CEMP-ET

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

ETL 1110-1-181

Technical Letter
No. 1110-1-181

12 January 1998

Engineering and Design
PROCUREMENT OF ENERGY EFFICIENT
LIQUID CHILLERS

Distribution Restriction Statement

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1. Purpose. This letter provides guidance in evaluating, comparing, and procuring a liquid chiller with the most applicable energy efficiency for a specific application.

2. Applicability. This guidance is applicable to all HQUSACE elements and USACE commands having Army and Air Force military and/or civil works construction responsibility.

3. References. See Appendix A.

4. Distribution. Approved for public release, distribution is unlimited.

5. Action. The enclosed criteria will be used in the design and procurement of any type of liquid chiller.

6. Implementation. This letter will have routine application of military construction as defined in paragraph 8c, ER 1110-345-100.

FOR THE COMMANDER:

3 Appendices
APP A - References
APP B - Efficiency Comparisons
APP C - Sample Economic Comparisons

KISUK CHEUNG, P.E.
Chief, Engineering and Construction Division
Directorate of Military Programs

Appendix A

References

1. Executive Order

   Executive Order 12902, Energy Efficiency and Water Conservation at Federal Facilities

2. Code of Federal Regulation (CFR)

   10 CFR Part 435, Energy Conservation Voluntary Performance Standards for New Buildings; Mandatory for Federal Buildings.

3. Air-Conditioning and Refrigeration Institute(ARI)

   a. ARI 550, Centrifugal or Rotary Screw Water-Chilling Packages.

   b. ARI 560, Absorption Water Chilling and Water Heating Packages.

   c. ARI 590, Positive Displacement Compressor Water-Chilling Packages

4. American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE)

   a. ASHRAE Handbook, Refrigeration Systems and Applications

   b. ASHRAE 90.1, Energy Efficiency Design of New Buildings Except Low-Rise Residential Buildings

5. National Institute of Standards and Technology Interagency Report

   Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis 1996

Appendix B

Efficiency Comparisons

B-1. BACKGROUND. The procurement of liquid chillers is very difficult when trying to specify the best applicable energy efficiency. Efficiencies of liquid chillers vary greatly based upon a number of different factors. Some of the factors include:

a. Chiller type.

b. Site specific conditions (i.e., outdoor design temperatures, supply water design temperatures, etc.).

c. Commercial availability.

d. Heat recovery.

e. Refrigerant type (i.e., R-22, R-123, R-134a, etc.).

B-2. ENERGY EFFICIENT PRODUCTS. To encourage the procurement of energy efficient products where practical and cost effective, the President of the United States signed into law Executive Order 12902 on March 1994. The key items in the Executive Order which deals with the procurement of energy efficient products by federal agencies is presented below. The efficiency values presented in the designer's notes of the Corps of Engineers Guide Specification (CEGS) 15650 "CENTRAL REFRIGERATED AIR-CONDITIONING SYSTEM" were developed based upon Executive Order 12902.

> "Section 507.(a).(2) To further encourage a market for highly-energy-efficient products, each agency shall increase, to the extent practical and cost effective, purchases of products that are in the upper 25 percent of energy efficiency for all similar products, or products that are at least 10 percent more efficient than the minimum level that meets Federal standards. This requirement shall apply wherever such information is available, either through Federal or industry approved testing and rating procedures."

B-3. ENERGY PERFORMANCE TERMS. Efficiency rating procedures for liquid chillers are defined in ARI 550, ARI 560, and ARI 590 as applicable. The following paragraphs are explanations of typical terms used by ARI to define efficient ratings of liquid chillers.

a. Coefficient of Performance (COP). The COP rating of a liquid chiller is equal to the net equipment cooling capacity divided by the total power input to the unit, including controls. COP values are dimensionless.

b. Energy Efficiency Ratio (EER). The EER rating of a liquid chiller is equal to the net equipment cooling capacity divided by the total power input to the unit, including controls. EER values are expressed in Btuh/Watt. EER is typically used to rate the cooling efficiency of a liquid chiller running at full load conditions.

c. Integrated Part-Load Value (IPLV). The IPLV rating of a liquid

chiller represents a single numeric representation of part load efficiency at different load points. The different load points of a chiller are determined based upon standard ARI rating conditions. The standard rating conditions are defined in ARI 550, ARI 560, or ARI 590 as applicable. IPLV values are expressed either as kW/ton or are dimentionless

d. Application Part-Load Value (APLV). The APLV rating of a liquid chiller represents a single numeric representation of part load efficiency at different load points. The different load points of a chiller are determined based upon site specific rating conditions. APLV values are expressed either as kW/ton or are dimentionless.

B-4. LIQUID CHILLER TYPES. Liquid chiller designs are either the vapor compression type or the absorption type. Both designs rely on a cycle of condensation and evaporation to produce cooling. Refer to the "ASHRAE HANDBOOK, Refrigeration Systems and Applications" for a thorough explanation of each type of chiller system.

