PROJECT REPORT

COOLERADO H80 FIELD REPORT

University House at UC Davis
&
Embry-Riddle Aeronautical University and Fleet & Family Services Building at NAWS China Lake

December 20, 2013

WESTERN COOLING EFFICIENCY CENTER

UC DAVIS
UNIVERSITY OF CALIFORNIA

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ABOUT THE WCEC

The Western Cooling Efficiency Center was established along side the UC Davis Energy Efficiency Center in 2007 through a grant from the California Clean Energy Fund and in partnership with California Energy Commission Public Interest Energy Research Program. The Center partners with industry stakeholders to advance cooling-technology innovation by applying technologies and programs that reduce energy, water consumption and peak electricity demand associated with cooling in the Western United States.

ABOUT SPEED

The State Partnership for Energy Efficient Demonstrations (SPEED) program drives the market adoption of energy efficient technologies as a part of California's commitment to a clean energy future. Managed through the California Institute for Energy and Environment (CIEE), SPEED has been highly successful in conducting more than 100 demonstrations and other technology-transfer projects to showcase the benefits of best-in-class technology solutions in installations across the state. SPEED is a program of the Public Interest Energy Research (PIER) program of the California Energy Commission.

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1.0 EXECUTIVE SUMMARY

Cooling and ventilation accounts for 50% of peak demand energy and over 25% of total energy used in California's commercial buildings. Especially in hot-dry climates, there are many opportunities to reduce energy use from these systems without sacrificing comfort by employing climate-appropriate technologies. Specifically the use of evaporative technologies in hot-dry climates have great potential to reduce both total energy use in HVAC and significantly reduce peak-demand.

Acceptance of new HVAC technologies is typically a slow process with many market barriers. A typical commercial HVAC product runs for more than 15-years before being replaced. Because of this, it becomes a more difficult proposition for a manufacturer to change up their production formula unless market demand can be realized. In light of this, The California Energy Commission's Public Interest Energy Research (PIER) program gave initial funding to the Western Cooling Efficiency Center at UC Davis (WCEC) to create a program that works to advance the market introduction of commercialized climate-appropriate products. This program, called the Western Cooling Challenge, is a multi-winner ongoing competition that encourages HVAC manufacturers to develop climate-appropriate rooftop packaged air conditioning equipment (RTU) that is at least 40% more efficient in laboratory tests than standard, DOE 2010 RTUs. The Challenge advocates for WCC Certified equipment to major stakeholders including Utilities and government agencies. Because of market barriers, the Challenge encourages participants to consider design factors that are not strictly energy related, such as cost-effectiveness, system reliability, and non-energy code compliance when creating a new HVAC unit. WCEC also works with the manufacturers to aid in the design process, to help maximize product efficacy.

Integral to the creation of the Western Cooling Challenge is WCEC's partnership with the California Institute for Energy and Environment (CIEE) in the management and procurement of demonstration sites. CIEE has managed over 100 demonstration sites in the PIER State Partnership for Energy Efficiency Demonstrations (SPEED) program.

The Western Cooling Challenge includes the certification of the first climate-appropriate RTU from a major manufacturer: the Trane Voyager DC. WCEC facilitated the installation of five Voyager DC systems for pilot study and analyzed the performance data for these systems. Also, WCEC expanded the product scope for the Challenge to include other climate-appropriate technologies such as Dedicated Outside Air Systems and Indirect evaporative add-ons in 4 pilot field evaluations for these technologies.

