Energy Savings from Indirect Evaporative Pre-Cooling: Control Strategies and Commissioning

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ABSTRACT

Package rooftop air conditioning units (RTU) with evaporative pre-cooling systems were installed at an Agricultural History Museum and conference center in the northern Sacramento Valley in California, a hot and dry summer climate region. The evaporative pre-coolers serve to extend the economizer range of the RTU's.

A commissioning team monitored the performance of the RTU evaporative pre-coolers. The purpose of the monitoring was to determine if changes were warranted to optimize the system's energy efficiency. The commissioning process revealed that the RTU evaporative pre-coolers were being controlled by the economizer control cycle. With this control cycle, the evaporative pre-cooler operates when the outdoor air temperature is falling below the space return air temperature. This means that the pre-cooler will never operate at peak load conditions.

The conference center is an assembly occupancy. Building codes require significant levels of outdoor air for ventilation. The evaporative pre-cooler system provides the means to significantly offset the energy requirements for cooling down and heating up this ventilation air. A DOE2 energy simulation analysis indicated that the evaporative pre-cooler could cut energy use by over 50% if it were working correctly.

Our investigation concludes that in buildings with high outdoor air requirements, evaporative pre-cooling, using building exhaust air as the indirect evaporative cooling source, significantly reduce building energy consumption. This evaporative pre-cooling technology works in any climate, regardless of outdoor conditions, since the return air stream exhausted from the building provides a relatively constant temperature and humidity source for evaporative cooling. An added benefit is that the evaporative pre-cooler heat exchanger recovers heat from the exhausted air stream in cold weather.

Introduction

Energy efficiency considerations are creating a demand for application of indirect evaporative cooling systems in non-residential buildings. Building codes require most new commercial, institutional and industrial buildings such as health care facilities, manufacturing and assembly, high technology, schools facilities to bring in high volumes of outdoor ventilation air. This high outside air requirement creates a significant energy penalty for the typical vapor-compression HVAC system. Evaporative pre-cooling systems, using the building exhaust air as a relatively constant temperature and humidity source, can significantly reduce building energy consumption and peak demand in both summer and winter.

Depending on the application, savings estimates of evaporative cooling systems vary from 50% to 80% in annual heating and cooling energy over equivalently sized conventional HVAC systems. Indirect evaporative pre-cooling systems use a heat exchanger between the exhaust air and outside air streams. This heat exchanger recovers heating and cooling energy from the space exhaust air stream depending on the season. The indirect evaporative pre-cooler further reduces the temperature of the outside air stream during the cooling season. It does this by taking advantage of the relatively constant temperature and humidity conditions of the exhaust air from the space as shown in Figure 1.

In many cases, negative experiences and lack of knowledge impede application of evaporative cooling technology. Many designers and owners perceive that evaporative cooling systems require higher maintenance, or increase the risk of health problems by bacterial infection. Such barriers are slowly being overcome though promotion and demonstration of evaporative cooling applications in the commercial and industrial sectors.

