21st Century Cooling Strategies for Large Retail Facilities in Dry Climates

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ABSTRACT

In the Western U.S. where high population growth rates are causing increasing demand for electricity, energy-efficient cooling systems are an attractive potential substitute for "peaker plants," and efficient cooling systems also offer significant savings in energy costs and greenhouse gas emissions. With traditional cooling systems, high cooling loads now translate to significant electrical loads. Chain retail buildings offer a particular peak reduction opportunity because they typically experience large cooling loads due to long occupancy schedules, significant internal gains, and large roof areas. Rising energy costs and increased recognition of environmental stewardship responsibilities are encouraging some retailers toward higher levels of energy efficiency. From a societal perspective, many advantages can derive from a strategic effort to implement improved cooling systems in chain retail facilities. The opportunities for reducing cooling system peak demands and annual energy use are greatest in dry climates, where large daily temperature swings, low humidity, and clear night skies facilitate application of evaporative, radiative, and thermal storage features.

This paper presents early efforts of a collaborative between university, utility, governmental, and chain retail stakeholders to identify, evaluate, and demonstrate advanced cooling technologies that might significantly reduce peak demands and annual energy use in dry climates. Results shown in this paper suggest that for existing stores, retrofit and replacement strategies offer indirect and direct evaporative pre-cooling, dedicated ventilation air, and off-peak thermal storage (coupled with advanced chillers and "night wet-bulb" cooling) offer energy savings between 27% and 63%, and demand reduction between 30 and 84%, with paybacks (without incentives, under "mature market" assumptions) less than 5 years except for the thermal storage case. In new stores, the addition of radiant floor cooling to the thermal storage system can increase cooling energy and demand savings to 74% and 88%, respectively.

Introduction

Building cooling loads have large impact on electricity costs in the Western U.S. because they drive the need for new generation capacity. Many centers of rapid population growth in the West experience warm summer days and cool summer nights, resulting in cooling load spikes that result in poor load factors for cooling systems. Reducing the size of cooling systems, improving efficiencies, and moving cooling loads to off-peak hours are among the most important strategies available for minimizing future electric bills.

Hot, dry climates contribute to future problems under the status quo. Conventional practice in the Western U.S. installs air conditioning equipment that is designed to work virtually anywhere, such as in climates that require consider significant dehumidification. In the West, these cooling systems often dehumidify unnecessarily, increasing loads and operating costs by as much as 20%. Other issues include inattention to integrated design opportunities, and use of oversized systems that cycle frequently and inefficiently in cool night and morning conditions. Large compressors, blowers and ducts, sized for peak conditions, increase installed costs as well as ongoing operating costs.

Opportunities abound for turning Western climates and building methods to advantage rather than disadvantage. Dry outdoor air can be used to evaporatively cool ventilation and condenser air, reducing peak afternoon demand and energy use. Indirect evaporative methods can pre-cool both ventilation and return air without adding moisture. Concrete slabs and building mass offer major opportunities for storing cooling generated more efficiently in cool night conditions, coupled with a variety of "natural" cooling sources that can discharge substantial quantities of heat to the night environment. By storing cooling to reduce the peak, these strategies also facilitate smaller duct and blower systems, saving energy all year.

While government and utility programs have encouraged many of these technologies, a long term comprehensive program is needed to identify key needs, catalog technologies—both existing and to be developed—that satisfy the needs, help guide them through the research, development and demonstration (RD&D) labyrinth, and then help overcome their major market barriers. In response to a 2005 "challenge grant" opportunity offered by the California Clean Energy Fund (CalCEF), the University of California-Davis (UC Davis) was selected in 2006 to implement a new Energy Efficiency Center (EEC). UC Davis's proposal included a cooling center designed to mesh market transformation activities with strategic RD&D to expedite the commercialization of technologies that take advantage of dry-climate opportunities. The UC Davis Western Cooling Efficiency Center (WCEC) was launched in 2007 with a specific and long-range focus on cooling systems that make technical and economic sense for the dry climates typical of the Western U.S.

