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Cool Storage Thaws the Home Market

by Peter Weiss

Cool storage systems make ice or cold water at night and deliver cold air to the house during the day. These systems, which reduce peak electricity use, may soon be widely available for residences.

We store thermal energy every day, in portable coolers, thermos bottles, and ice packs, but we rarely think of it on the scale of a house or larger building. Yet in chilly Northern Europe, home heat storage has been popular since the 1940s. There, most residences are charged more for electricity used during the daytime than at other hours. So, many Europeans use storage systems that warm bricks at night, when electricity is relatively cheap, to hold the heat until the next day. The day's heating requirements are then met by tapping the stored heat without having to use expensive daytime electricity.

Most U.S. utilities are different than European utilities because their peak occurs during hot summer afternoons. As a result, electricity is most expensive to generate during summer afternoons. Cool storage systems accumulate a reservoir of "coolth" during the night and use this to cool a building during peak-demand hours. This strategy uses much less peak electricity than a conventional air conditioner. Commercial building owners in this country have already discovered the large savings possible by using this cooling strategy. Because large commercial users are charged time-of-use (TOU) rates (i.e, they pay less for electricity consumed during the night than during the day), cool storage pays off for them (see box).[1]

Many U.S. utilities offer optional time-of-use rates for residences, but few people know about them or have developed strategies for capitalizing on them. As the cost of producing peak electricity rises and the utilities push to shift more electricity use out of the peak daytime hours, residential TOU rates may become more common, perhaps even mandatory (see "Time of Use Rates," *EA&R*, Jul/Aug '87).

To date, the significant developments in cool storage products have taken place only in the commercial sector. Nonetheless, at least one residential cool storage system is almost "off-the-shelf," and numerous other promising prototypes are being tested. This article explores residential cool storage: how it works, its present state, and what the future will bring.

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Time of Use Rates

"Burning the midnight oil" could burn up fewer dollars if you are on time-of-use rates (and your lamp is electric). Large businesses pay for electricity according to the time of use as well as the quantity. They can reduce their bills considerably by shifting their usage to low demand times. In the next few years many homeowners as well will have the opportunity to select time-of use (TOU) pricing.

In a manner analogous to telephone charges, TOU rates are higher for "day" than "night" or weekend electricity consumption. Typically the "day" rate is in effect for the six to twelve weekday hours of heaviest or "peak" demand. The remaining hours and weekends are at the lower off-peak rate. In general, the peak rate is substantially higher than a uniform, non-TOU rate while the off-peak charge is lower. The percent difference between on and off peak rates varies from utility to utility. Pacific Gas and Electric Company, as an example, charges during the summer (when its seasonal demand is at its greatest) 22" per peak kWh and 5" per kWh off-peak. PG&E's non-TOU rate is 10.3"/kWh for large residential users.

At least 75 utilities in this country offer optional TOU rates to residential customers. TOU customers pay a higher monthly base charge because the TOU meters are more expensive and bills are more complex. However residences that have above-average electricity use can benefit substantially if they select TOU rates and can move a large amount of their electricity use to off-peak hours via load-shifting techniques such as thermal energy storage.

Use More Energy but Save Money

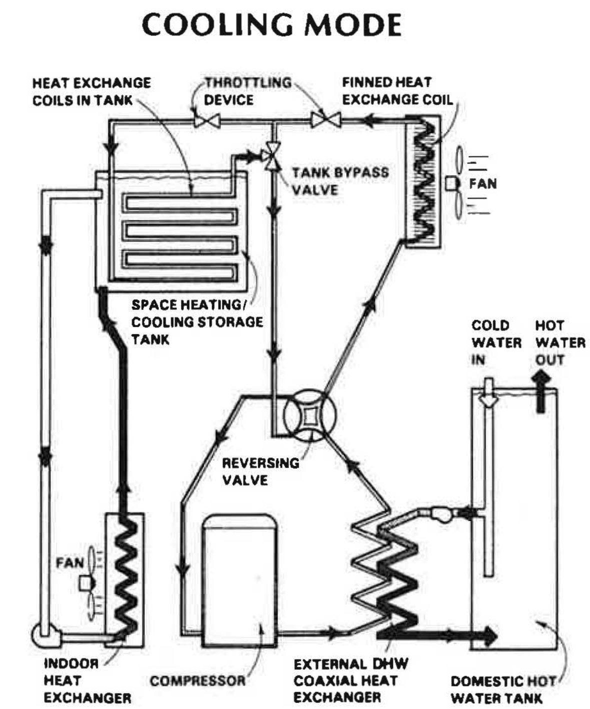
Cool storage is not an energy-saving technique. In fact, most cool storage systems use more energy than the conventional air-conditioning equipment they replace.

