ABSTRACT

Based on an experimental residential retrofit incorporating thermal storage, and extensive subsequent modeling, a commercial design was developed and implemented to use hot thermal storage to significantly reduce electric demand and utility energy costs during the cooling season as well as the heating season.

To achieve air conditioning savings, the system separates dehumidification from sensible cooling; dehumidifies by desiccant absorption, using heat from storage to dry the desiccant; and then cools at an elevated temperature improving overall system efficiency.

Efficient heat for desiccant regeneration is provided by a selective-energy system coupled with thermal storage. The selective-energy system incorporates diesel cogeneration, solar energy and offset electric resistance heating.

Estimated energy and first cost savings, as compared with an all-electric VAV HVAC system, are: 30 to 50% in ductwork size and cost; 50% to 80% in fan energy; 25% in air handling equipment; 20 to 25% in utility energy for refrigeration; 10 to 20% in refrigeration equipment; and space savings due to smaller ductwork and equipment.

INTRODUCTION

Based on an experimental residential retrofit incorporating thermal storage, and extensive subsequent modeling, a commercial design was developed and implemented to use hot thermal storage to significantly reduce electric demand and utility energy costs during the cooling season as well as the heating season. Described in this paper are the experimental retrofit and monitoring program data, as well as the commercial system developed for a historic Pennsylvania courthouse and the adjoining new wing, with the following goals: (1) Improving the overall thermodynamic efficiency of building systems incorporating hot water thermal storage; (2) utilizing hot thermal storage to achieve substantial savings throughout the year, not just in winter; and (3) thereby increasing the productivity of hot thermal storage systems in small facilities.

To achieve air conditioning savings, the courthouse system separates dehumidification from sensible cooling; dehumidifies by desiccant absorption, using heat from storage to dry the desiccant; and then, not needing to chill to the condensation dew point, cools at an elevated temperature improving overall system efficiency. Summer savings in utility costs for refrigeration are based on two factors: the direct reduction resulting from removal of latent cooling/dehumidification from the refrigeration load; and an increase in the cooling coefficient of performance (COP) due to higher-temperature sensible cooling.

To be cost-effective, the HVAC system requires an efficient source of heat for desiccant regeneration. This is provided by a selective-energy system coupled with hot water thermal storage. The selective-energy system incorporates diesel cogeneration, solar energy and off-peak electric resistance heating. The system is operational except for the solar subsystem, which is currently being added. The next and final planned addition is a computer-based energy management system (EMS) to automatically shift among energy sources based on weather data, occupancy requirements and utility rate structure, to minimize utility energy costs. Currently the selections are done manually.

When the computer-based EMS is installed, a monitoring system will be implemented to gather detailed data on actual energy consumption and costs. Based on design analyses, it is estimated that the system will save in the order of 60% in annual energy operating costs, compared with an all-electric VAV (variable-air-volume) air conditioning system. As to the first cost, the payback period for the entire system, including the solar and EMS subsystems, is five years. The cost of the system in a new facility would be comparable to or less than the cost of an all-electric VAV system.

Referred from the residential monitoring program are referred data on the seasonal and on/off-peak demand profile, as well as comparative data on billings based on before-and-after rates (standard versus time-of-day). With the addition of thermal storage the day/night demand distribution was shifted from 50/50 to the retrofit to 20/80 (in winter) after the retrofit. Savings in utility billings were 245 in winter, 125 in summer, and 215 on an annual basis. This data prompted the modeling and design effort at achieving similar savings in winter, which produced the commercial system for the courthouse.

THERMAL STORAGE IN ENERGY-INTEGRATED COMMERCIAL SYSTEM

In order to minimize energy costs at the Monroe County Court House in Stroudsburg, Pennsylvania, an energy-integrated HVAC system (Fig. 1) replaced on an old steam heating system for the 39th century courthouse and its adjoining new wing. The three-story, reinforced concrete structure contains office space, courtrooms, judges' chambers and hearing rooms. The facility totals 310,230 sq ft, with 173,800 in the old courthouse and 32,450 in the addition.

Heat is used in place of refrigeration to energize latent cooling/dehumidification. This is made possible by shifting the dehumidification task to a
moisture-absorbing desiccant which requires heat for
desiccant regeneration.

SELECTIVE-ENERGY SYSTEM AND THERMAL STORAGE

Heat is provided by a selective-energy system
whose efficiency and flexibility is increased by use
of an 8,000-gallon thermal storage tank that is
maintained at 150-180°F. The storage tank is heated
at night by electric resistance heaters, to take ad-
vantage of off-peak utility rates, and during the
day by solar energy (now being added) and back-up
heat from a 175-kw diesel cogeneration system. Both
the cogenerator and the solar system reduce electric
demand, and the electric heaters shift demand off-
peak.

