OFFICE BUILDING USES ICE STORAGE, HEAT RECOVERY, AND COLD-AIR DISTRIBUTION

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INTRODUCTION

Ice storage offers many opportunities to use other technologies, such as heat recovery and cold-air distribution. In fact, by using them, the designer can improve the efficiency and lower the construction cost of an ice system.

This paper presents a case study of a large (550,000 square feet) office building which combines these ideas into one HVAC system. By integrating these technologies to take advantage of the unique characteristics of ice storage, the engineers created a system that provided a 1-1/2 year simple payback. The system reduces operating costs by over $0.16 per square foot each year, yet it increased the net HVAC budget by only $0.22 per square foot.

SYSTEM OVERVIEW AND ECONOMICS

The 550,000 square foot office building is located in Addison, Texas, north of Dallas. It is owned by Sunbelt Savings -- one of the "few" Texas savings and loan institutions that was still afloat at the time of writing this paper. The owner asked the engineers to meet two objectives: provide a state-of-the-art system, but do it

include the following features:

1. Partial Ice Storage

Two centrifugal, glycol chillers and 90 ice storage tanks are located in the lower parking levels (see Figure 1). The chillers operate at night to make ice, which is then used the next afternoon to supplement chiller cooling. Ice storage reduces 800 kW from the peak electric demand, saves about $55,000 each year in demand charges, and initially earned a cash incentive of more than $200,000 from the local utility. (See Table 1, which provides a summary of the system's incremental costs and savings.)

2. Heat Recovery

One of the glycol chillers has a double-bundle condenser to recover heat in the winter. During the winter days, heat is removed from the building's interior and stored in the ice tanks. Then at night, the heat recovery chiller removes this heat from the tanks and delivers it to the building's perimeter office spaces. The extra cost for the heat recovery system was about $60,000, but it will supply about two-thirds of the buildings annual heating needs and save an estimated $30,000 each year in electric heating costs.

3. Cold-Air Distribution

Ice storage delivers 34 F water to the cooling coils of four large, built-up air handling units, which supply air at 44 F. Compared to a standard supply air temperature of 55 F, the colder supply air temperature has four benefits:

* First, it reduced the air quantities, duct sizes, and air-handling units by about one-third, and squeezed $90,000 from the air system cost.

* Second, the reduced air quantities also lowered the total fan power by 140 brake-horsepower, which will save an estimated $12,500 in annual fan energy costs.

* Third, the smaller air-handling units gave the owner an extra 3,500 square feet of usable lease space.

about 40%.

4. After-Hours Cooling

The ice system also eliminated the cost of a condenser water loop for night-time cooling. Normally, night-time cooling loads are too small to practically operate a centrifugal chiller. The owner's options included installing a condenser water loop or a 200 ton reciprocating compressor. Both would have cost an extra $50,000. With ice storage, though, the chillers already operate at night, and with slightly modified piping and controls the chillers can simultaneously satisfy after-hours cooling and make ice.

ICE STORAGE

Ice Storage Tanks

The heart of the HVAC system is the 90 ice tanks located on the lower parking level. These tanks are connected in parallel with the centrifugal chillers so that the

TABLE 1
Comparison of Alternate HVAC Schemes and Costs

Incremental Storage Costs & Savings	Standard Design		Modified Storage	
Increnental System Costs:	Quantity	Added Cost	Quantity	Added Cost
1) Ice Storage....(ton-hours required)	0	Base	7500	$450,000
2) Central plant................(tons)	1400	Base	1150	($31,250)
3) Utility incentive..............(kW)	0	Base	850	($215,000)
4) Air systems...................(cfm)	540,000	Base	360,000	($90,000)
5) Heat recovery................(tons)	0	Base	550	$60,000
6) Condenser water loop.........(tons)	200	Base	0	($50,000)
Net incremental cost..........($)		Base		$124,250
Annual Savings:				
1) Demand savings.............($/year)		Base		$55,250
2) Chiller penalty............($/year)		Base		($5,000)
3) Fan savings................($/year)		Base		$12,500
4) Heat recovery..............($/year)		Base		$30,000
Total savings...........($/year)		Base		$92,750
Simple payback...........(years)		Base		1.34

