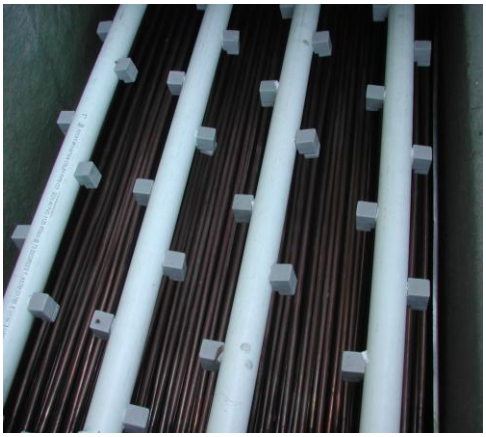
Customer Advanced Technologies Program Presents…



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About the Customer Advanced Technologies Program…

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to encourage the use and evaluation of new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), indirect/direct evaporative cooling, non-chemical water treatment systems and a variety of other technologies.

For more program information, please visit: http://www.smud.org/en/education-safety/Pages/cat.aspx

Executive Summary

For the past two years, SMUD has been working with Beutler Corporation and SMUD customers to test a new residential air conditioning system known as the AquaChill. AquaChill is a water-cooled air conditioning system that shows great promise. Laboratory testing has shown that the AquaChill is much more energy-efficient than conventional air-cooled units - especially when outside temperatures climb over the century mark.

During the summer of 2008, thirty prototype AquaChill units were installed and monitored to determine the potential peak load reduction and energy savings. Unfortunately most of these units experienced problems with reliability. After examining monitoring and field inspection data, Beutler completely redesigned the AquaChill and replaced all thirty of the prototypes at no cost to the participating customers. The new units were monitored during the summer of 2009. The data was analyzed and compared to usage data for typical single family homes in SMUD's service territory. The new AquaChill units:

- Operated smoothly with no known major reliability problems.
- Would reduce air conditioning energy consumption by 29% for a typical single family home in SMUD's service territory.
- Would save 1.09 kW in peak kW verses a typical single family home with a four-ton unit in SMUD's service territory (Figure 1).
- Consumed only 1.3 gallons of water per ton-hour.
- Showed no visible signs of water scaling on the condenser coils.
- Cost around $650 per ton more than basic California Title 24 compliant systems.

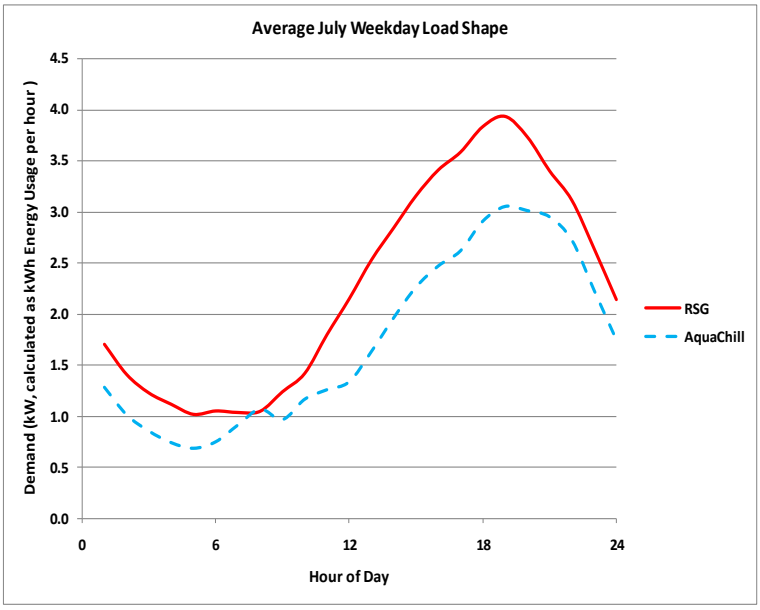

Figure 1: Average July 2009 household weekday electric demand for the AquaChill sites (dashed blue profile) and for typical residences in SMUD's territory (solid red profile). The average difference between the two groups during the 4PM-7PM period is 0.92 kW. Simulations suggest peak demand savings of 1.09 kW for a four-ton unit.

