Technology Installation Review

WhiteCap™ Roof Spray Cooling System

Cooling Technology for Warm, Dry Climates

WhiteCap is an integrated roof surface and spray cooling system that is suitable for warm, dry climates. WhiteCap provides a means to evaporatively and radiatively cool water by spraying it over a building roof at night. The cooled water is collected from the roof surface, filtered, and stored for use the following day, where it is used to cool the building either in conventional HVAC systems or by passive cooling of the roof deck or building floor.

This technology installation review outlines the theory behind the WhiteCap system and its design, construction, and operation in three specific design configurations. It then describes the construction, design, and performance of a WhiteCap system recently installed on a Federal building in Nogales, Arizona. Finally, the case study outlines specific considerations for determining whether WhiteCap systems are an appropriate energy-saving technology for existing or proposed building applications at other sites.

Theory and Operation

The WhiteCap system (Marketed by Roof Science Corporation [RSC] of California) comes in three basic design configurations. In all configurations, a water spray system consisting of a piping grid and conventional water spray nozzles is installed on the roof surface and connected to a water pumping and filtration system. During the cooling season, water is sprayed over the roof surface at night. This water is first cooled by evaporation during the spray process and then further cooled by radiation to the night sky. The water cycles through this spray-cooling process until it is cooled to approximately 45-50°F, and then it is stored for later use in providing cooling to the building. Different methods of cooled water storage and ways that water is used to cool the building result in a number of different configurations of the WhiteCap system. The three principal design configurations are discussed below.

WhiteCapR System

In the original WhiteCapR system (see Figure 1a), the roof is constructed to allow a 3-inch-thick layer of water to stay on the roof surface at all times. Interlocking, 4-inch-thick, polystyrene panels float on the surface of the water. These panels are coated with a white, fire-resistant, protective coating and insulate the water layer and roof from heat gain during the day. Spray nozzles are mounted flush with the upper surface of the panels and the spray-system piping runs on the roof surface below. Water is pumped to the nozzles from the water layer on the roof. The spray-cooled water landing on the top of the insulation panels leaks down through joints between the insulation panels and returns to the roof surface, where it is stored for use during the day. The insulating panels reduce any heat gain to the water due to high outside air temperatures or solar radiation during the day. Water cooled at night during the spray process provides passive building cooling via conduction through the roof of the building and to either building space directly below the roof or to the air in a return-air plenum.

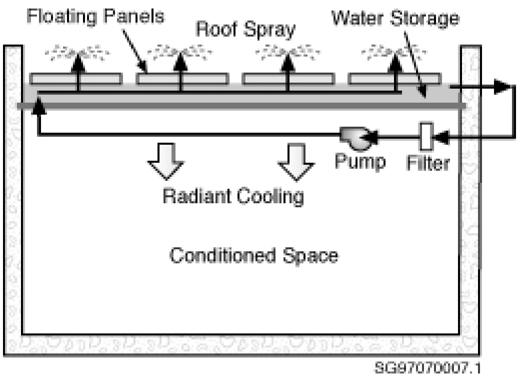

Figure 1a. WhiteCapR System

Because the roof is used for water storage in the WhiteCapR design, building roofs must be level and strong enough to support the weight of water and panels (typically 16-18 lb/ft^2) on a regular basis. This is not as significant an obstacle as it sounds because the weight of a conventional gravel roofing covering may be 50% of the weight of water in the WhiteCapR system. In addition, live roofing loads on the floating panels (such as snow loads or persons walking on the roof) become less significant with WhiteCapR because any weight on the floating panels displaces an equivalent weight of water underneath the panels. This displaced water load first spreads the weight over the entire wetted roof surface and then eventually drains off the roof, removing the live load completely from the roof.

WhiteCapT System

In a WhiteCapT system (Figure 1b), spray-cooled water drains from the roof at night and is stored in a storage tank. When the building requires cooling during the day, cold water can be pumped from the storage tank to cooling coils in a forced-air cooling system. Advantages of the WhiteCapT system over the original WhiteCapR system include ease of retrofit to existing buildings and the ability to use roofs that are not completely level. Because water is not stored on the roof, building construction loads are not increased by the WhiteCapT system, and the roof can be conventionally insulated. However, the WhiteCapT design may increase building fan power requirements because of the addition of new water cooling coils to the HVAC system.