The WCEC has forged an alliance of stakeholder "partners" that includes the California Energy Commission and major utilities, manufacturers, retailers, HVAC designers, and HVAC contractors. The WCEC has sought with several of its early initiatives to affect the chain retail industry. This focus is based on the expectation that success with major retail firms can have high impact, since these firms can roll out a new technology relatively quickly when convinced of its viability. Also, the retailers have an opportunity to educate the public, through in-store displays, about new cooling technologies. Both Wal-Mart and Target have been extremely valuable partners in early WCEC activities. Also, these two firms and the WCEC are participating in a new national Retailer Energy Alliance or REA (managed by the U.S. Department of Energy) that is engaging other retailers in activities that can accelerate the implementation of a wide range of energy-efficiency strategies and systems in the retail industry.

This paper presents a status review of potential cooling systems for retail applications in the Western U.S., based on WCEC work to date, for both new, replacement, and retrofit applications. Since this work is ongoing, not all potential systems are fully evaluated; therefore, this paper also recommends activities to further clarify preferred future cooling strategies for the Western U.S.

Objectives

The major objectives of this work were (and are) to:

1. Present and discuss an array of advanced cooling technologies, each capable of reducing cooling peak demand and annual energy use by at least 20% in chain retail applications.
2. Evaluate the economic potential of these advanced cooling technologies for chain retail retrofit, replacement, and new construction applications.
3. Recommend future activities to further define cooling efficiency and demand reduction opportunities and economics in the chain retail sector.

Methodology

The analyses used to develop the results and conclusions presented in this paper apply to a single, generalized retail example in a single climate. We used a calibrated base case simulation completed by others for an actual store, then normalized the results to an assumed 100,000 sq. ft. store size. We also developed specifications for base case HVAC equipment (packaged rooftop units, or RTUs) based on selection of DOE minimum performance requirements for RTUs. Since our goal was to evaluate alternative cooling systems, we did not consider possible cooling load reduction strategies outside the cooling system, such as improving the building envelope or reducing internal gains from lighting or non-HVAC equipment. However, we did consider load reductions that can be accomplished within the cooling system, such as reducing the ventilation load by pre-cooling incoming air, and reducing heat gain from blowers.

With the base case selected, we listed potential cooling energy-efficiency measures or alternative systems, and categorized them into three application alternatives: retrofit, replacement, and new construction. Retrofit alternatives involve accessories that can be added to the base case system; replacements involve removing and replacing base case equipment on existing stores; and new construction involves substituting alternate designs for the base case HVAC equipment that would otherwise have been installed on new stores. For each category, we developed comparative data on performance, installed costs, added maintenance and water costs if applicable, development status, and probable direct paybacks. Because the WCEC focus is on technologies that can significantly reduce both peak demand and annual energy use, we did not independently consider:

1. evolutionary improvements that reduce peak demand or energy use but not both
2. technologies that do not promise at least 25% demand and energy use reduction in major Western U.S. markets.

We used the same base case for all three application scenarios based on the following logic:

1. Major retrofit measures will likely be applied to RTUs that are no more than 6-8 years old, because normal anticipated RTU life is 15 years, and retailers are unlikely to retrofit accessories on RTUs with less than half their life remaining. The DOE minimum RTU performance level has not changed in the last eight years.

2. In the replacement scenario, owners must replace older RTUs with units that meet current performance requirements.

Performance estimating for the advanced cooling systems considered here is challenging because for many, calibrated simulations are not yet available. Generally, we have developed "best projection" estimates based on experience and/or data from past field or lab tests. These estimates are typically more reliable for sizing and peak demand than they are for annual energy use. Installed costs, which vary even for base case systems by location and economic conditions, are more variable for less familiar HVAC systems. We estimated installed costs based on medium volume scenarios, under which utility incentives are typically necessary to "bridge the gap," helping to spur larger volume and lower long-term costs. We developed detailed performance and costing spreadsheets to assure comparability in both the performance and costing elements of the work. "Immediate" costs may be 10-20% higher than these estimates, especially on less-proven concepts. To avoid the complexity of utility demand charges, we sorted kWh used into peak and non-peak categories, and applied a higher energy charge to on-peak use.

In economic analyses we have shown the impact of both a mid-range "startup" credit of $750/kW saved, and an alternate $1500/kW credit recognizing the "power plant" value of cooling demand reduction. From the results we draw conclusions and recommendations regarding further work needed to accelerate the implementation of more energy efficient cooling in the Western U.S. chain retail market sector.