Currently, SMUD offers customers a $1,100 incentive to install the AquaChill system as part of a limited-time pilot program. However, even though the AquaChill offers outstanding peak performance compared to conventional air conditioning, it is not yet clear how SMUD will value peak demand reduction in the future. For more rebate program information, please visit SMUD's Web site at www.smud.org.

Introduction

Hot summer days are not only uncomfortable but drive SMUD's peak load as customers turn on their air conditioners. Unfortunately, the performance of conventional air conditioners drops during hot weather conditions. For the past two years, SMUD has been working with Beutler Corporation and SMUD customers to test a new residential air conditioning system known as the AquaChill. AquaChill is a water-cooled air conditioning system that shows great promise for reducing electrical load during SMUD's peak periods.

During the summer of 2009, monitoring data was collected for 26 AquaChill units installed at the homes of residential SMUD customers. Analysis of this data indicates that the AquaChill system performs much better than comparable high efficiency air conditioners on hot summer days. This report reviews basic air conditioning principles, the AquaChill design and the results of SMUD's research efforts.

The Basic Refrigeration Cycle

Before we discuss AquaChill, it may be helpful to review some basic air conditioning concepts. In simple terms, air conditioning systems are designed to transfer heat from indoors to the outdoors (Figure 2). This is accomplished by using heat exchangers (similar to the radiator in your car), a compressor, fans and substances known as refrigerants. The real key to this process is the refrigerant. By using a compressor and a refrigerant metering device (valve) to change the pressure of the refrigerant, we cause it to change from a liquid to a gaseous state and change temperatures. This characteristic enables us to use refrigerants to transfer a lot of heat from one location (e.g. inside) to another (e.g. outside). The residential market sector is currently dominated by systems that transfer heat from the conditioned space to the outside air (air-cooled systems).

