrigeration circuit has enough excess capacity during low-load conditions to cool the air, leaving the cooling coil below 32^{o}F.

SEMCO also modified the control of the active desiccant system to optimize space cooling rather than dehumidification until Georgia Tech could deliver additional sensible cooling to the high-sensible zone using the existing building system. This modification resulted in minimizing the run time of the active desiccant wheel portion of the system. This cooling modification will be easily completed by Georgia Tech before the next cooling season.

An additional installation challenge was that the existing reheat boxes were sized for approximately 50EF entering air during the heating season. Since the DBC design approach selected for this project does not offer any heating season energy recovery (i.e., no return air path is available), the outdoor air introduced during the heating-season needed to be preheated. As shown in Fig. 20, the novel heat pump integration provided enough preheat energy to meet this requirement.

4.2 SYSTEM DESCRIPTION AND SCHEMATIC

A schematic is provided as Fig. 21 to show the projected, design-day performance for the active desiccant system installed at the Baker Research Building. These performance data were based upon the original space design sensible-heat loads and the supply air temperature delivered by the original HVAC system before the addition of the high-heat source discussed in Sect. 4.1.

The original design overcooled a mixture of outdoor and return air to approximately 53°F and then reheated at the zones as necessary to maintain the desired space temperature. Since most of the laboratory area that is now served by the active desiccant system had a low sensible load (before the addition of the new heat source), low lighting, and no windows, and since the air exchange rate within the space was very high, the supply air reheat boxes serving each space typically heated the supply air to 65 to 68EF.

As shown in Fig. 21, the objective of the active desiccant system was to minimize or eliminate the need for reheating and to remove most or all of the latent load from the conventional cooling coil. At the design condition shown, the active desiccant wheel handles approximately 75% of the latent load. The design