Base Case

To limit the work scope we assumed a 100,000 sq. ft. "general merchandise plus stock room" scenario. This means we neglected smaller spaces like personnel offices and rental spaces that are common in some large stores. The store design uses tilt-up concrete walls and a corrugated steel roof deck topped with rigid insulation and a white single-ply roofing membrane. We also assumed no daylighting in the base case store. These envelope measures are typical of current chain retail construction in the Western U.S. We developed our performance estimates based on a Sacramento location.

To estimate base case performance, we started with an EnergyPlus simulation completed for a major retailer by researchers at the Lawrence Berkeley National Laboratory (LBNL). The model had been reasonably calibrated to monitoring data. A concurrent paper by the LBNL researchers and others using the same simulation (Haves et. al. "Benchmarking and Equipment and Controls Assessment for a 'Big Box' Retail Chain", ACEEE 2008) provides benchmark comparative energy use for seven U.S. cities, including three in the West (Pasadena, Phoenix, Seattle). Compared to Sacramento, cooling energy use and therefore energy savings from advanced cooling measures will likely be much higher in Phoenix, slightly lower in Pasadena, and much lower in Seattle.

We adjusted model results for our assumed floor space, and assumed that the base case high-efficiency rooftop units (RTUs) with total capacity of 200 tons (500 sq.ft per ton) specified for the 100,000 sq. ft. general merchandise and stock room were appropriate for our simplified 100,000 sq. ft. store. We then determined base case cooling system peak demand from manufacturer's data for ten- 20 ton base case RTUs, and determined base case annual energy use from area-weighted results of the LBNL simulation. The ten 20-ton units are distributed on the roof to provide relatively uniform cooling delivery throughout the store. Table 1 summarizes key base case HVAC data.

Table 1. 100,000 Sq. Ft. Store: HVAC Base Case

Location	Sacramento CA
Design day dry bulb deg F	101
Concurrent wet bulb deg F	71
Daily occupancy hours	6 AM - 2 AM
Occupancy days per week	7
Ventilation air cfm	20,000
Exhaust cfm	10,000
System nominal tons	200
Number of rooftop units	10
Average RTU capacity, tons	20
Supply air cfm	70,000
Cooling kW/ton at design condition	0.85
Concurrent supply blower kW/ton	0.15
Concurrent exhaust blower kW/ton	0.03
Total kW at design condition	206
Annual kWh cooling energy	221,860
Estimated summer on-peak	40%
Annual kWh blower energy	262,800
Estimated % summer on-peak	15%
Total annual HVAC kWh	484,660
Average $/kWh on-peak	$0.24
Average $/kWh non-peak	$0.12
Total annual HVAC electricity cost	$73,539

Some major retailers now use dedicated outdoor air RTUs so that the blowers in the remaining (non-outdoor air) RTUs can operate intermittently instead of continuously. This strategy offers major annual energy savings because otherwise, all RTU blowers must run continuously during occupancy to deliver code-required fresh air. In the base case, the supply blowers use 13% more energy annually compared to the total of compressor and condenser fan energy.

Measures Evaluated

Table 2 provides brief descriptions of the ten measures considered in the three application categories (retrofit, replacement, new construction). Tables 3 and 4 identify savings sources and technology status.

Retrofit Packages

For newer stores with relatively efficient RTUs, the most appropriate strategy for improving cooling performance is to apply retrofittable accessories to the existing RTUs. The major strategies for modifying existing RTUs to meet the savings goals are as follows:

1. Reduce condensing temperatures during peak and normal cooling operation
2. Reduce ventilation air inlet temperatures, thus allowing reduced constant blower speeds
3. Reduce blower power in non-peak conditions, while maintaining required ventilation air

We identified four conceptual retrofit packages capable of satisfying the 25% demand and energy savings targets, as listed in Table 2. The first three use evaporative processes, and the fourth uses water storage cooled by a radiant roof system for application to the ventilation air. The first two are similar in function but different in configuration; they lower both the condensing and ventilation air temperatures. The dual evaporative "Package 1" places a rigid evaporative media component at each RTU to pre-cool the condenser air. Sump water is circulated through an indirect cooling coil at the ventilation air intake before wetting the media. Package 2 uses cooling towers to deliver evaporatively-cooled water to multiple RTUs. At each RTU, the water circulates through an indirect ventilation coil (as in Package #1) and through a refrigerant-to-water "sub-cooling" heat exchanger, where it significantly lowers the condensing temperature.