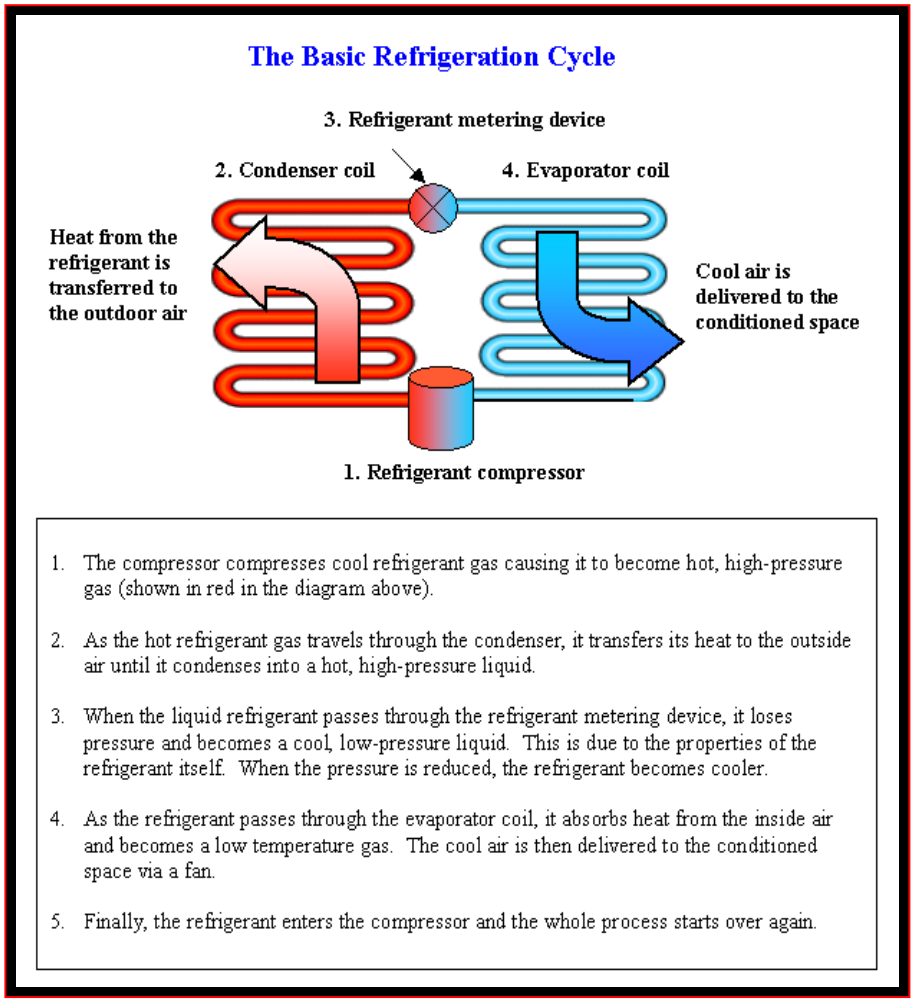

Figure 2: The Basic Refrigeration Cycle

A "Ton" of Air Conditioning

Have you ever heard someone mention that they just purchased a "four-ton" air conditioning system? Does that mean it weighs 8,000 pounds? Thankfully no. Since air conditioners come in all different shapes and sizes, a standard has been developed to quantify the cooling capacity or amount of heat that the system is designed to transfer. Heat is quantified by a unit of measurement known as the British Thermal Unit (BTU). Technically speaking, a BTU is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit - roughly the amount of heat contained in a wooden kitchen match. The term "ton" refers to the ability of a system to remove the equivalent amount of heat that a 2,000-pound (one ton) block of ice would as it melts over 24 hours. This requires transferring 288,000 BTUs in 24 hours or 12,000 BTUs per hour (BTUh). *Thus a 'four-ton' system would have a cooling capacity of 48,000 BTUh (12,000 BTUh per ton x 4 tons).*

What Are EER and SEER?

There are several major equipment manufacturers and a myriad of options to choose from. So how do we know which systems are the most energy efficient? In order to help consumers make informed decisions, two rating systems have been developed to rate the efficiency of residential air conditioning systems: Energy Efficiency Ratio (EER) and Seasonal Energy Efficiency Ratio (SEER).

- **Energy Efficiency Ratio (EER)** compares the cooling capacity (in BTUs) to the amount of power (in Watts) a system requires. It is based upon a single point measurement that is taken at an outside air temperature of 95°F. As a point of reference, systems that are over twenty years old usually have an EER of about 6 to 8, while newer systems are available with EERs as high as 14.

  Example:

  What is the EER of a one-ton air conditioner that requires 1,000 Watts of power when the temperature outside is 95°F?

  Answer: EER = 12,000 BTU ÷ 1,000 Watts

  EER = 12 BTU/Watt or simply an "EER of 12"

  The problem with EER is that it does not tell us how air conditioners perform at any other weather condition. Therefore the Seasonal Energy Efficiency Ratio (SEER) was developed for rating the efficiency of residential air conditioning systems.

- **Seasonal Energy Efficiency Ratio (SEER)** was originally intended to more accurately reflect overall system efficiency on a seasonal basis. Essentially, the higher the SEER, the more energy efficient the system. However, since SEER is primarily based upon measurements taken at an outside air temperature of 82°F, there is growing concern that it may not be the best metric for units operating in hot dry climates. There is growing consensus that the SEER metric is more applicable to humid climates than hot dry climates such as Sacramento. Finally, since there appears to be no reliable correlation between SEER and EER, many electric utilities in the western region of the United States still require minimum EER ratings for their commercial and residential rebate

programs. Despite these shortcomings, consumers should still consider both EER and SEER when choosing a new air conditioner.

How Badly Does Hot Weather Affect the Performance of Air-Cooled Systems?

The graph below (Figure 3) shows the effect that outside air temperature has upon the performance of a three-ton, air-cooled system that is currently available from a well-known manufacturer. Note as the outside air temperature climbs, the cooling capacity of this air conditioning system is reduced by as much as 24 percent. Since experienced contractors and mechanical engineers know that this is typical for air-cooled systems, they frequently install oversized units to compensate.

