THERMAL STORAGE WITH ICE HARVESTING SYSTEMS

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ABSTRACT

Application of Harvesting Ice Storage Systems

Thermal storage systems are becoming widely accepted techniques for utility load management. This paper discusses the principles of ice harvesting equipment and their application to the multi-use environments. The potential for application of low dew point environments in terms of comfort and system energy consumption will also be discussed. Several case studies will be the installations of harvesting thermal storage systems.

INTRODUCTION

Load management is resource management for the electric utility company. The power plant and distribution network are significant investments, which yield the maximum return on investment when continuously used at or near full capacity. Diverse loads violate sound economic practice for the utility. One way of addressing load management for the air conditioning load is through thermal storage. This paper will discuss the application of ice harvesting equipment as a load management device for the electrical utility. By reducing the size of the installed chiller or by pre-venting chiller operation during peak periods, demand may be conserved.

EQUIPMENT DESCRIPTION

The Turbo Icemaking Heat Pump and Ice Generator is basically a simplified version of the Turbo Industrial Plate Ice Maker. The machine is a simple direct expansion refrigeration system whose evaporator consists of multiple vertical plates. The evaporator section is mounted above a water storage tank. Water is pumped from the storage tank at low head (usually 12 to 20 feet) and distributed over the plates where it flows in a thin film down the plates and returns to the storage tank by gravity. If the water temperature is warm, the machine functions as a Baudelot chiller. If the water temperature is low, some of the water is frozen on the plates into sheets of ice about 3/16" to 1/4" thick. Periodically the ice is released from 1/12 to 1/3 of the plates by reversing the refrigerant flow to these plates. By not allowing the ice thickness to build up, heat transfer is kept high, a distinct advantage over conventional ice builders. The equipment is available as an R model (remote) in which only the plates, refrigerant piping, valves, accumulator, and refrigerant controls are packaged for connection to remote refrigeration condensing units in sizes from 7.5 tons to 300 tons. A complete package utilizing evaporator section, compressor, water cooled condenser, all controls and single point electrical connection is available in sizes from 7.5 tons to 245 tons. Complete packages with evaporative condensers are available in sizes from 7.5 tons to 150 tons. Complete packages for use with remote condensers are available in sizes from 7.5 tons to 300 tons.

THERMAL STORAGE STRATEGIES

- Daily Load Shifting
- Weekly Load Shifting
- Daily Load Leveling
- Weekly Load Leveling

Operating Mode

The cool storage operating mode desired determines the size of storage capacity required, or the amount of space available for storage influences the operating mode selected.

Load Shifting/Full Storage

The load shifting system provides enough storage to meet a building's full on-peak cooling requirements. The building load profile in Figure 1 illustrates how the cooling load demand occurs in a conventional cooling system. Figure 3 shows how full storage displaces the cooling demand to times when other electrical loads (noncooling loads, e.g., lighting and motors) are negligible and during "shoulder hours" when the loads start to increase prior to normal building occupancy. As a result, all storage cooling occurs during off-peak periods thus affecting demand cost savings.

Proceedings of the Third Symposium on Improving Building Systems in Hot and Humid Climates, Arlington, TX, November 18-19, 1986
Load Leveling/Partial Storage

A partial storage system runs many more hours than a full storage system, so less demand reduction is obtained. However, partial storage is initially less expensive than full storage because less storage capacity refrigeration equipment is used.

When load leveling cool storage mode is used, capacities of the storage system and refrigeration equipment are selected so that design-day cooling load can be met by continuous operation of the refrigeration equipment. This strategy minimizes compressor capacity requirements and significantly reduces the space cooling contribution to the building's peak demand. As illustrated in Figure 4, the overall effect of this operating mode is to level the cooling component of the building's load. During peak hours, part of the cooling load is met directly by the compressor and part by storage. The storage required for the partial mode of operation must be adequate to supply all the building cooling load not met directly by the refrigeration equipment. In the situation illustrated in Figure 4, about 60 percent of the building's peak-hour cooling load would be supplied from storage. The fraction met by the compressor increases on either side of the peak until, during "shoulder" hours, compressor output equals the direct cooling load and part of the compressor output goes into storage. During off-peak hours, the refrigeration equipment is devoted entirely to cooling the storage medium. Weekly cycles use the same principle but allow storage of ice on weekends, thereby reducing the size for the refrigeration system and increasing the tank size.

EQUIPMENT OPERATION AND SIZING

Harvesting Ice Generators and Storage Systems

Harvesting ice generators separate the function of making ice and storing ice. Ice is formed on the outside of flat plate heat exchangers arranged in vertical banks on an economic thickness usually not greater than 0.25 inches. The ice is harvested by introducing hot refrigerant gas into the tubes of these evaporator plates. The hot gas warms the plate breaking the bond between the ice and the plate. The ice drops off into a storage tank. During off-peak hours, the ice is harvested in 20 to 40 seconds.

The plates are grouped in sets of two or three, such that the heat of rejection from the active plates is used to provide the heat to harvest one set at a time.

