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 preventing 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 foot) 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.

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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 is required, and because smaller capacity refrigeration equipment is used.

When load leveling cool storage mode is used, capacities of the storage system and refrigeration equipment are selected so the 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 exceeds 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 to an economic thickness usually not greater than 0.25 inches. The ice is harvested by introducing hot refrigerant gas into the inside of the heat exchanger plates. The hot gas warms the plate breaking the bond between the ice and the plate. The ice drops off into a storage tank. Figure 5 shows a schematic of the plate generating ice and harvesting ice. Figure 6 shows the application of ice storage for a chilled water air-conditioning application.

Ice is generated on the plates by circulating 32°F water for a 20 to 30 minute build cycle and harvesting 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 33°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 the ice that is stored in the tank very quickly. The ice is characteristically less than 6" x 6" x 0.25" with 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 stored in this fashion 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 are 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 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:

$$I = T\text{-}H/(NHI + 1.3 * NHC)$$

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:

$$V = NHI * I * 83.3/DI$$

WHERE

V = VOLUME

DI = DENSITY OF ICE IN STACK

$(DI = 27.8\ lb/ft^3)$

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 ft^2 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 FT^2 OFFICE BUILDING

TIME	MON	TUE	WED	THUR	FRI	SAT SUN	TOTAL
midnight	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6:00	209.83	150.84	150.84	150.84	150.84	0.00	813,19
7:00	166.85	151.69	151.69	151.69	151.69	0.00	773.61
8:00	191.29	139.04	139.04	139.04	139.04	0.00	747.45
9:00	198.88	153.37	153.37	153.37	153.37	0.00	812.36
10:00	200.56	182.87	182.87	182.87	182.87	0.00	932.04
11:00	196.35	184.30	184.30	184.30	184.30	0.00	933.55
noon	192.13	187.23	187.23	187.23	187.23	0.00	941.05
1:00	195.51	196.82	196.82	196.82	196.82	0.00	982.79
2:00	211.52	204.78	204.78	204.78	204.78	0.00	1030.64
3:00	225.00	216.57	216.57	216.57	216.57	0.00	1091.28
4:00	168.54	167.70	167.70	167.70	167.70	0.00	839.34
5:00	132.30	132.30	132.30	132.30	132.30	0.00	661.50
6:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL	2288.76	2067.51	2067.51	2067.51	2067.51	0.0	10558.00
ON PEAK	1125.00	1105.40	1105.40	1105.40	1105.40	0.00	5546.60
OFF PEAK	1163.76	962.11	962.11	962.11	962.11	0.00	5012.20
HRS ON PK	8.00	8.00	8.00	8.00	8.00	0.00	40,00
HRS OFF PK	16.00	16.00	16.00	16.00	16.00	24.00	128.00

Table 1

2. DAILY LOAD LEVELING EXAMPLE

<u>Sizing Conditions</u>

Peak period duration 8 hours (12:00 - 8 pm)

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. <u>Daily Load Leveling</u> - Based on Tuesday Load

COMPRESSOR TONS
= (2067.51/(12+1.3(12)) = 75.0 tons

STORAGE
= (75.0 ton)(12 hr)
= 900 ton-hr

VOLUME
= (900 ton-hr)(3 ft^3ton-hr)
= 2,700 ft^3

B. <u>Daily Load Leveling</u> - Based on Monday Draw Down Load

COMPRESSOR TONS
= 75.0 TONS

STORAGE
= 900 + (2288.76 - 2067.51)
= 1,121 ton-hr

VOLUME
= (1121 ton-hr)(3 ft^3/ton-hr)
= 3,363 ft^3

3. WEEKLY LOAD LEVELING EXAMPLE

Sizing Conditions

Peak period duration 8 hours
(12:00 - 8:00 pm)
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
= 10558.00/(5(12)(1.3)+5(12)+48)
= 57.0 tons
STORAGE
= (57.0 ton)(6 + 24 + 24 + 6)
= 3,420 ton-hr
VOLUME = (3420 ton-hr)(3 ft^3/ton-hr)
= 10,260 ft^3

4. DAILY LOAD SHIFTING

Sizing Conditions
Peak period duration 8 hours
(12:00 - 8:00 pm)
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)(10 hr) = 1,160 ton-hr
VOLUME = (1160 ton-hr)(3ft^3/ton-hr)
= 3,480 ft^3