B-5. CURRENT ENERGY MANDATES. Minimum energy performance standards for electrically-driven liquid chillers (vapor compression type) in federal buildings are defined in 10 CFR 435.108 and ASHRAE 90.1. The energy parameters are based upon the standard rating conditions established in ARI 550 and ARI 590. At the time of publication of this ETL, minimum energy performance standards for other types of liquid chillers (i.e., absorption type chiller, gas engine-driven type chillers, etc.) were not specifically mandated by any federal regulations.

B-6. CHILLER EFFICIENCIES. Because of typical manufacturing practices, most liquid chillers are not available in multiple efficiencies for each available capacity. Only one model, and therefore, only one efficiency is available from a manufacturer for a given capacity. This is not the case; however, for large electrically-driven, water-cooled rotary screw or centrifugal type chillers (typically larger than 200 tons capacity). These type chillers can be supplied by manufacturers in numerous efficiencies for each capacity.

B-7. CURRENT ARMY CRITERIA. The Corps of Engineer's Guide Specification (CEGS) 15650 "Central Refrigerated Air-Conditioning System" contains the Army's current recommendations for minimum energy efficiencies for all types of liquid chillers. The recommendations in CEGS 15650; however, are not based upon the best commercially available chiller efficiencies. The recommendations are intended to meet or exceed any current energy mandates while also allowing competitive bidding among multiple manufacturers.

B-8. CHILLER PROCUREMENT. In the procurement process of a liquid chiller, minimum specification requirements (including efficiency) will be developed using CEGS 15650. In addition, the procurement contract should include a bid option that will allow each bidding Contractor the ability to supply an additional proposal(s) at no additional cost to the Government for providing a more efficient chiller than is specified. The Contractors must identify the first cost and efficiency of each additional proposal. In review of the Contractors' proposals, a

designer can compare and evaluate the baseline chiller proposals (per the specification) along with each of the additional chiller proposals. The designer will have to perform an economic comparison between each of the proposals in order to determine the optimum efficiency to select.

B-9. SAMPLE ECONOMIC COMPARISON. In comparing various chiller proposals, the designer must keep in mind that the chiller with the best part load or full load efficiency is not always the optimum chiller to select. Factors such as chiller first cost, chiller energy usage, available energy costs, etc. will all be influential in the chiller selection. As an example, refer to Appendix C for an economic comparison of various electrically-driven, water-cooled 200 ton centrifugal chillers.

Appendix C

Sample Economic Comparisons

C-1. OBJECTIVE. The objective of this Appendix is to perform a sample economical analysis to determine the optimum efficiency to specify for a specific chiller capacity. The type and size of chiller to be evaluated is an electrically-driven, water-cooled 200 ton centrifugal type unit. First cost and efficiency values used in the calculations and presented in Table C1 below are approximations. This data should not be used in any other economic comparisons.

Table C1. Typical Data for a 200 Ton Centrifugal Type Chiller

IPLV (kW/ton)	First Costs
0.70	$62,400
0.65	$64,400
0.62	$66,700
0.60	$71,000
0.58	$76,000

C-2. CALCULATIONS. Two example efficiency comparison calculations are provided in this Appendix. Example 1 calculations, as presented on pages C-4 through C-9, are based on energy costs without any demand charge factors. Example 2 calculations, as presented on pages C-10 through C-15, are based on energy costs which include demand charge factors. The terms and definitions used in the calculations are explained in the following paragraph. The calculations provide the most economical solutions for variable energy costs and variable chiller energy usage.

C-3. DEFINITIONS. The following is a list of terms and definitions used throughout the calculations.

a. Energy Costs. Optimum chiller efficiencies were determined using energy costs equal to 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08 and 0.09 $/kWh. These energy costs are typical values for what can be encountered across the country.

b. Equivalent Full-Load Hours (EFLH). Over a year’s period a chiller will operate at partial load the majority of the time. Full-load conditions are experienced only a small percentage of the time. For this exercise, the only way to estimate a chiller’s annual energy usage is to estimate the chiller’s annual full-load run hours or EFLH. For most typical chiller applications the EFLH can be approximated to be equal to 50% of a chiller’s estimated run hours over a year’s period (e.g., a chiller that is estimated to run approximately 8000 hours/year will have an EFLH of 4000). Optimum chiller efficiencies were determined in the attached calculations using EFLH equal to 1000, 2000, 3000, and 4000. Note: Instead of using the EFLH method to determine chiller energy usage, the ideal way to determine actual energy usage would be to model the installation using an annual energy load calculation program such as BLAST or Trane’s Trace 600.

c. First Cost Difference. The difference in first cost values of 2 different chillers is the first cost difference. In Table C3 for example, the first cost difference of the 0.65 kW/ton chiller verses the 0.70 chiller is equal to $2,000 ($64,400 - $62,400).

d. Annual Energy Usage. The chiller capacity times the chiller efficiency times the EFLH is the annual energy usage. In Table C3 for example, the annual energy usage of a 200 ton chiller with an efficiency of 0.70 kW/ton and an EFLH of 1,000 is equal to 140,000 kWh/year (200 x 0.70 x 1,000).