The "flash evaporative" technology (FET) in Package 3 uses a centralized high pressure pump and water filtration station; the pump sends filtered 175 psi water to misting nozzles between inlet screens and the condenser coil of selected RTUs. The misting system reduces the temperature of condenser inlet air virtually to the wet bulb temperature. Since the mist system does not treat ventilation air, three of the ten RTUs are equipped with the dual evaporative system of Package 1, and these three are reset to continuously deliver 100% outdoor air during occupancy hours. The seven units FET-equipped can then cycle in response to loads, saving substantial blower energy.

Table 2. Package Descriptions

Retrofit		
1	Dual evaporative	Direct evaporative pre-cooler on condenser coil; sump water circulated to indirect coil at vent air intake; water leaving coil feeds evaporative media; vent air cooling allows blower speed reduction.
2	Tower subcooling	Cooling tower(s) cool water pumped to sub-cooling heat exchangers and vent air pre-cooling coils at RTUs; like Package 1, vent air cooling allows blower speed reduction.
3	Flash evaporative	RTU field reset for dual evaporative, dedicated outdoor air; high pressure water sent to mist nozzles in screened enclosures at condenser coils; non-outdoor air RTUs cycle for blower energy savings.
4	Thermal storage 1	48,000 gallon water tank cooled by 60,000 sq. ft. night radiant roof cooling system. 4 RTUs deliver all vent air, include 4 row vent air water coils served by tank. Delivery tuned to maximize peak reduction.
Replacement		
1	Advanced RTUs	New "Western Cooling Challenge" RTUs combine indirect evaporative processes, exhaust air heat recovery, and VFD blowers to achieve at least 40% demand reduction and annual energy savings.
2	Thermal storage 2	Ice storage RTUs partially shift loads; VFD blowers link with modulating economizer dampers; heat recovery from building exhaust air.
3	Thermal storage 3	Chiller-cooled water storage, chilled water fan coils replace RTUs; fan coil field configured for dedicated outdoor air, remaining blowers cycle; air-cooled chiller eliminates water maintenance.
New Construction		
1	Hydronic radiant	Chiller loop serves hydronic radiant floor or ceiling sensible cooling, and ventilation air fan coils; additional return air fan coils as needed to satisfy loads.
2	Thermal storage 4	Same as #1 (hydronic radiant) with chilled water storage tank for full or partial load shift.
3	Thermal storage 5	Same as #2, but adds direct cooling of water storage from either a cooling tower or night radiant roof in mild weather.

Table 3. Savings Sources

Retrofit	*Demand Reduction*	*Annual Energy Use*
1 Dual evaporative	reduced condensing and vent air temperatures	Lower condensing and vent air temperatures, lower fixed blower speed
2 Tower subcooling	reduced condensing and vent air temperatures	Lower condenser and vent air temperatures, lower fixed blower speed
3 Flash evaporative	reduced condensing and vent air temperatures	blower savings from dedicated outdoor air
4 Thermal storage 1	reduced compressor, condenser fan sizing	efficient night sky cooling, blower savings from dedicated outdoor air
Replacement	***Demand Reduction***	***Annual Energy Use***
1 Advanced RTUs	reduced condensing and vent air temperatures	temperatures, lower blower speeds
2 Thermal storage 2	ice storage cooling, disabled compressor circuit	lower blower speeds, exhaust-cooled vent air
3 Thermal storage 3	no compressors on-peak	efficient chiller, lower condensing temperatures
New Construction	***Demand Reduction***	***Annual Energy Use***
1 Hydronic radiant	efficent chiller, less latent cooling, reduced blowers	efficient chiller, less latent cooling, reduced blowers
2 Thermal storage 4	reduced blowers, less latent cooling, no compressors on-peak	efficient night chiller, reduced latent & blowers
3 Thermal storage 5	reduced blowers, less latent cooling, no compressors on-peak	same as above plus partial "free" cooling

Retrofit Package 4 integrates an above-grade water storage tank behind the rear wall of the store, and the water is cooled by night sky radiation in an open flow pattern on the roof. Beginning at noon, cool tank water is pumped through vent air coils at four selected (from the ten) RTUs. One compressor and condenser fan will typically be disabled in these four RTUs to assure demand reduction. Annual energy savings derive from the highly efficient water cooling applied to vent air, and from curtailing vent air delivery from other RTUs, allowing their blowers to cycle off in no-load hours.