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

COMPRESSOR TONS = 116.0 tons
STORAGE
= 1160 ton-hr + (2288.76-2067.51)
= 1,381 ton-hr
VOLUME = (1381 ton-hr)(3ft^3/ton-hr)
= 4,143 ft^3

5. WEEKLY LOAD SHIFTING

Sizing Conditions
Peak period duration 8 hours
(12:00 - 8:00 pm)
Occupied period 12 hours
- 6 hours on-peak
- 6 hours off-peak
Total weekly load 10558.00 ton-hr

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

COMPRESSOR TONS
=(10558.00/(5(6)(1.3)+5(6)+5(4)+48)
= 77 tons

STORAGE
= (77 ton)(4 + 48 + 6) hr
= 4,466 ton-hr
VOLUME = (4466 ton-hr)(3 ft^3/ton-
= 4466 ton-hr)(3ft^3/ton-hr)
= 13,398 ft^3

6. EQUIPMENT AND STORAGE SELECTION USING QUICK SIZING CHARTS

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

SUMMARY FROM QUICK SIZING CHART

STRATEGY	STORAGE TON-HR*	STORAGE FT^3	COMPRESSOR TONS/SST/(KW/TON)		ON-PEAK KW**
Conventional	0	0		225/38/1.2	270
Daily Level	1121	3363	75/20/1	98/35/0.9	88+10
Daily Shift	1381	4143	116/20/1	151/35/0.9	0
Weekly Level	3420	10260	57/20/1	74/35/0.9	67.5
Weekly Shift	4466	13398	77/20/1	100/35/0.9	0

* Daily strategies include Monday draw down load storage.
** Also includes evaporatively cooled condenser KW.

7. FIRST COST EQUIPMENT COMPARISON WITH CONVENTIONAL*

SYSTEM SELECTION		FIRST COST CHILLER/STORAGE
A. Conventional Chiller 225 Ton (2 112.5 ton chillers at $300/ton)		$67,500
B. Daily Level - Ice Maker **	$62,000	
Evaporative Condenser	15,300	
Rebate ($250)(270-98)	-43,000	
Storage	16,000	
	$50,300	$50,300
C. Daily Shift - Ice Maker	$96,000	
Evaporative Condenser	20,600	
Rebate ($250)(270)	-67,500	
Storage	18,000	
	$67,100	$67,100
D. Weekly Level - Ice Maker	$45,600	
Evaporative Condenser	10,700	
Rebate ($250)(270-72)	-49,500	
Storage	35,910	
	$42,710	$42,710
E. Weekly Shift - Ice Maker	$62,000	
Evaporative Condenser	15,300	
Rebate ($250)(270)	-67,500	
Storage	48,000	
	$57,800	$57,800

* No credit for smaller piping, wiring, transformers, circuit breakers, etc. with thermal storage.

** Price includes evaporator section, compressor, motor, receiver, suction accumulator, valves, and refrigerant piping.

8. SIMPLE PAYBACK ANALYSIS

Demand Savings:

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

Daily Level (270-98)(\$80/KW)	=\$13,760
Daily Shift (270)(\$80/KW)	= 21,600
Weekly Level(270-72)(\$80/KW)	= 15,840
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

Conventional 53% on-peak 47% off-peak
(1400)(.53)(1.2KW/ton)(225 ton)(\$0.046) = \$9,215
(1400)(.47)(1.2KW/ton)(225 ton)(\$0.046) = 8,170
\$17,385

Daily Level 38% on-peak 62% off-peak
(1400)(.38)(.92KW/ton)(225 ton)(\$0.046) = \$5,065
(1400)(.62)(.96KW/ton)(225 ton)(\$0.046) = 8,619
\$13,684

Daily Shift 100% off-peak
(1400)(.96KW/ton)(225 ton)(\$0.046) = \$13,910

Weekly Level 26% on-peak 74% off-peak
(1400)(.26)(.92KW/ton)(225 ton)(\$0.046) = \$3,464
(1400)(.74)(.96KW/ton)(225 ton)(\$0.046) = 10,292
\$13,756

Weekly Shift 100% off-peak
(1400)(.98KW/ton)(225 ton)(\$0.046) = \$14,200

Simple Payback:

Strategy	First Cost	TS Premium	Demand Saving	Energy Saving	Simple Payback
Conventional	\$67,500	0	0	0	0.0
Daily Level	50,300	0	\$13,760	\$3,701	0.0
Daily Shift	67,000	0	21,600	3,475	0.0
Weekly Level	42,710	0	15,840	3,629	0.0
Weekly Shift	51,800	0	21,600	3,185	0.0

CONCLUSION:

Harvesting 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.