e. Demand Charges. Demand charges are additional charges or fees that utility companies require most installations to pay in addition to the energy usage charges. The structure of demand charges in comparison around the country vary significantly most specifically in price and length of occurrence. Demand charges can range in price from $6 per kW up to $11 per kW and can be incurred over an entire year or just certain months. Demand charges also often include additional rachet clauses which are typically used to determine an installation’s minimum demand charges. In example 1, no demand charges were included into the calculations. In example 2 on page C-10, a monthly demand charge of $8 per kW is used and are shown to occur 12 months out of the year. On page C-11, the annual demand charge is calculated to be the monthly demand charge times the number of months times the chiller capacity times the chiller efficiency. In Table C9 for example, the annual demand charge incurred by a 200 ton chiller with an efficiency of 0.70 kW/ton which incurs a monthly demand charge of $8 per kW over a 12 month period is equal to $13,400 (8 x 12 x 200 x 0.70).

f. Annual Energy Costs. A chiller’s annual energy usage times the energy cost plus any applicable demand charges is the annual energy costs. In Table C4 for example, a 200 ton chiller with an efficiency of 0.70 kW/ton operating under energy costs of 0.02 $/kWh has an annual energy cost of $2,800 (140,000 x 0.02).

g. Incremental Savings. The difference in the annual energy costs between 2 different chillers is the incremental savings. In Table C4 for example, the incremental savings for the chiller with an efficiency of 0.65 kW/ton verses the chiller with an efficiency of 0.70 kW/ton (both operate with an energy cost of 0.02 $/kWh) is equal to $200 ($2,800 - $2,600).

h. Discounted Savings. The incremental savings times the appropriate discount factor is the discounted savings. Discounted savings can be thought of as a number which represents what the projected savings of selecting one chiller verses another will be over a certain length of time. The discount factor (or uniform present worth factor) used in the calculations was taken from NISTIR 85-3273-10. NISTIR 85-3273-10 includes energy price indices and discount factors for performing life-cycle cost analysis of energy conservation projects. The discount factor was determined based upon the United States average for commercial applications over a 20 year economic life. In Table C4 for example, the discounted savings for the chiller with an efficiency of 0.65 kW/ton verses the chiller with an efficiency of 0.70 kW/ton (both operate with an energy cost of 0.02 $/kWh) is equal to $2,618

($200 x 13.09).

i. Simple Payback. The first cost difference divided by the incremental savings is the simple payback. Typically, the point at which an alternative becomes attractive is where the simple payback is equal to 10 years or less. Simple payback, however, does not take into account any increases in energy costs nor any increases in interest rates over time. Because of this, simple payback should only be used as an initial indicator as to the selection of an alternative (the SIR should be the decisive comparison). In Table C4 for example, the simple payback for selecting a chiller with an efficiency of 0.65 kW/ton verses selecting a chiller with an efficiency of 0.70 kW/ton (both operate with an energy cost of 0.02 $/kWh) is equal to 10 years ($2,000 / $200).

j. Net Present Value (NPV). The first cost of a chiller minus the total discounted savings is the NPV. In Table C4 for example, the NPV of a chiller with an efficiency of 0.58 kW/ton operating with an energy cost of 0.02 $/kWh is equal to $69,717 ($76,000 - $2,618 - $1,571 - $1,047 - $1,047). In comparing alternatives using NPV the alternative with the smaller NPV is typically the one selected, however, for these calculations the primary decision of choosing a particular alternative is based upon the Savings-to-Investment Ratio (SIR) as defined in the following paragraph.

k. Savings-to-Investment Ratio (SIR). The discounted savings divided by the first cost difference is the SIR. In the example calculations, the SIR was the value that was used to determine when one alternative was more economical than another. The optimum alternative is established when the SIR first exceeds the value of 1.00.

C-4. SUMMARY OF RESULTS. Figures C1 and C2 as shown on the following pages are graphical representations of the results of these calculations. Note in Figure C1 that the optimum efficiencies varies significantly with EFLH and the chiller capacities. For example, the optimum IPLV to specify for a 200 ton chiller that operates for 1,000 EFLH at 0.03 $/kWh is 0.62 whereas the optimum IPLV to specify for a 200 ton chiller that operates for 4,000 EFLH at 0.08 $/kWh is 0.58. Table C2 is a numerical representation of the results of these calculations. Note in Figure C2 that the optimum efficiency for all EFLHs and energy costs is 0.58. The high efficiency chiller was alway economical because of the demand charge factors that were included. Designers performing economical comparisons between different efficiency liquid chillers should always research and incorporate applicable demand charges due to their large impact on the comparisons.