During hot weather conditions, refrigeration compressors must operate at higher pressures. Consequently, these systems require more energy on hot summer days – precisely when we are being asked to conserve electricity! Hot weather conditions have a significant detrimental impact upon the performance of air-cooled air conditioning systems.

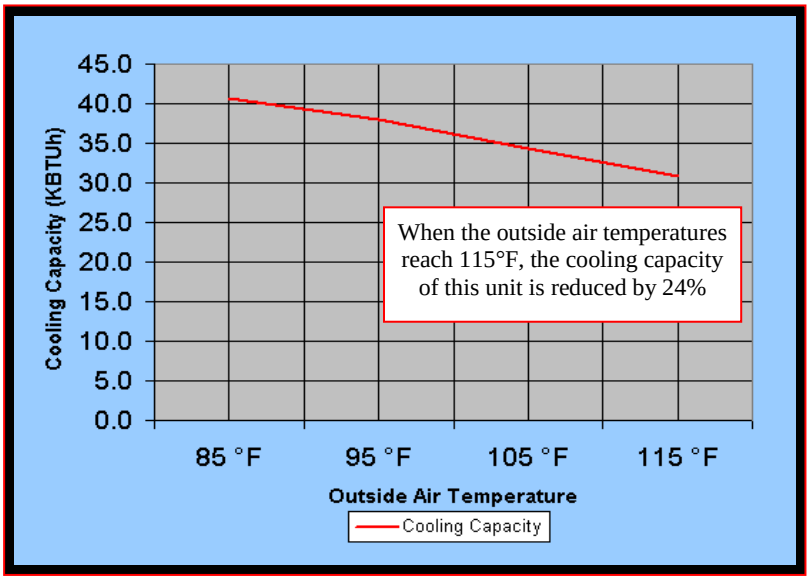

Figure 3: The effects of hot weather upon the performance of a typical 3-ton, air-cooled air conditioner. Note the dramatic decrease in performance at higher temperatures.

Water-Cooled Air Conditioners

It's no secret that water-cooled air conditioning systems are much more energy-efficient than air-cooled systems. Historically, this is one reason why water-cooled systems have dominated the market for large commercial cooling applications. Water-cooled systems are more efficient for one simple reason: It is easier to reject heat into water than into air. In fact one gallon of water can absorb 3,500 times more heat than a gallon of air! The fact that water is so much more effective at absorbing heat than air allows water-cooled systems to operate at much lower pressures. Since the energy consumption of a refrigeration compressor is directly related to the pressure it must produce, water-cooled systems require much less energy. Unlike air-cooled systems, the efficiency of water-cooled air-conditioners in dry climates is relatively constant - even during very hot weather conditions.

Although water-cooled systems have been used for commercial applications for many years, they are still uncommon for residential applications. Why haven't they caught on? One word: maintenance. Previous attempts to promote residential water-cooled air conditioning systems have been hampered by problems related to the formation of scale on the condenser coils and clogged spray nozzles. Hard water scale impedes heat transfer and may cause premature compressor failures. Commercial customers have effectively dealt with this issue through preventative maintenance and water treatment programs. Since

commercial systems are typically larger and used more often than residential systems, the energy savings usually offsets the increased maintenance costs. One manufacturer may have developed a way to help overcome this hurdle. Let's take a closer look at the AquaChill.

The AquaChill

Overview

Air conditioning systems use compressors, condenser coils, evaporator coils, fans and refrigerant metering devices to transfer heat from the indoors to outdoors. These components may be contained in one housing (package units) or in two separate housings (split systems). The AquaChill is a split system air conditioner that uses the same components as a conventional air-cooled system, plus a few more. The main difference is that AquaChill uses water instead of air to remove the heat from the refrigerant within the condenser coil. Since water usually contains several dissolved minerals, water-cooled systems often experience problems with hard water scale. According to Beutler, they have addressed this concern by using the following strategies:

Figure 4: AquaChill's condenser coil consists of a bundle of flexible tubes that are suspended above the water basin. If hard water scale forms on the condenser tubes, it is dislodged by the expansion, contraction and vibration associated with normal operation of the unit.