DEMONSTRATION SAVINGS: UC DAVIS & CHINA LAKE (for September 2012)	
Peak Savings	25-37%
Cooling Energy & Co_2 Savings	11-29%
Water Usage	315 gal/day

This document summarizes the field test portion of the Western Cooling Challenge on a prototype hybrid RTU, the Coolerado H80, at two different locations: University House at the University of California Davis and Embry-Riddle Aeronautical University and Fleet & Family Services Building at NAWS China Lake. The project demonstrates the efficacy of this specific manufacturer's climate appropriate RTU product and includes efficiency data, energy use, modes of operation data and cumulative energy consumption as compared to the existing equipment. Through monitoring of this RTU in climate zone 12 (UC Davis location) and climate zone 14 (China Lake location), it was determined that this RTU saw average cooling savings of 29% and a reduction of peak demand by up to 37%. Even with these savings the first cost was quite significant. This cost, along with operational factors led the manufacturer's decision to discontinue production of the H80. The savings potential from this product and its Indirect Evaporative cooling has helped increase the availability of other climate appropriate HVAC products and solutions.

After evaluating the Coolerado H80, WCEC, SPEED and PIER learned about the advantages and disadvantages of this particular system. These points are detailed further in section 5.

2.0 ABOUT THE TECHNOLOGY

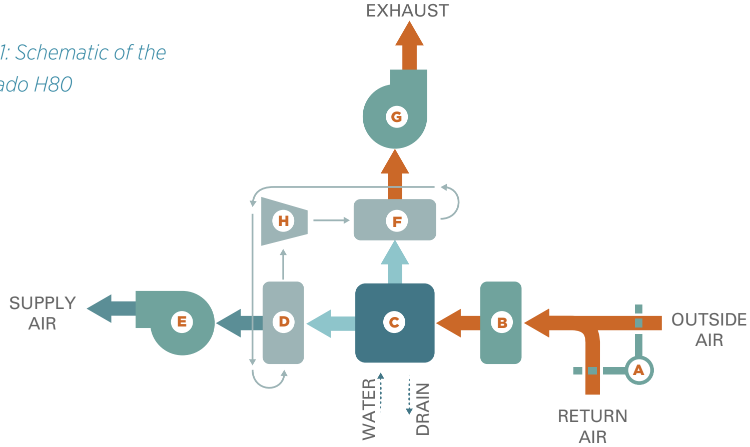
The core of Coolerado's hybrid rooftop unit is an innovative indirect evaporative cooler which employs the Maisotsenko Cycle to condition air evaporatively, but without adding humidity. A mixture of room air and outside air is drawn into the indirect evaporative heat exchanger through dry passages; a portion of this air bleeds to separate wetted passages where evaporation occurs. The separate passages are arranged as a cross-flow heat exchanger so that cooling from evaporation in the wet passages is transferred to air in the dry passages while all added humidity remains in the wet passage and is exhausted. Coolerado calls its indirect evaporative device an HMX, for Heat and Mass Exchanger, and uses this term to indicate when the unit is operating in an evaporative only mode

The indirect evaporative cooler can operate alone or in conjunction with the two stage vapor-compression system providing additional cooling capacity when needed. When the compressor operates, exhaust from the indirect evaporative cooler is used for cooling the condenser. Since it is cooler than outside air, this enhances the capacity and efficiency of the vapor compression system. The supply and exhaust fans are both variable speed, driven by electronically commutated motors, which enable part load operation when only a fraction of the full load capacity is needed.

Motorized dampers control the balance of outside air and return air, and the system operates with a minimum outside air fraction of approximately 45%. Since the flow rate of mixed air must feed the supply air stream and the condenser air stream, the system cannot operate as recirculation only. The benefit of this fact is an improved indoor air quality due to increased ventilation rate. When there is no call for cooling, the variable speed supply fan, driven by an electronically commutated permanent magnet motor, operates at a minimum speed to maintain minimum ventilation rates with low fan energy use.

Water for the evaporative cooler is delivered directly to the media without need for a pump. There is no sump for the system, and water is only delivered as needed according to the anticipated evaporation rate. Water treatment is not needed, and the potential for mineral deposits is managed by supplying excess water to flush the heat exchanger and avoid adherence of solids.