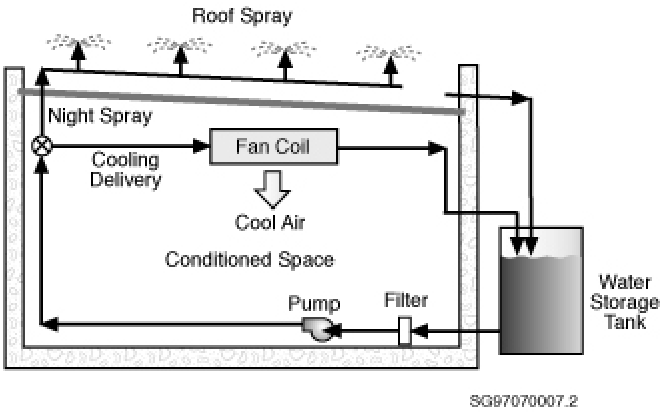

Figure 1b. WhiteCapT System

WhiteCapF System

A third design, called WhiteCapF (Figure 1c), calls for the spray-cooled water to be channeled through coils embedded in the slab floor of the building, and the cooling energy is stored in the massive building slab, reducing or eliminating the need for water storage. In this configuration, most of the cooling is achieved through radiative and convective interchange between the building floor and the occupied space, as shown in Figure 1c. Because water coils are embedded in the slab, builders must plan for WhiteCapF very early in the building construction.

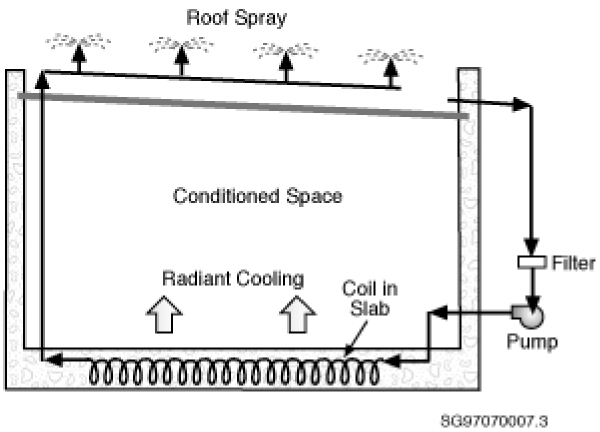

Figure 1c. WhiteCapF System

As of the date of this publication, no pure WhiteCapF designs have been constructed, although slab cooling has been implemented in conjunction with fan-coil cooling in a WhiteCapF/T design for a large California office building. Because of their similarities, the WhiteCapT design can be readily combined with the WhiteCapF design in new construction to form this type of hybrid system. In addition, the storage tank in the WhiteCapT system can be connected to a vapor-compression cooling system, allowing the WhiteCap system to pre-cool water in the storage tank with the vapor compression system providing even further cooling of the stored water.

Design Differences

WhiteCap differs from other roof-spray systems in that WhiteCap systems are designed to use night spray systems to cool water, which is later used for daytime cooling in the building. Other roof-spray technologies rely on the daytime spray to reduce peak roof temperatures and thus building cooling load. The principal advantage of WhiteCap over these other systems is that the WhiteCap spray cycle is done at night, resulting in the lowest possible water temperature for use in building cooling. WhiteCap systems use a control algorithm that relies on daytime peak temperature and evening water temperature measurements to estimate the number of spray hours needed to achieve a target cool water storage temperature. Spray cycle start time is then established by counting backwards from a 6 a.m. target completion time. This algorithm ensures operation of the spray system during the most beneficial cool morning hours. Actual spray operation continues at night until the target tank temperature is reached or the building begins regular operation.

All WhiteCap configurations have as their primary benefit a reduction in building cooling energy use. Other potential WhiteCap benefits can include extended roof life (with the WhiteCapR configuration) and enhanced fire protection as well as the reduction in peak building cooling load and possible downsizing of mechanical cooling equipment.

Potential disadvantages of incorporating WhiteCap systems into conventional HVAC cooling systems include increased first cost of construction, increased risk of water damage, increased water usage and increased building maintenance requirements.

Performance Issues

WhiteCap performance is primarily dependent on outdoor wet-bulb temperature, and secondarily on nighttime sky temperature. Water cooling is accomplished first during the spray process, as direct evaporation of some of the water spray into the air reduces the temperature of the remaining water spray. In theory, the lowest possible temperature that could be reached using spray cooling alone is the outdoor wet-bulb temperature. Practical considerations limit the minimum water temperature that can be obtained using spray cooling alone to a few degrees above the wet-bulb temperature. However, WhiteCap can reduce the temperature of the water to below the wet-bulb temperature by radiating heat to the night sky.