By installing cool storage, electricity consumers on TOU rates save money, not electricity. The total electricity bill may drop if low nighttime rates are available. Of course, the savings depend heavily on the rate structure imposed by a particular utility in a particular area and on the capacity and efficiency of the cool storage unit being used.

How Does Cool Storage Work?

First, it is important to recall how a conventional air-conditioning system operates. In a typical, centralized split system, the compressor and the condenser coil are placed outside the house and the cooling (evaporator) coil is installed inside, in the same ducts that are used for heating. A fan blows air through the ducts. The system is controlled by a thermostat. When the temperature rises above the thermostat's setting, the refrigeration cycle kicks in, and expels heat to the outdoors until the internal temperature has fallen to the desired level.

Cool storage systems use the same refrigeration cycle (compressor, condenser and cooling coils); however, instead of cooling the household air directly, they cool an intermediate material, called the storage medium, and then use it to cool the air. Because they are not cooling the air directly, these systems can cool the storage medium at any time, regardless of the indoor temperature. If the temperature is already comfortable in the house, the extra coldness or "coolth" produced by the cool storage unit is retained in the insulated storage medium.



Courtesy of Phenix

Figure 1. Diagram of a Phenix storage system in cooling mode.

Cool storage systems extract heat from—that is, they cool—the storage medium during off-peak hours when electricity is less expensive. A tank insulates the low temperature medium until it is needed on peak. At that time, all or part of the cooling needs are met from storage. Using stored coolth can cut electricity demand during the peak time period to only the amount needed to run the system's pump and fan. During the peak period, the compressor is shut off by an electronic command either from the utility or from the storage system's computer.

Cool storage systems have more plumbing than conventional air-conditioning units. First, a refrigeration unit "charges" the storage medium. In this process, a tank of water or a water-based solution is cooled to make ice, slush or just chilled water. During the day, the stored coolth is delivered to the living space by circulating chilled water or an intermediate heat-transfer fluid straight from the storage tank into one or more cooling coils in the supply ducts. Figure 1 shows an "integrated" system (heating, cooling and hot water heating in the same unit) in the cooling mode.

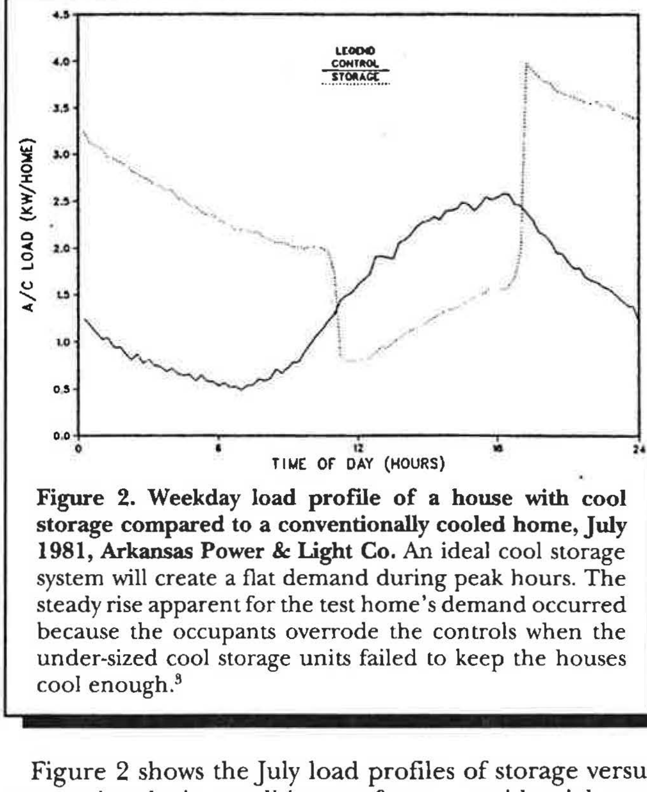


Figure 2. Weekday load profile of a house with cool storage compared to a conventionally cooled home, July 1981, Arkansas Power & Light Co. An ideal cool storage system will create a flat demand during peak hours. The steady rise apparent for the test home's demand occurred because the occupants overrode the controls when the under-sized cool storage units failed to keep the houses cool enough.[3]

