ECONOMIC ANALYSIS OF A CENTRAL ICE PLANT EXPORTING LOW TEMPERATURE WATER TO A COMPLEX OF BUILDINGS FOR A FINANCIAL INSTITUTION

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This paper assesses the economic aspects of an ice-based hybrid thermal energy storage system as a prime source of refrigeration and energy conservation for a cluster of structures representative of a campus or a small metropolitan business complex.

Comparisons of individual structure and overall site energy consumption are evaluated after a full year of operation. Plant operational strategies, load deferrals, low temperature distribution, capital cost avoidance for individual building chilling plants, expected reduction of energy costs per square foot of usable space and capital investment payback derived from the Central Thermal Energy Storage System are included in this paper.

PURPOSE

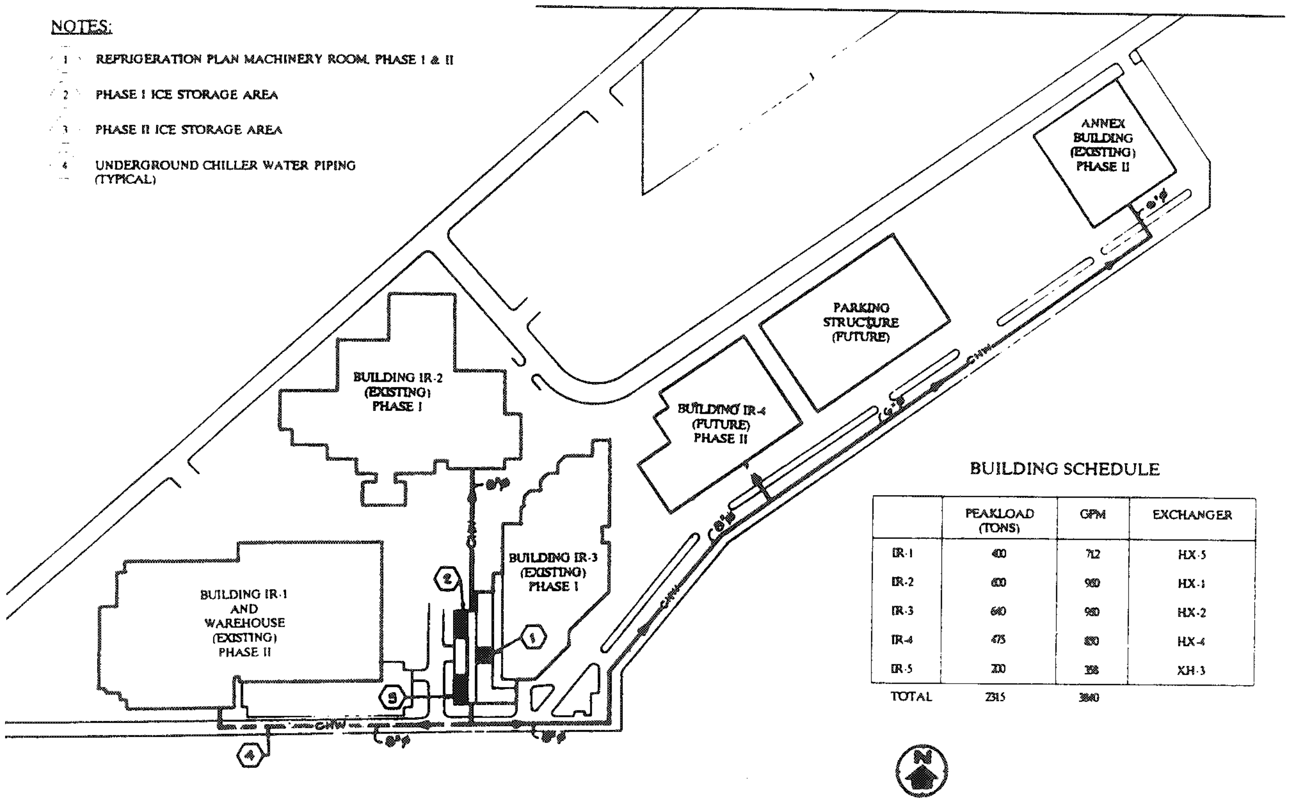
The Thermal Energy Storage System in this paper is located in Irwindale, California and it was implemented as a major source of energy conservation for two existing buildings and future buildings located on the campus site of a financial institution. Phase I of the Thermal Storage Facility was designed to furnish off-peak cooling to Building IR-2 (existing) and Building IR-3 (recently completed) with Phase II being designed at a later date to accommodate Building IR-1 (existing), the Annex Building (existing) and Building IR-4 (future). Figure 1 is a sketch of the Irwindale Campus Site.