The ice generator will operate as a chiller when warmer than 32°F water is supplied to the plates. Depending on the compressor capacity, plate length and water flow rate, with a water temperature on the plate of 55°F, the leaving water will be between 45°F and 37°F.

In Figure 7 chilled water is pumped from the storage tank to the load and returned to the ice generator. A low head recirculation pump is used to provide optimum flow over the heat exchanger as required. The system may be applied to load leveling or load shifting applications.

In load leveling applications, when no building load is present, ice is generated and the storage tank is charged. When a building load is present, the return chilled water flows directly over the plates and the ice generator functions as a high efficiency chiller. In load shifting applications, the ice load is present during off-peak hours. When a load is present during off-peak hours, the ice generator will behave as a chiller as in the load leveling application.

By decoupling the ice generation from the storage, additional capacity can be obtained without the addition of compressor capacity or heat exchange surface. This is accomplished by adding compressor run time. Weekend hours which are usually off peak can be used to generate ice. Weekend ice is then stored for supplemental use during the week. In this application a larger storage tank is used to store the weekend ice.

A characteristic of ice formed by building on flat plate heat exchangers is the ability to melt ice that is stored in the tank very quickly. The ice is characterized by having a stacking density of 25 to 30 pounds per cubic foot. The ice contact area with the return water is quite large and the water velocities through the stack are quite low. A twenty-four hour charge of ice in the storage tank can be melted in less than 30 minutes. Ice storage in this way may be used for emergency cooling systems requiring large capacity for short durations.

Refrigeration systems used with this system may be reciprocating, screw or centrifugal. Suction temperatures may be relatively constant between 20°F and 21°F. Condensing temperatures will vary with the type of heat rejection used and the ambient conditions. As with any ice generation system, evaporative condensers or cooling towers are used.
towers are recommended to minimize the kw/ton.

Sizing the ice generator should take into account the number of hours that the system runs as a chiller and ice generator. Approximate sizing can be obtained from the following relation:

\[ I = \frac{T-H}{(NHI + 1.3 \times NHC)} \]

Where:
- \( I \) = ICE MAKING CAPACITY
- \( T-H \) = TON HOURS REQUIRED
- \( NHI \) = NUMBER OF HOURS IN THE ICE MAKING MODE
- \( NHC \) = NUMBER OF HOURS IN THE CHILLER MODE

Storage requirements may be approximated as follows:

\[ V = NHI \times I \times 83.3/DI \]

Where:
- \( V \) = VOLUME
- \( DI \) = DENSITY OF ICE IN STACK (\( DI = 27.8 \text{ lb/ft}^3 \))

APPLICATION EXAMPLES

The load profile in Figure 1 represents a Tuesday load on a typical office building. Figure 2 shows the typical Monday cooling load. The difference in the two profiles is the residual heat stored in the building over the weekend. In the sizing examples that follow, Table 1 is used to show the profile. For each daily strategy the compressor/refrigeration system will be sized for Tuesday loads and weekend hours will be used to store extra cooling to meet the Monday draw down loads.

ENERGY DEMAND

THERMAL STORAGE SIZING EXAMPLE:

90,000 ft² OFFICE BUILDING

EXAMPLE INCLUDES:

1. DESIGN WEEK LOAD PROFILE.
2. DAILY LOAD LEVELING SIZING.
3. WEEKLY LOAD LEVELING SIZING.
4. DAILY LOAD SHIFTING SIZING.
5. WEEKLY LOAD SHIFTING SIZING.
6. SELECTION SUMMARY.
7. SYSTEM FIRST COST COMPARISON.
8. SIMPLE PAYBACK ANALYSIS

1. DESIGN WEEK LOAD PROFILE FOR 90,000 FT² OFFICE BUILDING

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Storage Requirements may be approximated as follows:

\[ V = NHI \times I \times 83.3/DI \]

WHERE:
- \( V \) = VOLUME
- \( DI \) = DENSITY OF ICE IN STACK (\( DI = 27.8 \text{ lb/ft}^3 \))

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Total: 2288.76 ton-hr

ON MAX: 1125.00
OFF MAX: 1105.40
ON MIN: 962.11
OFF MIN: 962.11

Table 1

2. DAILY LOAD LEVELING EXAMPLE

Sizing Conditions
Peak period duration 8 hours (12:00 - 8 pm)
Occupied period 12 hours
Peak period - 6 hours on-peak
- 6 hours off-peak

Tuesday load 2067.51 ton-hr

A. Daily Load Leveling - Based on Tuesday Load

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<th>COMPRESSOR TONS</th>
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<td>VOLUME</td>
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<td>(900 ton-hr) (1 ft³/ton-hr)</td>
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<td>2,700 ft³</td>
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B. Daily Load Leveling - Based on Monday Draw Down Load

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<td>(900 ton-hr) (1 ft³/ton-hr)</td>
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<td>2,700 ft³</td>
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3. WEEKLY LOAD LEVELING EXAMPLE