- **Condenser coil design** - The condenser coil consists of a bundle of flexible tubes that are suspended above the water basin (Figure 4). If hard water scale forms on the condenser tubes, it will be dislodged by the expansion, contraction and vibration associated with normal operation of the unit. The pieces of scale should then fall into the basin of the unit where they can be easily removed.

- **Wide spray nozzles** - The AquaChill uses water distribution nozzles with very wide openings (Figure 5). This helps prevent clogging due to hard water scale deposits.

- **Sacrificial anodes** - The coils are protected from corrosion by the use of sacrificial anodes within the water basins, similar to the rods used in water heaters. Depending on water conditions, these rods will need to be periodically replaced.

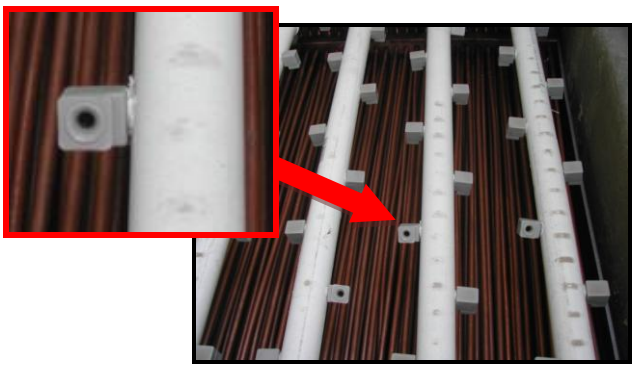

Figure 5: The AquaChill's water spray nozzles have very wide openings. This helps prevent clogging due to hard water scale.

Is AquaChill Energy Efficient?

According to literature provided by the manufacturer, the AquaChill has an EER of 15 and maintains it even at higher temperatures (Figure 6). Beutler also claims that the AquaChill units use very little water, less than three gallons of water per hour of usage for each ton of nameplate cooling capacity.

Of course the real question was how well would the AquaChill system perform in the field under real world conditions? To answer this question, thirty units were installed and extensively monitored. The results are presented in the following sections.

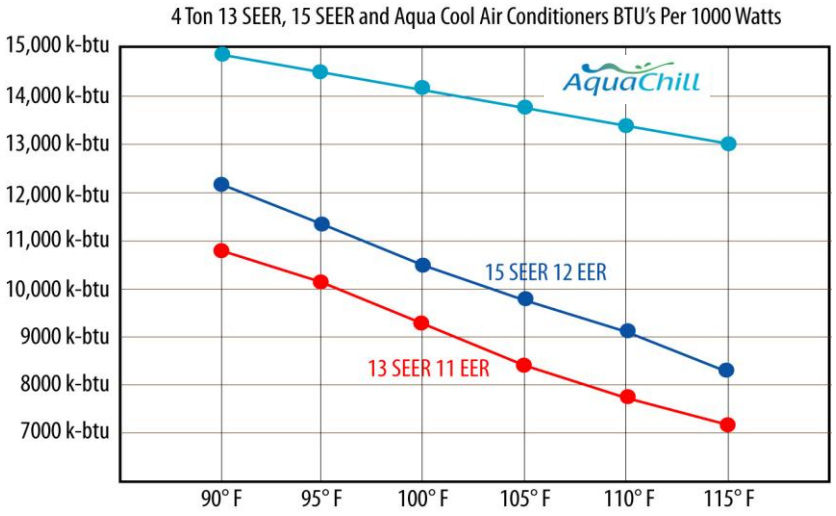

Figure 6: According to literature provided by the manufacturer, the AquaChill has an EER of 15 and maintains it even at higher temperatures.

The SMUD Experience

Overview

In 2008 SMUD began to work with Beutler, ADM Associates Inc. and SMUD customers to test the AquaChill. The goals for this research project were to:

1. Measure kW to determine peak demand savings
2. Measure kWh consumption to determine energy savings
3. Monitor water consumption
4. Inspect the units to check for presence of scale and other potential problems
5. Determine the short-term reliability system

Participants were offered $3,000 research grants in exchange for a two-year monitoring access agreement. During the summer of 2008, thirty AquaChill units were installed. Since these units were installed at various times during the summer, the length of the data collection period varied.