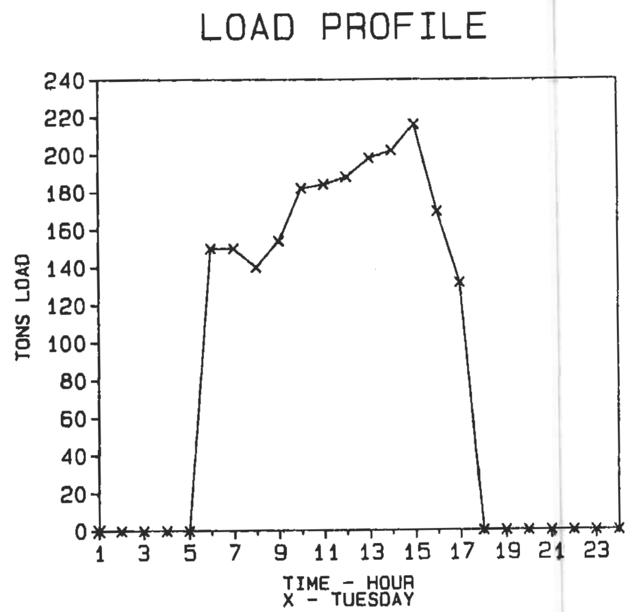

FIGURE 1

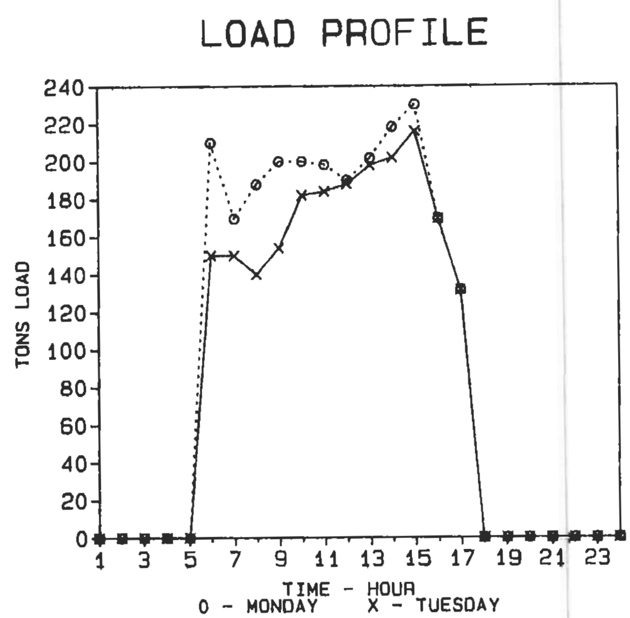

FIGURE 2

ICE MAKER PLATE MODULE

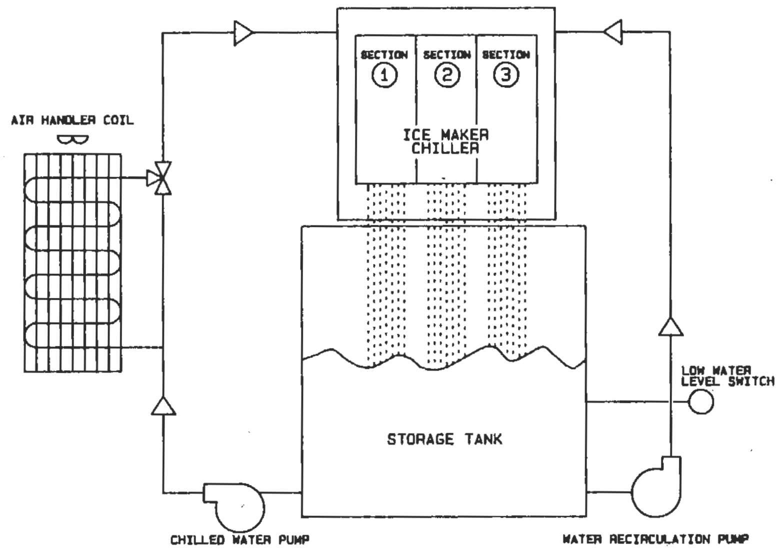

FIGURE 7

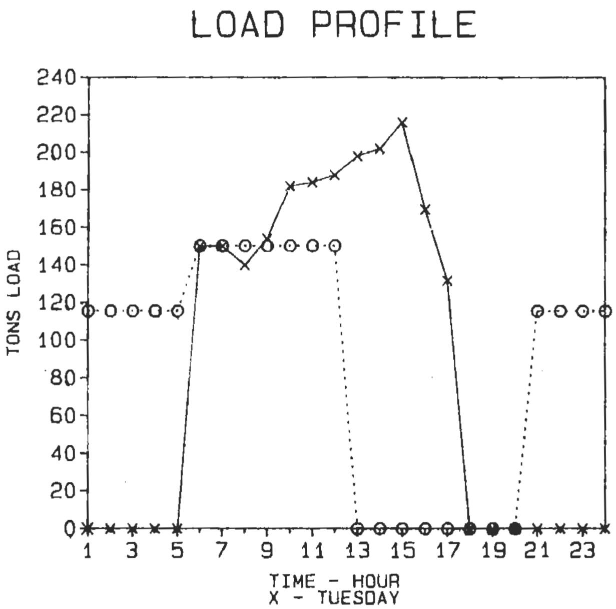