Figure C1. Optimum IPLVs for a 200 Ton Centrifugal Chiller (Example 1)

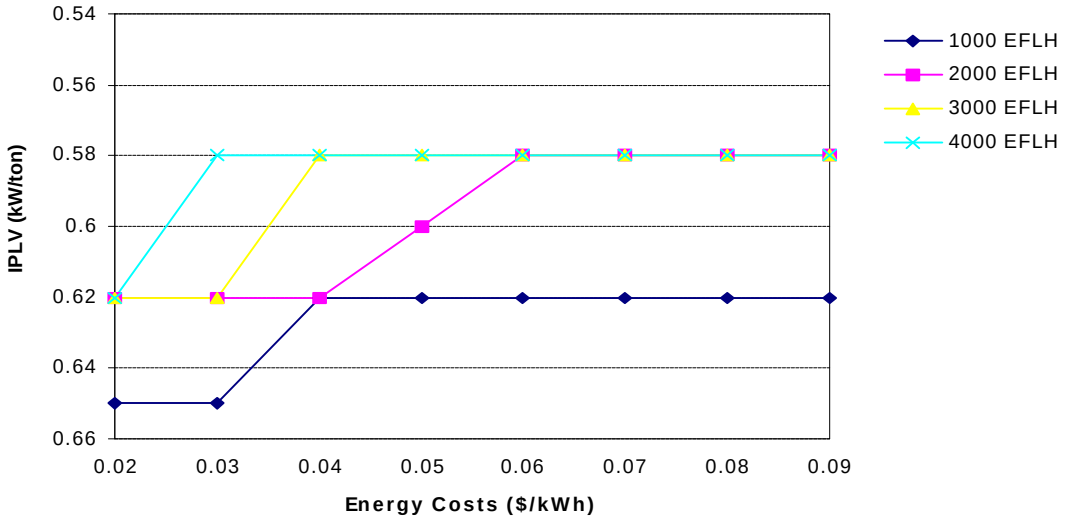

Table C2. Summation of Optimum IPLV*

	Energy Costs ($/kWh)							
EFLH	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1000 EFLH	0.65	0.62	0.62	0.62	0.62	0.62	0.62	0.6
2000 EFLH	0.62	0.62	0.62	0.58	0.58	0.58	0.58	0.58
3000 EFLH	0.62	0.6	0.58	0.58	0.58	0.58	0.58	0.58
4000 EFLH	0.62	0.58	0.58	0.58	0.58	0.58	0.58	0.58

* The optimum IPLV is established when the SIR values calculated in Tables C4, C5, C6 and C7 approach 1.00. SIR values which are below 1.00 are not viewed as cost effective. Table C3 provides a summary of the energy usage calculations.

Calculation Constants:

Chiller Capacity =	200	tons
Economic Life =	20	years
Discount Factor =	13.09	
Monthly Demand Charge =	$0.00	per kw
Demand Charge No. of Months =	12	months
Non-Energy Savings Annual Recurring (+/-) =	0	
Non-Recurring Savings (+/-) =	0	

Table C3. Energy Usage and Demand Charge Calculations.
(Example 1)

EFLH	IPLV	First Costs	First Cost Difference	Energy Usage (kwh/yr)	Demand Charge ($/yr)
1000	0.70	$62,400	-	140,000	0
	0.65	$64,400	$2,000	130,000	0
	0.62	$66,700	$2,300	124,000	0
	0.60	$71,000	$4,300	120,000	0
	0.58	$76,000	$5,000	116,000	0
2000	0.70	$62,400	-	280,000	0
	0.65	$64,400	$2,000	260,000	0
	0.62	$66,700	$2,300	248,000	0
	0.60	$71,000	$4,300	240,000	0
	0.58	$76,000	$5,000	232,000	0
3000	0.70	$62,400	-	420,000	0
	0.65	$64,400	$2,000	390,000	0
	0.62	$66,700	$2,300	372,000	0
	0.60	$71,000	$4,300	360,000	0
	0.58	$76,000	$5,000	348,000	0
4000	0.70	$62,400	-	560,000	0
	0.65	$64,400	$2,000	520,000	0
	0.62	$66,700	$2,300	496,000	0
	0.60	$71,000	$4,300	480,000	0
	0.58	$76,000	$5,000	464,000	0

Table C4. SIR Comparison for 200 Ton Chillers running at an EFLH of 1000. (Example 1)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$2,800	-	-	-	$62,400	-
	0.65	$2,600	$200	$2,618	10.00	$61,782	1.31
	0.62	$2,480	$120	$1,571	19.17	$62,511	0.68
	0.60	$2,400	$80	$1,047	53.75	$65,764	0.24
	0.58	$2,320	$80	$1,047	62.50	$69,717	0.21
0.03	0.70	$4,200	-	-	-	$62,400	-
	0.65	$3,900	$300	$3,927	6.67	$60,473	1.96
	0.62	$3,720	$180	$2,356	12.78	$60,417	1.02
	0.60	$3,600	$120	$1,571	35.83	$63,146	0.37
	0.58	$3,480	$120	$1,571	41.67	$66,575	0.31
0.04	0.70	$5,600	-	-	-	$62,400	-
	0.65	$5,200	$400	$5,236	5.00	$59,164	2.62
	0.62	$4,960	$240	$3,142	9.58	$58,322	1.37
	0.60	$4,800	$160	$2,094	26.88	$60,528	0.49
	0.58	$4,640	$160	$2,094	31.25	$63,434	0.42
0.05	0.70	$7,000	-	-	-	$62,400	-
	0.65	$6,500	$500	$6,545	4.00	$57,855	3.27
	0.62	$6,200	$300	$3,927	7.67	$56,228	1.71
	0.60	$6,000	$200	$2,618	21.50	$57,910	0.61
	0.58	$5,800	$200	$2,618	25.00	$60,292	0.52
0.06	0.70	$8,400	-	-	-	$62,400	-
	0.65	$7,800	$600	$7,854	3.33	$56,546	3.93
	0.62	$7,440	$360	$4,712	6.39	$54,134	2.05
	0.60	$7,200	$240	$3,142	17.92	$55,292	0.73
	0.58	$6,960	$240	$3,142	20.83	$57,150	0.63
0.07	0.70	$9,800	-	-	-	$62,400	-
	0.65	$9,100	$700	$9,163	2.86	$55,237	4.58
	0.62	$8,680	$420	$5,498	5.48	$52,039	2.39
	0.60	$8,400	$280	$3,665	15.36	$52,674	0.85
	0.58	$8,120	$280	$3,665	17.86	$54,009	0.73
0.08	0.70	$11,200	-	-	-	$62,400	-
	0.65	$10,400	$800	$10,472	2.50	$53,928	5.24
	0.62	$9,920	$480	$6,283	4.79	$49,945	2.73
	0.60	$9,600	$320	$4,189	13.44	$50,056	0.97
	0.58	$9,280	$320	$4,189	15.62	$50,867	0.84
0.09	0.70	$12,600	-	-	-	$62,400	-
	0.65	$11,700	$900	$11,781	2.22	$52,619	5.89
	0.62	$11,160	$540	$7,069	4.26	$47,850	3.07
	0.60	$10,800	$360	$4,712	11.94	$47,438	1.10
	0.58	$10,440	$360	$4,712	13.89	$47,726	0.94