Figure 1: Schematic of the Coolerado H80



A. Motorized dampers
B. Filtration
C. Indirect Evap. Cooler
D. DX evaporator
E. Variable speed supply blower
F. DX condenser
G. Variable speed exhaust blower
H. Compressor

FEATURES AND BENEFITS

- Variable speed supply fan reduces energy used for continuous ventilation by more than 90%
- Delivers more fresh air when cooling while demanding less energy
- Indirect evaporative cooler conditions air without adding or removing moisture
- Vapor compression system covers cooling load during hours when indirect evaporative capacity is insufficient
- Indirect evaporative cooler extends economizer operating hours
- Replaces conventional 5 ton rooftop package air conditioner (unit is heavier than conventional 5-ton RTU)
- Does not require water treatment (water connection required)

3.0 DEMONSTRATION: UNIVERSITY HOUSE AT UC DAVIS

A Coolerado H80 was installed at the University House at the University of California Davis. The building is a single story wood structure. Originally constructed as a home in 1908, it has since been converted to an office which houses Services for International Students & Scholars. The hybrid was installed in place of an antiquated 7 ton RTU with vapor compression cooling and gas heating. The existing equipment was a constant volume machine, and delivered roughly 1,625 cfm supply air. The outside air damper position was fixed to provide some fresh air when the system was operating, and there was no economizer. The supply fan only operated in conjunction with a call for heating or cooling, rather than operating to provide continuous ventilation during all occupied hours. The existing equipment was monitored for six weeks prior to the replacement, and the baseline sensible space cooling COP was observed to range between 1.8 and 2.5 depending on outside air temperature, as plotted in Figure 2.

The H80 was installed in August 2010, and was observed for beta testing and troubleshooting over the following year, during which time numerous minor changes were made to the system. In August 2011, Coolerado replaced the indirect evaporative heat exchanger to remedy a manufacturing defect that caused a minor water leak, and replaced the secondary fan with one that would move more air than the original. The results presented here reflect operation in September 2011, after these revisions were conducted.

Coolerado H80 installed at the University House at UC Davis

FIGURE 2: SENSIBLE ROOM COP OVER OUTSIDE AIR TEMPERATURE

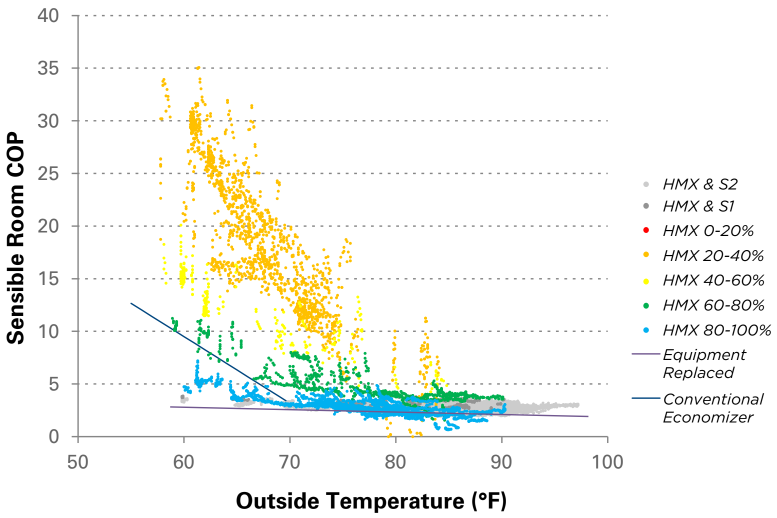


Figure 2: Sensible Room COP for the Coolerado H80 at different operating modes and outside air temperatures. Replaced equiment included.