Cooling via night sky radiation relies on the fact that the effective temperature of the night sky can be significantly cooler than the ambient air temperature. Thus, an object set outside at night will radiate more heat to the night sky than it will absorb from the night sky and the net loss of heat will cause the object to cool below the surrounding air temperature. In the WhiteCap system, most of the cooling via night sky radiation occurs as the water film left on the roof from the spray process exchanges radiant heat with the night sky. Although evaporative/radiative cooling ponds have been used in the past for building cooling, they are typically much smaller than the buildings that they serve. The large roof area available for the WhiteCap system allows for substantial radiative cooling at relatively little additional building cost.

The effective nighttime sky temperature is a function of both the dry-bulb air temperature and the humidity content of the air, with higher humidity reducing the differential between the effective sky temperature and dry-bulb air temperature. Although not an easily measured parameter, sky temperature data are available in Typical Meteorological Year (TMY) weather data files or can be estimated from other weather parameters using established algorithms (M. Martin and P. Berdahl 1984).

In previous experimental work with WhiteCapR technology in California (California Energy Commission 1992), the Davis Energy Group (DEG), RSC's, parent company, developed an algorithm for estimating hourly cooling energy supplied by the WhiteCap system during operation. The algorithm describes the cooling energy provided during the spray process as:

$Q\ (Btu/ft^2\text{-}hr) = 1.16*(T_{csr}-T_{db}) + 1.68*(T_{db} - T_{wb}) + 0.125*(\Omega_a-\Omega_b)$ (1)

Where

$\Omega_a = (0.01*(T_{csr}+460°F))^4$

$\Omega_b = (0.01*(T_{sky}+460°F))^4$

T_{csr} = Temperature of the water before spray (°F)

T_{db} = Dry-bulb ambient air temperature (°F)

T_{wb} = Dry-bulb ambient air temperature (°F)

T_{sky} = Sky temperature (°F)

The same studies have shown that the minimum water temperature reached during operation was typically 5-10°F less than the minimum dry-bulb air temperature reached at night. The algorithm has been implemented in a research version of the MICROPAS building energy simulation program used by the state of California for estimating building energy use. RSC has used this program to predict the benefits of WhiteCap at various other building sites. Insofar as cooling the water for storage, all WhiteCap systems appear to have similar performance.

Manufacturer's Claims and Potential Savings

Data from past installations of the WhiteCapR system have been analyzed by RSC and have shown these systems to have effective Seasonal Energy Efficiency Ratios (SEERs) of 50-100 [California Energy Commission, 1992]. This compares with SEERs of 8-15 with conventional-packaged HVAC equipment. In studies of existing WhiteCap installations in commercial buildings, WhiteCap systems have provided between 30% and 60% of the buildings' annual cooling loads. As an added benefit, RSC also claims reduction in required capacity of conventional cooling systems. In dry climates, where summer dry-bulb air temperatures fall below 65°F at night, typical WhiteCap system capacities are 25 ton-hours per 1,000 ft^2 of roof spray area. Performance of the WhiteCap technology is strongly dependent on climatic conditions, however, and prior to WhiteCap implementation, performance should be estimated using Equation (1), shown previously.

Aside from energy savings, other benefits claimed for WhiteCapR systems include an extended roof life. This is suggested because most of the degradation to a building roof surface occurs because of weathering caused by large daily temperature variations and by ultraviolet radiation from the sun. However, WhiteCapR roof systems protect the roof with a water layer and insulation panels and little degradation to the actual roof surface is expected over time. Long term panel life has not been established; however, no problems with short panel life have been reported from any of the previous WhiteCapR installations.

RSC also suggests that the use of WhiteCap technology can offset the peak load enough in most buildings to allow for downsizing the mechanical cooling system. The ability to do this will be strongly dependent on weather conditions during the peak cooling days. Climates that are relatively dry year round may derive substantial peak cooling reductions year round. Climates that have relatively humid peak cooling seasons will see more limited reductions in the peak mechanical cooling capacity required for the building.

Typical installed costs for the WhiteCap system can vary significantly depending on specific system designs and building requirements. Installed component costs are estimated by RSC to be between \$2.50/ft^2 and \$4.50/ft^2 of roof spray cooling for buildings with 20,000 ft^2 to 50,000 ft^2 roof area. In new building construction, however, it is the incremental cost of the WhiteCap roofing system and HVAC components over the cost of a more conventional roof construction and HVAC system that is the actual cost to the site. This is particularly true of the original WhiteCapR technology, where the roof design will change to accommodate the technology. In many new buildings however, the opportunity to downsize the building chiller can greatly reduce the incremental cost for the WhiteCap system.