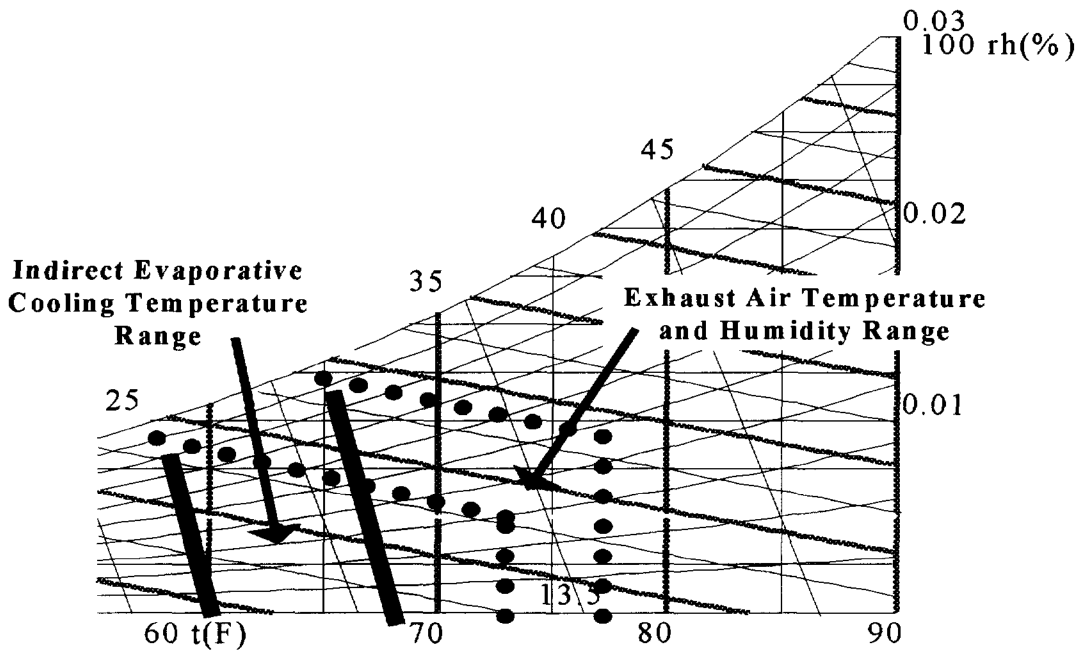


Figure 1

Scope of the Project

In order to promote the advantageous use of this technology, a utility sponsored the performance investigation and commissioning of a packaged evaporative pre-cooling system installed at the Agriculture History Center in Woodland, California. The commissioning team monitored the operation of the evaporative pre-cooling system. The Ag. History Center consists of a large agricultural truck and farm implement museum space and a conference center with gift shop, offices and conference center. The purpose of the monitoring was to determine the effectiveness of the conference center evaporative pre-cooling unit, to commission the unit to assure that it was operating as designed and to recommend improvements that could enhance its performance.

This project is part of a utility program that seeks to promote evaporative cooling as an alternative to vapor compression cooling for small commercial buildings. The energy cost benefits have been documented in numerous studies (Chen et. al. 1992; Hunn and Peterson, 1996; Watt, 1992) The project will result in a case study to demonstrate to design firms and building owners the advantages of evaporative cooling. An additional purpose of the project was for the utility company to investigate the system's performance since funds were provided for the owner to install the evaporative cooler system as part of a new construction rebate program.

The conference center indirect evaporative pre-coolers supplement and extend the economizer range for the three roof top unit (RTU) package air conditioning systems. The RTU's, which include one 8 ½ ton and two 4 ton units, serve the large meeting rooms at the conference center. The gift shop and office area have a separate 4 ton roof top unit without evaporative cooling. The kitchen has a separate make-up air unit with a direct evaporative cooler, which is not included in this paper. All of the roof top units have gas heating. The indirect evaporative cooling (IEC) units were made by a separate manufacturer but were factory installed and sold as a package with the RTU's. Figures 2 and 3 show the installation of the RTU's and evaporative pre-coolers on the conference center roof. The 8-½ ton unit, serving one area of the conference center, is the subject of this report.

Figure 4 is a schematic diagram of the unit. The unit draws outside air to be drawn through the IEC heat exchanger before passing through the DX cooling coil. Return air is exhausted through the wet side of the IEC heat exchanger. Depending on ventilation requirements, a portion of the return air mixed with the outside air and directed through the DX coil of the RTU. There are two linked dampers which control the direction of return air flow and the amount of outside air allowed into the RTU. The dampers are set to maintain a minimum OA intake to meet building code ventilation requirements.

Methodology

Commissioning on this unit was performed in two phases. The first phase was to install monitoring equipment and obtain detailed measurements of the performance of the RTU and evaporative pre-cooler. This included monitoring of temperature and humidity at key points in the unit, power, indoor space temperature and humidity, space occupancy, and spot measurements of system air flow. The second phase included the analysis of the monitored data and building energy simulation modeling to determine potential energy savings that could result from a fully commissioned system.

Monitoring Equipment Installation

Individual battery-powered data loggers were used to monitor the dry bulb temperature (DB) and the relative humidity (RH) at various internal and external points of the RTU. Return air (RA) DB and RH were measured at the return grille in the conference room and in the return air duct just below the unit. Supply air (SA) DB and RH were measured in the supply duct beneath the unit. Evaporatively cooled air (EA) was measured by two DB and RH sensors placed in the mixing area between the pre-cooler and cooling coil. Also, secondary air stream exhaust air (EXH) DB and RH were measured by placing the sensors just below the exhaust air dampers. These sensors were radiantly shielded from the dampers, which were translucent and exposed to direct sunlight. Figure 4 shows the location of measured temperature and relative humidity points in the RTU.