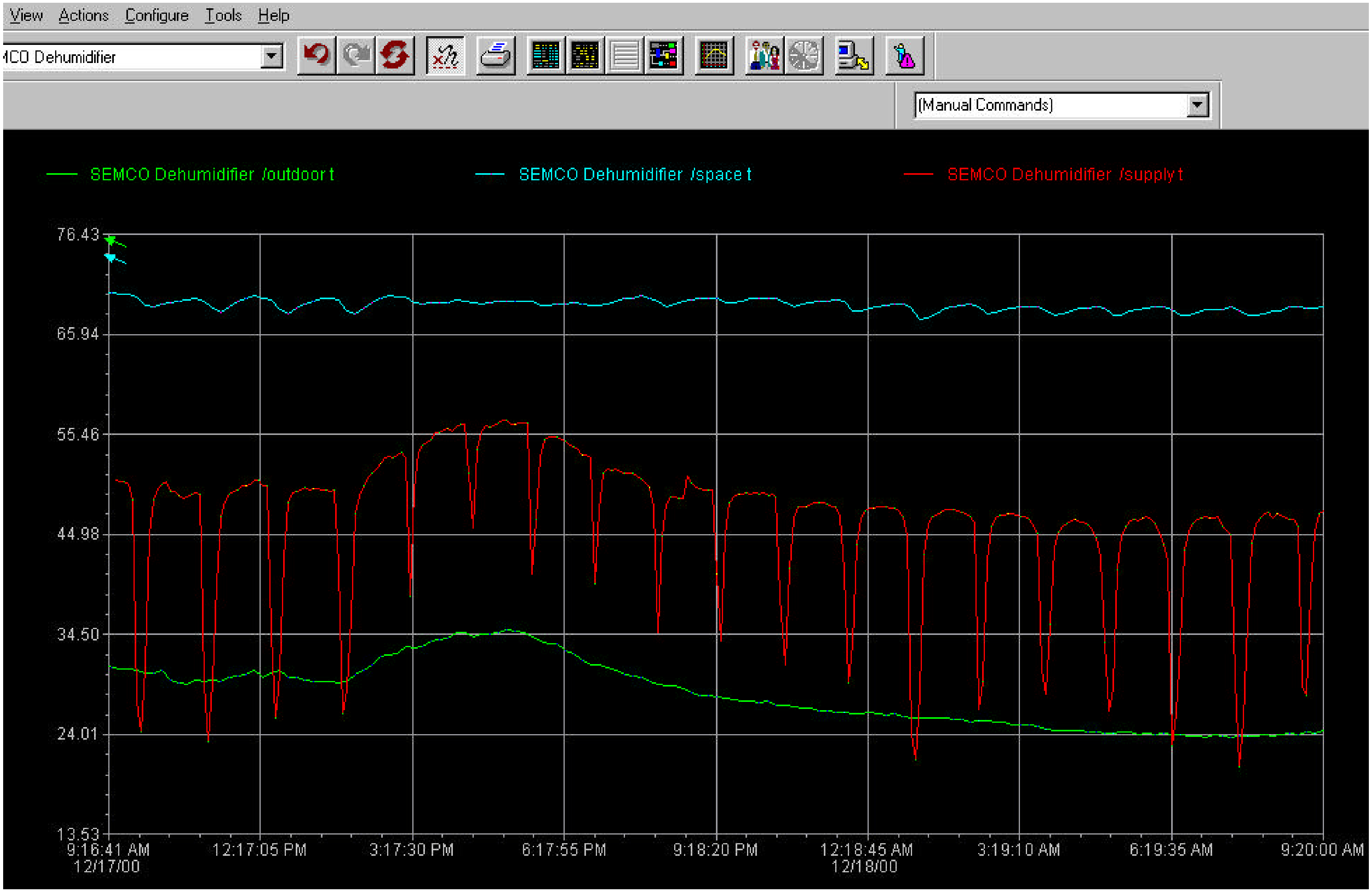

Fig. 20. Performance of the desiccant-based cooling system heat pump operation during the heating season—outdoor, supply, and space temperatures.