Figure 2 shows the July load profiles of storage versus conventional air conditioners from a residential cool storage field study. The control homes (with conventional air conditioning) reach their peak in the middle of the day, just when the utility's other customers also demand the most power The "well" shape of the test homes' load is typical of cool storage. Cool storage systems demand power mostly outside of the peak period. A cool storage unit's compressor runs during off-peak hours to build ice. It shuts off as the peak period begins; only enough electricity to run pumps and a fan is required in the on-peak "well." As the peak period ends, the compressor comes on line again, causing the demand to return to the off-peak level.

What's the Best Medium?

The experts are still arguing about the ideal storage medium. Many factors affect the choice, including cost, efficiency, and space.

Many commercial cool storage systems use chilled water, but ice storage is favored for residential applications. Ice is the most compact way to store coolth because of the phase change (freezing) that takes place. Because so much heat—the latent heat of fusion—must be removed from water to freeze it, a quantity of ice represents a large amount of heat removed, or coolth stored. By comparison, the amount of heat removed to simply lower the temperature of water, called "sensible" heat (i.e., what we feel) is relatively small. A chilled water tank must contain seven times the volume of water to provide the same storage as ice.

Ice is not a perfect storage medium, however. Its space-saving benefit is offset by lower conversion efficiencies. Worse, since ice-makers work at a lower temperature than conventional air conditioners, completely new refrigeration equipment must be installed. So, current ice-making, residential cool storage systems are only practical for new homes or by homeowners who are completely replacing their present cooling system.

Other options will be available soon. Two new types of storage media—eutectic salts and clathrates—have been developed (see box below). These media freeze at a higher temperature. This means that conventional air conditioners can be coupled to them and that more coolth can be stored in a given volume. They may enable the development of a compact cool storage system that can be retrofitted.

Sizing a System

The capacity of cool storage systems is measured in ton-hours.[2]

A conventional three-ton air-conditioner is considered adequate for handling a typical residential cooling load (a large house in Texas or Florida would need much more). How do we determine the size of an equivalent cool storage unit? As an example, let us assume that on the hottest days the conventional unit would be working at full load continuously during a peak eight-hour period. For a cool storage unit to match that performance just from storage the unit must have a stored cooling capacity of 24 ton-hours (3 tons x 8 hr = 24 tons). Because this hypothetical full storage unit has 16 hours to charge before delivering its coolth, it theoretically needs to be only a 1.5-ton system, half the size of the conventional air conditioner. (Of course, storage and conversion losses cause its necessary capacity to be higher.) These savings in air-conditioning capacity can partly offset storage costs.

Performance

Residential cool storage systems are not available on the mass market, and they are too new to have proven themselves equal to conventional air conditioning in terms of comfort and reliability. However, prototype cool storage equipment has been field tested, so some measures of system performance are available.

During 1980 to 1982, Oak Ridge National Laboratory (ORNL) field-tested cool storage equipment in 208 homes in five different regions of the United States.[3]

Types of Cool Storage Media

The key requirement in a cool storage system is the medium in which the "coolth" is stored. Four types of storage media are used: chilled water, ice, eutectic salts and clathrates. Each has its own advantages with respect to system design and performance.

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Chilled Water

Chilled water systems have low energy density so the storage tanks must be large. Big tanks make the systems too bulky for most residential cooling needs and increase costs. These systems function in the same temperature range as conventional air-conditioning equipment. Therefore, they can be retrofit into existing cooling systems and are more energy-efficient than ice storage units.

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Ice

Ice units are compact because of the high energy density of ice and low cooling fluid temperatures. Because ice systems can be small and because the storage medium is so inexpensive, the initial costs for these units are lower than for other media.

Ice storage systems are unsuitable for retrofit to existing cooling plants because conventional air-conditioning equipment is not made to function at such low temperatures. Ice systems are also thermodynamically less efficient because they extract heat at a lower temperature.

