HOT THERMAL STORAGE/SELECTIVE ENERGY SYSTEM REDUCES ELECTRIC DEMAND FOR SPACE COOLING AS WELL AS HEATING IN COMMERCIAL APPLICATION

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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 off-peak 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; 30% in fan energy; 25% in air handling equipment; 20 to 40% 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 for commercial 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.

Reported from the residential monitoring program are metered 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 before the retrofit to 20/80 (in winter) after the retrofit. Savings in utility billings were 24% in winter, 12% in summer, and 21% on an annual basis. This data prompted the modeling and design effort aimed at achieving similar savings in summer, 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 an old steam heating system for the 19th 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 110,230 sq ft, with 77,580 in the old courthouse and 32,650 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

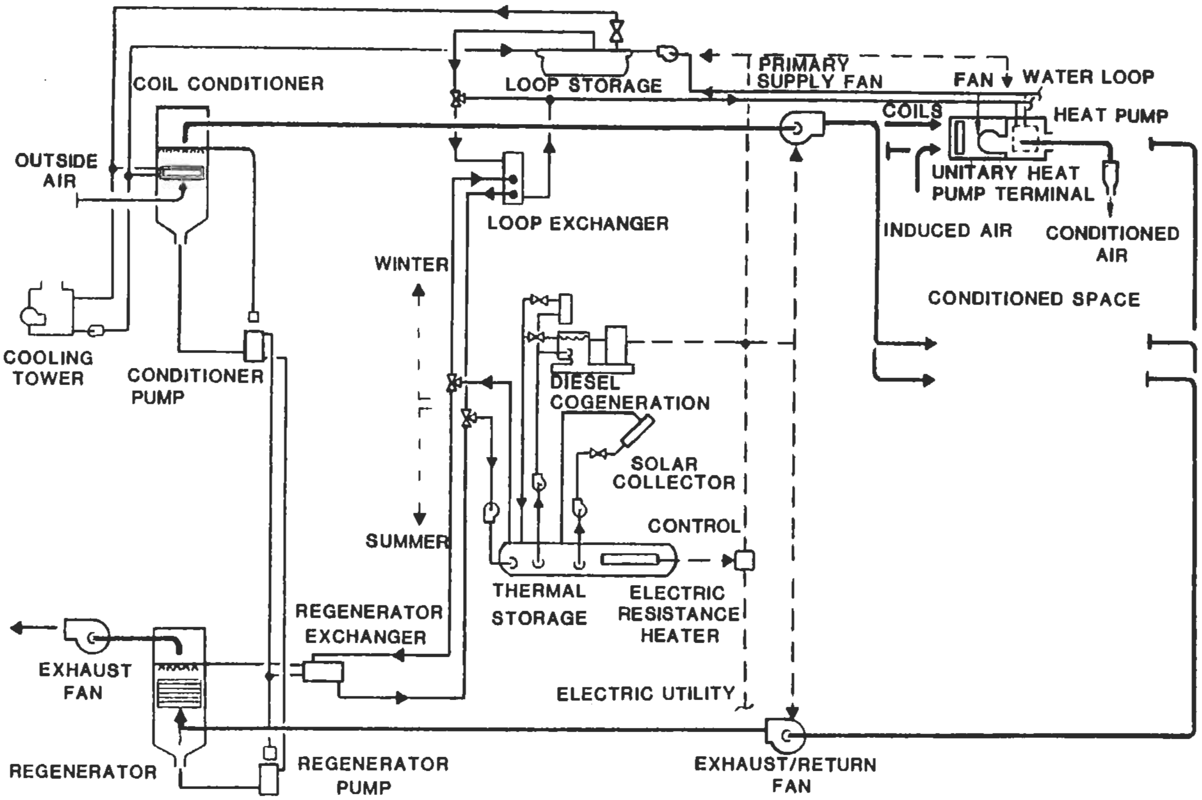

Fig. 1 Energy-integrated commercial HVAC system in which hot water thermal storage supports both summer cooling and winter heating

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 advantage 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 required 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 generates electricity to power sensible cooling. Cogeneration reduces the collector area requirement and also provides standby power for use during utility power outages.

Located in a central plant are the thermal storage, diesel cogeneration and desiccant dehumidification 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 heating 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 dehumidification 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 unitary 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 70°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 need 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.

Outside air passes through the conditioner where moisture is absorbed by a spray of cool desiccant. The moisture-laden desiccant cycles to the regenerator to be dried or reconcentrated for re-use.

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 exiting 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. Nonrefrigerated cooling tower water 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 selective-energy system whose energy sources are fuel for the cogenerator, solar energy, and off-peak electricity.

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. The constant flow maintains uniform air flow patterns and ventilation to maintain healthful air quality throughout the occupied spaces.