Table C5. SIR Comparison for 200 Ton Chillers running at an EFLH of 2000. (Example 1)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$5,600	-	-	-	$62,400	-
	0.65	$5,200	$400	$5,236	5.00	$59,164	2.62
	0.62	$4,960	$240	$3,142	9.58	$58,322	1.37
	0.60	$4,800	$160	$2,094	26.88	$60,528	0.49
	0.58	$4,640	$160	$2,094	31.25	$63,434	0.42
0.03	0.70	$8,400	-	-	-	$62,400	-
	0.65	$7,800	$600	$7,854	3.33	$56,546	3.93
	0.62	$7,440	$360	$4,712	6.39	$54,134	2.05
	0.60	$7,200	$240	$3,142	17.92	$55,292	0.73
	0.58	$6,960	$240	$3,142	20.83	$57,150	0.63
0.04	0.70	$11,200	-	-	-	$62,400	-
	0.65	$10,400	$800	$10,472	2.50	$53,928	5.24
	0.62	$9,920	$480	$6,283	4.79	$49,945	2.73
	0.60	$9,600	$320	$4,189	13.44	$50,056	0.97
	0.58	$9,280	$320	$4,189	15.62	$50,867	0.84
0.05	0.70	$14,000	-	-	-	$62,400	-
	0.65	$13,000	$1,000	$13,090	2.00	$51,310	6.55
	0.62	$12,400	$600	$7,854	3.83	$45,756	3.41
	0.60	$12,000	$400	$5,236	10.75	$44,820	1.22
	0.58	$11,600	$400	$5,236	12.50	$44,584	1.05
0.06	0.70	$16,800	-	-	-	$62,400	-
	0.65	$15,600	$1,200	$15,708	1.67	$48,692	7.85
	0.62	$14,880	$720	$9,425	3.19	$41,567	4.10
	0.60	$14,400	$480	$6,283	8.96	$39,584	1.46
	0.58	$13,920	$480	$6,283	10.42	$38,301	1.26
0.07	0.70	$19,600	-	-	-	$62,400	-
	0.65	$18,200	$1,400	$18,326	1.43	$46,074	9.16
	0.62	$17,360	$840	$10,996	2.74	$37,378	4.78
	0.60	$16,800	$560	$7,330	7.68	$34,348	1.70
	0.58	$16,240	$560	$7,330	8.93	$32,018	1.47
0.08	0.70	$22,400	-	-	-	$62,400	-
	0.65	$20,800	$1,600	$20,944	1.25	$43,456	10.47
	0.62	$19,840	$960	$12,566	2.40	$33,190	5.46
	0.60	$19,200	$640	$8,378	6.72	$29,112	1.95
	0.58	$18,560	$640	$8,378	7.81	$25,734	1.68
0.09	0.70	$25,200	-	-	-	$62,400	-
	0.65	$23,400	$1,800	$23,562	1.11	$40,838	11.78
	0.62	$22,320	$1,080	$14,137	2.13	$29,001	6.15
	0.60	$21,600	$720	$9,425	5.97	$23,876	2.19
	0.58	$20,880	$720	$9,425	6.94	$19,451	1.88