Thermal energy storage feasibility studies were made for both Buildings IR-2 (existing) and Building IR-3 (future at the time) to determine the possibility of integrating an off-peak cooling system into the existing campus to service both existing and new buildings. The Phase I portion of the Thermal Storage Facility was calculated to have a maximum simple pay-back of 1-1/2 years with energy savings approaching $200,000 per year.

Construction drawings were prepared for a central plant located in the service area of the newly designed Building IR-3 which was shortly to commence construction. The Machinery Room, which was originally sized for a Chiller Plant in Building IR-3 only (300,000 ft^2 of office space), was dedicated for all the refrigeration equipment required to provide cooling for all campus buildings (1,200,000 sq. ft. of office space). An area approximately 160 ft. long by 40 ft. wide was used to contain the ice storage equipment plus all the condenser and high pressure receiver.

OPERATING FEATURES

The Thermal Storage Plant provides total chilled water capability for Building IR-3 (peak load = 650 tons) and on-peak chilled water capacity for Building IR-2 (peak load = 600 tons). The refrigeration equipment is powered through a separate Southern California Edison (SCE) meter on a TOU-8-SOP schedule whereas the chilled water pumping equipment is powered through a SCE



BUILDING SCHEDULE

	PEAKLOAD (TONS)	GPM	EXCHANGER
IR-1	400	712	HX-5
IR-2	600	980	HX-1
IR-3	640	980	HX-2
IR-4	475	850	HX-4
IR-5	200	358	XH-3
TOTAL	2315	3840	

Figure 1. Irwindale Campus Distribution Plan

meter on a TOU-8 schedule. The refrigeration plant operates during off-peak and super-off-peak periods to manufacture all the ice required for the daily demand. This ice is melted off during on-peak and partial mid-peak periods by pumping water across the ice tubes and over to the air handling units through distribution piping in each building. When all the ice is melted off, or no more ice is required, this equipment will shut down and repeat the cycle the following day. If all the ice is melted and building IR-3 demands chilled water during mid-peak or off-peak hours, one of the ice bank evaporators is used at a higher saturated suction temperature to operate as a chiller barrel, thus furnishing chilled water directly to the air handling units during mid-peak demand periods.

Phase I of the Thermal Storage Plant was completed within budget and now operates successfully with capacities and energy savings far above those predicted during the feasibility analyses. Some of the more significant features of this plant are as follows:

- Central Cooling plant for 600,000 ft^2 of office building with future capacity for an additional 600,000 ft^2.
- Total on-peak deferral (1,200 tons/hour) through use of ice storage during the summer months.
- Total full day deferral through use of ice storage during Spring, Fall, and Winter months.
- Operating cost savings of over $200,000 per year compared to a conventional chiller plant.
- Steady production of 38°F water to all air handling units regardless of outside weather conditions.
- Availability of 900 Hp of compressor capacity as back-up in the event of loss of ice storage or should additional cooling be required beyond the stored ice capacity.
- Compressor operation is restricted to night time during ice building ensuring quiet operation of only chilled water pumps during the day. This

also allows time for routine maintenance of the plant equipment during the day.

- Constant availability of 38°F water allows for better dehumidification over and above that normally achieved with conventional chilled water equipment. This becomes an added advantage in laboratory areas or production areas where humidity control is often times the prevailing force.
- The refrigerant charge is an environmentally accepted R-22.

PLANT DESCRIPTION

The Thermal Energy Storage Plant (Phase I) was designed to furnish cold water at 34°F from a central location to Building IR-2 and Building IR-3 through a primary pumping loop. Chilled water at 38°F is distributed throughout each building on a secondary pumping loop via heat exchangers located in each building.