Development and Past Installations

DEG first began work on the WhiteCap technology in 1979. The first WhiteCapR prototype was installed on a residence garage in 1982 and monitored for 10 years. During the early phases of this testing, the group's experiments with the technology suggested it was practical and showed significant energy savings potential. In 1987, DEG won a grant from the California Energy Commission Energy Technologies Advancement Program (ETAP) to further develop the WhiteCap technology. In 1991, a 6,500 ft^2 WhiteCapR demonstration was put together on the California Office of State Printing facility in Sacramento, California, and evaluated extensively by DEG and the California Energy Commission. Further interest in the technology spread in the energy community. After extensive evaluation, the National Institute of Science and Technology (NIST) recommended WhiteCap for funding under the DOE Energy-Related Inventions Program (ERIP). The ERIP grant, awarded in 1994, supports new demonstrations of the technology as well as implementation issues such as building code certifications. NIST research estimated annual WhiteCap energy savings potential of 585 million kWh in the low rise commercial building market (assuming 5% penetration over a 10-year period for new construction).

In 1994, RSC emerged as a spin-off from DEG with a goal to market WhiteCap technology. Although originally spurred on by a strong belief in the energy and building life benefits of the WhiteCapR design, RSC has found it difficult to convince building owners to use the water-ballasted roofing system or to convince code officials about the safety of these systems. For this reason, since 1995 RSC has focused on promoting the WhiteCapT and WhitecapF designs. Net energy benefits are similar with all three configurations, although the designs using cooling coil delivery systems may have additional fan energy penalties and system design costs. Existing WhiteCap installations are shown in Table 1.

Table 1. Existing WhiteCap Installations

Site	Installation Date	Size (ft^2)	Configuration
Davis, CA Garage Prototype	1982	250	WhiteCapR
University of Nebraska Energy Research Center	1989	1,000	WhiteCapR
ETAP demonstration site Sacramento. CA. Office of	1991	6,500	WhiteCapR/F

State Printing			
Bourne home, Davis, CA	1993	1,900	WhiteCapR/F
Verifone Office building (ACT^2 Retrofit Project)	1995	6,000	WhiteCapT
Auburn, CA, Office Bldg. Retrofit	1994	7,500	WhiteCapT
Los Angeles, CA, Economic Development Dept. Bldg.	1996	27,000	WhiteCapF/T
Nogales, AZ, Border Station	1996	5,600	WhiteCapT
Davis, CA, Solar Cooperative Housing	1996	9,500	WhiteCapR/F

Maintenance/Service Requirements

WhiteCap systems are simple in design and control, and properly designed systems should have relatively low maintenance requirements. However, the limited number of installations have resulted in each installation being a test case and learning platform for future installations.

With WhiteCap systems, the main requirement is to keep the water spray system operating. To keep the system free from particulates, WhiteCap filters all water passing through the system with a large sand filtration system. The filter is set on an automatic backwash cycle so that it regularly cleans itself. Reports from past installations have not demonstrated a need for water treatment to prevent bacteria or algal growth as would be required by most open cooling tower systems (California Energy Commission, 1992). This is most likely because the water is not exposed to light for prolonged periods and plant growth cannot be sustained. Water treatment to prevent scale developing inside the spray pipes and coils has also not proved necessary in any of the existing installations, and ordinary tap water is used for makeup to the system. Installations in sites with more dissolved minerals in the water supply may want to consider such treatment for WhiteCapT and WhiteCapF installations.

Spray tubes are installed on a slight slope with a small hole drilled into the lowest end of the tube to allow all water to leak out at the end of a spray cycle. This prevents ice developing inside any of the tubes during cool weather (in dry climates, night sky radiation can cause ice to start forming even on relatively mild nights).

WhiteCap control algorithms are encoded in a microprocessor controller and can be field adjusted for specific installations. The controllers have a 10-year battery backup, and control settings are unaffected by power loss.

Other Considerations

Storage space is a significant consideration for WhiteCapT designs. To store significant amounts of thermal cooling energy requires large volumes of the cool water produced through the WhiteCap roof spray system. Providing for the necessary storage may be a significant expense for some sites.

Water cost is not expected to be a significant expense for WhiteCap system designs. Past evaluations have suggested typical water usage to be from 0.15 to 0.20 gallons/kBtu cooling provided by the WhiteCap system (R. Bourne and C. Carew 1996). However, it should be pointed out that water costs associated with WhiteCap cooling systems are comparable to water costs associated with mechanical cooling systems relying on evaporative heat rejection systems (such as cooling towers).

