A Solar Thermal System for Industrial Dehumidification and Steam Generation

Jonathan B. Maxwell*, Mark D'Antonio*, E. Thomas Henkel**,
William Rigos***, Ken May****, and Kevin Creamer*****

*ERS, 13 Railroad Square, Haverhill, MA 01832, jmaxwell@ers-inc.com, mdantonio@ers-inc.com
**Sustainable Energy Consulting, 3 Mt. Bolus Road, Chapel Hill, NC 27514, hen2589@bellsouth.net
***Steinway & Sons, One Steinway Place Long Island City, NY 11105, brigos@steinway.com
****Abengoa IST, 11500 West 13th Ave, Lakewood, Colorado 80215, Ken.May@solar.abengoa.com
****Sunshine Plus Solar, 15 Fourth Avenue, Smithtown , NY 11787, sunsfree@optonline.net

ABSTRACT

This paper introduces a solar thermal system that can be used to power an absorption chiller, generate low pressure steam, or both simultaneously. The project is only the fourth known solar thermal-driven double absorption chiller project installed in the United States. It is also the largest and only industrial project so far.

Steinway & Sons in New York City is installing tracking parabolic trough solar energy collectors to generate 340°F hot water. In summer months, the hot water will drive a 99-ton double-effect absorption chiller to provide dehumidification and cooling. The dual-fuel chiller will use natural gas when solar is not available. When dehumidification is not needed and the collectors can generate hot water above 275°F, the hot water will circulate through a steam generator and produce 15-psig steam to offset a portion of the plant's 1,200 kBtu/hr load. After federal tax benefits and a NYSERDA grant, net cumulative positive cash flow is forecast in less than 5 years.

Keywords: solar thermal, parabolic trough collector, absorption chiller, steam generation

1 THE APPLICATION

Steinway & Sons manufactures their legendary pianos in the Queens borough of New York City. Their manufacturing facility was built in the 1870s and is not air conditioned. In their fourth-floor Action Department, employees build the hammer assemblies that strike the piano strings. The department's heating system injects steam into the space as needed to manage humidity in the winter but has no means of dehumidifying or otherwise conditioning the space in the summer. Maintaining consistent humidity is important in order to control moisture content of the wood components in the assembly.

Steinway chose to add cooling and dehumidification control to ensure product quality. Installing a conventional packaged rooftop system was an option, but ultimately they decided to install a solar-powered system instead. The system being installed will have lower overall operating costs than the air-cooled option and is projected to pay for itself in less than 5 years due to quality and productivity gains. The incremental cost over that of conventional cooling will pay for itself in less than 2 years.

2 THE SOLAR THERMAL SYSTEM

Figure 1 illustrates key components of the proposed system. All the components shown in the diagram are new.