Ice is built daily by a refrigeration plant located in Building IR-3. The plant comprises three open drive horizontal screw compressors, two evaporative condensers, one high pressure surge receiver, one vertical refrigerant recirculating unit with two 10 Hp recirculating pumps and five top feed horizontal galvanized steel tube evaporators. The ice bank evaporators are each located in separate 1 ft. thick wall concrete tanks each measuring 28 ft. long x 10 ft. wide x 19 ft. high. Each tank is full of water and enclosed with insulated removable steel covers. Three primary chilled water pumps, two operating and one standby, horizontal end suction centrifugal type are also located in the refrigeration plant Machinery Room.

On a daily cycle, the compressors operate at full capacity to generate low temperature refrigerant liquid which is used in the recirculating unit. The low temperature refrigerant liquid is pumped to the ice bank evaporators submerged in water in the concrete tanks. Each coil is designed to build 1.4" thick ice on the outer tube of each bundle until 100,000 lbs of ice is made. 120,000 lbs/tank can be made at 1.8" ice thickness. The refrigerant vapor/liquid is returned to the refrigerant recirculating unit and the cycle is repeated until all tanks have a full ice build.

During the ice melting cycle, the primary chilled water pumps circulate water from the ice storage tanks to each heat exchanger and back as long as chilled water is required. The air agitator pump constantly distributes air bubbles amongst the evaporator tubes to ensure an even ice build and ice melt.

Each concrete storage tank contains one ice bank evaporator which is directly piped to the refrigeration system. A series of refrigerant control valves operate the flow of refrigerant to the evaporator based upon a timing schedule and the amount of ice programmed to be built. The concrete tanks are also full of water which is piped directly to the primary chilled water circulating system. The flow of water is regulated through automatic control valves based upon a timing schedule and the demand for chilled water.

The entire plant and energy exports are monitored and controlled 24 hours per day by a central microprocessor-based control system. Figure 2 shows a simplified block diagram for the system. Table 1 summarizes operating parameters and performance data.

Sequence of Plant Operation

The Thermal Energy Storage Plant is designed to build ice at night during cheaper energy periods and utilize this stored energy during the daytime when energy is more costly by using pumping horsepower only to meet the cooling demand normally achieved through the use of packaged chillers. The peak load of 1,260 tons for the two Buildings combined can be supplied through the use of two 50 Hp pumps with an actual energy efficiency of 0.05 KW/ton. This compares with 1.0 KW/ton for a conventional chiller plant which would operate on the same rate schedule during the on-peak period.

The refrigeration equipment located in Building IR-3 is metered independently from the remainder of the building on a TOU-8-SOP schedule. During the Summer months (July, August and September), the refrigeration equipment operates during the off-peak and super-off-peak periods to build ice on the evaporator tubes located in the ice storage tanks. These periods extend from 6:00 a.m. to 10:00 a.m. and 9:00 p.m. to midnight for the off-peak and from midnight to 6:00 a.m. for the super-off-peak. Depending upon the outdoor wet bulb temperature, the time required to build a full charge of ice is between 7 to 9 hours.

The primary chilled water pumps located in Building IR-3 operate on the building's TOU-8 meter. During the Summer months, pump P-1 pumps chilled water (34°F) to building IR-2 throughout the on-peak period from noon to 6:00 p.m. During this time, the chillers in Building IR-2 are shut down. For milder times of the year, chilled water (34°F) is pumped from the Thermal Energy Storage Plant continuously allowing the Chiller Plant to remain idle all day or as long as ice is available. When ice is no longer available, the chiller plant in IR-3 is started up to provide cooling to the building during mid-peak periods only. (This occurred only two days in 1989, during a Santa Ana wind condition).

Primary chilled water pump P-3 pumps chilled water (34°F) from the ice storage tanks to Building IR-3 during on-peak periods in the Summer months. As in the case with Building IR-2, ice is used to provide cooling for as much of the day as possible until all the ice is melted. When no more ice is available, the Refrigeration Plant, with one dedicated ice bank evaporator, will operate in a "chiller mode" to provide chilled water (40°F) to Building IR-3 as required.

When all the ice is melted off the evaporator tubes, the refrigeration cycle is repeated at the commencement of the off-peak period.