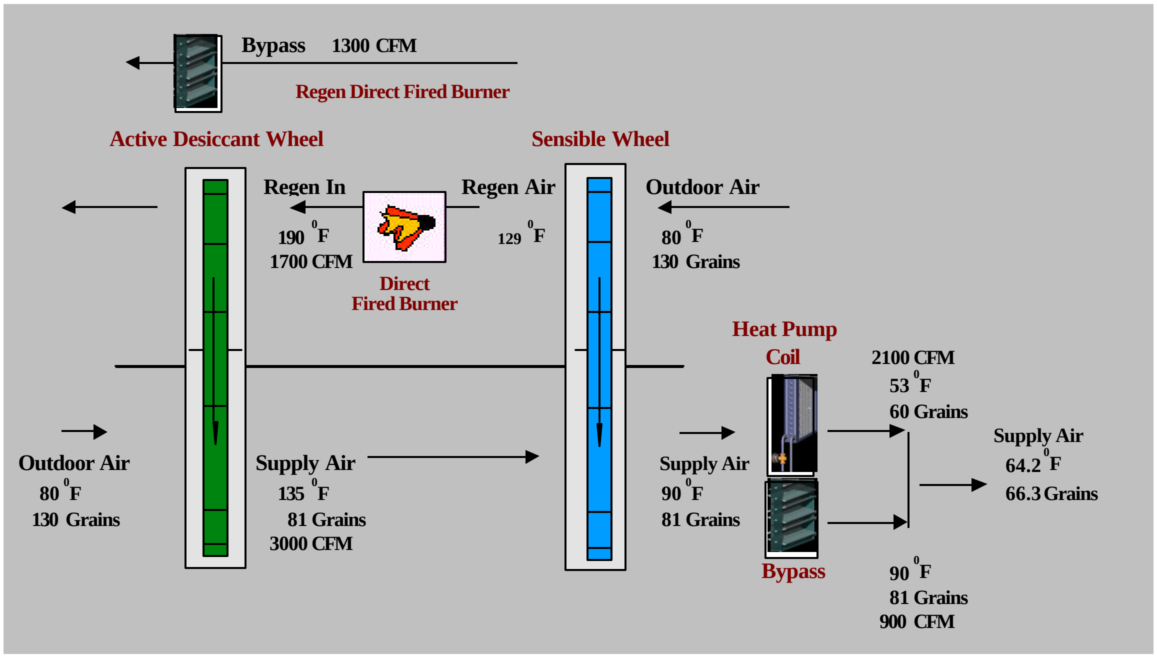

Fig. 21. A schematic showing the latent design-day projected performance for the desiccant-based cooling active desiccant system installed atop the Baker Research Building.

schematic shows some of the supply air bypassing the cooling coil. This is done to enhance the dehumidification capacity of the cooling coil when the active wheel does not handle the entire latent load.

At off-peak operating conditions, such as the actual performance data shown for the Baker Research Building in Fig. 22, the active desiccant wheel can process the entire latent load. This is clear from the figure, since the absolute humidity level (grains) leaving the cooling coil and introduced to the space is the same as that of the air leaving the active desiccant wheel.

As mentioned in Sect. 2.1, the requirement for mechanical post-cooling would have been reduced by applying an evaporative cooling section to the incoming regeneration air stream before the sensible-only wheel. Modeling suggests that evaporative cooling would save energy. However, the Georgia Tech maintenance staff viewed this option as a significant negative, so it was omitted. Omitting the evaporative cooling section significantly reduced the maintenance required by this system.

The omission did increase the amount of post-cooling energy required, but it also reduced the need for regeneration energy because warmer air is introduced to the gas heater. In addition, the regeneration air is drier than it would be after an evaporative cooling section, so the dehumidification efficiency is increased. Customer satisfaction and the regeneration energy savings justified the elimination of the evaporative cooling section for this project.