building's cooling load can be met by using either the ice tanks, the chillers, or both (look at Figure 2). Each tank is about 6 feet in diameter, 6 feet high, and contains thousands of feet of spiral wound plastic tubing surrounded by water. Each night a 24 F glycol/water solution (25% ethylene glycol) circulates through the tubing in the tanks to produce up to 600,000 pounds of ice, which can provide about 7,500 ton-hours of cooling the next day.

Glycol Chillers

The centrifugal chillers are three stage compressors that produce low temperature glycol at relatively high efficiencies. For example, each chiller produces a 34 F solution at an efficiency of 0.76 kW/ton to provide 568 tons of cooling capacity. Likewise, each chiller produces a 24 F solution at an efficiency of 0.85 kW/ton to provide 425 tons of ice-making capacity. Note that in the ice-making mode, each chiller provides only 75% of its standard capacity. However, the compressors still operate at relatively high efficiencies and compare favorably to positive displacement machines that require about 1.0 kW/ton.

The chiller capacity is slightly smaller than the building's peak load (1150 tons of capacity to meet a 1400 ton cooling load) because ice storage is available to supplement the load. The smaller chillers reduced costs by another $30,000. These chillers, however, incur a slight energy penalty of about $5,000 each year, because they cannot make ice as efficiently as they make chilled water.

System Operation: Hybrid Partial Storage

Some engineers support the use of partial storage. This strategy uses less storage and smaller chillers which operate 24 hours each day. It is cost-competitive with a standard HVAC system, but it may provide smaller savings and constrained operating flexibility.

Others support the use of full storage. This strategy uses enough storage to meet all cooling needs during the utility's on-peak hours. It provides the greatest demand savings and operating flexibility, but it may not be cost-competitive without substantial cash incentives.

The author submits that the best design (which was used in this project) may be a hybrid of the two. With this strategy, the storage and chiller sizes fall somewhere between the partial and full storage strategies. One-half of the chillers operate 24 hours each day (as in partial storage), while the other half shuts down during the on-peak hours (similar to full storage). The idea is to vary the use of chillers and storage to optimize the overall costs and savings. The hybrid system of this project operates as follows:

1. During the on-peak hours, one chiller is completely off; the second one runs, but it is demand limited to meet the minimum base load of about 500 tons. Storage is used to meet the remaining load, which is the most diversified part; this obtains the optimal demand reduction and savings with the least investment in storage.

2. Both chillers operate to meet most of the

cooling needs before the on-peak hours. This conserves the storage so that it can be used during the on-peak period. Alternatively, the chillers of a partial storage system would be too small to meet the cooling load before the on-peak hours. As a result, storage would be wasted to provide cooling when savings could not be realized.

HEAT RECOVERY

Since the ice storage tanks had already been bought and paid for, it only made sense to find some way to reuse them for heat storage. This would reduce electric costs and improve the system's overall payback.

Sequence of Operation

The project's heat recovery system does not provide heating around the clock; it provides heating only at night when the building is unoccupied. Generally, it costs much more to install a heat recovery system that has the flexibility to provide heating and cooling anytime of the day. Fortunately, about 80% of the heating needs occur at night. The idea, then, is to satisfy the greatest portion of heating with the least first cost.

(Note: Some people have trouble believing that ice storage can be used to heat a building. For those people, the following paragraph explains how it works. If the explanation is not clear, the author asks you to trust him on this point.)

In operation, the heat recovery system works in two steps. First, ice is melted during the day to cool the interior spaces. Now as long as you believe that cooling is really the removal of heat, then you can visualize this process as the removal of heat from the interior. The tanks absorb this heat as the ice melts. (Obviously, it takes heat to melt ice.) Then at night, the heat recovery chiller removes this heat to refreeze the melted ice. The heat removed from the tanks is rejected to a double-bundle condenser, where a 95 F water solution is produced and delivered to the air-handling units.