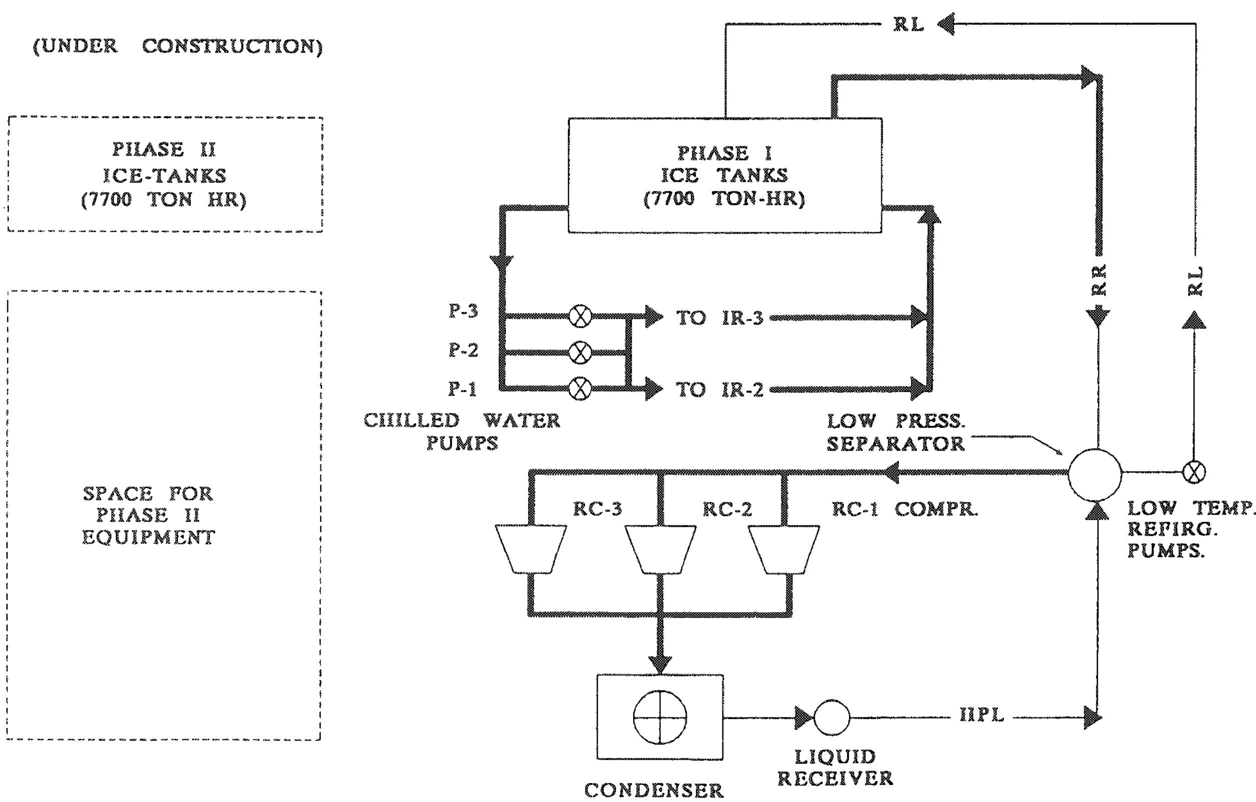


Figure 2. T.E.S. System Schematic Diagram

Table 1. Plant Statistical Performance Data

- Compressors: (3) screw open-drive 300 Hp. Ea.
- Evaporative condensers: (2) Axial fans 80 Hp. Total
- Liquid (R-22) Recirculating unit: 580 gpm (2) 10 Hp. Pumps
- High Pressure Receiver: Surge-type 9000 lbs cap.
- Hybrid Evaporator-Coils: (5) Sectionalized Top-Feed Type
- Oil Cooling pumps: (One stand-by) 3 Hp. Ea. Water System
- Chilled Water Pumps: (3) 50 Hp. Ea. 950 gpm flow to 1920 gpm flow
- Heat Exchangers: (2) Low Approach Plate type 39°F Water Outlet.
- Microprocessor Based Control System: Plant Control - Feeding Distribution
- Total Plant Capacity at 20°F SST: = 846 Ton/Hr Ice Maker
- Total Plant Capacity @ 30°F SST: = 1050 Ton/Hr Chiller Mode
- Total Ice Storage Capacity @ 1.4" Ice = 500,000 lbs.
- Total Ice Storage Capacity @ 1.8" Ice = 600,000 lbs.
- Energy Stored, Latent and Sensible = 6,500 Ton-Hr. (Min.)
- Energy Stored, Latent and Sensible = 7,700 Ton-Hr. (Max.)
- Net Density of Stored Energy, Ton-Hr/Ft^3: = 0.314
- Net Area Density, Ton-Hr/Ft^2 = 5.50
- Exporting Water Temperatures: = 34°F - 42°F