3.1 RESULTS

Figures 2 illustrates the variation in the sensible room coefficient of performance (CoP) for each operating mode as a function of outside air temperature. The plot bins operating modes into 5 HMX only modes (indirect evaporative cooling modes) categorized by fan speed percentile, and also 2 HMX + DX modes where both the HMX and the vapor compression systems are operating. Sensible room performance is used because it more closely approximates the useful cooling of a system in a western climate by only crediting sensible cooling of the room air. As shown in the figure, the Coolerado's efficiency is greater than the equipment replaced, especially at cooler temperatures. In fact, the Coolerado is, in many cases, more efficient than a modeled conventional economizer. The efficiency numbers are greater for the Coolerado, but the overall energy savings that this might suggest is somewhat offset by the fact that the Coolerado brings in a significantly larger volume of ventilation air that it then must cool to set-point.

The Coolerado H80s' systems operate at a multitude of varying speeds depending on capacity demand. This variance is the key to much of the efficiency gains over constant speed systems. What is of particular interest is the percentage of cooling time for the more efficient operating modes (ie: HMX only) are running versus the runtime when full capacity is demanded and the second stage compressor kicks in. Measured performance for the Coolerado H80 shows significant energy saving compared to the 7-ton system that was replaced. In particular, peak demand savings for periods above 95°F were 25%.

Figure 3 shows the Coolerado responding to capacity demands at specific outside air temperatures by varying cooling modes to meet the required kBTU of capacity. The plot bins operating modes into 5 HMX only modes (indirect evaporative cooling modes) categorized by fan speed percentile, and also 2 HMX + DX modes where both the HMX and the vapor compression systems are operating, 2 Heating modes and a ventilation only mode*. As shown in Figure 3, when outside air temperatures are below 85°F in the early afternoon a significant portion of the cooling is served by the HMX system alone.

FIGURE 3: ROOM COOLING KBTU FOR MONTH OF SEPTEMBER

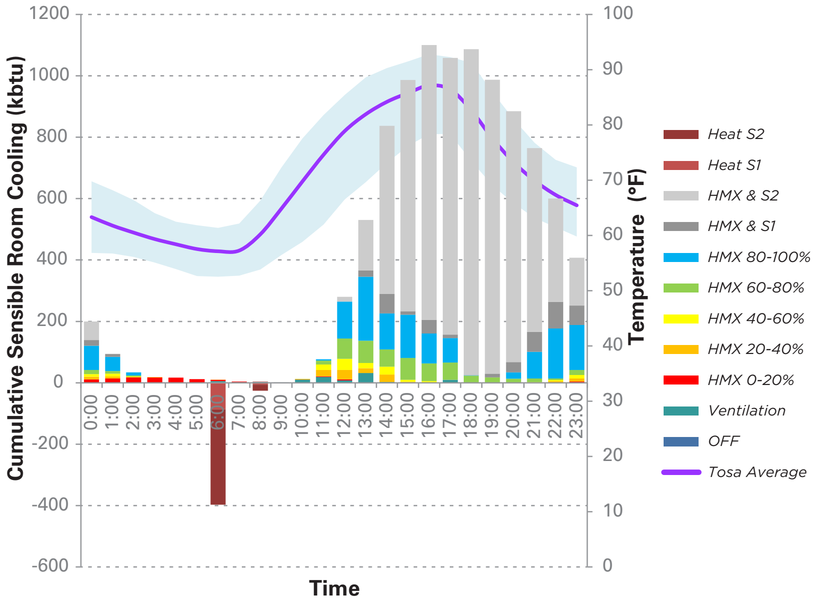
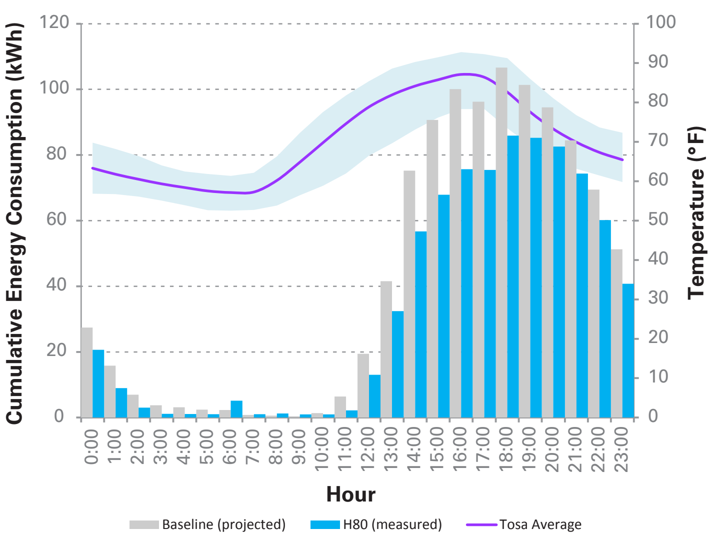