With the addition of the solar collectors,
which will provide about 35% of the total heat re-
quired for regeneration, the cogeneration system
will be used only on cloudy days and when humidity
exceeds design levels. When it operates to provide
regeneration heat, the system simultaneously gener-
ates electricity to power sensible cooling. Cogener-
ation reduces the collector area requirement and
also provides standby power for use during utility
power outages.

Located in a central plant are the thermal stor-
age, diesel cogeneration and desiccant dehumidifica-
tion systems. All sensible cooling and heating are
done at terminal unitary heat pumps, which operate
at an efficient 55°F evaporative temperature since
there is no requirement to chill deeply to condense
out moisture.

The thermal storage tank serves as a heat
source for the unitary heat pump system in winter
and for the desiccant system in summer. Storage
provides heat to the terminal unitary heat pumps via
a closed-loop water system which links the heat
pumps and which has its own 3,000-gallon closed-
loop storage tank.

UNITARY HEAT PUMPS AND THERMAL STORAGE

Terminal unitary heat pumps linked to thermal
storage tanks and to the cooling tower are used in
both applications described in this paper. Unitary
heat pumps are small, terminal reverse-cycle air
conditioners which recirculate air locally and heat
or cool as needed. They have a self-contained heat-
and cooling capability due to a reversing valve
that regulates the flow of hot and cold refrigerant
gas.

When dehumidification is by condensation, a
central refrigeration plant is more efficient than
terminal unitary heat pumps. However, when dehumid-
ification is by desiccant absorption and the heat
pumps can operate at a higher, dry-coil temperature,
their overall efficiency increases significantly.

When unitary heat pumps are combined with desiccant
dehumidification, the cooling mode COP of the uni-
tary heat pumps increases by about 25%.

The terminal heat pumps are joined by a closed
water loop; some can be in a heating mode while
others are cooling or off. An example is a winter-
day when solar gains through south-facing windows require heat removal, while north wall losses require heating. In this case heat is simultaneously added to and drawn from the water loop by different unitary heat pumps.

When the temperature of the water loop drops below 90°F, it draws heat from the solar system or the high-temperature storage tank. When the temperature of the water loop rises above the upper limit (80-90°F), heat is rejected via the cooling tower.

With a unitary heat pump system, there is no access for both hot and chilled water piping. Additional savings in pipe and space are obtained by using the return side of the system's water loop as the fire sprinkler system.

DESICCANT DEHUMIDIFICATION SUBSYSTEM

The desiccant subsystem includes two chambers: a conditioner (dehumidifier) and a desiccant regenerator (concentrator). The desiccant used in this system is the liquid desiccant lithium chloride, which is a non-toxic, non- corrosive, bactericidal, antifreeze solution often used in hospitals. The desiccant is heated and sprayed into the regenerator, where moisture is removed and recycled for reuse.

The desiccant is heated and sprayed into the regenerator, where moisture is removed in a warm, dry, exhaust air stream passing through the chamber. Heat in the exhaust air stream is recovered and used to preheat the air entering the regenerator. The air is dried to 31 grains/lb (grains of moisture per pound of dry air).

This process requires cooling in the conditioner and heating in the regenerator. A refrigerated cooling tower provides the cooling, which is needed to remove latent heat released by the moisture absorption process. Heat for regeneration, as described previously, comes from the solar system or the electrical energy system.

AIR DISTRIBUTION IN DESICCANT/TERMINAL COOLING SYSTEM

The minimum quantity of outside air required for ventilation is distributed at a constant volume from the central plant to terminal unitary heat pumps. This minimum air distribution is practical when a desiccant is used, as it is not in conventional systems, since the air is drier and the ventilation quantity is adequate to handle the space humidity load.

The unitary heat pumps mix the dry air with a constant volume of locally recirculated air, cool the air sensibly and supply it in a constant volume to the rooms. It passes through the tents uniform air flow patterns and ventilation to maintain healthful air quality throughout the occupied spaces.

SAVINGS

Based on design analysis and experience in implementing solar systems, it is estimated that energy and first cost savings from the desiccant/solar-electric-energy system, as compared with an all-electric VAV Hvac system, are as follows: (1) a savings of 30 to 50% in ductwork size and cost, depending on building size and layout (based on distribution of only outside air from the central plant); (2) a net savings of 25% in fan energy; (3) a net savings of 25% in air handling equipment (central/terminal costs); (4) a savings of 20 to 40% in utility energy for refrigeration (based on removing dehumidification from the refrigeration system and improving the cooling COP due to higher-temperature sensible cooling); (5) a savings of 15 to 20% in refrigeration equipment, based on smaller equipment due to reduced load and more efficient handling of the remaining load; (6) a savings in space due to smaller ductwork and equipment; loss less space is needed for a mechanical equipment room, vertical shafts and floor-ceiling space between occupied floors.

