

Technical and Economic Assessment Of Solar Thermal Absorption Cooling Systems in Small Commercial Buildings

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ABSTRACT

This article presents the results of an initial assessment of the technical and economic feasibility of supplemental solar thermal absorption cooling systems for small commercial and institutional buildings in the Southwestern United States. Solar thermal absorption cooling systems use chillers powered by solar energy rather than natural gas or electricity. The following factors may position solar thermal absorption cooling systems as a competitive alternative to conventional electric or natural-gas-driven air conditioning:

- Recent technology advances have occurred in concentrating solar thermal direct flow vacuum tube-type collectors.
- The Energy Policy Act of 2005 includes a non-capped 30% investment tax credit for solar thermal cooling systems on commercial buildings.
- Natural gas retail prices are near record highs, increasing peak electricity rates.

- Use of renewable energy powered cooling systems can lead to lower electric demand and reduced power plant emissions.

Initial assessment results show that solar thermal cooling systems are feasible in areas with a confluence of high solar insolation, high cooling demand, and high electric rates, achieving payback of less than 8 years in typical five-story buildings. In smaller commercial and institutional buildings, solar thermal absorption cooling system life-cycle costs are also favorable in comparison to conventional cooling systems.

BACKGROUND

With rising energy prices and the growing acceptance of the threat of global warming, renewable energy systems are poised to make gains in market share. Historically, market barriers to renewable energy sources, such as low fossil fuel prices and the intermittency of renewable resources, limited the attractiveness of renewable energy systems. With the proper application of renewable energy systems, these barriers may be overcome, removing renewable energy from its status as a largely niche-application.

One potential renewable energy application is solar thermal absorption cooling systems (STACS). STACS use solar energy for space cooling, ideally matching a renewable energy resource to seasonal and hourly changes in electric power grid load. The same high solar insolation and temperatures that make air conditioning a prime contributor to peak electric demand also provide the greatest amount of energy to the solar thermal absorption cooling system.

STACS have some advantages compared to electric chillers powered from the grid or offsite renewable energy sources. STACS take advantage of renewable energy at the point of demand, reducing strain on the power grid. As population growth continues in the warmer regions of the country, such as the Southwest, broad implementation of STACS can reduce the consequent strain on the power grid and delay the need for transmission and/or generation upgrades. Moreover, at a peak efficiency of 40%, STACS have been shown to be more efficient than commercially available thin-film photovoltaic cells.

The Energy Policy Act of 2005 also positions STACS as an attractive alternative to electric or natural-gas-driven air conditioning. The Act

includes a non-capped 30% investment tax credit for solar systems on commercial buildings, reducing system cost and making it competitive with traditional alternatives.

This article presents the results of a feasibility study for replacing current electric chillers with a STACS augmented by smaller electric chillers. Understanding that STACS will be most cost effective in hotter, sunnier climates, cities in the U.S. Southwest are considered as potential markets.

STACS TECHNOLOGY DESCRIPTION

Solar thermal absorption cooling systems (STACS) for buildings use water heated in an array of solar collectors to boil a lithium bromide- or ammonia-water solution for use in an absorption chiller. The primary STACS components are the solar collectors and the absorption chiller.

Concentrating Solar Collectors

A limited number of American manufacturers offer building rooftop concentrating solar collectors. The solar water loop consists of vacuum heat pipes installed vertically or horizontally.

In a typical vertical configuration, the system consists of copper heat pipe enclosed in an evacuated glass tube. The heat pipe contains a small amount of a volatile liquid with no air. When the lower end is heated, the liquid evaporates and the resultant vapor travels to the top (cooler) part of the heat pipe. As the vapor cools, it condenses, transferring its heat to the solution in the absorption chiller.

In a direct flow vacuum tube system, which can either be installed horizontally or vertically, the heat pipe is replaced by a coaxial set of copper tubes. The heat transfer fluid flows into the inner pipe and returns at a higher temperature through the outer pipe back into the heating circuit. This direct flow pattern through the collector tubes enables vertical or horizontal installation without support stands.