When working in the field of emerging technologies, problems often occur. This project was no exception. Unfortunately the original units were plagued with a variety of problems ranging from control circuit board problems to refrigerant leaks. The project team analyzed monitored data and service records to identify the cause of the problems and develop solutions. Ultimately, the AquaChill was completely redesigned and re-tested in the laboratory.

After the new version of the AquaChill was tested and approved by Environmental Testing Laboratories (ETL) Beutler stepped up to the plate and replaced all thirty units. SMUD supported this effort by offering additional $1,000 research grants, so there was no additional cost for the replacement units to research project participants.

Improvements for the AquaChill include:

- New roto-molded plastic housings are much stronger and more attractive than the original fiberglass cabinets.
- Higher quality refrigeration compressors.
- Original custom-made electronic control boards were replaced with proven HVAC control components. This improved reliability.
- Condenser coils are now manufactured by Beutler and use plastic manifolds to prevent damage to the copper tubing from vibration.
- An upgraded condenser fan assembly.
- Upgraded purge and circulating pumps.

Monitoring Results

SMUD hired ADM and Associates Inc. to monitor the performance of the AquaChill units. In the summer of 2009, ADM installed monitoring equipment on 29 units. Since three units were installed in new construction applications and did not operate during the summer of 2009, the data was limited to 26 AquaChill units. This data was analyzed and compared against energy usage data for typical single family homes in SMUD's service territory to determine the potential peak demand reduction and energy savings. The results are presented below.

Peak Period Performance

During 2007 and 2008, SMUD conducted a study (unrelated to this effort) of household energy consumption. This study provided some key insights into air conditioning usage for typical single and multi-family homes in SMUD service territory. Figure 7 shows the average electric demand profiles for 26 AquaChill test sites verses typical homes. The average difference between the two groups during the 4PM-7PM period is 0.92 kW. Our simulations suggest that, on a peak day (i.e. hottest day of July), the average expected savings for a home with a 4-ton unit would be about 1.09 kW.

- The average EER of the AquaChill units was calculated at 13.4. This includes periods when the outside temperatures rose to 106°F.
- AquaChill units exhibited essentially the same performance over a wide range of outdoor dry bulb temperatures. ADM's field monitoring found that the average efficiency of the AquaChill units was 13.4 EER during the July 14-19 heat wave, which is virtually indistinguishable from the 13.4 EER measured over the entire summer. It is for this reason that the AquaChill units can reduce demand by over 1 kW per household.