Replacement Packages

The "replacement packages" are most appropriate for older stores where RTUs are within the last five years of their useful life. The most straightforward strategy (replacement Packages 1 and 2) places new, higher efficiency RTUs on the curbs of the removed units. Unfortunately, there are no current RTUs with 30% higher efficiency than the 12 EER base case unit. However, several firms are currently developing RTUs that can achieve the desired targets, and the "Western Cooling Challenge" is soliciting others. Package 1 applies evaporative heat exchange in the RTU to cool both condenser and ventilation air. Some of these units will apply building exhaust air to improve evaporative performance. Package 2 applies an ice storage strategy similar to that described for Retrofit Package 4, also incorporating VFDs and modulating economizer dampers to allow reduced blower energy consumption; and exhaust air heat recovery for additional annual energy savings.

Replacement Package 3 eliminates on-peak compressor operation by adding a large central chilled water tank next to the store and replacing the RTUs with chilled water fan coils mounted on the RTU curbs. A 100 ton air-cooled chiller runs mostly at night and in relatively cool morning and late evening conditions. Four fan coils are configured as 100% outdoor air units; the other six include two-position economizer dampers and can cycle in response to loads, saving blower energy.

Table 4. Technology Status Summary

Retrofit	
1 Dual evaporative	In use since 1998; installed on approximately 2000 tons in California and Arizona
2 Tower subcooling	Proposed, not yet field-tested
3 Flash evaporative	One major monitored field test project in Florida
4 Thermal storage 1	Three non-residential retrofit installations in 1994-97; not marketed since
Replacement	
1 Advanced RTUs	two prototypes, 6 units in field tests; Western Cooling Challenge soliciting more designs
2 Thermal storage 2	TBD
3 Thermal storage 3	not yet demonstrated on retail; proposed for major retailer, multiple stores
New Construction	
1 Hydronic radiant	demonstrated by major retailer in new Las Vegas store
2 Thermal storage 4	not yet demonstrated on full store
3 Thermal storage 5	prior non-retail projects; elements tested by major retailer, no full store

New Construction Packages

All three new construction packages take advantage of radiant cooling delivery systems to reduce blower energy consumption and peak demand. Performance and cost estimates are based on the low-cost tubing system currently available for placement in floor slabs, but in the future, lower-cost (than currently available) ceiling-based systems could deliver more cooling and further reduce blower energy. Package 1 couples a chiller with the radiant floor and fan coils. Since the floor handles much of the sensible load, three fan coils are configured for 100% outdoor air and the remaining two can cycle in response to loads. The system is designed for 52F water delivery temperature at peak, improving compressor efficiency; a “mix-back” strategy limits floor water temperature to 56F to prevent condensation.

New Packages 2 and 3 include chilled water storage to shift compressor operation off-peak. Package 2 relies on the air-cooled chiller, while Package 3 adds a “night radiant roof” to cool the tank water with chiller backup. The system flows water down the roof surface at night, cooling the water by radiation to the sky (as in retrofit Package 4). Water returns through roof drains to the storage tank, where it is filtered. The tank is oversized so that seasonal rainfall can replace the small water loss expected in the roof flow process.

Results

Table 5 summarizes results. In the **Retrofit** category, the three evaporative systems show relatively similar performance in terms of both peak reduction and annual energy savings. The most fully developed of these three is the dual evaporative package. Compared to Package 1, the tower subcooling package shows greater projected savings at slightly greater cost. These two have relatively comparable (and attractive) paybacks under the incentive 1 scenario. Between them, Package 1 is less invasive, requiring no new equipment pads or supports on the roof, and not requiring cutting into the refrigerant lines. But the cooling towers of Package 2 may have longer life and/or lower maintenance costs than the exposed vertical evaporative pre-coolers of Package 1. Package 3 is particularly interesting because of its lower projected cost and lower maintenance requirements, although it needs elements of either Package 1 or Package 2 to derive ventilation air savings. But its condenser screen system may need extra strengthening for some rooftop wind conditions.