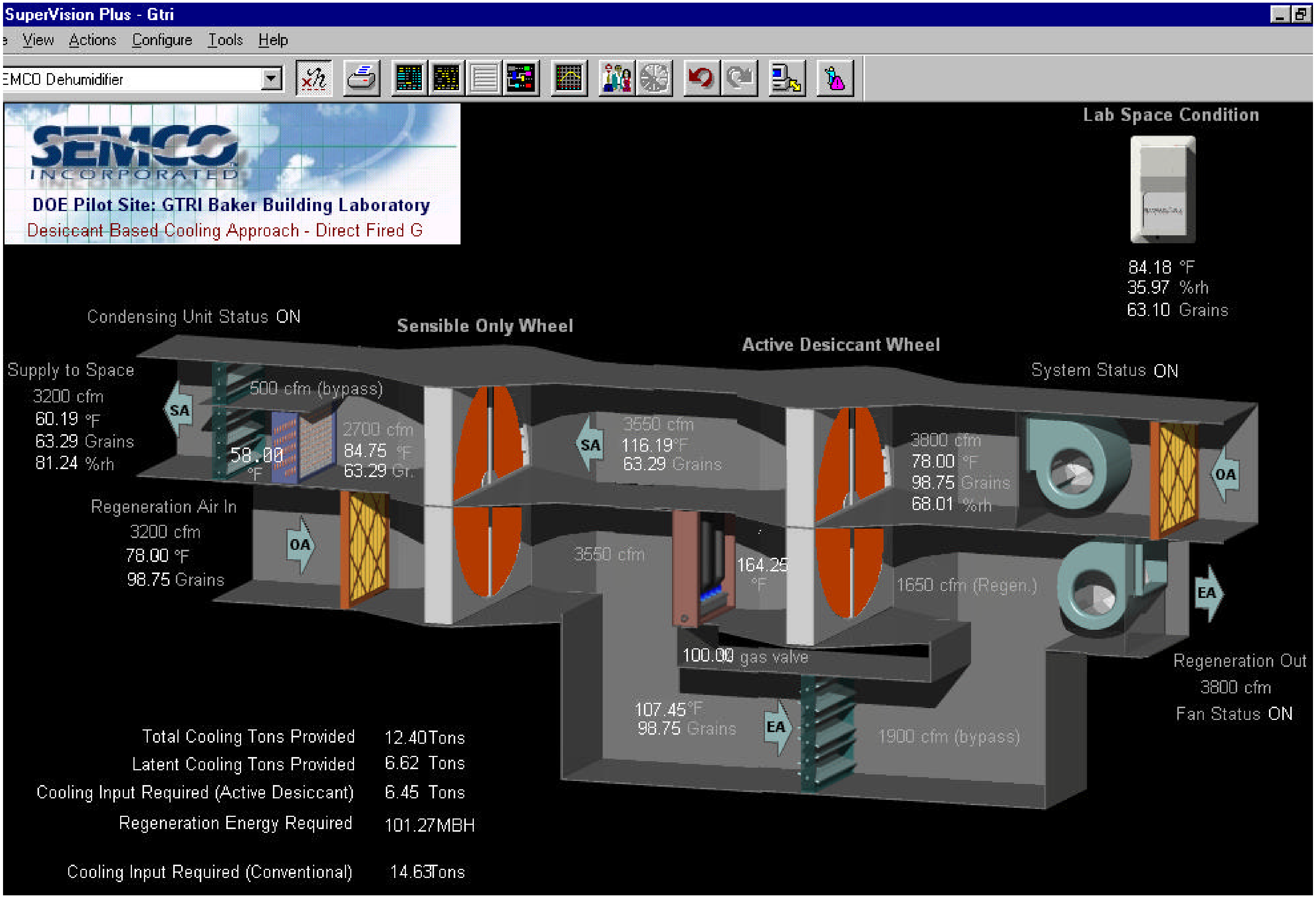

Fig. 22. Actual performance of the desiccant-based cooling system installed at the Baker Research Building at typical cooling season conditions.

4.3 CONTROLS, INSTRUMENTATION, AND DATA ACQUISITION

The control/monitoring system used at the Berry College site was also used in the system installed at Georgia Tech (see Sect. 3.3 and Figs. 9, 10, and 12). As at the Berry College site, performance data could be viewed and collected remotely (Figs. 20 and 22).

As with the Berry project, a customized control software program and graphics package was developed by SEMCO for the Georgia Tech installation. The control system monitored the temperature and humidity in one of the main lab areas and, based on the space conditions, modulated the heat pump, direct-fired gas burner, and operation of the regeneration air fan.

Approximately eight highly accurate temperature sensors (RTDs) and five high-quality RH sensors were used to control and instrument this active desiccant system. In addition, full modulation and safety controls were provided for the direct-fired gas burner and the hot gas bypass for the heat pump condensing section. All points, in addition to numerous status and start/stop signals, could be viewed and trended using the DDC controlling and monitoring software.

As at the Berry College site, the controls required for this project were delivered most effectively and economically by the DDC control package. As a result, the additional cost associated with the monitoring function was minimal compared with the benefit provided.

Again, the software program was developed to include an embedded macro to accumulate energy savings provided by the active desiccant versus the conventional cooling approach. The actual operation of the system thus far has not allowed for an effective use of this reporting function because of the unanticipated high sensible load in the space containing the signal conditioner.

4.4 SYSTEM PERFORMANCE DATA

The performance objective for this pilot installation was to pressurize the served laboratory spaces with 100% outdoor air in order to isolate them from the recirculating system serving the rest of the facility. The active desiccant system was designed to provide effective temperature and humidity control. It also was designed with high-efficiency filtration to minimize particulate introduction and contamination of the laboratory environment.

With the exception of the one lab space where temperature control was complicated by the unanticipated excessive sensible load, the system performed very well during heating and cooling seasons in all regards. There was little down-time and minimal maintenance.