Case Study Description

This document describes the performance of a WhiteCap roofing system installed on a Port of Entry station building in Nogales, Arizona. Nogales is located in the high desert country of southern Arizona at an altitude of approximately 4,000 feet, and was thought to represent an excellent climate for a WhiteCap system.

The building used in the WhiteCap demonstration is single-story, 8,340 ft^2 in floor area. The building is owned by the General Services Administration (GSA) and is used to control and process commercial transport between the United States and Mexico. It is occupied by approximately 30 persons during the day from both U.S. Immigration and U.S. Customs' offices. Built in 1974, it has concrete walls and built-up roof construction. Adjacent to the building is an approximately 7,500-ft^2-canopy which covers a secondary inspection area for private vehicles. A single 8,500-cfm air handler serves eight zones in the building. Although originally constructed as a dual-deck, air-handling system, the air handler presently is not used as such. Heating and cooling equipment schedules do not allow the building boiler and chilled water system to operate simultaneously.

The chilled water system uses a two-compressor, air-cooled chiller, with the air passing over evaporative cooling pads before passing over the chiller's condenser. Both compressors are equally sized at 21.5 tons, yielding a total chiller capacity of 43 tons. The building's original chiller is still used. According to site personnel, only one of the two chiller compressors ever operates at a time, the other compressor being locked out from use.

Originally, a WhiteCap demonstration was to be added to the roof of a new building constructed at the site, but funding limitations stalled construction of the new building. Because of GSA's interest in the technology, a scaled-down WhiteCapT system (see Figure 1b) was installed as a retrofit to the parking canopy, with the energy benefit applied to the adjacent Port of Entry building. An array of 44 spray heads and piping were installed on the parking canopy to provide 5,600 ft^2 of spray coverage for the WhiteCap system. Figure 2 shows a photo of the existing system with the roof spray in operation. Previously existing roof drainage on the canopy was channeled to 4-inch piping running down the two longest sides of the canopy. These roof drainage lines were then channeled into a single 5-inch pipe that empties into the top of a 10,500-gallon, site-constructed, cold-water storage tank. During operation, the entire roof sprinkler system is fed by a single 3-inch water line from the base of the cold water storage tank.

Figure 2. Nogales WhiteCap System

The WhiteCap pump system uses a single 3/4-hp pool filtration pump to provide the night water spray, the filtration of tank water, and to send water through a 4-row cooling coil installed in front of the existing HVAC coils in the system.

The major construction activity for this project was fabrication of the water storage tank. The tank is of wood frame wall construction, with 2 x 10 studs spaced 12 inches on center. R-30 fiberglass batt insulation was used to insulate the sides of the tank. The top and bottom are insulated to R-25 and R10.8, respectively, using rigid foam insulation. Plywood faces the interior and exterior faces of each panel. Exterior dimensions of the tank are approximately 9 ft high, 27 ft long, by 8 ft wide. A custom-made liner hangs inside the tank to hold water. Figure 3 shows a picture of the tank taken prior to the application of a stucco finish over the plywood surface.

Figure 3. Nogales Water Storage Tank (under construction)

Installation of the WhiteCap system was begun on September 1996 and completed over a 10-day period. Total cost for design and construction of the system was approximately $28,500. Table 2 shows approximate installed costs for this type and size of system when retrofit to an existing building. These unit costs for the Nogales installation are based on a 6,000-ft^2 spray area, a 10,500-gallon storage tank, and approximately 250-foot separation between the cooling coil and the farthest roof drain location. The Nogales installation costs are relatively high on a per unit basis because of the small size of the project. The largest single component cost, that of the storage tank, can be expected to drop to approximately $1.00/gallon or less for tanks 30,000 gallons or larger.

Table 2. Installed Costs for WhiteCapT Retrofit (estimated from Nogales demonstration)

Item	Estimated Cost
Roof Spray Piping Array	$400 per 1000ft^2 of roof coverage
Cooling Coil	$1500 per 1000ft gallons
Pump/Filter Hardware & Controls	$700 per 1000ft^2 of roof
Connecting Piping	$16 per lineal foot drain to coil

Monitoring

A "bare bones" monitoring system was installed at the WhiteCap demonstration in Nogales. This system monitored the following points:

- outdoor air temperature
- upper storage tank temperature
- lower storage tank temperature
- return air temperature

- pump operation (on or off).