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Eutectic Salts

Eutectic salts are salt hydrates (a salt hydrate is a complex ion formed by the union of a salt and water) with a high freezing temperature (46-50°F) and a high latent heat of fusion (41 to 88 BTU/lb, vs. 144 BTU/lb for ice). They have only recently emerged from the laboratory. Eutectic salts can couple with existing air-conditioning equipment with no loss in compressor efficiency. Since they have a lower latent heat of fusion than plain ice, they require up to twice the storage volume of ice systems.

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Clathrates

Another new class of substances designed for cool storage applications are clathrates or gas hydrates. They are made by introducing noble gases or other "guest molecules" into the structure of water. Thermal Energy Storage, Inc. of San Diego is developing a cool storage system using their own clathrate. Freon refrigerant gas is the guest molecule. The clathrate freezes at 48°F but has a latent heat of fusion of 122 BTU/lb.

Like eutectic salts, clathrates can couple to conventional air-conditioning units without any derating of efficiency or storage capacity. Being new and available only in small quantity, clathrates are the most expensive medium.

COOLING

The field test used equipment from four manufacturers: A.O. Smith Corporation, Carrier Corporation, Girton Manufacturing Company and Calmac Manufacturing Company. All of the systems had problems, including: undersized compressors, insufficient cool storage capacity, excessive energy consumption, large standby losses and poor reliability. Customers were dissatisfied as well, reporting that cool storage units required too much maintenance, did not provide the desired level of comfort and occupied too much of their yard space with unsightly hardware. The noise of the compressors functioning during the night also disturbed some residents.

Energy use was expected to increase for houses with cool storage systems. However, homes tested in the ORNL study used up to twice the energy of similar homes using conventional space cooling methods! Researchers attributed this excessive energy use to two primary causes: (1) condenser inefficiency and (2) standby losses from imperfectly sealed, insulated and located storage tanks.

Decreased condenser efficiency is an unavoidable penalty for pumping heat across a greater temperature differential (when ice is made). However the losses discovered in this study were also attributed to poor design. Manufacturers used refrigeration systems optimized for air-conditioning temperatures to make ice. At the lower temperatures the refrigeration units' efficiency dropped. As the study noted, "the greatest opportunities in improving residential ice storage equipment lie in the area of improved refrigeration systems. Many refrigeration systems suitable for ice storage systems have been successfully used in commercial applications. However, these refrigeration systems are not commonly used in residential applications."

Why Choose Cool Storage ?

The main reason to install cool storage is the anticipated savings on electricity bills. Residential cool storage is also intrinsically superior to conventional air conditioning on several counts. It can provide zone cooling of a building with a single system. Its cooling capacity can be modulated (by drawing or not drawing from stored coolth) without degradation of refrigeration system performance. And, cool storage can handle relatively large peak cooling loads without requiring a refrigeration system sized to those peaks. The advantages and drawbacks of cool storage are summarized in Table 1.

Today's residential cool storage systems are likely to perform much better than did the equipment in the ORNL study. The systems built for that study represented the first attempts to retrofit existing air-conditioning equipment to ice-making machines. Because of the study's disappointing results, the manufacturers modified their approach. Indeed, three of the four manufacturers in the study quit making residential cool storage systems (see box on page 12).

Some new residential systems claim to offer cool storage with an energy savings over conventional systems. Researchers are assessing these claims for new, "integrated" systems. Such systems did not exist at the time of the ORNL study although the researchers had the foresight to propose in their recommendations that "dual systems where storage is used for both heating and cooling may help increase the cost-effectiveness of cool storage equipment."

Two systems, the Phenix "THP/3" and UHR Corporation's "MAX" system boost energy efficiency by using the heat removed during cooling to heat water for domestic needs. Both manufacturers say their systems use less energy overall—provided the hot water load is high enough—than other equivalent combinations of heating and cooling equipment. The unavoidable inefficiencies of ice-making still exist in these products. For instance, the Phenix unit's energy consumption for cooling remains 20 percent greater than that of conventional equipment.