A weather station was installed on the conference center roof to measure outdoor air temperature (OA) and relative humidity. The OA temperature sensor was aspirated and shielded from direct solar radiation. Temperatures in the RTU and weather station were measured with thermistors, which have an accuracy of ± 1 °F at 77 °F. Conference center RTU unit relative humidities were measured with capacitance RH sensors, which have an accuracy of < ± 3% at 67 °F.

In the conference center space, two strategically located occupancy sensors, a temperature sensor at the thermostat and one additional temperature sensor on the opposite wall from the thermostat were installed. The RA sensor measured the relative humidity of the space. Conference center temperatures were measured with sensors accurate to ± 1 °F. Relative humidity sensor accuracy in the conference center was 5%. Conference center sensor placement is indicated in Figure 4.

Temperature and relative humidity data was recorded on 10 minute intervals for all sensors. This interval was chosen in anticipation of anticipated long-cycling of the conference room unit. The conference center unit data revealed shorter than expected cycling periods and suggested using a shorter recording interval in follow-up monitoring.

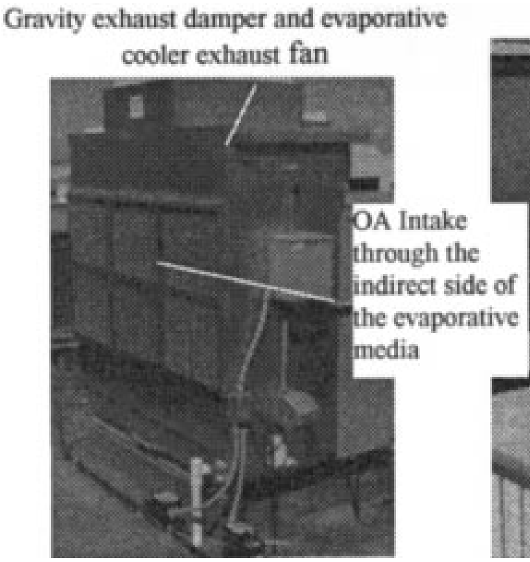


Figure 2

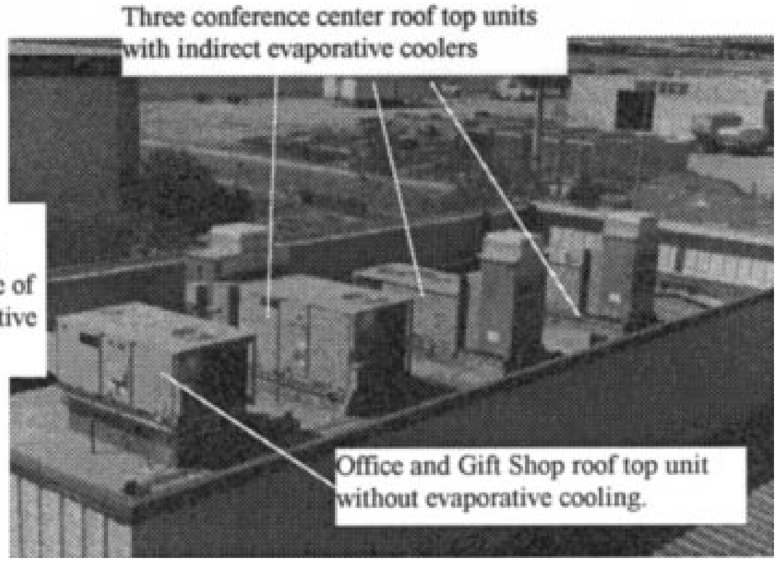


Figure 3

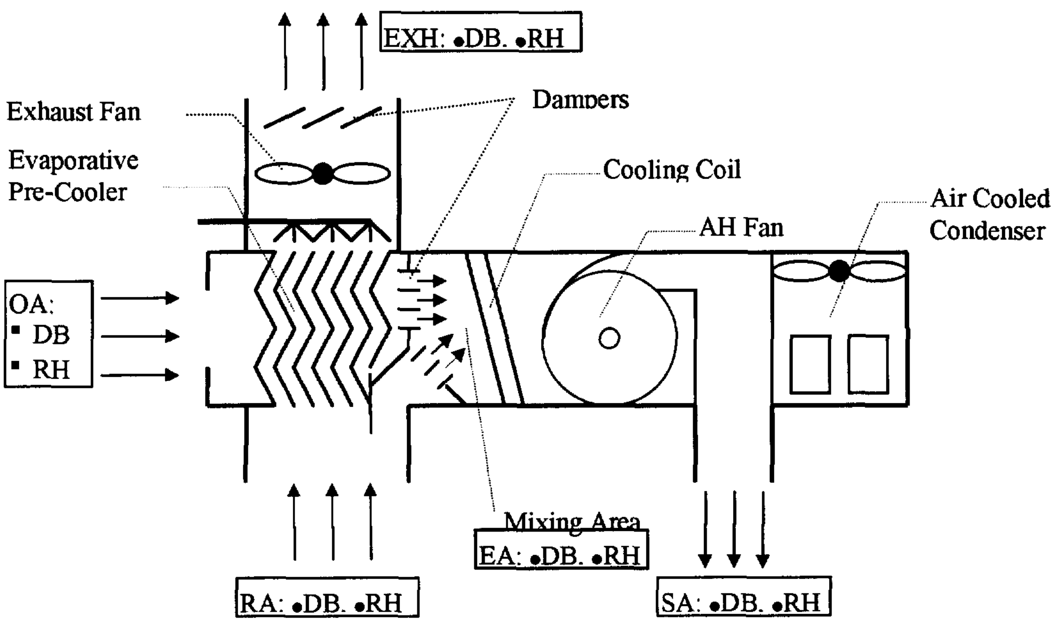


Figure 4. Conference Center RTU

Three-phase current was measured for the conference center units with 100 amp current transducers. Current was read at one minute intervals and every 10 minutes the average of the past 10 readings was recorded. A 'calibration' of current transducer signals against true RMS power was obtained from separate test data for each unit. Simultaneous readings of transducer current and true