Data were originally collected at 10-minute intervals using a Datataker programmable data logger and downloaded to RSC. The data collection system was installed primarily as a tool to troubleshoot and notify RSC of any potential problems with the WhiteCap operation. Although not designed as a tool for detailed energy savings calculations, the change in average tank temperature during the spray cycle can provide a rough estimate of the thermal cooling energy provided by the WhiteCap installation. Unfortunately, communication difficulties were experienced early in 1996, and only the data from the first month after installation were collected in 1996 (September 25, 1996, to October 24, 1996). A site visit in January 1997 corrected the problem, and data collection resumed on January 26, 1997. On a later site visit (March 10, 1997), the data logger was reprogrammed to take data at 15-minute intervals.

The system was operated until March 26, 1997. On that date, a rupture in the tank wall occurred, draining the system and forestalling any operation until its repair on April 12, 1997, by RSC. Since that time, the system has been in more or less continuous operation. The system has been shut down for brief periods (1 to 3 days) either to accommodate repair to unrelated building systems or to prevent overcooling of the building.

Measured Performance

Measured performance for the Nogales WhiteCapT system is based on the daily reduction in tank temperature achieved during the spray cycle. Two temperature sensors were originally installed in the tank system; however, only one remained functioning after repair of the tank in April, and as such, can only provide a rough indication of tank water temperature. In addition, not all of the cooling going to the tank is eventually used in the building. Sensible heat gains through the tank walls, as well as losses in the distribution system, will reduce the actual cooling energy supplied to the building.

An hourly estimate of tank storage losses was made by multiplying the calculated tank wall conductance (UA ~ 41 Btu/hr-F) by the temperature difference between stored water and ambient air. This calculation was done only for the hours the building is occupied, since nighttime storage losses are included in the measurement of nighttime tank temperature change. This analysis showed that typical tank losses averaged approximately 2.0% of cooling energy provided to the tank. The net cooling energy supplied to the building is calculated as the cooling energy supplied to the tank minus the storage losses. Net cooling energy supplied to the building is shown in Figure 4 for the period from April 15, 1997, to June 23, 1997. The reduction in supplied cooling apparent in the month of July is believed to be due to the onset of the relatively humid "monsoon" season for this part of Arizona. Better performance is anticipated toward the later months of the cooling season (late August and September).

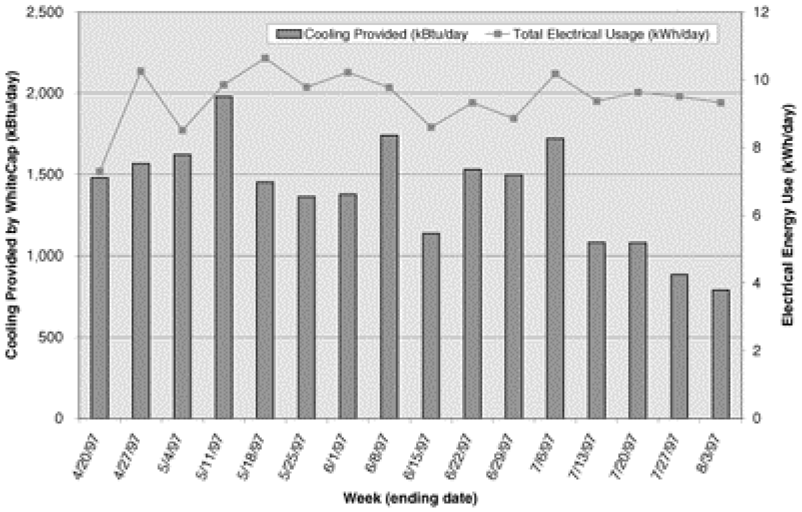

Figure 4. WhiteCap Energy Savings for Nogales Installation

The system has pumping power requirements estimated at 0.47 kW (3/4 hp motor at 2/3 load) when operating in either the spray or cooling mode. No pre-retrofit or post-retrofit electrical power measurements were taken of the air-handling unit fan. Although the installation of the WhiteCapT water coil increased the pressure drop in the fan system, the total post-retrofit air flow was not reset to the pre-retrofit air flow, and the actual fan power requirements may have been reduced by the new coil installation. No such energy credit is given to WhiteCap here because this is more an artifact of the installation than a WhiteCap benefit.

Had the fan airflow been reset to the original fan volume, the additional fan power requirements would have been approximately 0.41 kW for additional fan power (based on a design pressure drop of 0.15 in. w.g. for the WhiteCap cooling coil, an airflow rate of 9,400 cfm, and a combined fan/motor efficiency estimated at 54%).