Keeping Construction Costs Down

"Now," you might ask, "what does the air-handling units do with the heated water? Weren't these units designed as cold-air distribution systems?" The answer, of course, is yes and no.

Most heat recovery systems cost more because of the extra hot water piping, heating coils, and controls. To eliminate these extras, the contractor developed a scheme that reused the existing air-handlers and water risers. It works like this:

1. Description. Two of the four air-handlers serve the south side of the building, while the other two serve the north. A north unit is connected to a south unit through a series of crossover ducts that run between the main supply air risers. (Look at Figures 1 and 2.) The water coils in the south units receive chilled water only. The north units, however, have the option to receive either chilled or heated water.

2. Operation. If cooling and heating are required at night, chilled water is delivered to the south units, while heated water is delivered to the north units. To provide heating on an unoccupied floor, the floor damper at the south supply riser is closed, the floor damper at the north supply riser is opened, and heated air is delivered from the north unit, through the crossover ducts, and to the south side of the building. Likewise, to provide cooling on a floor, the north floor damper is closed, the south floor damper is opened, and cold air from the south unit is sent through the crossover duct to the north side of the building.

Heat Recovery vs. Economizer Cycles

Some engineers contend that heat recovery only wastes energy. Why? "Because," they say, "the chillers must operate to provide cooling when an outside air economizer cycle could have been used for free cooling." The notion, of course, is absolutely absurd. A heat recovery chiller can absorb about 3 kWh of heat for every 1 kWh expended. (The 1 kWh of compressor heat can also be reclaimed.) Thus every kWh used for cooling provides about 4 kWh of heating. An economizer cycle, on the other hand, saves only 1 kWh of cooling energy for every 3 kWh of heating energy that is rejected. The choice is obvious.

COLD AIR DESIGN

Little needs to be said about the virtues of cold-air. It saves money; it saves energy; it saves space. However, it does not save the engineer the trouble of paying attention to some design details. The most important are noted below.

Cooling Coil Selection

This project uses 10 row cooling coils, which must cool mixed air from an 85 F to a 42 F temperature. The coil's water side operates on a 24 F rise between a 34 F supply and a 58 F return temperature. Because of the high temperature rises, the water velocities within the coils are generally outside the range at which cooling coils are rated. It is very important that the manufacturer double-check his selection.

Terminal Devices

Usually, it is difficult to dump 44 F air directly into the space. For this project, the contractor designed special blending boxes that handle about 6,000 CFM each. To reduce the cost of the secondary ductwork, the contractor controlled the boxes to provide 50 F rather than 55 F supply air. The result is that the secondary ductwork is sized on a 25 F rather than a standard 20 F temperature rise.

Latent vs. Total Cooling Loads

Some engineers worry that cold-air designs increase the design cooling load because of the increased latent ventilation load. It is true that more moisture is removed from the outside air as it is cooled to 42 F. However, the smaller fans and corresponding reduction in fan heat gains offset this cooling load.

CONCLUSIONS

By itself, ice storage would have provided about a three year simple payback. However, by incorporating heat recovery and cold-air distribution, the payback was reduced to less than 1-1/2 years.

Cold-air provided the most significant reductions. Overall, the air side cost was reduced by $75 per ton, and the smaller air-handlers gave the owner an additional 3,500 square feet of usable lease space. The rental income from this could be almost as substantial as the system's total savings.

Heat recovery improved the overall payback. By reusing the ice tanks to absorb heat, enough heat can be removed from the building's interior to meet most of the building's heating needs on the perimeter.

This project emphasizes the need for the designer to examine several options. In this case, the optimal solution was neither a full or partial storage system, but a combination of the two.