Figure 3: Average sensible room cooling in kbtu for month of September

One would expect the HMX system to handle more of the cooling needs when outside air temperatures are below 80°F in the late afternoon, but this is not the case in this field study. In fact, the Coolerado spent roughly 55% of cooling hours operating with the vapor compression system and was not able to maintain the set point during all cooling hours. The likely reason is due to the increased building loads because of built up heat during the peak hours. The system's capacity requires full operation even past 21:00 (outdoor temperature average of 70°F) because it is still working to reduce the built up load during the peak hours. This is likely a result of the system being sized slightly smaller than required, the thermal loads in the building are much greater than expected due to duct or envelope leakage, or both. The opposite effect is also observed at 13:00 when the building has been cooled the night before, thus not requiring as much compressor power even though the average outdoor temperature is 85°F.

FIGURE 4: CUMULATIVE ENERGY CONSUMPTION IN SEPTEMBER H80 VS. BASELINE



Even though the 5-ton Coolerado may have had capacity issues in this application and ran at maximum capacity for the majority of cooling hours, the Coolerado H80 used roughly 11% less energy than the RTU that was replaced and energy during peak hours was reduced by 25% (during periods of 95°F and above). Given that the indirect evaporative cooler in this system can generally achieve a 4°F wet bulb approach, one would expect much larger savings if the system was installed to serve a smaller load, thus reducing the vapor compression operating hours.

Water use in this system was observed to be more than 250 gallons per day, depending on the outdoor air conditions and cooling load. It should be noted that globally, the amount of energy saved through improved efficiency may more than offset the water consumed by displacing upstream water consumption for power generation. Scale formation due to hard water was not observed to cause any performance degradation.

**The ventilation only mode pulls mixed air from the return and outside airstreams through the IEC while the exhaust fan is off. Since cooling for the IEC requires the exhaust fan to run air through the wet channels, the air in ventilation mode is not cooled.*

4.0 DEMONSTRATION: CHINA LAKE

A Coolerado H80 was installed at the Embry-Riddle Aeronautical University, Fleet & Family Services at NAWS China Lake. The building is roughly 1,000 square feet and includes 4 rooms: 1 office and 3 meeting rooms. The construction consists of concrete masonry walls with no insulation, metal doors, and an attic with inadequate insulation. The ductwork was found to be poorly balanced. This caused difficulty in attaining equal flow to the supply diffusers, leading to huge variations of temperature in the supplied zones. The room with the thermostat and the largest thermal load received the least amount of airflow (roughly only 200CFM of cooling from a unit that puts out 1,500CFM of cooling). Conversely, the room that received the largest amount of cooling (roughly 600CFM) had the least thermal loads due to its northern exposure orientation. Also of note, the ductwork system was found to leak roughly 30-40% of its supply air to unconditioned space.

The Coolerado H80 was installed in April 2012 and replaced a single-zone, constant volume rooftop unit. Monitoring data was collected for the period of July 2012-Fall 2013. The results presented in this report reflect the data collected for the month of September 2012 as this month had a good range of temperatures to pull from.