The flow loops can also be configured to run through parabolic trough collectors that have greater efficiencies. These systems often have optional tracking mechanisms that are an added expense. There are also additional maintenance and service requirements for both the tracking device and for keeping the reflecting surfaces clean.

Figure 1 displays a typical bank of solar thermal collectors.



Figure 1. Solar Thermal Collectors

Source: www.broad.com

Absorption Chillers

The use of absorption chiller technology was popular in the 1960s, but diminished with the gas curtailments of the 1970s. Absorption chillers today have gained acceptance in some Asian markets, but are just beginning to again be recognized in the United States.

Absorption chillers use heat as the primary energy source. Compared with modern electric chillers, absorption chillers have a low coefficient of performance (COP), generally limiting absorption chillers to applications with abundant process waste heat or solar thermal energy. The economics are sometimes more favorable for hybrid systems which combine absorption chillers for use during on-peak electric hours (e.g. to meet summer cooling loads) and electric chillers for base load operation.

The heat boils a lithium bromide (LiBr)- or ammonia-water solution (absorption chillers do not use a CFC or HCFC refrigerant) to produce refrigerant vapor for the cooling of a chilled water loop. In a typical cooling application, the chilled water is pumped to fan coil units throughout the building where internal building air is blown across the coils, providing interior space cooling.

Either a single-effect or double-effect chiller can be used, depending on available heat and the cooling requirements. Single-effect chillers use one generator, condenser, absorber and evaporator; have a low COP (~0.7); and have lower water temperature requirements (<200°F).

Double-effect chillers use an additional generator, supplied with waste heat from the compressor, to vaporize additional refrigerant. Double effect chillers require a higher temperature heat input ($>300^{\circ}\text{F}$) and have a greater COP (1.0 to 1.2) than single-effect chillers.

Beyond the applications discussed in this paper, absorption equipment can be optimized to recycle thermal energy from power generation equipment. This combination offers significant opportunities for maximizing fuel efficiency. Distributed power generation sites can benefit from integration with absorption chillers, especially for gas turbine inlet cooling, process cooling, and air conditioning in buildings.

System Description

The system analyzed in this paper is a commercially available array of concentrating parabolic troughs installed on a flat-roofed, five-story, commercial or institutional building. The solar troughs supply heat to a double-effect LiBr absorption chiller that provides space cooling for the building. In times of greatest cooling demand, STACS act to reduce peak electricity demand from an installed electric chiller. The analyzed STACS can also be configured to supply hot water to the building at times when the system's output exceeds the building's cooling demand. Thus, the solar thermal absorption cooling system reduces the energy use of both the electric chiller air conditioning system and of the natural gas water heater. Figure 2 displays an idealized STACS layout.

Table 1 lists system configuration data.

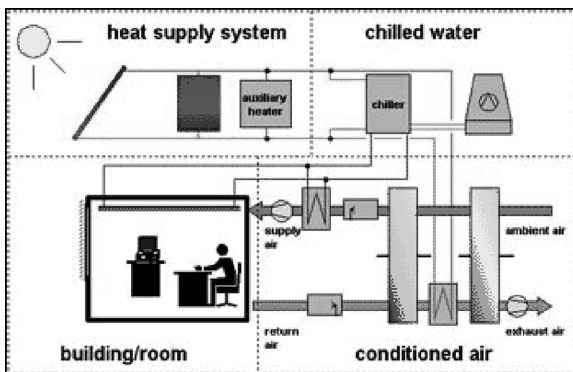


Figure 2. STACS Layout

Table 1. STACS Configuration Data

| | |
|---|-------------------------------|
| Size of Solar Array | 14,000 square feet |
| STACS Chiller Size (from preliminary analysis) | 165 tons (580 kW) |
| Backup Electric Chiller Size (from preliminary analysis) | 106 tons (373 kW) |
| Solar Thermal Collector Efficiency | 40% [Reference 1] |
| STACS Electricity Use at Full Load | 29 kW [Reference 1] |
| STACS Heat Source Water Outlet/Inlet Temperature | 356°F/329°F [Reference 1] |
| STACS Heat Source Water Flow Rate | 113 gpm [Reference 1] |
| Electric Chiller COP | 4.0 |
| Building Operating Hours | 8 AM to 7 PM, 7 days per week |
| Setback During Non-business Hours | 50% of regular cooling demand |

This article does not consider ammonia-water absorption chillers, which are more common in refrigeration applications.