SAVINGS

Based on design analyses and experience in implementing similar systems, it is estimated that energy and first cost savings from the desiccant/selective-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 30% 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 10 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: 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 hot water boiler from 24-hour, as-needed 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 50% 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 now-applicable time-of-day rate with the standard-rate billings that would apply without the off-peaking retrofit. The comparison is valid because total demand is essentially unchanged. Savings for the year totaled $2,700 or 21% -- 24% for winter months only, and 12% for summer.

The retrofit 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 heat pumps, the boiler, and a swimming pool -- and 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 became a thermal storage tank which is held at 70-80°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 as they either heat or cool their respective spaces. The water loop integrates these demands and, as necessary, 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.

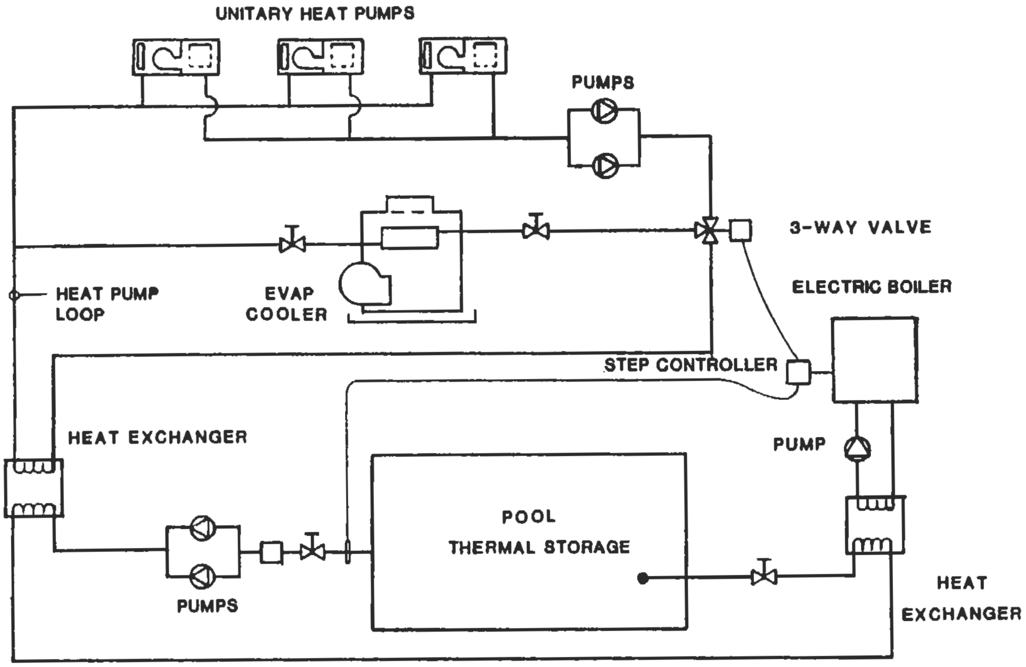

Fig. 2 Residential retrofit linking an existing swimming pool, electric boiler and unitary heat pump system. Using the pool as a thermal storage tank permitted night-only operation of the electric boiler heat source.

Electric Utility Billing Data

Vosko Residence, Stroudsburg, PA

Period			Kilowatt Hours				Monthly Electric Billing Data		
From	To	Total Days	Total	On-Peak	Off-Peak	% Off-Peak	@ Time-of-Day Rate*	@ Standard Rate**	Savings from Time-of-Day Rate
12/9/81	2/1/82	54	42,960	7,680	35,280	82%	$ 2,383	$ 3,328	$ 945
2/1/82	3/3/82	30	24,720	4,480	20,240	82	1,495	1,908	413
3/3/82	4/1/82	29	17,280	3,200	14,080	81	1,051	1,348	297
4/1/82	5/3/82	32	13,760	3,200	10,560	77	874	1,100	226
5/3/82	6/2/82	30	8,320	3,280	5,040	77	607	701	94
6/2/82	7/1/82	29	9,760	3,840	5,920	61	711	807	96
7/1/82	8/2/82	32	11,760	5,200	6,560	56	856	916	60
8/2/82	8/31/82	29	8,000	2,720	5,280	66	540	652	112
8/31/82	9/30/82	30	9,440	3,680	5,760	61	662	753	91
9/30/82	10/29/82	29	7,840	2,160	5,680	72	502	641	139
10/29/82	12/1/82	33	12,960	2,640	10,320	80	772	1,000	228
Year Totals		357	166,800	42,080	124,720	75%	$10,453	$13,154	$2,701
Winter Totals		207	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: 3.5¢/kwh off-peak (8PM-8AM); 8.8¢/kwh on-peak (8AM-8PM).

**Standard Rate: 5.6¢/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 systems 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 36°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. Terminals mix the primary air with locally recirculated air and supply the air at a constant volume to the occupied spaces, to maintain a uniform air flow pattern for uniform ventilation.