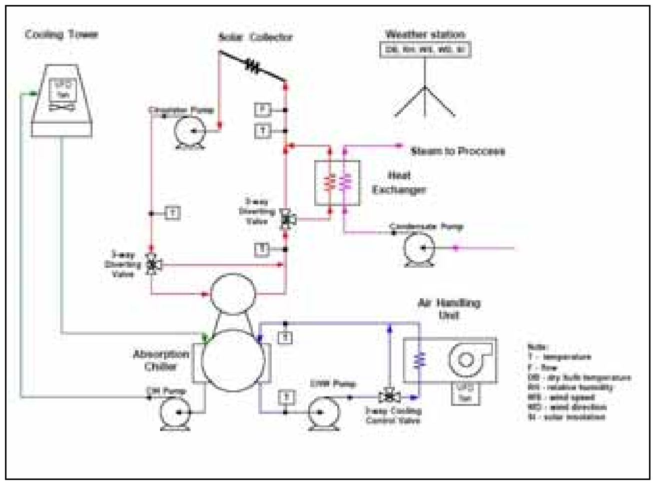

Figure 1: Solar Thermal System Components

Thirty-eight Abengoa Model PT-1 solar collectors mounted on the roof concentrate heat onto evacuated glass tubes, heating a pressurized water and glycol mixture from nominally 320ºF to 340ºF (the red loop in diagram). A collector is shown in Figure 2. The actual temperature varies with solar availability but is limited to 350ºF maximum. When cooling is needed the diverting valve directs this hot water to a 99-ton double-effect absorption chiller. The chiller has a rated coefficient of performance (COP) of 1.39 and integrated part load value (IPLV) of 1.586. The dual-fuel chiller uses natural gas when solar is not available and cooling is needed.

Figure 2: Abengoa IST Parabolic Solar Collectors (stowed position)

The chiller otherwise operates like other conventional chillers, cooling chilled water for the air handling unit (the blue loop in Figure 1.) and rejecting condenser heat to a cooling tower (the green loop in Figure 1).

When dehumidification is not needed and the collectors can generate hot water above 275°F, the hot water will circulate through a steam generator heat exchanger and produce 15-psig process steam to offset a portion of the plant's 1,200 kBtu/hr load (the magenta loop in Figure 1).

3 SINGLE EFFECT VERSUS DOUBLE EFFECT SOLAR THERMAL COOLING

Single-effect absorption chillers are more common and less expensive than double-effect chillers. This project captures the benefits of the double-effect design.

A double-effect (2E) absorption chiller driven by steam or hot water has a coefficient of performance (COP) of 1.1 to 1.6 depending on design and operating conditions, almost twice the efficiency of a single-effect unit. However it requires a heating fluid supply temperature of over 300˚F. Single-effect chillers can operate effectively with water at or below 200˚F. Concentrating solar thermal collectors can consistently provide such high operating temperatures[1] and operate with a collection efficiency more than double that of other collectors. Therefore the conversion efficiency for space cooling is four times better than non-concentrating solar thermal systems with single-effect chillers. The benefits of the system compared to a flat plate and single effect system include:

- Four times the efficiency (tons of cooling per square foot of collector area)
- Less than half the roof space required per ton of cooling
- Can generate low pressure steam when cooling is not needed

Solar systems' roof-mounted solar collectors also significantly reduce solar gain to the building, thus reducing the building A/C load.

The downstate New York market is a good market for such a system because absorption cooling is a relatively familiar technology to engineers and operators there, which is not true in all parts of the country. Furthermore, certain parts of New York City are capacity strained in mid-summer, precisely when this system most relieves the electrical distribution system of load. Also, electric rates are significantly higher than the national average. These advantages were found to outweigh the disadvantage of having lower direct solar resources there than in some other regions.

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[1] The world's first solar-driven 2E absorption chiller was installed in Sacramento, CA in 1997 by the Solargenix Energy-affiliated company, Solar Enterprises International. This solar HVAC project featured a 20-ton chiller and non-tracking Integrated Compound Parabolic Concentrating (ICPC) evacuated tube solar thermal collectors. Solargenix installed a hot-water fired 50-ton Broad 2E absorption chiller with a tracking solar thermal collection system in Raleigh in 2002. These two demonstration projects verify that building-integrated concentrating solar thermal collectors can consistently deliver the required high temperature solar hot water to load and confirm that solar-driven 2E absorption chiller is a viable solar application.

4 PERFORMANCE

ERS analysts measured internal loads, computed the hourly building envelope cooling loads and compared them with the solar availability to estimate the amount of useful heat that delivered to the cooling and steam generation systems. Figures 3 and 4 illustrate hourly building cooling load and solar availability in the summer, as modeled by Sustainable Energy Consulting. Note that the solar curve does not correspond exactly to usable cooling capacity because the system cannot effectively use the solar heat until the system warms up in the morning to the chiller's operating temperature. Data from a smaller parabolic system installed at Carnegie Mellon University in Pittsburgh[2] suggests that solar driven cooling for this application will be effective starting at about 11 a.m.