METHODOLOGY

The analysis compares the cost of two options for replacing an aged electric chiller: (1) using a modern electric chiller (4.0 COP), or (2) using STACS combined with a smaller electric chiller. The analysis uses a model to calculate expected building cooling loads, choose an appropriately sized cooling system, and compare relative energy use and costs for the two options. The options are compared for a model five-story building in two cities in the Southwestern United States, San Diego and Albuquerque.

Expected Building Cooling Load Determination

Building cooling load is a function of local temperatures, in addition to building use, occupancy, and design. In favor of a detailed

building design model, which is being constructed as a follow-on to the work described in this paper, the model defines the relationship of building cooling load and cooling degree days as follows:

$$E_{\text{cooling}} = 0.0034 \cdot \text{CDD}$$

where,

$$\begin{aligned} E_{\text{cooling}} &= \text{kWh/ft}^2 \text{ required to annually cool the building} \\ \text{CDD} &= \text{30-year average annual cooling degree days by} \\ &\quad \text{census region [Reference 2]} \end{aligned}$$

This relationship derives from a linear curve fit between the listed building electric loads in each Census region [Reference 3] and the 30-year average of the number of cooling degree days in the corresponding Census regions [Reference 2]. Substituting site cooling degree data from Reference 4 therefore yields expected annual electric cooling loads for model buildings in the subject cities.

The model further apportions the calculated annual electric cooling loads into hourly increments of electric cooling load. The increments are scaled based on typical daily temperature variations in each month, obtained from Reference 5. Based on the analyzed building floor space, total building cooling load and hourly demand are determined. Reference 6 indicates an average installed electric chiller COP of 2.75, which relates building cooling load to electric usage and demand.

STACS Sizing

Given the greater cooling demands in the Southwest, all preliminary model runs indicated that STACS sizing would be limited by available roof space for siting solar collectors as opposed to building cooling demand. Using a five-story building model, Reference 7 indicates an expected floor space of 97,000 ft² leading to an expected roof area of approximately 20,000 ft². Reference 8 indicates that only 70% of available roof space would be available for placing the solar collectors, limiting STACS size to 14,000 ft² of solar collectors.

The cooling potential of STACS is a function of the amount of hot water supply produced from the solar collectors. Reference 1 indicates the solar collector loop flow rate for multiple STACS sizes. Given the amount of available solar radiation (Reference 9, 1990 global horizontal radiation data used to account for both direct and diffuse radiation) and the loop flow rates, the total hot water supply in each hour is de-

terminated. STACS chiller size is set equal to that which can be supplied from the maximum available hot water [Reference 1]. Available STACS cooling is scaled hourly based on supplied versus maximum hot water flow rate. A backup electric chiller is also present to meet building cooling demand during times when the solar hot water cannot supply enough heat to the chiller.

Comparing Costs of STACS and Electric Chillers

To compare the costs of the two options, the total annual energy costs to cool the building in each case are calculated. The STACS electricity use is scaled based on its loading level. Electric chiller energy use is determined using a 4.0 COP. References 10 and 11 specify the current electric rates at the subject sites, including demand charges and kilowatt-hour rates for peak, off-peak, and seasonal periods.

The energy savings resulting from using excess STACS capacity to produce hot water are also calculated. The hot water from the STACS system offsets natural gas that would be used to heat water in a boiler with 56% efficiency [Reference 12]. The amount of hot water produced by STACS is capped at the national average for hot water usage levels in commercial buildings, provided by Reference 3. This analysis assumed that the produced hot water would be consumed evenly during business hours throughout the year. Reference 13 provides the average April 2006 retail price of natural gas for commercial end-users.

The net annual energy savings of STACS are compared to net system capital costs in each case. Reference 1 specifies a \$32.52 per square foot installed cost of the solar array. Reference 14 also specifies a \$625/ton installed cost of the double-effect STACS chiller and a \$340/ton electric chiller. All costs for the solar thermal array and absorption chiller are discounted by 30% to account for the renewable energy tax credit that was passed as part of the Energy Policy Act of 2005.