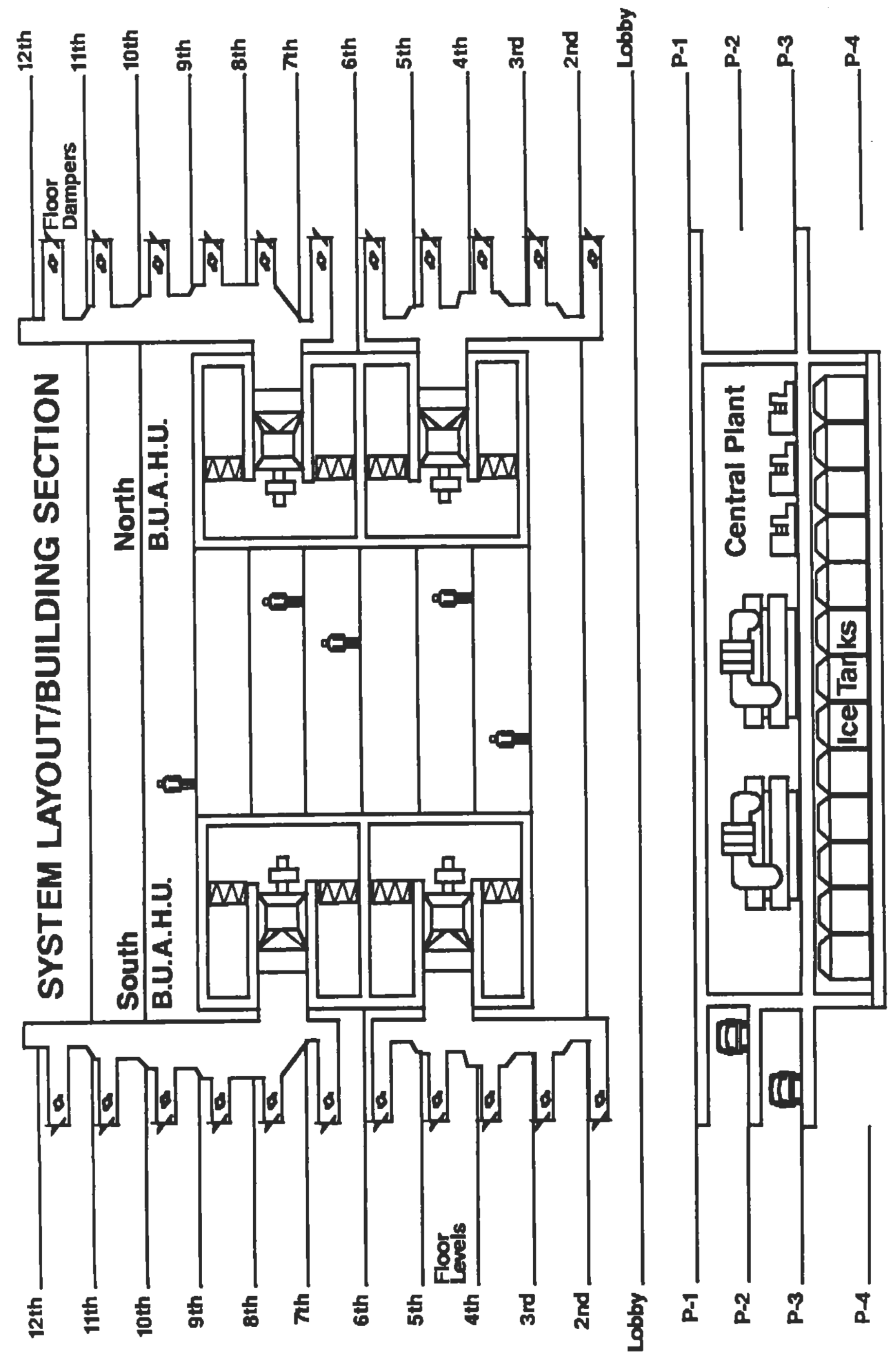
SYSTEM LAYOUT/BUILDING SECTION
South
B.U.A.H.U.
North
B.U.A.H.U.
Floor Dampers
Floor Levels
Central Plant
Ice Tanks
12th
11th
10th
9th
8th
7th
6th
5th
4th
3rd
2nd
Lobby
P-1
P-2
P-3
P-4