The pump electrical load is multiplied by the pump operating time to provide estimated electrical energy requirements for the WhiteCap system, also shown in Figure 4.

Over the period from April 15, 1997, to August 3, 1997, the WhiteCap system provided an average daily cooling energy of 1.39 million Btu/day while using an estimated 9.37 kWh/day of pumping energy. To provide a comparison with other cooling systems, the

WhiteCap operated with an average Energy Efficiency Ratio (EER) of 149 over this time period. Assuming a COP of 2.8 for the existing chiller system and using an avoided electrical energy cost of $0.055/kWh (Citizens Utility LGS Rate Schedule 1997), the WhiteCap installation has saved an average of 1,020 kWh/week in cooling energy—worth $56/week in cooling energy savings.

The existing installation is not controlled for demand reduction, instead allowing for cooling operation during all occupied hours. Analysis of the measured data indicates that WhiteCap cooling rates of approximately 93,000, 103,000, 85,000, and 78,000 Btu/hr were experienced during peak temperature periods in April, May, June and July, respectively. Once pumping energy is subtracted, these suggest that a typical demand reduction of approximately 9 kW/month will be realized even with the present control strategy—worth an additional $85/month to the site for each month of operation.

Site personnel report that the existing chiller is enabled for seven months of the year, allowing for an estimated $2,290/yr electrical cost savings.

Because the existing WhiteCap system provides some level of cooling during all operating hours, modification of the control strategy to further reduce demand will reduce energy savings. RSC is working on control algorithms that will optimize demand reduction and energy savings to reduce total electrical cost in other installations. In the long run, however, greater energy cost savings may be realized by plumbing the main chilled water loop directly to the WhiteCap storage tank. WhiteCap spray cooling would be used to cool the storage tank at night, and the chiller used to maintain the tank water temperature low throughout the morning. Both cooling coils would use cold water from the storage tank during the cooling process, and the chiller could be shut down during peak demand periods.

Maintenance Issues

Periodic maintenance requirements for the WhiteCap system are shown in Table 3 and are relatively minor. Most of the maintenance was already being done through the site's scheduled preventative-maintenance routine. The only new maintenance requirement is for cleaning of the WhiteCap HVAC coil. Costs for the five-year cleaning are estimated at $230 for labor and chemicals.

Table 3. Nogales WhiteCapT Maintenance Requirements

	Maintenance Frequency		
	Monthly	**Annually**	**Every 5 years**
Chilled		Inspect filter and roll to	Clean WhiteCap HVAC coil,

Water Coil		new section and replace if necessary	removing accumulated dust and debris
Roof Drains	Check/clean roof drains and inspect roof surface	Clear debris from rooftop	

In addition, site personnel report that they regularly check the controller as well as examine the tank water level. Normally, however, the system is relatively maintenance free. Automatic controls backflush the filter on a regular basis and automatic fill valves replace tank water loss.

Although scheduled maintenance is minimal, the Nogales WhiteCap demonstration has experienced some difficulties in operation, most of which can be traced to installation and control issues. These include minor freeze damage and general degradation to the original PVC roof spray piping, leaking filters, and the ruptured storage tank discussed previously. The original PVC piping for the spray grid was completely replaced with copper by RSC, and small holes were drilled in the end of each new spray section to completely drain water and prevent any further freeze damage to the spray grid. Local contractors for RSC repaired the tank and leaking filters. The GSA contract with RSC provides for a 10-year service plan during which RSC is responsible for any repairs to the newly installed system components. Regional GSA administration reports that RSC has been extremely responsive to the problems encountered.

It should be noted that WhiteCap is not tied to any one storage tank design. A number of conventional, insulated storage tank options are available for WhiteCapF systems; however, given site constraints, the rectangular wood-frame storage tank was chosen as the most suitable option for the Nogales installation.

In addition to the above, the WhiteCap cooling mode has been manually shut off in several instances where the WhiteCap system was overcooling the space. As with any new system, more familiarity with the controls and capability of the system should, over time, result in less need for manual intervention.

Economics

A comparison of the life-cycle cost for the WhiteCap system as opposed to the existing chiller system was made using FEMP's Building Life Cycle Cost (BLCC) computer program and the first costs, energy and demand cost savings, and additional maintenance costs outlined previously. System life was estimated at 25 years with the existing chiller used as the basis for comparison. Economic criteria were the default criteria assumed for Federal energy conservation projects. The resulting BLCC output showed the Nogales WhiteCap installation has a discounted payback of 16 years (simple payback in 12 years), with a savings-to-investment ratio of 1.43 and an adjusted internal rate of return of 5.59%.