Table 5. Savings and Economics

Retrofit	kWh Saved	$/yr Saved	kW Saved	Incr Cost	Incentive 1	Payback 1	Incentive 2	Payback 2
1 Dual evaporative	145,398	$19,927	62	$82,800	$46,350	1.8	$92,700	-0.5
2 Tower subcooling	157,030	$21,761	68	$97,053	$50,985	2.1	$101,970	-0.2
3 Flash evaporative	151,087	$21,824	62	$38,160	$46,350	-0.4	$92,700	-2.5
4 Thermal storage 1	222,860	$33,017	62	$94,560	$46,350	1.5	$92,700	0.1
Replacement	**kWh Saved**	**$/yr Saved**	**kW Saved**	**Cost**	**Incentive 1**	**Payback 1**	**Incentive 2**	**Payback 2**
1 Advanced RTUs	242,330	$36,769	82	$160,000	$61,864	2.7	$123,728	1.0
2 Thermal storage 2	analysis incomplete							
3 Thermal storage 3	286,354	$46,718	174	$359,522	$130,613	4.9	$261,225	2.1
New Construction	**kWh Saved**	**$/yr Saved**	**kW Saved**	**Incr Cost**	**Incentive 1**	**Payback 1**	**Incentive 2**	**Payback 2**
1 Hydronic radiant	300,429	$47,211	116	$251,220	$87,150	3.5	$174,300	1.6
2 Thermal storage 4	285,602	$46,467	180	$285,332	$135,300	3.2	$270,600	0.3
3 Thermal storage 5	359,275	$54,404	182	$307,700	$136,800	3.1	$273,600	0.6

Economic Scenario 1 based on $750/kW saved
Economic Scenario 2 based on $1500/kW saved

Package 4 also looks promising, though it requires more on-site construction than the others. It offers significantly greater energy savings than the other three, likely has the lowest maintenance requirement, will use much less water because its cooling is mostly radiative, and cleans the roof to reduce cooling loads (no credit was taken for this benefit in the analysis). If a photovoltaic array is present, the roof water system can also clean the array to maintain its electrical output.

All four retrofit packages promise simple paybacks of less than 2.1 years under the $750/kW rebate scenario, and the first three show immediate paybacks under the $1500/kW scenario. Even without incentives (add payback years equal to incremental cost divided by $/yr saved) the retrofit packages all promise paybacks of less than 5 years.

In the **Replacement** category, the projected demand savings vary from 40% for the advanced rooftop units (Package 1) to 85% for the off-peak chilled water storage system (Package 3). Energy savings are projected to be about 27% greater for Package 3 compared to Package 1. But, the predicted payback is better for Package 1 than for Package 3. The replacement RTUs of Package 1 will probably require greater maintenance than Package 3, as they each are of multiple-compressor designs and include indirect evaporative cooling features. The Package 1 initial cost estimate includes a three-year maintenance contract, but added maintenance has not been assumed thereafter.

Without incentives (again, add payback years equal to incremental cost divided by $/yr saved) neither of the replacement packages for which analyses are complete shows paybacks attractive enough for most chain retainers under their current five year maximum payback criterion.

In the **New Construction** category, the greatest peak reduction and annual cost savings are projected for Package 3, which minimizes chiller operation among the three alternatives, and (like Package 2) does not operate the chiller on-peak. Package 3 shows slightly higher peak reduction than Package 2. Package 1 has the lowest peak reduction of the three alternatives, because it must operate the chiller half-time through the peak period. However, Package 1, which uses a fluid cooler to cool the floor whenever possible, saves more energy than Package 2, which can only cool water with its air-cooled chiller.

The projected paybacks are less than four years for all three new construction packages under the $750/kW incentive scenario, and less than 2 years under the $1500/kW scenario. As for the replacement case, none of the new construction packages shows attractive paybacks without utility incentives.

Results Discussion

These results, while clearly preliminary and applying only to California valley climates, suggest that there are at least three cost-effective cooling strategies that can reduce both peak demand and annual energy consumption by at least 25% on some Western U.S. chain retail facilities, under each of the three application scenarios (retrofit, replacement, new construction). From this starting point the key questions are:

1. How should regulators, utilities, and chain retailers proceed to verify this potential for a wider range of climates and facility types?
2. If the results are proven sound, under what priorities should incentives be created that induce more rapid implementation of proven systems?

One of the difficulties with drawing strong conclusions from this study is that few of the technologies are proven in the marketplace. In the past it has been difficult for emerging cooling technologies to establish themselves, especially if they have regional applicability, as is the case for all ten technology packages evaluated here. Since it is usually most valuable to society for multiple suppliers to compete, it appears wise to provide "volume demonstration" opportunities that seek field test data for all technologies that appear able to meet specified performance criteria. But what should the criteria be? Should there be a minimum performance level, and if so, should it establish a comparable level for both demand reduction and annual energy savings, such as the 25%/25% requirement applied in this study?