FIGURE 3

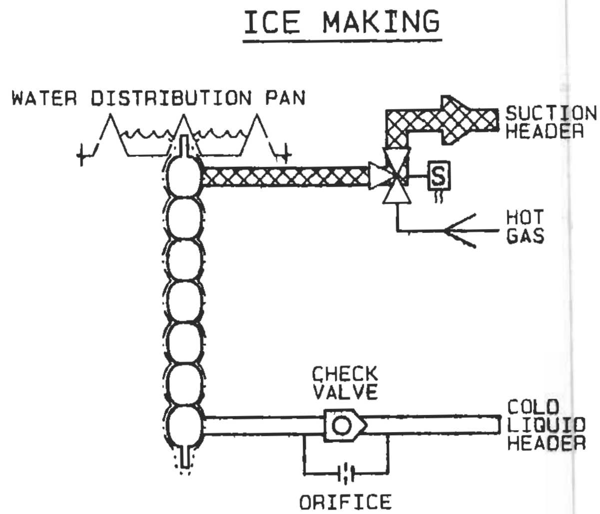

FIGURE 5

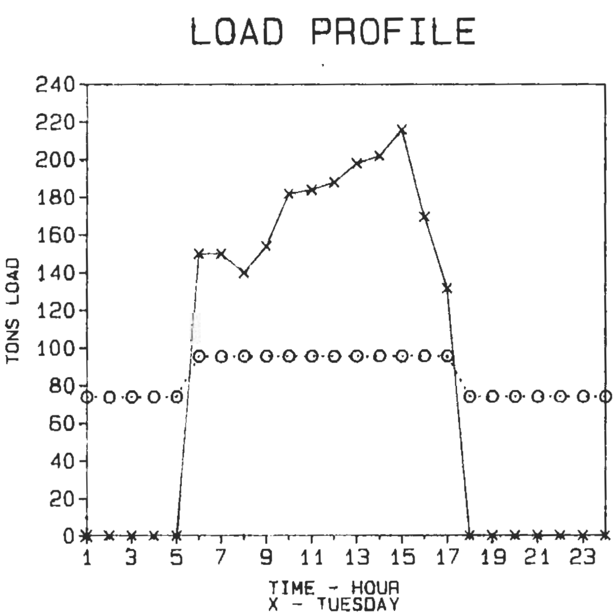

FIGURE 4

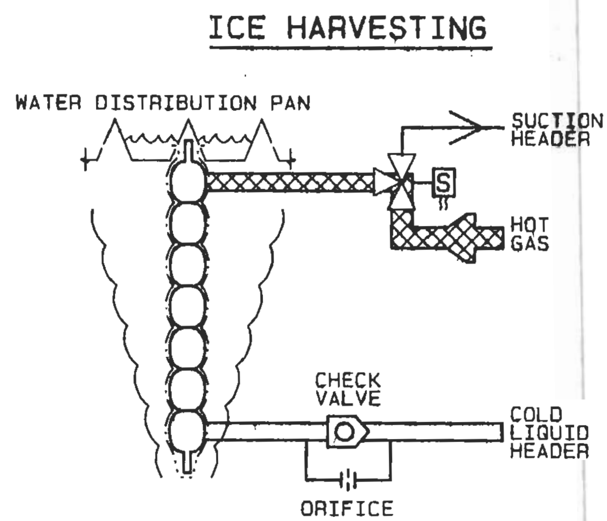

FIGURE 6

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