THERMAL STORAGE IN EXPERIMENTAL RESIDENTIAL RETROFIT

In an all-electric residential retrofit in Stroudsburg, Pennsylvania, thermal storage was the key to shifting a resistance heat water boiler from 24-hour, always-on operation to night-only, as-needed operation, significantly reducing utility peak demand and taking advantage of off-peak rates. (See Fig. 2 for system diagram.)

Overall, utility demand was shifted from 90% off-peak to 80% off-peak in winter, with a 75% annual off-peak average. Table 1 summarizes the electric utility billing data for the first full year of the retrofit (1982). It compares on- and off-peak kilowatt hours throughout the year, and contrasts utility billings based on the non-applicable time-of-day rate with the standard-rate billings that would apply without the off-peak retrofit.

The retrofit/ret was undertaken by the owner specifically to reduce high utility costs. The residence has a unitary heat pump system connected to the resistance boiler, which operated whenever the heat pump system required heat. The solution used existing subsystems -- the resistance boiler, and a swimming pool -- interfaced them in a new way for the specific purpose of shifting utility demand to off-peak hours.

The boiler was disconnected from the heat pumps. It was connected instead via a heat exchanger to the 75,000-gallon swimming pool. The swimming pool served as a thermal storage tank which is held at 70-90°F with no detriment to its recreational function. The pool/storage tank serves as a heat source for the closed water loop that links the terminal heat pumps.

The heat pumps draw heat from or reject heat to the closed water loop, which either heat or cool their respective spaces. The water loop integrates these demands and, as needed, draws heat from the pool or rejects heat to the atmosphere via the cooling tower.

In winter a black pool cover acts as a solar absorber during the day, so that on a 24-hour basis there is no net loss from the pool surface. The electric resistance boiler operates at night, when needed, to maintain a constant pool temperature.

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Fig. 2 Residential retrofit linking an existing swimming pool, electric boiler and unitary heat pump system. Using the pool as a thermal storage tank permitted night-only operation of the electric boiler heat source.

### Electric Utility Billing Data

**Vosko Residence, Stroudsburg, PA**

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<th>Period</th>
<th>Total</th>
<th>Off-Peak</th>
<th>% Off-Peak</th>
<th># Time-of-Day Rate</th>
<th># Standard Rate**</th>
<th>Savings from Time-of-Day Rate</th>
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| Year Totals | 357 | 166,800 | 42,080 | 124,720 | 75% | $10,453 | $13,154 | $2,701 |
| Winter Totals | 297 | 119,520 | 23,360 | 96,160 | 80% | $7,077 | $9,325 | $2,248 |

Source: Data from Metropolitan Edison Company, Reading, Pennsylvania.

Note: Retrofit of the Vosko residence used thermal storage to shift utility demand from 50% off-peak to 80% off-peak in winter (75% off-peak on annual basis). As a result, time-of-day utility rates reduced utility costs by 24% in winter (21% on annual basis). Total demand remained effectively constant.

*Time-of-Day Rate: 3.5c/kwh off-peak (8PM-8AM); 8.8c/kwh on-peak (8AM-8PM).

**Standard Rate: 5.6c/kwh flat rate, plus a monthly demand charge which in this case is approx. $84/month.
CONCLUSION

The spread and acceptance of thermal storage techniques depend largely upon two factors: demonstrated cost-effectiveness and the know-how to duplicate it. The development work reported here demonstrates that it is practical to achieve substantial reductions in peak electric demand, for summer air conditioning as well as winter heating, by using an energy-integrated system design approach that incorporates hot thermal storage, desiccant dehumidification, and a selective-energy system. Utilities can be expected increasingly to provide cost-sharing support for thermal storage systems with a demonstrated capability of reducing peak electric demand year-round. Such support is cheaper for the utilities than foregoing the savings and adding new electric generating capacity.

Based on the experience reported here, a system is currently under design for a commercial facility that will couple hot and cold thermal storage with 24-hour cogeneration operation to provide 100% of the air conditioning requirement for the 12-hour day. The cogeneration will provide heat for desiccant regeneration and will provide cooling as follows: 50% via ice storage and 50% via absorption chiller. During night operation, cogenerated heat will regenerate the desiccant while cogenerated electricity creates ice. During day operation, cogenerated heat will run an absorption chiller while cogenerated electricity runs fans, pumps and lights.

In this new system, conditioning and air distribution are as follows: Outside ventilation air is dehumidified in a central desiccant conditioner, then mixed with some recirculated air. The air is cooled in two stages, first with 55°F chilled water from the absorption chiller, then with 42°F chilled water from ice storage. The very cold primary air (42°F) is distributed at variable volume to fan induction terminals. Because the air is very cold, the quantity required is about 50% less than the quantity usually distributed in an all-electric VAV system. Terminal air mixes the primary air with locally recirculated air and supplies the air at a constant volume to the occupied spaces, to maintain a uniform airflow pattern for uniform ventilation.