Table C6. SIR Comparison for 200 Ton Chillers running at an EFLH of 3000. (Example 1)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$8,400	-	-	-	$62,400	-
	0.65	$7,800	$600	$7,854	3.33	$56,546	3.93
	0.62	$7,440	$360	$4,712	6.39	$54,134	2.05
	0.60	$7,200	$240	$3,142	17.92	$55,292	0.73
	0.58	$6,960	$240	$3,142	20.83	$57,150	0.63
0.03	0.70	$12,600	-	-	-	$62,400	-
	0.65	$11,700	$900	$11,781	2.22	$52,619	5.89
	0.62	$11,160	$540	$7,069	4.26	$47,850	3.07
	0.60	$10,800	$360	$4,712	11.94	$47,438	1.10
	0.58	$10,440	$360	$4,712	13.89	$47,726	0.94
0.04	0.70	$16,800	-	-	-	$62,400	-
	0.65	$15,600	$1,200	$15,708	1.67	$48,692	7.85
	0.62	$14,880	$720	$9,425	3.19	$41,567	4.10
	0.60	$14,400	$480	$6,283	8.96	$39,584	1.46
	0.58	$13,920	$480	$6,283	10.42	$38,301	1.26
0.05	0.70	$21,000	-	-	-	$62,400	-
	0.65	$19,500	$1,500	$19,635	1.33	$44,765	9.82
	0.62	$18,600	$900	$11,781	2.56	$35,284	5.12
	0.60	$18,000	$600	$7,854	7.17	$31,730	1.83
	0.58	$17,400	$600	$7,854	8.33	$28,876	1.57
0.06	0.70	$25,200	-	-	-	$62,400	-
	0.65	$23,400	$1,800	$23,562	1.11	$40,838	11.78
	0.62	$22,320	$1,080	$14,137	2.13	$29,001	6.15
	0.60	$21,600	$720	$9,425	5.97	$23,876	2.19
	0.58	$20,880	$720	$9,425	6.94	$19,451	1.88
0.07	0.70	$29,400	-	-	-	$62,400	-
	0.65	$27,300	$2,100	$27,489	0.95	$36,911	13.74
	0.62	$26,040	$1,260	$16,493	1.83	$22,718	7.17
	0.60	$25,200	$840	$10,996	5.12	$16,022	2.56
	0.58	$24,360	$840	$10,996	5.95	$10,026	2.20
0.08	0.70	$33,600	-	-	-	$62,400	-
	0.65	$31,200	$2,400	$31,416	0.83	$32,984	15.71
	0.62	$29,760	$1,440	$18,850	1.60	$16,434	8.20
	0.60	$28,800	$960	$12,566	4.48	$8,168	2.92
	0.58	$27,840	$960	$12,566	5.21	$602	2.51
0.09	0.70	$37,800	-	-	-	$62,400	-
	0.65	$35,100	$2,700	$35,343	0.74	$29,057	17.67
	0.62	$33,480	$1,620	$21,206	1.42	$10,151	9.22
	0.60	$32,400	$1,080	$14,137	3.98	$314	3.29
	0.58	$31,320	$1,080	$14,137	4.63	($8,823)	2.83

Table C7. SIR Comparison for 200 Ton Chillers running at an EFLH of 4000. (Example 1)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$11,200	-	-	-	$62,400	-
	0.65	$10,400	$800	$10,472	2.50	$53,928	5.24
	0.62	$9,920	$480	$6,283	4.79	$49,945	2.73
	0.60	$9,600	$320	$4,189	13.44	$50,056	0.97
	0.58	$9,280	$320	$4,189	15.62	$50,867	0.84
0.03	0.70	$16,800	-	-	-	$62,400	-
	0.65	$15,600	$1,200	$15,708	1.67	$48,692	7.85
	0.62	$14,880	$720	$9,425	3.19	$41,567	4.10
	0.60	$14,400	$480	$6,283	8.96	$39,584	1.46
	0.58	$13,920	$480	$6,283	10.42	$38,301	1.26
0.04	0.70	$22,400	-	-	-	$62,400	-
	0.65	$20,800	$1,600	$20,944	1.25	$43,456	10.47
	0.62	$19,840	$960	$12,566	2.40	$33,190	5.46
	0.60	$19,200	$640	$8,378	6.72	$29,112	1.95
	0.58	$18,560	$640	$8,378	7.81	$25,734	1.68
0.05	0.70	$28,000	-	-	-	$62,400	-
	0.65	$26,000	$2,000	$26,180	1.00	$38,220	13.09
	0.62	$24,800	$1,200	$15,708	1.92	$24,812	6.83
	0.60	$24,000	$800	$10,472	5.38	$18,640	2.44
	0.58	$23,200	$800	$10,472	6.25	$13,168	2.09
0.06	0.70	$33,600	-	-	-	$62,400	-
	0.65	$31,200	$2,400	$31,416	0.83	$32,984	15.71
	0.62	$29,760	$1,440	$18,850	1.60	$16,434	8.20
	0.60	$28,800	$960	$12,566	4.48	$8,168	2.92
	0.58	$27,840	$960	$12,566	5.21	$602	2.51
0.07	0.70	$39,200	-	-	-	$62,400	-
	0.65	$36,400	$2,800	$36,652	0.71	$27,748	18.33
	0.62	$34,720	$1,680	$21,991	1.37	$8,057	9.56
	0.60	$33,600	$1,120	$14,661	3.84	($2,304)	3.41
	0.58	$32,480	$1,120	$14,661	4.46	($11,965)	2.93
0.08	0.70	$44,800	-	-	-	$62,400	-
	0.65	$41,600	$3,200	$41,888	0.63	$22,512	20.94
	0.62	$39,680	$1,920	$25,133	1.20	($321)	10.93
	0.60	$38,400	$1,280	$16,755	3.36	($12,776)	3.90
	0.58	$37,120	$1,280	$16,755	3.91	($24,531)	3.35
0.09	0.70	$50,400	-	-	-	$62,400	-
	0.65	$46,800	$3,600	$47,124	0.56	$17,276	23.56
	0.62	$44,640	$2,160	$28,274	1.06	($8,698)	12.29
	0.60	$43,200	$1,440	$18,850	2.99	($23,248)	4.38
	0.58	$41,760	$1,440	$18,850	3.47	($37,098)	3.77