Connected Air Conditioning Loads

(Bldg IR-2 & IR-3, 10 Hrs per day, 20 days/mo. in ton-hr.)

Jan	=	150,400	July	=	220,400
Feb	=	176,400	Aug.	=	219,600
March	=	192,400	Sept.	=	210,200
April	=	201,400	Oct.	=	197,400
May	=	206,400	Nov.	=	174,800
June	=	220,400	Dec.	=	163,000

Total Yearly Ton-Hr = 2,332,800

ECONOMIC ANALYSIS

A. Conventional Chiller System as originally designed for building IR-3 without chilled water piping interconnecting building IR-2 (lowest bid) - **$879.732.00**

B. The Thermal Energy Storage System ice plant for Buildings IR-2 & IR-3 with interconnecting piping (installed cost). - **$1,469,764.00**

Power Consumption

Conventional Chiller System	= 0.98 kw/ton
Ice System Operating in a Chiller Mode (32°F SST)	= 0.87 kw/ton
Chilled Water (From Ice-Pump Only)	= 0.06 kw/ton
Ice Building (At Full Capacity-Night Time)	= 0.87 kw/ton

Current Southern California Edison Rate Structure

TOU-8 Schedule up to 2KV:

Summer	Energy $/kwh	Demand $/kw
On-peak	0.11000	14.45
Mid-peak	0.08902	2.25
Off-peak	0.05012	---
Winter		
Mid-peak	0.10001	---
Off-peak	0.05012	---

TOU-8-SOP Schedule up to 2KV:

Summer	Energy $/kwh	Demand $/kw
On-peak	0.10164	36.00
Mid-peak	0.10164	0.95
Off-peak	0.06692	---
Super-off-peak	0.03512	---
Winter		
Mid-peak	0.07691	0.50 (Spring-Fall Also)
Off-peak	0.07141	---
Super-off-peak	0.03512	---

Operating Cost Based on Actual 1987 Rates (slightly lower than current rates):

Annual operating cost for a conventional chiller system (IR-2 & IR-3)

Energy charges for on-peak chiller load (Table 2)	=	$ 67,158
Energy charges for mid-peak chiller load (Table 3)	=	137,689
Energy charges for off-peak chiller load (Table 4)	=	10,994
Demand charges for on-peak chiller load (Table 5)	=	64,197
Demand charges for mid-peak chiller load (Table 6)	=	4,801
Demand charges (non-time related) for chiller load (Table 7)	=	33,832
Subtotal for Demand	=	$102,830
Chiller Annual TOTAL		**$318,671/Year**

Annual operating cost for the ice storage system

Energy charges for chilled water from ice, on/mid-peak (Table 8)	=	$ 9,875
Energy charges for ice building, off-peak (Table 9)	=	16,649
Energy charges for ice building, super-off-peak (Table 10)	=	44,248
Energy charges for ice system in chiller mode, off-peak (Table 11)	=	18,812
Energy charges for ice system in chiller mode, mid-peak (Table 12)	=	27,842
Demand charges for ice system in chiller mode, mid-peak (Table 13)	=	3,333
Demand charges for ice system in ice depleting mode, on-peak (Table 14)	=	7,326
Demand charges (non-time related) for ice storage system (Table 15)	=	23,820
Subtotal for Demand	=	$34,479
T.E.S. Annual TOTAL		**$151,905/Year**

The operating cost savings for each of the VAV air handling unit systems as extracted from the feasibility studies are: (35% of total fans energy cost)