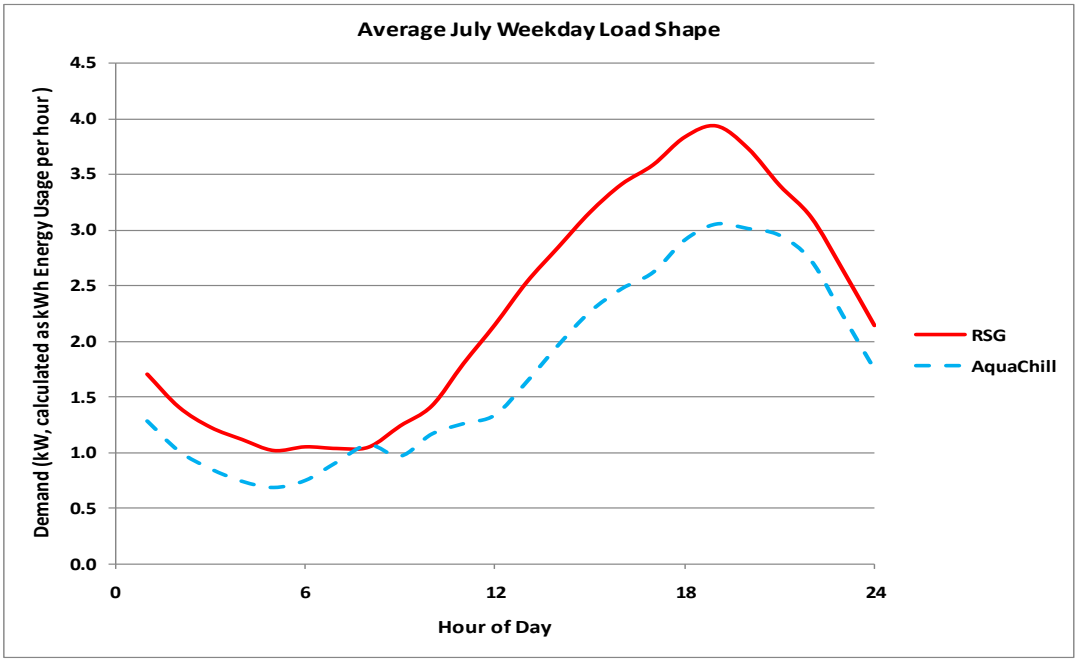

Figure 7: Average July 2009 household weekday electric demand (average kWh of energy usage attributable to each hour) for the AquaChill sites (dashed blue profile) and for typical residences in SMUD's territory (solid red profile). The average difference between the two groups during the 4PM-7PM period is 0.92 kW. Simulations suggest peak demand savings of 1.09 kW for a home with a 4-ton unit.

Energy Savings Potential

Data from SMUD's 2007-2008 study suggests that the typical single-family home in SMUD service territory requires around 1,580 kWh of energy for space cooling per year. The average energy usages for the AquaChill sites were determined with a regression of observed energy usage versus maximum daily temperature for 26 sites. The regression was then seeded with actual temperature data for May-August 2009 and data for September and October. This regression suggests that the average AquaChill site uses approximately 1,118 kWh of energy for cooling per year. Based upon these calculations, the AquaChill could produce savings of 462 kWh per year for a typical single-family home in SMUD service territory (Figure 8).