Sizing Conditions

Peak period duration 8 hours
Occupied period 12 hours
- 6 hours on-peak
- 6 hours off-peak
Total weekly load 10,558.00 ton-hr

A. Weekly Load Leveling - Based on Total Weekly Cooling Load

COMPRESSOR TONS
= 10,558.00/(5(6)(1.3)+5(6)+48)
= 57.0 tons

STORAGE
= (57.0 ton)(6 + 24 + 24 + 6)
= 3,420 ton-hr

VOLUME
= (3,420 ton-hr)/3 ft^3/ton-hr
= 1,140 ft^3

4. DAILY LOAD SHIFTING

Sizing Conditions

Peak period duration 8 hours
Occupied period 12 hours
- 6 hours on-peak
- 6 hours off-peak
Tuesday load 2067.51 ton-hr
Monday load including draw down is 2288.76 ton-hr

A. Daily Load Shifting - Based on Tuesday Load

COMPRESSOR TONS
= 2067.51/(6(1.3)+10)
= 116.0 tons

STORAGE
= (116.0 ton-hr)(10 hr)
= 1,160 ton-hr

VOLUME
= (1,160 ton-hr)/3 ft^3/ton-hr
= 386.7 ft^3

B. Daily Load Shifting - Based on Monday Draw Down Load

COMPRESSOR TONS
= 116.0 tons

STORAGE
= 1,160 ton-hr + (2288.76-2067.51)
= 2,421.25 ton-hr

VOLUME
= (2,421.25 ton-hr)/3 ft^3/ton-hr
= 807.1 ft^3

5. WEEKLY LOAD SHIFTING

Sizing Conditions

Peak period duration 8 hours
Occupied period 12 hours
- 6 hours on-peak
- 6 hours off-peak
Total weekly load 10,558.00 ton-hr

A. Weekly Load Shifting - Based on Total Weekly Cooling Load

COMPRESSOR TONS
= 10,558.00/(5(6)(1.3)+5(6)+48)
= 77 tons

B. Weekly Load Shifting - Based on Total Weekly Cooling Load

STORAGE
= (77 ton)(4 + 6 + 6 hr
= 4,666 ton-hr

VOLUME
= (4,666 ton-hr)/(3 ft^3/ton-hr)
= 1,555 ft^3

6. EQUIPMENT AND STORAGE SELECTION USING QUICK SIZING CHARTS

Sizing Conditions

Peak period duration 8 hours
Occupied period 12 hours
- 6 hours on-peak
- 6 hours off-peak

SUMMARY FROM QUICK SIZING CHART

7. FIRST COST EQUIPMENT COMPARISON WITH CONVENTIONAL

A. Conventional Chiller 225 Ton
   (2 112.5 ton chillers at $300/ton)
   $67,500

B. Daily Level - Ice Maker
   Evaporative Condenser
   Rebate ($250)(270-90)
   $43,000
   Storage
   $10,000
   $73,000

C. Weekly Level - Ice Maker
   Evaporative Condenser
   Rebate ($250)(270-135)
   $49,500
   Storage
   $18,000
   $67,500

D. Weekly Level - Ice Maker
   Evaporative Condenser
   Rebate ($250)(270-27)
   $49,500
   Storage
   $30,000
   $79,500

E. Weekly Level - Ice Maker
   Evaporative Condenser
   Rebate ($250)(270-135)
   $49,500
   Storage
   $18,000
   $67,500

* No credit for smaller piping, wiring, transformers, circuit breakers, etc. with this storage.
** Price includes evaporator section, compressor, motor, receiver, water accumulator, valves, and refrigerant piping.
8. SIMPLE PAYBACK ANALYSIS

Demand Savings:
DPL - approximately $0.046/KW shifted annual savings (based on peak demand for four summer months with 80% ratchet at $7.65/KW demand charge)

Daily Level 270-95 ($80/KW) = $11,760
Daily Shift 270 ($80/KW) = 21,600
Weekly Level 270-75 ($80/KW) = 12,640
Weekly Shift 270 ($80/KW) = 21,600

Energy Savings:
DPL rates approximately $0.046 on-peak $0.046 off-peak (including fuel adjustment)

EFLH = 1400

Daily Level 360 off-peak $80/KW = $21,600
Weekly Level 420 off-peak $80/KW = $21,600

Simple Payback:

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<th>Strategy</th>
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CONCLUSION:

Harnessing ice makers are an effective tool in the utility load management plan. By reducing installed refrigeration capacity, or insuring that equipment does not run on peak, the same generating capacity can serve many more customers. Turbo Refrigerating Company meets this need by providing high efficiency, low maintenance, and highly reliable thermal storage systems.
Figure 7

Proceedings of the Third Symposium on Improving Building Systems in Hot and Humid Climates, Arlington, TX, November 18-19, 1986
LOAD PROFILE

ICE MAKING

LOAD PROFILE

ICE HARVESTING

Figure 3

Figure 5

Figure 4

Figure 6