UHR's MAX systems have been under field study by Virginia Power since May 1985. The data show that, compared to similar control houses with three ton heat pumps and electric water heaters, the MAX system significantly reduces peak demand. The test houses also, as claimed,

Table 1. Pros and Cons of Residential Cool Storage

PROS	CONS
Reduction of peak electricity use (lower utility bill with TOU rates)	Increased first cost
Greater capacity from smaller refrigeration unit	Cannot retrofit to existing cooling equipment (ice systems)
Zone cooling with one system	Storage tanks take up extra space
Capacity modulated without hurting refrigeration unit performance	Increased overall energy use (except, possibly, integrated systems)
	Unproven technology (unfamiliar to HVAC repair personnel)

use less overall energy. Can the MAX system legitimately take credit for the improved efficiency? A desuperheater on a conventional air-conditioner would also cut demand (see "Stalking the Wild Desuperheater," *EA&R*, Jul/Aug '85). Many of the energy savings in the test homes were due to lower "appliance" loads, not reduced "comfort conditioning" (heating/cooling) demands. Virginia Power analysts, however, argue that the lower "appliance" loads in MAX houses could really be due to the storage system's presence. First, they say, the test house occupants may be inspired by the presence of a load-management system (the MAX) to be more conservation-oriented. Secondly, they propose that control homes may use fans more, a "comfort-conditioning" load that they couldn't monitor as such. More extensive studies are needed to settle the question. In any event, the MAX's load-shifting potential is undisputed. Virginia Power reports that summer peak load is reduced by 43 percent compared to the control group and that with the TOU rates granted the MAX customers, the annual savings is approximately $400 on utility bills.[4]

Phenix systems so far have only been lab-tested and computer-simulated. In 1987, Sacramento Municipal Utility District (Sacramento, Calif.) launched a two-year field study of 30 Phenix-equipped homes and 30 comparable homes with conventional heat pumps and gas water heating. No data from the field tests are available so far.

How Do the Customers Like It?

Only two residential cool storage developers actually have units installed in homes. Three years ago, UHR installed its phase 1 (chilled water) MAX systems in 12 houses in the Washington, D.C., region, three years ago. Phenix has had prototype systems in a comparable number of homes near Sacramento, Calif., for about three years, plus newer versions in another Sacramento suburb since 1987. The UHR and Phenix systems are both "integrated," but they are quite different in design and in the climates where they are being used. Sacramento has hotter and much drier summer weather than the Washington D.C. area. *Home Energy* contacted one owner of a Phenix-equipped home and two UHR MAX users. The Phenix owner had just moved into his home in March

Courtesy of Phenix

A Phenix cool storage system being installed.

1988, whereas the MAX users have had their systems between two and three years.

The Phenix customer is very pleased with the thermal energy storage concept and because "my bills are low." At the same time, he is irked by his lack of control over the system. In previous homes (which used conventional air conditioning and gas heat), he simply left the heating and cooling off during the moderate spring and fall seasons. Even though he turns the Phenix thermostat to "off" during mild weather, the system still insists on making ice—probably because the outside temperature is hotter than a preset threshold. He's concerned because he won't use the system for a week or ten days but "every morning it runs for two or three hours... I'm paying for energy that I'm not using. I think that's one of the shortcomings of the system," he complains. Sudden changes in temperature outpace the Phenix system. If the ambient temperature is very hot for a couple of days and then quickly turns cold, resistance heating has to be used because the storage tank has been made cold and takes many hours to reheat. Despite such disappointments, the Phenix customer is delighted with the storage unit's ability to shift load to off-peak: "I was shocked that the amount of peak hour energy we used was so low. It was just amazing!"

One of the UHR MAX system users recalled that "it was kind of rocky at first. You have to understand, we were one of the first units they put in. Now I don't even notice it anymore," he says. "It's just part of the house." Compared to the heat pump with electric hot water that preceded the MAX system, he thinks the comfort is about the same but the monthly cost is "significantly cheaper." "I hear horror stories from neighbors [without the MAX system] about their bills." He appreciates the "huge" hot water tank for the large number of showers it will store and doesn't mind the space lost to tanks because they are in the basement. To him, the MAX system sounds different than the heat pump that was removed; it's a little louder, and at first the noise was "unusual" but now he no longer notices it.

The other MAX customer found the noise to be "typical of any forced-air system." He too did not mind that the MAX system uses more basement space than the heat pump it replaced. With outdoor temperatures in the "high 90's and quite humid," he finds that the MAX system easily maintains the house at 70°F. He says, "It works just like air conditioning. We like it real cool and it works."