RMS power were manually recorded as the conference Center unit was cycled through operation of the evaporative cooling water pump only, AHU fan only, and each compressor (two compressors total). It was not possible to cycle the evaporative pre-cooler exhaust fan without significant modifications to the control system.

Short Term Tests

A volumetric airflow hood was used to measure conference center supply and return air flows. The flow hood's rated accuracy was ±25 cfm. The thermostat was set at a low temperature to activate the cooling system. The airflow in the three return registers and eight supply registers for the conference center were measured. At least 5 points were taken and averaged per measurement. Register labels are shown in Figure 4. The sum of the supply flow was taken as the fan flow, a method that does not consider duct leakage. The ducts were located in the space between the roof and conference room ceiling (the conference room was a built-up substructure, with an insulated ceiling). Any duct air leakage was essentially lost to outside through this well-vented space.

Measurements of airflow out of the closed exhaust dampers were made with a volumetric flow hood. Although the measurements were crude (the flow hood did not completely cover the dampers, and there were strong breezes during the measurement period which affect both the actual airflow and the flow measurement) the test revealed approximately 240 CFM airflow from the dampers, when wedged open, and no measurable flow when closed. (Three measurements were made: once with the flow hood over a flat surface - i.e. no flow, once with the flow hood over the closed exhaust dampers, and once with the flow hood over wedged-open exhaust dampers. At least 11 data points in each case were taken and averaged. The results: 71 cfm over flat surface, 68 cfm over closed exhaust dampers and 310 cfm over wedged-open exhaust dampers)