4.1 RESULTS

FIGURE 5: CUMULATIVE SENSIBLE ROOM COOLING KBTU FOR SEPTEMBER 2012

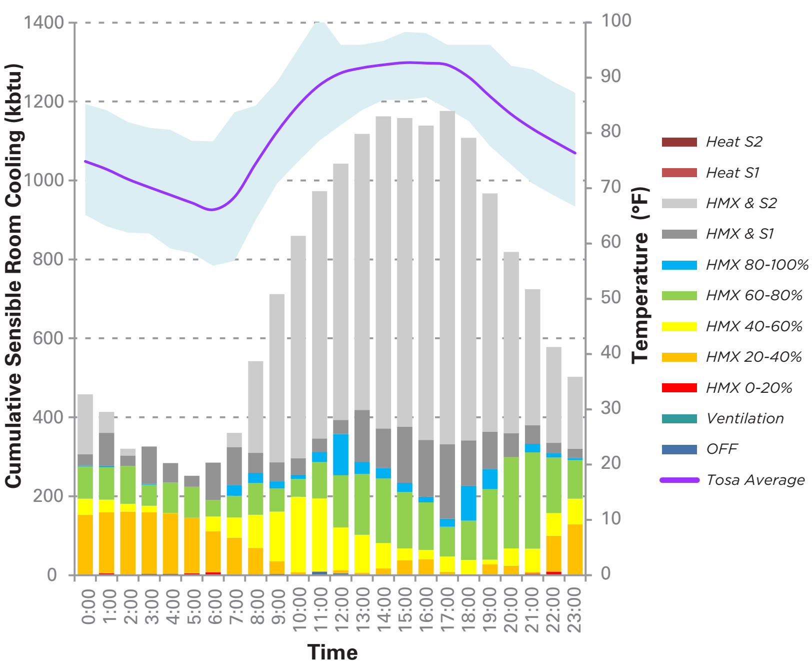


Figure 5: Average sensible room cooling in kbtu for month of September

Figure 5 shows the Coolerado responding to capacity demands at specific outside air temperatures by varying cooling modes to meet the required kBTU of capacity. The plot bins operating modes into 5 HMX only modes (indirect evaporative cooling modes) categorized by fan speed percentile, and also 2 HMX + DX modes where both the HMX and the vapor compression systems are operating, 2 Heating modes and a ventilation only mode*. As shown in Figure 5, a significant portion of the overall cooling, roughly over 35%, is served by the HMX system alone. The likely reasons for the added HMX effectiveness are due mainly to the relatively small floorspace served by this unit in this installation (approximately 1,000 square feet), and its location in one of the most ideal climate zones for evaporative cooling, climate zone 14.

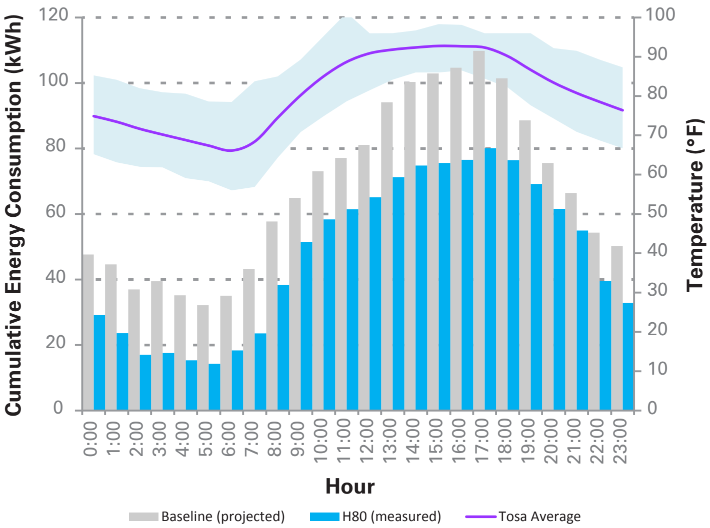
Unfortunately, access to the site prior to installation of the H80 was not possible, and therefore there is no specific energy data for the unit that was replaced.