Figure 22 is a snapshot of actual performance on a typical cooling season day, shown here as a sample of the graphics screen provided by the DDC/monitoring system provided for this pilot site. As shown, 6.5 tons of cooling energy input results in a 12.4 ton total cooling output, of which 6.6 tons is latent. Approximately 100,000 Btu of gas heating is used for regeneration of the active desiccant wheel. A conventional cooling approach would have required 14.6 tons of cooling input to accomplish the same dehumidification and cooling function.

Reheating energy is also saved in the laboratory areas other than the space with the excessive sensible heat load. In those areas, the delivered air temperature has typically been 65 to 68EF. With a conventional approach, the outdoor air would have been cooled to approximately 55EF to obtain the humidity level of 63 grains/lb and then heated by the reheat boxes serving the laboratory before being introduced to the space.

As part of a separate research phase of this program, the ability of the active desiccant to remove airborne gaseous pollutants from the outdoor air is being investigated. This ability would result in perhaps the most important benefit of this application, since at the Baker Building, as at most research and medical facilities, the outdoor air available for building ventilation and indoor contaminant dilution is of less than ideal quality. The laboratories served by this system specialize in measuring very low levels of various contaminants in air samples. The instrumentation is easier to operate and provides more consistent data if the ambient environment is as free from contaminants as possible. As a result, removing contaminants from the outdoor air used for laboratory ventilation is beneficial to both indoor air quality and the function of the facility.

Preliminary laboratory testing of the active desiccant wheel installed at this site has shown that it can attain very high removal percentages for a wide range of contaminants while simultaneously dehumidifying the outdoor air. Results of this comprehensive testing will be available within the next 12 months.

4.5 ENERGY SAVINGS

An estimated 21,000 ton-hours were saved by the DBC system over a 1-year time frame, compared with the requirements of a conventional system operated to provide similar conditions. The energy required for regeneration of the active dehumidification wheel was estimated at approximately 362 million BTU.

Using typical energy costs for the Atlanta area, Georgia Tech saved approximately $3100 because of the active desiccant system. This does not include the reheat energy savings that were estimated to be an additional $480 per year.

As is typically the case for active desiccant systems, energy savings are only one factor in the justification process. In this case, the improved humidity control, the offset chilled water requirements, the high-efficiency filtration capability, and the promise of removal of gaseous contaminants from the outdoor air used for building ventilation all served to justify the use of the technology.

4.6 CONCLUSIONS

The pilot installation at Georgia Tech has been successful. The field-monitored performance of the desiccant system has been as expected, and the reliability has been excellent. The unanticipated addition of heat-generating equipment in one of the main lab areas made it necessary to operate the system primarily to control the sensible load. It was designed to handle building and ventilation air latent loads. As a result, the active portion of the system ran less often than anticipated and required more cooling capacity than was allocated in the original design to maintain the temperature setpoint in the laboratory containing the signal conditioner. In all other areas, the system performed as desired.

Additional sensible cooling will be provided to this hot lab area before the next cooling season, and the DBC system will then be operated as originally anticipated. Otherwise, the monitored performance and the feedback from the building occupants have been very positive.

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APPENDIX A

The text from an article in the January/February 2000 *Cool Times* newsletter of the American Gas Cooling Center.

SEMCO Dehumidification Systems Combined with Conventional Trane Components Installed and Monitored at Two Field Test Sites.

A research laboratory and landmark college dormitory are serving as field test sites for active desiccant wheels and systems manufactured by SEMCO Inc. combined with conventional HVAC components manufactured by The Trane Company. These demonstration sites, both located in the state of Georgia, are the result of the second phase of a U.S. Department of Energy (DOE) research and development program managed by Lockheed Martin Energy Systems.