Building IR-2	=	$15,822
Building IR-3	=	$15,147
VAV Annual Total		**$30,969**

(Equivalent of 344,100 Kwh)

Table 2. Energy Charges for Conventional Chiller System (Building IR-2 and Building IR-3) TOU-8 On-Peak only

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.98	-	-	-	-	-
February	.98	-	-	-	-	-
March	.98	-	-	-	-	-
April	.98	-	-	-	-	-
May	.98	-	-	-	-	-
June	.98	632 592	19 580	132	.102	16,966
July	.98	636 596	623 584	132	.102	17,080
August	.98	630 590	617 578	132	.102	16,910
September	.98	604 564	592 553	132	.102	16,202
October	.98	-	-	-	-	-
November	.98	-	-	-	-	-
December	.98	-	-	-	-	-

TOTAL: $67,158

Table 3. Energy Charges for Conventional Chiller System (Building IR-3 and Partial Building IR-2) TOU-8 Mid-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	0.98	389 447*	381 438	230 184	.0832	13,996
February	0.98	462 518*	453 508	200 140	.0832	13,445
March	0.98	511 568*	501 557	230 138	.0832	15,982
April	0.98	530 588*	519 576	220 138	.0832	16,113
May	0.98	545 603*	534 591	230 138	.0832	17,004
June	0.98	512	502	88	.0773	3,415
July	0.98	516	506	92	.0773	3,598
August	0.98	513	503	92	.0773	3,577
September	0.98	489	479	88	.0773	3,258
October	0.98	540 557*	529 546	230 161	.0832	17,437
November	0.98	453 519*	444 509	220 154	.0832	14,649
December	0.98	425 482*	417 472	230 184	.0832	15,205

*IR-2 Building

TOTAL: 137,679

Table 4. Energy Charges for Conventional Chiller System (Building IR-3 Only) TOU-8 Off-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$KWH	Energy Charges $
January	.98	278	272	46	.0501	627
February	.98	382	374	40	.0501	749
March	.98	427	418	46	.0501	963
April	.98	442	433	44	.0501	955
May	.98	456	447	46	.0501	1,030
June	.98	471	462	44	.0501	1,018
July	.98	476	466	46	.0501	1,074
August	.98	472	463	46	.0501	1,067
September	.98	450	441	44	.0501	972
October	.98	415	407	46	.0501	938
November	.98	376	368	44	.0501	811
December	.98	350	343	46	.0501	790

TOTAL: $10,994

Table 5. Time Related Demand Charges for Conventional Chiller System TOU-8 Schedule On-Peak

Month	KW/Ton	Max. Tons	Max. KW	$/KW	Demand Charges $
January	.98	-	-	-	-
February	.98	-	-	-	-
March	.98	-	-	-	-
April	.98	-	-	-	-
May	.98	-	-	-	-
June	.98	1240	1215	13.25	16,099
July	.98	1257	1232	13.25	16,324
August	.98	1231	1206	13.25	15,980
September	.98	1216	1192	13.25	15,794
October	.98	-	-	-	-
November	.98	-	-	-	-
December	.98	-	-	-	-

TOTAL: $64,197

Table 6. Time Related Demand Charges for Conventional Chiller System (Building IR-3 Only) TOU-8 Schedule Mid-Peak

Month	KW/Ton	Max. Tons	Max. KW	$/KW	Demand Charges $
January	.98	-	-	-	-
February	.98	-	-	-	-
March	.98	-	-	-	-
April	.98	-	-	-	-
May	.98	-	-	-	-
June	.98	605	593	2.05	1,216
July	.98	609	597	2.05	1,223
August	.98	602	590	2.05	1,209
September	.98	574	563	2.05	1,153
October	.98	-	-	-	-
November	.98	-	-	-	-
December	.98	-	-	-	-

TOTAL: $4,801

Table 7. Non-Time Related Demand Charges for Conventional Chiller System TOU-8 Schedule

Month	Max. KW	$/KW	Demand Charges ($)
January	850	2.7	853
February	989	2.7	2,670
March	1013	2.7	2,735
April	1112	2.7	3,002
May	1310	2.7	3,527
June	1215	2.7	3,281
July	1232	2.7	3,327
August	1206	2.7	3,256
September	1192	2.7	3,218
October	1038	2.7	2,803
November	991	2.7	2,676
December	916	2.7	2,474