**The ventilation only mode pulls mixed air from the return and outside airstreams through the IEC while the exhaust fan is off. Since cooling for the IEC requires the exhaust fan to run air through the wet channels, the air in ventilation mode is not cooled.*

For illustrative purposes, Figure 6 shows a modelled estimate of energy consumption of the equipment replaced based on the pre-install data for the original RTU used in the UC Davis installation. Figure 6 shows cumulative energy consumption for the H80 at China Lake as compared to the modelled baseline. Unlike the H80 UC Davis installation, the H80's performance at China Lake looks to be much more in line with its predicted specifications. The H80's overall energy savings for the month of September is 29% when compared to our modelled replacement unit. Energy reduction during peak hours was even greater, reduced by 1.9kW, or 37% over the predicted baseline. These results are quite favorable, especially considering the supply airflow rate for the H80 was measured at 30% lower than the nameplate. This reduction in supply airflow was due to restrictions placed in the distribution system in order to balance the air supplied to each room. One can also reasonably assume that the overall cooling portion supplied by just the HMX system alone (roughly 35%) and energy savings could be increased significantly by sealing the ductwork. The duct leakage to unconditioned space was observed to be between 30-40%, and thus the system had to overcome this large reduction in conditioned airflow by running at a higher capacity, or more specifically, running more often in combined HMX and compressor modes.

Water use in this system was observed to be more than the UC Davis installation, roughly 315 gallons per day on average in September. The increased water consumption is likely due to the hotter, drier climate conditions at USN China Lake. A minimal amount of solid deposits were found at the heat exchanger inlet and exhaust, though no build-up was found in the heat exchanger channels and thus, no performance degradation was observed.

FIGURE 6: CUMULATIVE ENERGY CONSUMPTION IN SEPTEMBER H80 VS. BASELINE



5.0 CONCLUSION & LESSONS LEARNED

The field results for the H80 show that a hybrid approach to cooling can save considerable energy, with even greater savings during peak hours. The caveat to this is that an RTU is only as strong as the weakest link within a conditioned environment. The UC Davis installation clearly shows that the H80 was not appropriately sized for the building loads. It is possible that energy savings could have been greater with just a new, energy efficient 7-ton standard RTU over the H80 simply because it could supply the capacity for the building easier and thus, could run at part loads longer than what was observed with the H80. Even the China Lake results are likely lower than what could be achieved because of the other building factors such as the heavy prevalence of duct leaks and severely unbalanced airflow. Ultimately, the sum of the mechanical systems in a building including proper sizing of equipment/installation, envelope tightness, radiant gains, duct leakage and balance play a large role in a given system's overall energy efficiency success, therefore purchasing decisions for energy efficiency technology should keep these factors in mind before deciding on a system.

The variability in testing technology on a diverse set of mechanical systems and setups are the main reason why the Western Cooling Challenge certification process only judges system performance through laboratory benchmarking. This helps to create an equal playing field and it allows for objective comparisons between isolated pieces of technology tested by the Cooling Challenge.

Coolerado's prototype evaporative DX hybrid technology as tested has been discontinued by the manufacturer. However, the lessons learned from field testing of this prototype have informed the implementation of the Western Cooling Challenge and paved the way for more viable indirect evaporative products now entering the market.

By effectively creating a hybrid evaporative RTU, this product and its subsequent laboratory testing results have acted as a catalyst for other manufacturers to push for the creation of similar systems, and to advance evaporative cooling as a legitimate energy efficiency technology for hot/dry climates. For example, the Trane Voyager DC is an entirely new hybrid RTU by a major manufacturer that has now also met the Challenge requirements in the lab and is currently being pilot tested in 4 locations across California. The Challenge is now also testing Dedicated Outdoor Air Systems (DOAS) from Munters, and Indirect Evaporative retrofits from both Seeley and Coolerado as a result of the Challenge's successful outreach to the industry.