RESULTS

The results of the preliminary analysis show that STACS have an expected simple payback of 8 years in a typical five-story building in San Diego and Albuquerque. Figure 3 displays the total cooling demand of the building, broken down by the portions met by the STACS system and the backup electric chiller.

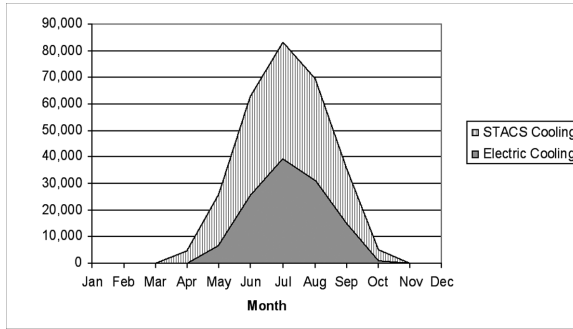


Figure 3. Albuquerque Cooling Energy

The results indicate that using STACS in a typical five-story building will offset approximately 40,000 ton-hr of cooling energy in each of the peak cooling months.

Figure 4 displays the expected monthly savings that would be realized by using STACS, broken down by reduced electricity use for cooling and reduced natural gas consumption for water heating.

As shown in Figure 4, STACS savings are dominated in the summer months by cooling. In the shoulder and winter months, STACS can also achieve significant savings through water heating.

The preliminary analysis also shows significantly shorter payback periods for single-story buildings. The prime limitation of STACS cooling capacity is the area available for installing the solar collectors. In single-story buildings, which comprise approximately 43% of the com-

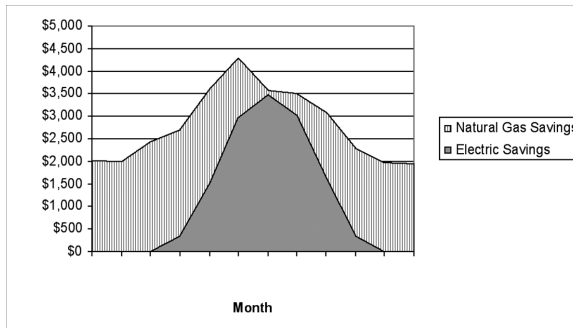


Figure 4. STACS Savings Contributions

Table 2. Model Summary Results

| <i>City</i> | <i>STACS Cost</i> | <i>Electric Savings</i> | <i>Water Heating Savings</i> | <i>Simple Payback (years)</i> |
|-------------|-------------------|-------------------------|------------------------------|-------------------------------|
| Albuquerque | \$326,814 | \$21,167 | \$20,111 | 7.9 |
| San Diego | \$326,814 | \$17,494 | \$25,292 | 7.6 |

mercial floor space in the United States [Reference 7], the ratio of available roof space to cooling area is smaller, allowing the STACS systems to cover a greater percentage of the building cooling load.

CONCLUSIONS

In the on-site energy market for privately-owned buildings, paybacks of two to three years are desirable; five to seven years are sometimes acceptable, and anything over ten years is not economic. Payback periods for publicly-owned buildings (e.g., institutions such as schools, municipal buildings, federal government buildings, jails, etc.) might be extended longer than for privately-owned buildings. Consequently, the model results show that STACS can be a cost-effective option relative to electric chillers in areas with significant cooling demand, solar insolation, and electric prices.

As electric and natural gas rates increase, solar cooling will become an even more economically attractive option for building owners. Utilities may find value in solar cooling technologies' ability to shed peak cooling load off the grid. Utilities are also developing incentive programs to encourage peak load shedding, such as California's 20/20 Program, which rewards end-users who can shed 20% of their peak load with 20% rate reductions.

Although the savings from STACS are attractive, system output is limited by the available area for placing the solar collectors. The economic attractiveness would be further improved if more area were made available for placing solar collectors.

Finally, the current model is limited by the general application of the Commercial Building Energy Consumption Survey data. Consequently, a model is currently being developed to perform feasibility

calculations for individual buildings. The model will be released as a web-based calculator.

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