Applicability of the Technology

To decide if WhiteCap systems represent an appropriate cooling system alternative for a particular site, consider the following:

- Climate: Although WhiteCap systems will provide cooling in most U.S. climates, performance is enhanced in climates with a dry cooling season. As mentioned previously, dry climates offer more opportunity for capacity reduction of the mechanical cooling system. Typical WhiteCap capacity in dry climates is approximately 25 ton-hours/day per 1,000 ft^2 of roof spray area.
- Roof construction: For WhiteCapR designs, roofs must be dead level and capable of supporting the water and component weight of the WhiteCapR system. In addition, the existence of roof insulation or roof plenum will impact the energy savings with WhiteCapR technology. Also, determine whether building codes require that roofs meet Class A Underwriter's Laboratories (U.L.) fire protection criteria. Roof construction with WhiteCapR systems has not been certified as meeting these requirements because the U.L. test requires that the roof be dry during the test (such as might be the case during winter weather). Any fire-protection advantages gained by having the water pond and roof spray system operating during the cooling season has not been recognized by U.L. tests.
- New or retrofit construction: WhiteCapR and WhiteCapF designs are much better suited to new construction than to retrofit application. WhiteCapT is well suited to building retrofits.
- Water Storage: If WhiteCapT technology is being considered, the storage tank placement must be examined up-front. As a rule of thumb, allow about 2 gallons of storage for each square foot of spray area with this system. For an 8-foot water height, this results in 33.4 ft^2 of tank area for each 1,000 ft^2 of roof spray area.
- Demand Control: Consider whether demand reduction is a desired feature for the site. WhiteCapR and WhiteCapF systems have limited control of the timing of the WhiteCap cooling benefits. WhiteCapT systems can be designed to provide precise timing of the cooling benefits; however, this may be at the expense of the energy savings. Sites interested in demand control are encouraged to consider plumbing mechanically chilled water to the WhiteCap storage tank, allowing for maximum energy and demand savings. This design will also allow for greater reduction in chiller capacity, with significant first cost savings for new buildings.
- Bear in mind that although the technology is simple and energy savings are proven, experience with real installations is still limited. Consider this carefully when deciding whether to reduce mechanical cooling capacity in exchange for WhiteCap cooling. Also consider that although WhiteCap maintenance is relatively minor, any new technology requires that the operators understand how it works, what maintenance is required, and what to do in case of failure.
- Cost-effectiveness will be based on electrical cost and rate structure, mechanical cooling efficiency, WhiteCap installation costs, and building cooling loads. Mechanical cooling efficiency estimates can be made from equipment performance tables or through consultation with the equipment manufacturer. Installation costs will vary considerably in the case of building retrofits; however, for a first cut, the installation costs for small systems can be estimated from the data provided for the Nogales demonstration. Total costs/ft^2 of spray area can be expected to drop for larger installations. A reasonable first estimate for WhiteCap installation costs for new buildings 30,000 ft^2 or larger would be \$2.50/ft^2. In certain instances, WhiteCap costs

may be offset considerably by downsizing conventional HVAC components. Daily building cooling loads can be estimated using building simulation models, or, in the case of retrofit construction, analysis of previous building energy use.
- Consider any utility incentives for reduction of building electrical energy use or demand. Because of the uniqueness of the technology and the potential for large savings, utilities may be interested in providing special incentives. As with any cool-storage technology, consider the use of time-of-use electrical rate schedules.

Because of the various design configurations and climatic performance variation, WhiteCap energy savings are best estimated using a building energy simulation. Interested parties should consult RSC for such an analysis.

Technology in Perspective

WhiteCap systems represent an effective energy-saving technology that is suitable for application in many Federal buildings. In particular, the WhiteCapT system design, as used in the Nogales demonstration, represents a simple and practical energy technology to be used in conjunction with conventional mechanical cooling systems. Installed correctly, the system should have little in the way of additional maintenance or operational requirements. It is recommended that energy managers in warm and relatively dry climates consider WhiteCap as a readily available technology that delivers on its performance claims. Cost-effectiveness of the technology, however, will be strongly dependent on climate, WhiteCap integration with mechanical cooling systems, and utility rate structure. Potential users of the technology should consider several WhiteCap system designs to determine the most cost-effective design for their site.

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References

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