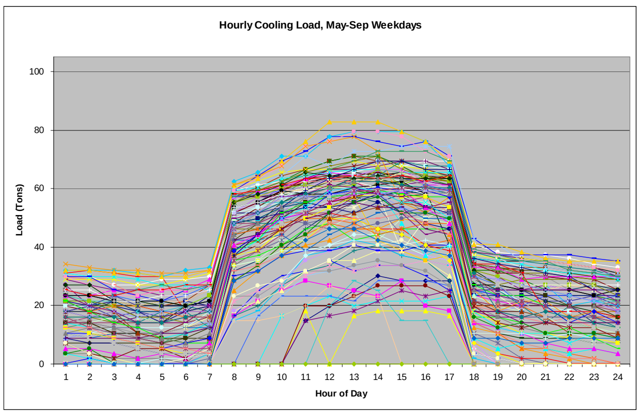

Figure 3: Building Cooling Load

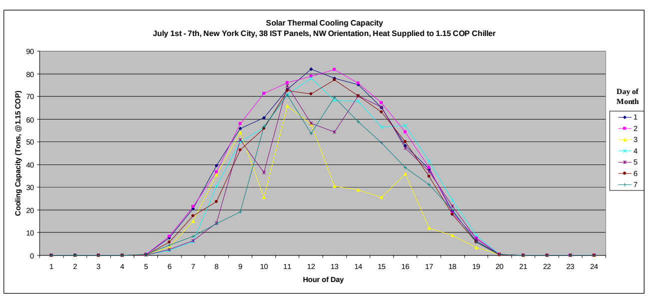

Figure 4: Solar Thermal Cooling Capacity

The lowest curve in Figure 4 illustrates the lesser production on a cloudy day.

About half the annual necessary energy is expected to be provided by solar, with the remainder by gas. The current gas and electric tariffs for Steinway are such that the energy cost of cooling with a gas-fired double-effect chiller is less than cooling with a packaged air-cooled electric system.

[2] *Test Report of Solar Cooling and Heating System for the Intelligent Workplace*, Ming Qu, David H. Archer, Carnegie Mellon University School of Architecture, 9 November 2007.

The building low pressure steam system provides process and space heating and humidification. In the summer the load is relatively constant and a minimum of about 50 boiler horsepower. Load increases in the winter. The minimum facility load exceeds the 800 kBtu/hr maximum production capacity of the solar thermal system by about 50%. This means that all solar energy captured by the collectors is usable by the system at all times. There is never a time when thermal production exceeds demand, which is part of what aids the project economics.

Figure 5 summarizes the projected production rate for the collector system.

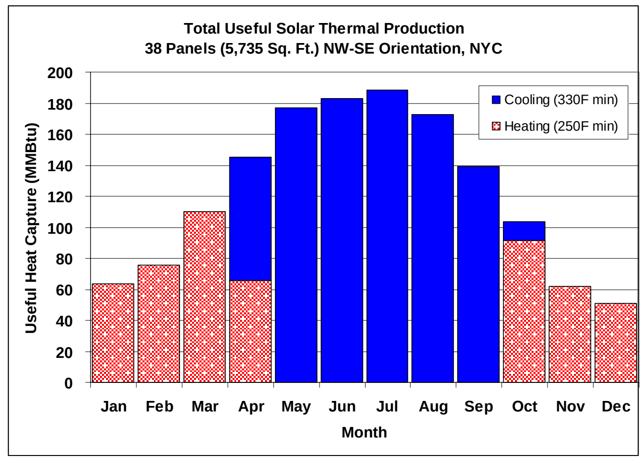

Figure 5: Projected Solar Thermal Production

If all available cooling is useful production and assuming a relatively modest annual average COP of 1.15, the total cooling effect would be about 80,000 ton-hours per year. Because there are periods when some of the cooling is not needed, the building model assumed a lesser amount of cooling production, about 50,000 ton-hours per year, and correspondingly higher steam generation.