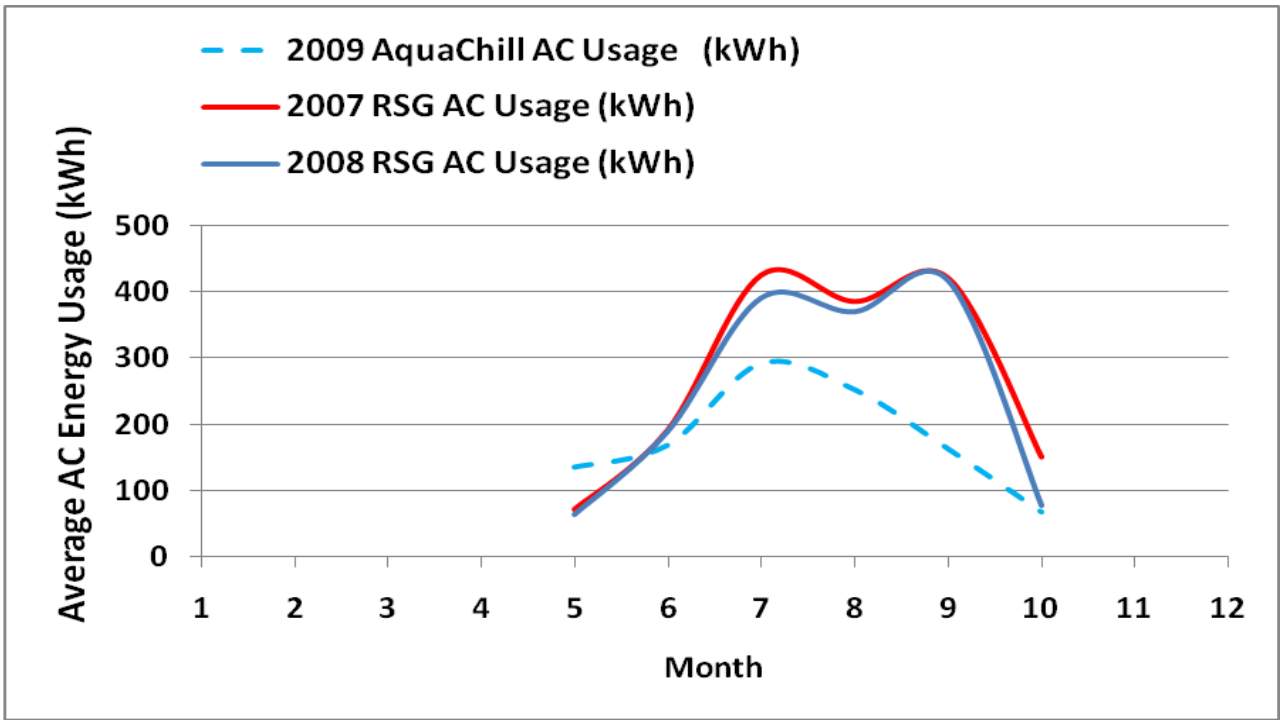

Figure 8: Average monthly air conditioning energy usage for AquaChill sites (dashed blue profile) and for the average single-family home (solid red profile). AquaChill could produce savings of 462 kWh per year for a typical single-family home in SMUD service territory. Source: ADM Associates Inc.

Water Usage Characteristics

Water usage is an ever growing concern in California, so it is important for these types of systems to use water in a very efficient manner. The water usage patterns for the first wave of AquaChill (2008) systems were very erratic and difficult to analyze. Fortunately the 2009 AquaChill units were much more stable. After analyzing the monitoring data for 2009, the following observations were made:

- AquaChill units use approximately 1,689 gallons of water for cooling per year, or approximately 4.6 gallons per day over the year. To put this in proper perspective, a family of three uses an average of 100,000 gallons of water per year.

- Water usage on peak (hot) days may exceed 60 gallons per house.

- In terms of gallons used per ton-hour of cooling provided, the AquaChill units required 1.3 gallons per ton-hour. This compares favorably to the manufacturer's usage prediction of 3 gallons per ton-hour.

Conclusions

AquaChill offers customers a high-efficiency option to standard air conditioning. Moreover, it provides substantial peak demand savings to SMUD compared to conventional, "high efficiency" air conditioning systems. Since it looks and feels like a conventional air conditioner (i.e. it's not a direct evaporative cooler), it should be relatively easy to integrate into the marketplace. The second generation units appear to be operating satisfactorily, however additional operational experience is needed to determine the long term reliability of the AquaChill.

Advantages

- Based upon laboratory tests and energy simulations, AquaChill is much more energy efficient than conventional air-cooled systems under hot weather conditions (temperatures > 100°F).
- Water cooled systems operate at lower head pressures – this may help extend the life of the refrigeration compressor.
- AquaChill is currently manufactured and installed by the same company – Beutler Corporation. Beutler has been in business for over 60 years. This unique situation provides customers with the benefit of single point responsibility from a well established local company.
- Uses only about 1.3 gallons/of water per-ton-hour.

Disadvantages

- Requires more maintenance than air-cooled systems (coil cleaning, pump intake screens).
- Long-term reliability is still unknown. Although Beutler has made several significant design modifications that should enhance system reliability, the long-term track record for the latest version of the AquaChill has not yet been established. Fortunately, Beutler offers a standard two year labor warranty, a five year parts warranty and a ten 10 year compressor warranty.

Technology Transfer

Currently, SMUD offers customers a $1,100 incentive to install the AquaChill system (as part of a limited-time pilot program). However, even though the AquaChill offers outstanding peak performance compared to conventional air conditioning, it is not yet clear how SMUD will value peak demand reduction in the future.

SMUD is in the process of revising our residential retrofit programs to emphasize whole house performance. The whole house performance approach emphasizes reducing a home's cooling load through building enclosure improvements (e.g., increased attic and wall insulation) and then using "right sized" air conditioning systems. Although technologies such as the AquaChill will almost certainly play an important role in the program, key decisions regarding program delivery and incentives have yet to be made. SMUD wishes to thank ADM Associates Inc., Beutler Corporation and SMUD customers for making this project possible.