WCEC is collaborating with Lawrence Berkeley National Laboratory to create a hybrid RTU module for energy plus building models. This module will allow engineers, energy managers and other stakeholders to properly assess the energy consumption and capacity for a variety of future hybrid RTUs in modelled buildings. Modelling these technologies can help determine the efficacy of these products for future rebate programs and to predict their success in a diverse set of commercial buildings. This field demonstration's empirical analysis of the behavior of the Coolerado H80 is invaluable to the realization of this type of module for energy modelling software.

SIMPLE ECONOMICS

The economics of installation of indirect evaporative cooling technologies like the H80 can be estimated by looking at the expected savings that can be achieved. For the month of September the H80 was found to use roughly 1500 kWh of electricity and is predicted to save 30% of energy as compared to a conventional air conditioner. Thus, for the month of September, the system is modeled to save 642 kWh of electricity. At $.14 / kWh, this would amount to savings of $90 in the month of September. Annual savings at this rate would be $1,080 / yr. With savings of over $1,000 per year, a significant portion of the cost premium for this energy savings technology can be justified.

LESSONS LEARNED

In the first installation at UC Davis, results showed the H80 to be highly sensitive to unexpected shutdowns of electricity or water. The IEC needs to stay wet to perform at its specification and the system required a manual reset to make it function properly after a shutdown. Newer iterations of the H80 have resolved this issue by employing 3 strategies: 1) If the unit loses power, it will automatically inject a surfactant into the IEC that accelerates the spread of water over the surface of the heat exchanger. 2) The system will shut down automatically if the water pressure delivered to the IEC drops below adequate levels, minimizing any potential damage to the IEC from drying out. 3) The system adds water intermittently to keep the IEC moist even when there is no call for cooling.

The added size and weight was not found to be a significant factor in

[1]Simple payback is calculated based on an average, mixed use commercial building sized at 1,800 square feet. Using the DOE Buildings Performance Database (bpd.lb.gov) shows a cooling electrical load of 49kBTU per sq. ft. This equals 14.35 kWh per sq. ft. per year x 1,800 sq.ft. = 25,830 kWh average electrical cooling usage a year. 25,830 kWh x $0.14 (a base case cost per kWh of energy in commercial buildings in California) = $3,616.20 per year cost for cooling

preventing installation. The unit does require a water connection, but this also was not found to be a significant factor. Water can usually be accessed near hose bibs placed on the exterior of buildings and plumbed to the units.

Another takeaway from the field testing of the H80 is the large fan power requirement due to the high pressure drop across the IEC heat exchanger. The design of the HMX requires that half the air driven through the unit be exhausted, leaving only half of that air available to provide space cooling. Due to the cube-law of fan power, doubling the fan flow rate to meet capacity demands actually increases fan energy use by 8 times. Future iterations of IEC heat exchangers will need to find a way to better balance wet bulb effectiveness and their resistance to airflow (pressure drop).

The H80 does not allow for 100% economizer operation because there is no bypass from the IEC to the supply stream. Therefore, all air that runs to the supply must first go through the IEC heat exchanger. Though IECs are proven to be much more efficient than their DX counterparts at high ambient temperatures, these systems are less efficient than 100% economizer modes at lower ambient temperatures. The reason for this again, is the pressure drop from the IEC requires higher fan energy and, even with the lower supply temperature coming from the IEC as opposed to an economizer, the actual supply flow rate from the IEC may not meet the capacity demand. Redesigning the system to allow for a bypass of the IEC during favorable outdoor air conditions could increase the efficiency of this unit.

The first cost and other operational issues caused the manufacturer to discontinue the H80.

6.0 Collaborators

California Energy Commission provided funding for the two demonstrations of the Coolerado H80 at UC Davis and China Lake. California Institute for Energy and Environment, UC Davis Western Cooling Efficiency Center, provided project management, technical guidance, and performance evaluation.

Any questions about this project, including technology costs, can be directed to:

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