5 DESIGN ISSUES

Steinway has managed the installation with the assistance of ERS, and has acted as their own general contractor. While the installation generally has proceeded as planned there have been two challenges for which future designers will want to give due consideration.

First, the heat transfer fluid selection process was not as easy as hoped. Water performs more efficiently than other fluids, but the system will operate in the winter in a climate that requires freeze protection. A drain-back system that empties the pipes whenever the water is not circulating was not feasible for this application. Using the steam generator system in reverse mode was an option but would have defeated part of the energy saving goals and hurt the economics. Thermal oils met the requirement, but they have relatively poor heat transfer properties at the system's design temperatures, so the heat recovery rate and chiller capacity would have had to be substantially derated with oils. Water with an antifreeze that was capable of 0ºF freeze protection and also resistant to breakdown at up to 350ºF was the best solution. The team ultimately selected an ethylene glycol-based fluid, DowTherm 4000, which is rated to 350ºF. Controls will be added to avoid operational temperatures in excess of 350ºF and fluid sample testing will be conducted with accelerated intervals. Such issues will not be a concern for applications with summer-only operation or in warmer climates.

Second, collector mounting was more difficult than expected. The collectors must be mounted securely enough to sustain hurricane-force winds, and while the collectors can be placed in low-drag stowing position, the requisite holding force is high. The vintage building on which the collectors are mounted is four stories high, was built to bear additional floors that never were added, and consequently has a 10-inch reinforced concrete deck. Sunshine Plus Solar performed the installation. Mounting the collectors required specialized anchors and structurally supporting highly loaded mounting pylons. In addition, a wind fence was installed to reduce loads acting on the collectors.

6 ECONOMICS

The total project capital cost is between $850,000 and $900,000. The air-cooled system option would have cost about $250,000.

NYSERDA provided a Research & Development grant that contributed funding for the initial feasibility study and project oversight by ERS as well as $300,000 towards the capital cost and advanced instrumentation. Federal tax credits and permitted accelerated depreciation improve the project economics. The tax credit pays for up to 30% of qualifying renewable system costs and is expected to be about $175,000. There are also New York-specific property tax advantages to the system.

In addition to the annual tax benefits during the first 5 years, the annual cash flow benefits for the equipment lifetime include the energy savings, potential sale of renewable energy credits (the system is being heavily instrumented), reduced manufacturing labor, reduced scrap, increased quality, and elimination of costs associated with a dedicated wood conditioning room that no longer is necessary. The maintenance costs for the system are expected to be slightly higher than for a conventional air-cooled system. Employee comfort and productivity are expected to increase but were not monetized.

These factors were incorporated into the economic analysis. The analysis was performed on an after-tax basis and has uneven cash flow streams because the modified accelerated cost recovery system (MACRS) is uneven. Figure 6 illustrates the cash flow compared to the alternative air-cooled system and to existing conditions. The system pays for the cost premium over air-cooled in less than 2 years and pays for itself over doing nothing in less than 5 years.

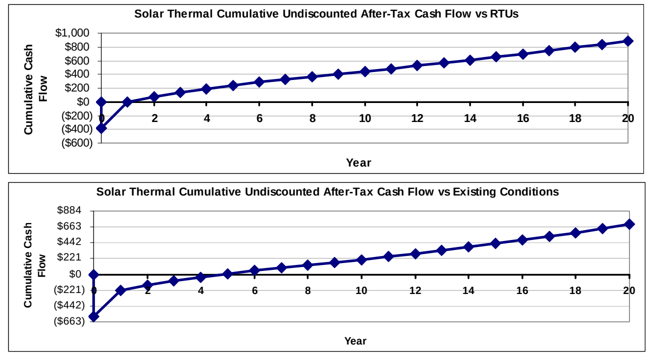

Figure 6: Project Cash Flow

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