TOTAL: $33,832

Table 8. Energy Charges for Ice Depletion TOU-8 on Peak/Mid-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.06	447 389	27 23	184 161	.0832	721
February	.06	518 462	31 28	140 120	.0832	641
March	.06	568 511	34 31	138 138	.0832	746
April	.06	588 530	35 32	132 132	.0832	736
May		603	36	138		
June	.06	632 592	38 36	132	.1072	1,047
July	.06	636 596	38 36	138	.1072	1,047
August	.06	630 590	38 35	138	.1072	1,033
September	.06	604 564	36 34	132	.1072	991
October	.06	557 540	33 32	161 115	.0832	748
November	.06	519 453	31 27	154 132	.0832	694
December	.06	482 425	29 26	184 138	.0832	742

TOTAL: $9,875

Table 9. Energy Charges for Ice Building IOU-8 SOP Off-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.87	846	737	35	.0503	1,297
February	.87	846	737	32	.0503	1,186
March	.87	846	737	39	.0503	1,446
April	.87	846	737	42	.0503	1,557
May	.87	846	737	35	.0503	1,297
June	.87	846	737	40	.0503	1,483
July	.87	846	737	46	.0456	1,546
August	.87	846	737	46	.0456	1,546
September	.87	846	737	35	.0456	1,176
October	.87	846	737	41	.0503	1,520
November	.87	846	737	33	.0503	1,223
December	.87	846	737	37	.0503	1,372

TOTAL: $16,649

Table 10. Energy Charges for Ice Building TOU-8 SOP Super-Off-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.87	846	737	138	.0372	3,783
February	.87	846	737	120	.0372	3,290
March	.87	846	737	138	.0372	3,783
April	.87	846	737	132	.0372	3,620
May	.87	846	737	138	.0372	3,783
June	.87	846	737	132	.0372	3,619
July	.87	846	737	138	.0372	3,783
August	.87	846	737	138	.0372	3,783
September	.87	846	737	132	.0372	3,619
October	.87	846	737	138	.0372	3,783
November	.87	846	737	132	.0372	3,619
December	.87	846	737	138	.0372	3,783
					TOTAL:	$44,248

Table 11. Energy Charges for Ice System in Chiller Mode TOU-8-SOP Off-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.87	278	242	46	.0503	560
February	.87	382	332	60	.0503	1,002
March	.87	427	371	69	.0503	1,288
April	.87	442	385	110	.0503	2,130
May	.87	456	397	115	.0503	2,296
June	.87	471	410	110	.0503	2,269
July	.87	476	414	92	.0456	1,737
August	.87	472	411	92	.0456	1,724
September	.87	450	392	88	.0456	1,573
October	.87	415	361	115	.0503	2,088
November	.87	376	327	66	.0503	1,086
December	.87	350	305	69	.0503	1,059
					TOTAL:	$18,812

Table 12. Energy Charges for Ice System in Chiller Mode TOU-8-SOP Mid-Peak

Month	KW/Ton	Avg. Tons	Avg. KW	Hours	$/KWH	Energy Charges $
January	.87	389	338	69	.0728	1,698
February	.87	462	402	60	.0728	1,756
March	.87	511	446	69	.0728	2,240
April	.87	530	461	22	.0655	664
May	.87	544	473	46	.0655	1,425
June	.87	592	515	44	.0655	1,484
July	.87	596	519	69	.1294	4,634
August	.87	590	513	69	.1294	4,580
September	.87	564	491	66	.1294	4,193
October	.87	540	470	46	.0655	1,416
November	.87	453	394	66	.0728	1,893
December	.87	425	370	69	.0728	1,859
					TOTAL:	$27,842

Table 13. Time Related Demand Charges for Ice Storage System (Chilled Water Mode) TOU-8-SOP Mid-Peak