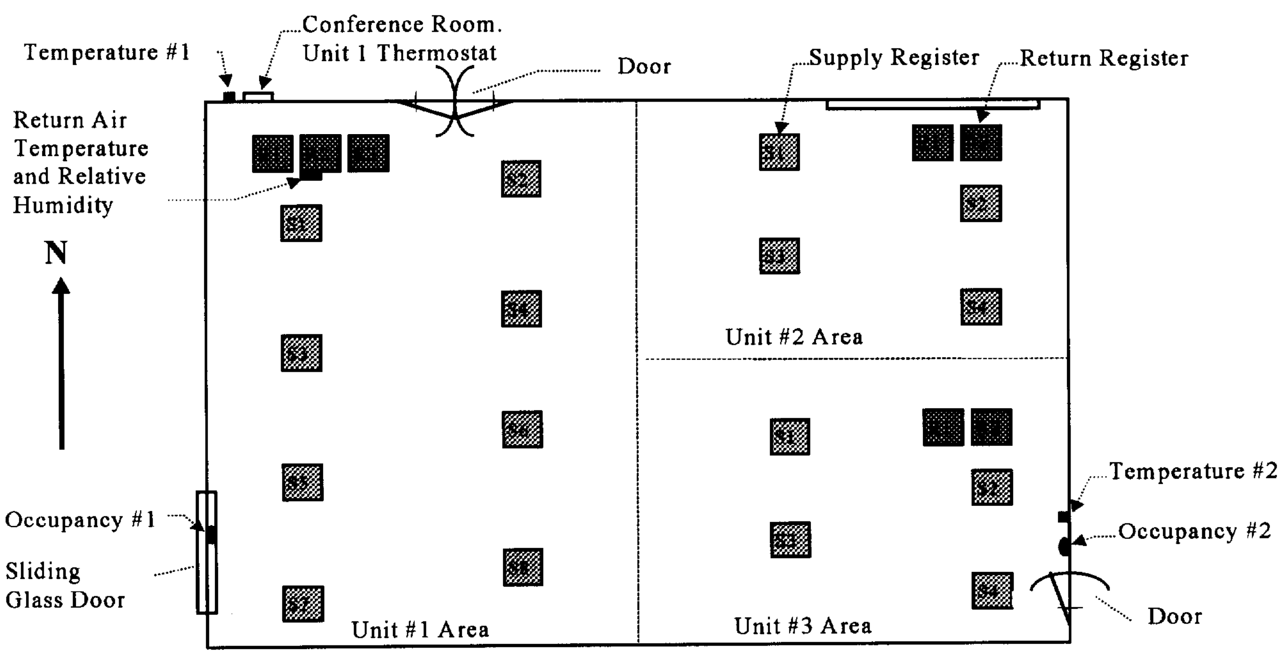


Figure 5. Conference center room and sensor placement.

DOE2 Simulation

The commissioning team used the DOE 2.1E building energy simulation tool to model the conference center space. The model has two components:

- A Base Case representing the as built building and HVAC system.
- A Proposed Case representing the as built building and HVAC system with a fully functioning evaporative pre-cooler system.

The model inputs were calibrated, to the extent possible, to measured data. This includes occupancy schedule, air delivery rates, thermostat setpoints, lighting power density, monitored weather data and occupant density. The conference center is a new building, thus, utility company billing history was not available for calibration purposes.

Modelling Results

The Doe 2 modeling results indicate that the evaporative pre-cooler, using the exhausted return air as a source, can meet the conference center cooling load on all but the hottest peak load periods. Energy use for the RTU compressors, condenser fans, supply air fans and exhaust air fans are reduced by around 50% annually. A bonus energy savings that is not normally considered with evaporative cooling is the wintertime heat recovery from the exhausted return air stream. This reduces the annual energy required to heat the outdoor air by nearly 50%.

Energy savings are significant but they are not adequate to offset the cost of the addition of the evaporative pre-coolers to the roof top units. Energy savings for each of the three roof tip units under consideration at the conference center are on the order of $400 to $500 per year. The add-on evaporative pre-coolers cost on the order of $3,000. This is over a six-year simple payback. Discussions with the pre-cooler manufacturer indicates that significant cost reductions would be available if the units were mass-produced and in widespread use.

Analysis of Air Flow Data

Table 1 shows the measured register air flows and the design air flows, as taken from blueprints of the conference center HVAC installation. The table clearly shows that the measured supply flows exceed the design values by 35% to 40%. This appears to be the result of considerably less external (to the RTU) static pressure drop in the duct and diffuser system than that shown on the design documents. The documents show 1.5 inches of external static. Calculations and measurements indicate only 0.5 inches external static pressure drop.