One of the SEMCO hybrid systems was retrofitted to the Baker Research Facility located on the campus of the Georgia Institute of Technology. The 3,500-cfm SEMCO system utilizes direct-fired gas to regenerate the active desiccant wheel and integrates a 10 Trane heat pump to provide post cooling and heating. The system maintains temperature and humidity conditions, while providing filtered outdoor air to replace exhaust air from laboratory hoods. The lab area houses the Georgia Tech Environmental Monitoring Branch, one of the most respected indoor air quality research groups in the country. This field test site was primarily selected because the sophisticated instrumentation (high-end mass-spectrometers) used by the researchers benefits from a clean environment with temperature and humidity control.

A second reason for selecting this site is to measure and quantify the SEMCO active desiccant wheel's effectiveness in removing airborne pollutants along with the moisture via co-sorption. Small-scale laboratory testing confirmed the equipment's capacity to remove outdoor air contaminants by up to 90%. The cost of completing this research was cut significantly by installing the active desiccant system at the same site as the high-end mass-spectrometers.

Another field test operates 65 miles north of Atlanta in an historic stone building constructed in the 1920s under the watchful eye of automobile mogul Henry Ford. Until recently, coeds living in Mary Hall, one of Berry College's original buildings, sweated out their studies with no central cooling. When the building was renovated in 1992, comfort cooling was added to the dormitory. However, the HVAC equipment was oversized for the building and rendered the dorm rooms anything but comfortable. It reduced the sensible load dramatically, but left the latent load uncontrolled.

"Students would run their thermostats down to 65° to 68°F trying to get the humidity and comfort level right," recalls Berry College Ben Elkins, P.E., who is the Director of the Physical Plant. He explains that each room has a fan coil unit and individual controls. As the building's temperature fell, the unchecked humidity collected indoors. Daily showers spiked the indoor humidity level and exacerbated unhealthy conditions. "Mary Hall was plagued with mold and mildew," says Elkins. Complaints of persistent odors became a perpetual reminder of the indoor air quality problem.

The college attempted to improve the conditions inside Mary Hall by dehumidifying the hallways with electrical dehumidification units placed strategically throughout the dormitory. Humidity dropped somewhat, but the noisy units created new complaints and the cost of operation was high.

In September 1999, a hybrid system was installed that combined SEMCO's total energy recovery (passive) technology with an active dehumidification system constructed from a SEMCO dehumidification wheel and standard Climate Changer modules produced by Trane. The hybrid system was installed in the dorm's basement, across from the conventional chiller. The hybrid system provides 100% outside air on a continuous basis to the occupants. New ductwork was added to introduce the outdoor air directly to each room in Mary Hall's East Wing. West Wing rooms remained unchanged to serve as the "control site" for comparative analysis.

Elkins compares Mary Hall to a cave, with thick stone walls ranging in depth from 18 to 24 inches. Despite the building's impenetrable exterior, the dehumidification system can remove up to 240 gallons of water from the atmosphere every 24 hours (750 gallons/day including the outdoor air load). Two SEMCO desiccant wheels operate in tandem to attract and remove moisture from the outdoor air at a high level of energy efficiency. The first desiccant wheel uses the energy contained within the exhaust air stream to cool and dehumidify the outdoor air. The second dehumidification wheel dries the outdoor air stream to a very low dewpoint as it is continually regenerated with hot water supplied by a small natural gas fired boiler.

"When we added this system," Elkins says, "we finally gained control of the humidity in East Mary. During set-up, we drove the dew point down to 26°F," he exclaims, noting that no lingering odor remains and humidity spikes no longer affect the building's comfort zone.

Both the Georgia Tech and the Berry College sites are fully instrumented and monitored remotely via a modem to document system effectiveness and track energy consumption. SEMCO plans to continue monitoring these projects through the summer of 2000, with a final report being made available to the industry soon thereafter. SEMCO technical consultant John Fischer says he expects the installations to demonstrate how "select applications benefit from the unique performance capabilities offered by active desiccant systems and that energy efficient, hybrid systems can be produced cost effectively if combined with conventional equipment components already available".

For more information regarding these pilot sites, contact John Fischer, tel. (770) 850-1030, fax (770) 850- 0780, or e-mail <johnfischer@worldnet.att.net>.

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