Month	KW/Ton	Max. Tons	Max. KW	$/KW	Demand Charges $
January	0.87	451	392	0.45	177
February	0.87	530	461	0.45	207
March	0.87	571	497	0.45	224
April	0.87	589	512	0.45	231
May	0.87	603	524	0.45	236
June	0.87	605	526	0.45	237
July	0.87	609	530	0.9	477
August	0.87	602	524	0.9	471
September	0.87	574	499	0.9	449
October	0.87	561	488	0.45	220
November	0.87	542	472	0.45	212
December	0.87	490	426	0.45	192
				TOTAL:	$3,333

Table 14. Time Related Demand Charges for Ice Storage System (Ice Depletion Mode) TOU-8-SOP On-Peak

Month	KW/Ton	Max. Tons	Max. KW	$/KW	Demand Charges $
January				_	-
February	-	-	-	-	-
March	-	-	-	-	-
April	-	-	-	-	-
May	-	-	-	-	-
June	-	-	-	-	-
July	0.06	1257	75	33.0	2,475
August	0.06	1231	74	33.0	2,442
September	0.06	1216	73	33.0	2,409
October	-	-	-	-	-
November	-	-	-	-	-
December	-	-	-	-	-
				TOTAL:	$7,326

Table 15. Non-Time Related Demand Charges for Ice Storage System TOU-8-SOP Schedule

Month	Max. KW	$/KW	Demand Charges ($)
January	735	2.7	1985
February	735	2.7	1985
March	735	2.7	1985
April	735	2.7	1985
May	735	2.7	1985
June	735	2.7	1985
July	735	2.7	1985
August	735	2.7	1985
September	735	2.7	1985
October	735	2.7	1985
November	735	2.7	1985
December	735	2.7	1985
		TOTAL:	$23,820

The combined operating cost savings for the entire system are:

Conventional Chiller Operating Costs	=	$318,671
Less: Ice Storage Operating Costs	=	-151,905
Refrigeration Side Savings	=	$166,766
Air Side Savings	=	$ 30,969
Total Savings		**$197,735** Year

ECONOMIC SUMMARY

Conventional Chiller on-peak kw consumption	=	1,232
Ice Storage Plant on-peak kw consumption	=	75
Net Deferred Load kw	=	1,157
Power Company (S.C.E.) Rebate @ $200 per kw deferred	=	$231,400

Simple Payback

Ice Storage System Construction Cost	=	$1,469,764
Conventional Chiller System Cost	=	879,732
Additional Cost for Ice Storage	=	$590,032
Less S.C.E. Rebate	=	-231,400
Net cost add for ice storage	=	$358,632
Annual Operating Cost Savings	=	$197,735
Simple Payback		**1.81 Years**

CONCLUSION

Ice Storage and its concepts have re-emerged as an exciting new technology to cope with today's high cost of energy and as a cost-effective vehicle for space cooling in the commercial sector as well.

Driven by utility companies incentive programs, large difference in utilities cost between "on-peak" and "off-peak" periods and a constant energy demand growth, thermal energy storage systems are becoming a viable alternative to conventional chilling plants.

The T.E.S. case studied in this paper revealed benefits reaching far beyond the economics and thermodynamics expectations as originally intended by the Designers. Findings retrieved after a full year of operation (1989) are revealing greater energy savings than expected. The owner calculated actual cost savings for the site is ranging in the order of *$250,000.*The main contributing factors enhancing the plant operation can be summarized by the following:

- Lower "off-peak" energy costs when operating the plant on a separate TOU-8-SOP meter for the refrigeration equipment (Night Operation Exclusively).
- Reduced pumping horsepower used to export lower temperature water.
- Reduced fan horsepower with lower air temperatures in the V.A.V. systems (35% cost reduction).
- Superior dehumidification capabilities during high-peak demands in humidity controlled areas.
- Full day operation on ice mode without chiller use for the entire year.
- On board computer program capable to produce only the required volume of ice for total campus demands (During mild seasons).

Although every care was taken not to oversize the refrigeration machinery and, erect a plant that was equal in all respects to the conventional chilling apparatus capabilities, the added evaporators surface with longer super-off-peak schedules of operation made this plant a "win-win" situation with *an actual payback of 1.43 years* for the additional capital investment.

Also, one of the principal advantages of the ice storage system described in this paper is the inherent ruggedness and reliability of its components. All materials and equipment employ conventional technology other than the designer imagination.

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