The Cool Storage Payoff for Utilities

Utilities want to find ways to reduce the peak demand placed on their electrical generating facilities. The electric utilities are well aware of the costs of adding to their generating capacity. They know that "load-shifting" or "load-leveling" techniques like thermal energy storage can be less expensive ways of meeting their peak demand. And, they are willing to pay for them.

Utilities pay handsome incentives to commercial building owners to install cool storage equipment. Cool storage inducement programs across the country offer $115 to $425 up front per kilowatt of load shifted out of the peak period. For a large user, that can mean a lump payment of as much as $300,000 for one cool storage conversion or installation.

Home Energy knows of only one such program to promote residential cool storage acceptance. In conjunction with its study of Phenix system performance, Sacramento Municipal Utility District (SMUD) is giving a $1000 incentive, per unit installed, to the home builder. The utility has also created a special, more favorable TOU rate schedule for the Phenix-equipped residences. Jerry Best, president of Phenix Heat Pump Systems, Inc., feels that since "economic benefits of the Phenix system accrue entirely to the utility, it is appropriate to give rate breaks and incentives to residential markets, as is done in the commercial sector."

Without a program of substantial financial inducements for residential cool storage, cool storage is too expensive to be popular. "We have the capability now to

What's Available for Residential Cool Storage?

Types of Systems

Ice-on-coil: Ice builds up on coils submerged in a water tank. Cold water is pumped through cooling coils.

Brine: A water tank freezes solid when glycol/water brine (antifreeze), below 32°F, passes through coils in the tank. Antifreeze circulates between the tank and cooling coils.

Eutectic Salt Ice: Plastic "bricks" full of eutectic salts freeze in a bath of chilled water. Cool water circulates in the cooling coils.

Ice Harvesting or Crystal Making: Ice pieces or slush fall into a tank and float. Chilled fluid from the bottom of the tank is drawn into the cooling coils.

(Source: ITSAC "Thermal Storage Advisories" and "Technical Bulletins." International Thermal Storage Advisory Council, 3769 Eagle Street, San Diego, California 92103.)

Products

The seven manufacturers below already offer cool storage systems for homes or will be marketing one soon.

Calmac Manufacturing Corporation
150 South Van Brunt Street
Englewood, New Jersey 07631
Tel: (201) 569-0420

Calmac's 5-ton brine system for small commercial buildings is called the Roofberg. The unit is too large for residential use but it is one of the first commercial units to approach residential size. Calmac is working on a true residential ice storage system designed to handle a utility-defined peak period of four hours entirely from storage.

O.E.M. Products, Inc.
1802 Turkey Creek Road
Plant City, Florida 33566
Tel: (813) 754-2649

OEM's prototype ice-on-coil system is sized specifically for residential requirements. The company is working on the project with Florida Power & Light and one OEM unit has been tested by Pacific Gas & Electric in Northern California. Some OEM units will be installed in homes this summer.

Phenix Heat Pump Systems, Inc.
P.O. Box 1240
Elk Grove, California 95624
Tel: (916) 689-8111

Phenix combines heating, cooling and domestic hot water in its 3-ton and 5-ton "THP/3—Three Function Thermal Energy Storage Heat Pump" systems. These ice-on-coil systems have a single tank for both cool and heat storage. The product has initially been tailored to the climate of California's Central Valley. In a joint effort with Sacramento Municipal Utility District (SMUD), Phenix is installing THP/3 systems in 357 new homes. Phenix systems are also being tested by the Tennessee Valley Authority (TVA), PG&E, and Southern California Edison (SoCal Ed). Of the manufacturers surveyed, Phenix claims to be nearest to selling an off-the-shelf residential cool storage unit.

Powell Energy Products, Inc.
P.O. Box 203
Powell, Ohio 43065-0203
Tel: (614) 881-5596

Powell manufactures the ISAC (Ice Storage AC) Retro Series, a small commercial unit that attempts to retrofit ice storage to conventional air conditioning systems. These ice-on-coil systems are unique in that they pump the refrigerant mixed with a liquid, rather than water or brine, to the air handlers. Powell invented and has patented the technique. Residential-sized prototypes, built in July 1987 and not yet installed in homes, are being tested by Powell and by a large HVAC manufacturer who is considering purchasing the whole Powell line.