The return air flow is as much as 100% less than design. This is a result of the indirect evaporative cooler exhaust fan being controlled 'off' 100% of the time during the monitoring period. Static pressure relief is accomplished through open doors and by exfiltration from the space rather than being returned through the RTU economizer damper.

From the air flow measurements, less than 50% of the RA was cycled through the partially opened RA damper and through the RTU DX coil/heating elements. The remainder of the supply air was not returned to the RTU but was exfiltrated through the doors and other openings in the space. The unit was operating at about 50% OA even when the assembly spaces were unoccupied. Ventilation code requirements only apply to the assembly spaces when they are occupied. At all other times the RTU could operate at a minimum OA setting.

This imposed a significant energy penalty on the operation of the RTU in both hot and cold weather. This energy penalty would be largely offset by the operation of the evaporative pre-cooler during hot weather. An additional benefit in winter would be the use of the indirect evaporative cooler air-to-air heat exchanger for exhaust air heat recovery and warming of the OA. However the exhaust fan did not operate and no measurements were made to investigate the heat recovery performance of the RTU.

Analysis of monitored data

Roof Top Unit (RTU) Amps: For the monitoring period, the evaporative cooler pump and the RTU fan appear to be running almost all of the time. The fan was turned to the 'manual on' operating mode apparently in anticipation of events at the conference center during the afternoon and evening. Observations by the monitoring team indicated that the evaporative cooler pump is running around the clock although the evaporative pre-cooler never operates.

Outside air (OA): The outdoor air and relative humidity follow a typical California Central Valley diurnal cycle for late summer, ranging from a low in the mid 60 °F at night to a high of approximately 90 °F in the late afternoon. Relative humidity varies from a low in the 20% during the day to approximately 45% at night. Examination of a psychrometric chart at these conditions shows the specific moisture content is relatively constant day and night.

Table 1. Conference Room Air Flows

Register Air Flows	Unit #1 Air Flow, CFM		Unit #2 Air Flow, CFM		Unit #3 Air Flow, CFM	
Register	Design	Measured	Design	Measured	Design	Measured
R1	1150	489	850	619	850	476
R2	1150	547	850	488	850	475
R3	1100	548				
Total Return	3400	1,584	1700	1,107	1700	951
S1	425	637	425	495	425	488
S2	425	654	425	601	425	574
S3	425	619	425	578	425	655
S4	425	644	425	540	425	602
S5	425	643				
S6	425	554				
S7	425	641				
S8	425	670				
Total Supply	3,400	5,062	1,700	2,214	1,700	2,319

Return Air (RA): The return air temperature is relatively constant through the monitoring period and is in the range of 68 to 72 °F. One would expect that the return air temperature would be closer to the room temperature or in the range of 75 to 78 °F. The return air temperature sensor is located at a return air grille in the conference center space. This location is within a few feet of a supply air grille.

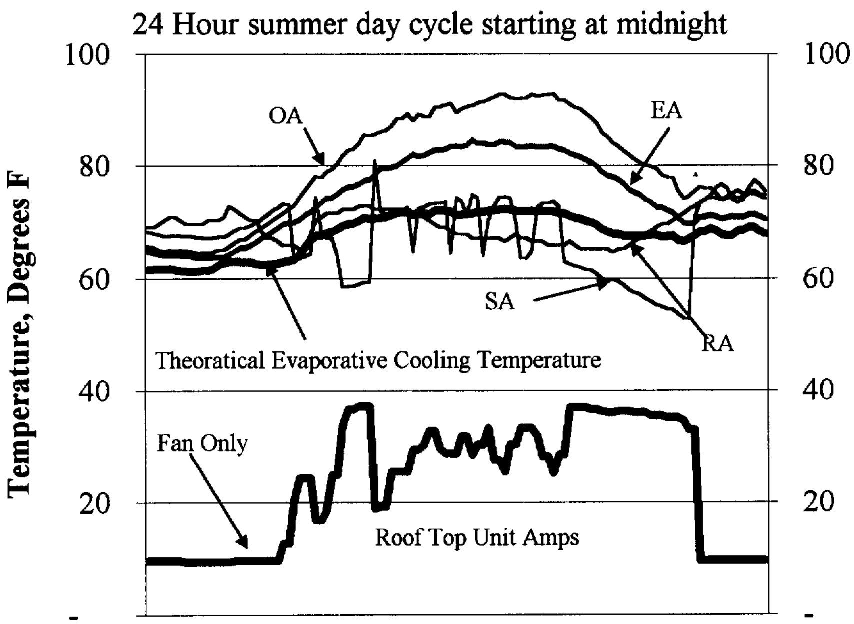
There is an apparent short circuit of cooler air from the supply air grille which is influencing the RA temperature. A subsequent decision was made to relocate the RA sensors to the RA duct just before it enters the RTU.