Figure C2. Optimum IPLVs for a 200 Ton Centrifugal Chiller (Example 2)

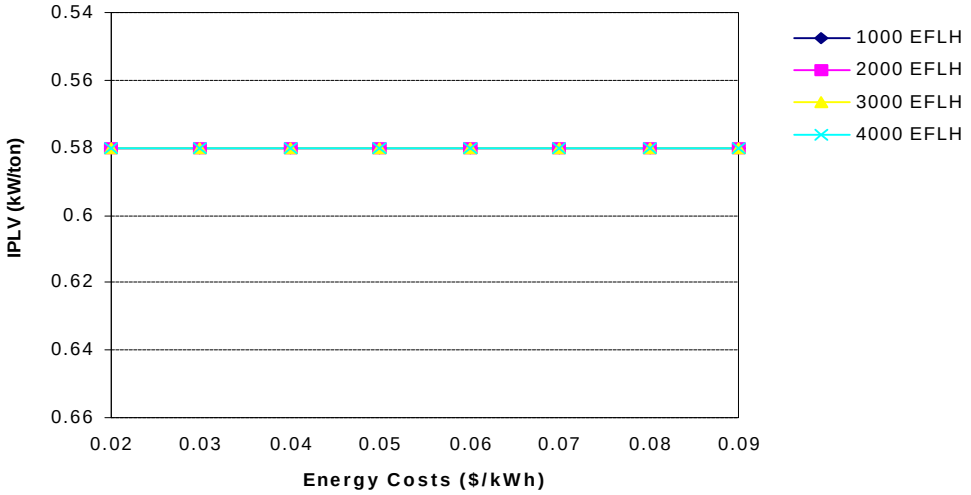

Table C8. Summation of Optimum IPLV*

	Energy Costs ($/kWh)							
EFLH	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1000 EFLH	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
2000 EFLH	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
3000 EFLH	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
4000 EFLH	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58

* The optimum IPLV is established when the SIR values calculated in Tables C10, C11, C12 and C13 approach 1.00. SIR values which are below 1.00 are not viewed as cost effective. Table C9 provides a summary of the energy usage calculations.

Calculation Constants:

Chiller Capacity =	200	tons
Economic Life =	20	years
Discount Factor =	13.09	
Monthly Demand Charge =	$8.00	per kw
Demand Charge No. of Months =	12	months
Non-Energy Savings Annual Recurring (+/-) =	0	
Non-Recurring Savings (+/-) =	0	

Table C9. Energy Usage and Demand Charge Calculations.
(Example 2)

EFLH	IPLV	First Costs	First Cost Difference	Energy Usage (kwh/yr)	Demand Charge ($/yr)
1000	0.70	$62,400	-	140,000	13,440
	0.65	$64,400	$2,000	130,000	12,480
	0.62	$66,700	$2,300	124,000	11,904
	0.60	$71,000	$4,300	120,000	11,520
	0.58	$76,000	$5,000	116,000	11,136
2000	0.70	$62,400	-	280,000	13,440
	0.65	$64,400	$2,000	260,000	12,480
	0.62	$66,700	$2,300	248,000	11,904
	0.60	$71,000	$4,300	240,000	11,520
	0.58	$76,000	$5,000	232,000	11,136
3000	0.70	$62,400	-	420,000	13,440
	0.65	$64,400	$2,000	390,000	12,480
	0.62	$66,700	$2,300	372,000	11,904
	0.60	$71,000	$4,300	360,000	11,520
	0.58	$76,000	$5,000	348,000	11,136
4000	0.70	$62,400	-	560,000	13,440
	0.65	$64,400	$2,000	520,000	12,480
	0.62	$66,700	$2,300	496,000	11,904
	0.60	$71,000	$4,300	480,000	11,520
	0.58	$76,000	$5,000	464,000	11,136