Thermal Energy Storage, Inc. (TESI)
8395 Camino Santa Fe
San Diego, California 92121
Tel: (619) 453-1395

TESI is demonstrating its proprietary clathrate, "compound ice," in a 30-to-40 ton model using conventional chillers. Although the demonstration unit is much too large for residential use, TESI is interested in building a small unit for homes. Southern California Edison has collaborated with TESI in the demonstration project. A TESI unit is also under test by Pacific Gas & Electric.

Turbo Refrigeration Co.
P.O. Box 396
Denton, Texas 76202
Tel: (817) 387-4301

In a pilot project, Turbo (a maker of commercial TES systems) built a 7 1/2-ton system for a very large home. Turbo reportedly has developed a residential-size ice harvester system, the first one of which will be installed in a home this summer. No information is yet available on how Turbo has down-sized bulky ice-harvesting methods to residential requirements.

UHR Corporation
4562 Eisenhower Ave.
Alexandria, Virginia 22304
Tel: (703) 370-0600

UHR Corporation has created the "MAX" TES unit which, like the Phenix THP/3, is an integrated system for the residential market. The prototype, which has been installed in a dozen sites in Virginia, is designed to handle a 3-ton air-conditioning load using chilled water as the storage medium. The next round of prototypes will make ice and circulate a glycol mixture. Florida Power & Light and—almost surely again, Virginia Power—will be field testing them. UHR has been working on development since 1980 with seed money or other help from Virginia Power, Florida Power & Light, and Pacific Gas & Electric. UHR intends to introduce the MAXes commercially in 1991.

offer an off-the-shelf unit," says Best. "But the unit is not economically viable without utility support in the form of TOU rates and, in many cases, builder incentives on top of that." Indeed, SMUD decided to offer inducements when it found there was a $3500 incremental cost for Phenix units over conventional equipment. Most utilities, however, are content to just provide seed monies to manufacturers and to conduct field and laboratory tests of equipment as it is developed.

The authors of a PG&E study of cool storage systems calculated payback times for residential cool storage.[5]

First, assuming no incentives from the utility for each avoided peak kilowatt, the researchers found the minimum payback time for ice systems to be 4.3 years and the maximum, 14 years. With a $400 per kW incentive included, the paybacks changed to immediate gains in the best case and to 9 years in the worst.

Don't Hold Your Breath

Residential cool storage is really in its infancy both from the utility and manufacturing points of view," says Don Geistert, a thermal storage expert at the Electric Power Research Institute (EPRI) in Palo Alto, Calif. "Anything in the production mode is three to seven years away."

The technology is, at best, almost ready for mass production. But the necessary ingredients for residential cool storage to catch on go beyond reliable equipment. They include widespread TOU rates, financial incentives (e.g., rebates from utilities who want to reduce peak demand), and reduced first cost. ■

Endnotes

1. The success of commercial cool storage systems is not as certain as it appears. According to Mary Ann Piette, a researcher at Lawrence Berkeley Laboratory in Berkeley, Calif., there are currently about 1000 cool storage systems in the U.S. Piette and colleagues analyzed cool storage systems in 11 commercial buildings and found that cost effectiveness is highly dependent on electricity rates (whether there are TOU rates and demand charges), the load profile for the building, proper system design, and perhaps most importantly, optimal operation of the system itself. Reference: Piette, M. A., and E. Wyatt. "Measured Energy Performance of Cool Storage in Commerical Buildings: An Update of BECA-LM." ACEEE 1988 Summer Study on Energy Efficiency in Buildings.
2. "Ton" is a rate of heat removal equal to 12,000 BTU/hr, which is the amount of coolth available from melting one ton of ice over 24 hours. This unit of measure is a vestige of the days when ice produced in factories was used to keep food, and sometime people, cool.
3. *Field Performance of Residential Thermal Storage Systems.* Prepared by Oak Ridge National Laboratory for the Electric Power Research Institute. EPRI Report # EM-4041. May 1985.
4. Dr. Richard A. Jainchell, coordinator market research marketing and economic development, Virginia Power. "UHR MAX System Load Study, May 1987—September 1987." Internal memorandum.
5. De Almeida, A., and J. Yokoe. "Residential Cool Storage: Peak Load Reduction Alternatives." Presented at the IEEE Summer Power Meeting. July 1987.