FIGURE 1

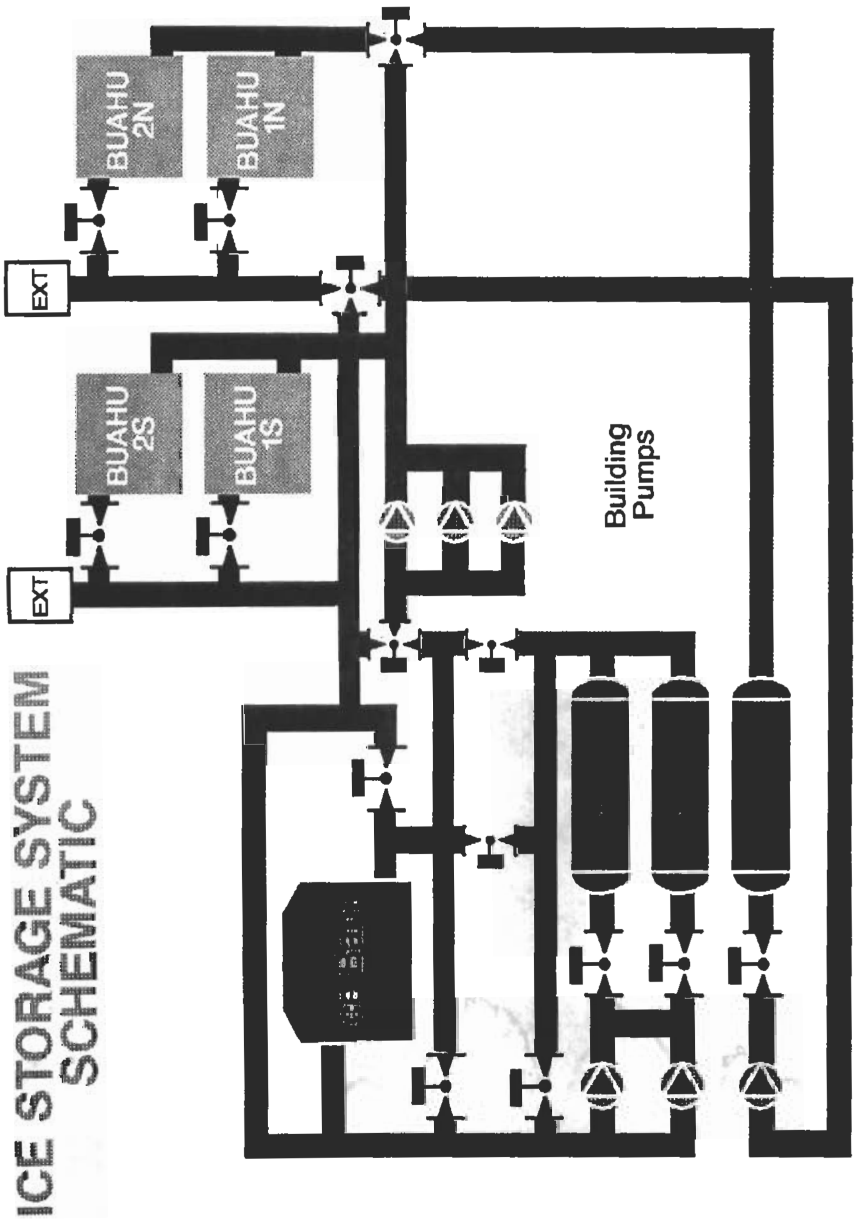
ICE STORAGE SYSTEM SCHEMATIC
EXT
BUAHU 2S
BUAHU 1S
EXT
BUAHU 2N
BUAHU 1N
Building Pumps

FIGURE 2