Supply air (SA): The SA temperature is in the low 60 °F range when the compressors are cycling. This is a few degrees warmer than one would normally expect for the SA. Measurement of air flow shows that the RTU is delivering around 5,000 CFM to the space. The design air flow for the space is 3,400 CFM at 60.6 °F SA. The warmer SA is directly attributable to the increased air delivery.

Evaporative Cooled Air (EA): The indirect evaporative cooler exhaust fan has not operated at any time during the monitoring period. The purpose of the exhaust fan is to exhaust and evaporativly cool the RA stream as it passes through the evaporative media. This exchange of heat between the two air streams could significantly reduce the temperature of the entering outdoor air. The indirectly evaporatively cooled OA serves as the fresh air intake for the RTU.

The EA temperature tracks the outdoor air temperature (OA) during the hottest periods of the a relatively insignificant set of monitored data since the exhaust fan was not operating at any

Figure 6



Typical 24 Hour Monitored Data Series

time during the monitoring period. A small fraction of the supply air was being exhausted through the evaporative pre-cooler. These data provide a reference point for the theoretical evaporatively cooled air temperature. If the exhaust fan were operating as designed, the exhaust air temperature would equal the theoretical evaporatively cooled air temperature.

Psychometric calculations, taking into consideration the effectiveness of the evaporative media and heat exchanger, indicate that indirect evaporatively cooled outdoor air temperature should be on the order of 58 to 62 degrees F range. This would be the case if the evaporative cooling system exhaust fan were operating. This is referred to as the Theoretical EA and is plotted on the chart as a thick line in

Figure 6. Note from the chart that if the evaporative cooler were operating as designed, it could satisfy the entire load with the exception of the heavy loads at peak occupancy periods in the evenings of a summer day. controller controls the evaporative pre-coolers.

The evaporative pre-cooler manufacturer notes that the RTU economizer cycle controller controls the evaporative pre-coolers. The pre-cooler exhaust fan is set to turn on when the economizer damper is in the 25% open position. It continues to operate as the economizer damper cycled through full open or 100% OA position. The economizer damper is typically 100% open when the OA temperature is lower than the RTU SA temperature. This is exactly opposite of the expected operation of the evaporative cooler exhaust fan. The fan should be on when the OA temperature is 65° F and rising and off or at low speed when the OA is below 65° F. To operate pre-cooler in this optimal mode, the RTU/evaporative pre-cooler control system needs a significant redesign or should be completely replaced.

Conclusions

The evaporative cooling installation at the Heidrick Agricultural Museum and conference center has most of the elements required for a successful installation. Parts of the installation do need to be improved upon or completely replaced in order to realize the full energy savings potential of the evaporative pre-cooler installation.

Monitored data and site observations indicate that the evaporative pre-cooler does not operate when the OA temperature is highest when it would provide the greatest energy savings. Measurements showed air dampers operating as would be expected from an economizer cycle, exactly the opposite of the expected pre-cooler operation.

The commissioning team therefore recommended control strategy changes for the RTU and other evaporatively pre-cooled systems on the roof. This control strategy, outlined in the previous section, was recommended to the building owners and their design team. Follow-up monitoring is planned to determine actual performance under the new control strategy. In addition, wintertime monitoring may be done to investigate the RTU's heat recovery performance.

Our investigation concludes that in buildings with high outdoor air requirements, evaporative pre-cooling, using building exhaust air as the indirect evaporative cooling source, offers the opportunity to significantly reduce building energy consumption. This evaporative pre-cooling technology works in any climate since the return air stream exhausted from the occupied spaces provides a relatively constant temperature and humidity source for evaporative cooling. An added benefit is that the evaporative pre-cooler heat exchanger recovers significant heat from the exhausted return air stream in cold weather.

References

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