We think the answer should be "yes" on both counts, based on the logic that cooling systems currently offer one of our best alternatives to building new generators. Cooling loads and utility peak loads align with near perfection, because cooling causes the peaks. Unlike residential cooling systems, whose "per system" benefits must be adjusted downward for "diversity," retail cooling systems are reliably on. And, repetition of store models means programs aimed at this market sector will likely have greater impact sooner if intelligently designed and implemented.

Offering incentives for cooling improvements with significant impact will make those improvements more visible, and will minimize lost opportunities. Reducing demand and energy use seem equally important. Demand reduction reduces the need for new generators, and thus should be the major justification for utility incentives. (And in line with the California commitment that energy efficiency should be "first in the loading order" for new generation, there is no reason that such incentives should be temporary, as long as there is continued growth in statewide or region-wide electricity demand.) Reducing energy use affects the bottom line for retailers, so energy savings are the logical cause for retailer investment in higher efficiency. In the future, reducing greenhouse gas emissions may also have monetary value to retailers, which could further improve paybacks on advanced cooling systems.

Applicability to new construction bears further discussion. Technology packages in the retrofit and replacement categories can obviously be applied to new stores as well, and they show better paybacks in many cases. Should their application be encouraged on new stores? We think not, for two reasons:

1. Generally they are less permanent than the packages evaluated for new construction; they use more, and more expensive, rooftop components whose outdoor exposure shortens life to 15-25 years vs. at least 50 years for major components in the selected new construction packages.
2. Their lower performance levels result in a lost opportunity cost which is most important with respect to the need for new generators, and of growing importance with respect to greenhouse gas emissions.

The role of on-site water use for cooling systems also bears further discussion. Water use and cost were quantified and included in estimates for all technology packages evaluated here, but non-quantitative issues remain. Many jurisdictions encourage water conservation and discourage evaporatively-based cooling systems. However, data for the Western U.S. suggests that advanced evaporative systems use less water on site than would have been used off-site to generate the electricity required to drive a conventional cooling system (Torcellini et. al, 2004). But the true bottom line is that the current large reservoir-based water systems in the West are not tenable in the long run. The reservoirs are silting up (Reiser, 1986), which reduces their capacity but not their evaporative loss. Eventually, the region must find a better water model. We suggest that this model might include capturing rain water on roofs for use as a cooling medium, a thermal storage medium, fire safety, gray water, and possibly, with treatment, as potable water. In any event, it seems unwise to curtail well-controlled water use for cooling systems, given the major economic and GHG benefits that advanced water-based cooling systems offer.

On-site water use will vary significantly among the ten packages evaluated here. In the retrofit category, the first two packages require the most water, followed by the third and the fourth in descending order of water use. In the replacement category, Package 3 will use much less water than will Package 1. In the new construction category, Package 2 will not use water on-site, and Package 2, with its fluid coolers, will use more water than will Package 3's sky radiative cooling. Also, retrofit Package 4 and new Package 3 will capture and store rain water from the roof.

Conclusions

Based on the results and discussion above, we draw the following conclusions:

1. There are multiple possible paths to significant cooling energy and demand savings for retail facilities in dry climates; all ten packages reviewed in this study warrant further evaluation.
2. At least in the scenarios studied, advanced cooling systems appear to offer a better economic value than new generators priced at $1500/kW.
3. Many of the ten cooling packages evaluated require more field testing before they should be eligible for aggressive incentive programs that recognize their value as peak generators.
4. In general, packages should be favored that offer the longest system life and significant reductions in both peak cooling demand and annual cooling energy use.

Recommendations

Based on these conclusions, we suggest the following ongoing activities:

1. Use a stakeholder group that includes utilities, retailers, and researchers to establish a roadmap for applying advanced cooling systems to new and existing retail facilities.
2. Seek state, regional, and federal support for establishing the roadmap and implementing key initial activities to prove the merit of reducing new generation needs using energy efficient, demand-reducing cooling systems on retail facilities.
3. Create near-term field test and demonstration opportunities for all ten packages evaluated in this study.
4. Implement monitoring efforts at the test sites to assess performance, maintainability, and potential improvements.
5. Create incentive programs that provide immediate markets for packages proven by monitoring results.

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