Table C10. SIR Comparison for 200 Ton Chillers running at an EFLH of 1000. (Example 2)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$16,240	-	-	-	$62,400	-
	0.65	$15,080	$1,160	$15,184	1.72	$49,216	7.59
	0.62	$14,384	$696	$9,111	3.30	$42,405	3.96
	0.60	$13,920	$464	$6,074	9.27	$40,631	1.41
	0.58	$13,456	$464	$6,074	10.78	$39,557	1.21
0.03	0.70	$17,640	-	-	-	$62,400	-
	0.65	$16,380	$1,260	$16,493	1.59	$47,907	8.25
	0.62	$15,624	$756	$9,896	3.04	$40,311	4.30
	0.60	$15,120	$504	$6,597	8.53	$38,013	1.53
	0.58	$14,616	$504	$6,597	9.92	$36,416	1.32
0.04	0.70	$19,040	-	-	-	$62,400	-
	0.65	$17,680	$1,360	$17,802	1.47	$46,598	8.90
	0.62	$16,864	$816	$10,681	2.82	$38,216	4.64
	0.60	$16,320	$544	$7,121	7.90	$35,395	1.66
	0.58	$15,776	$544	$7,121	9.19	$33,274	1.42
0.05	0.70	$20,440	-	-	-	$62,400	-
	0.65	$18,980	$1,460	$19,111	1.37	$45,289	9.56
	0.62	$18,104	$876	$11,467	2.63	$36,122	4.99
	0.60	$17,520	$584	$7,645	7.36	$32,777	1.78
	0.58	$16,936	$584	$7,645	8.56	$30,133	1.53
0.06	0.70	$21,840	-	-	-	$62,400	-
	0.65	$20,280	$1,560	$20,420	1.28	$43,980	10.21
	0.62	$19,344	$936	$12,252	2.46	$34,027	5.33
	0.60	$18,720	$624	$8,168	6.89	$30,159	1.90
	0.58	$18,096	$624	$8,168	8.01	$26,991	1.63
0.07	0.70	$23,240	-	-	-	$62,400	-
	0.65	$21,580	$1,660	$21,729	1.20	$42,671	10.86
	0.62	$20,584	$996	$13,038	2.31	$31,933	5.67
	0.60	$19,920	$664	$8,692	6.48	$27,541	2.02
	0.58	$19,256	$664	$8,692	7.53	$23,849	1.74
0.08	0.70	$24,640	-	-	-	$62,400	-
	0.65	$22,880	$1,760	$23,038	1.14	$41,362	11.52
	0.62	$21,824	$1,056	$13,823	2.18	$29,839	6.01
	0.60	$21,120	$704	$9,215	6.11	$24,923	2.14
	0.58	$20,416	$704	$9,215	7.10	$20,708	1.84
0.09	0.70	$26,040	-	-	-	$62,400	-
	0.65	$24,180	$1,860	$24,347	1.08	$40,053	12.17
	0.62	$23,064	$1,116	$14,608	2.06	$27,744	6.35
	0.60	$22,320	$744	$9,739	5.78	$22,305	2.26
	0.58	$21,576	$744	$9,739	6.72	$17,566	1.95

Table C11. SIR Comparison for 200 Ton Chillers running at an EFLH of 2000. (Example 2)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$19,040	-	-	-	$62,400	-
	0.65	$17,680	$1,360	$17,802	1.47	$46,598	8.90
	0.62	$16,864	$816	$10,681	2.82	$38,216	4.64
	0.60	$16,320	$544	$7,121	7.90	$35,395	1.66
	0.58	$15,776	$544	$7,121	9.19	$33,274	1.42
0.03	0.70	$21,840	-	-	-	$62,400	-
	0.65	$20,280	$1,560	$20,420	1.28	$43,980	10.21
	0.62	$19,344	$936	$12,252	2.46	$34,027	5.33
	0.60	$18,720	$624	$8,168	6.89	$30,159	1.90
	0.58	$18,096	$624	$8,168	8.01	$26,991	1.63
0.04	0.70	$24,640	-	-	-	$62,400	-
	0.65	$22,880	$1,760	$23,038	1.14	$41,362	11.52
	0.62	$21,824	$1,056	$13,823	2.18	$29,839	6.01
	0.60	$21,120	$704	$9,215	6.11	$24,923	2.14
	0.58	$20,416	$704	$9,215	7.10	$20,708	1.84
0.05	0.70	$27,440	-	-	-	$62,400	-
	0.65	$25,480	$1,960	$25,656	1.02	$38,744	12.83
	0.62	$24,304	$1,176	$15,394	1.96	$25,650	6.69
	0.60	$23,520	$784	$10,263	5.48	$19,687	2.39
	0.58	$22,736	$784	$10,263	6.38	$14,425	2.05
0.06	0.70	$30,240	-	-	-	$62,400	-
	0.65	$28,080	$2,160	$28,274	0.93	$36,126	14.14
	0.62	$26,784	$1,296	$16,965	1.77	$21,461	7.38
	0.60	$25,920	$864	$11,310	4.98	$14,451	2.63
	0.58	$25,056	$864	$11,310	5.79	$8,141	2.26
0.07	0.70	$33,040	-	-	-	$62,400	-
	0.65	$30,680	$2,360	$30,892	0.85	$33,508	15.45
	0.62	$29,264	$1,416	$18,535	1.62	$17,272	8.06
	0.60	$28,320	$944	$12,357	4.56	$9,215	2.87
	0.58	$27,376	$944	$12,357	5.30	$1,858	2.47
0.08	0.70	$35,840	-	-	-	$62,400	-
	0.65	$33,280	$2,560	$33,510	0.78	$30,890	16.76
	0.62	$31,744	$1,536	$20,106	1.50	$13,083	8.74
	0.60	$30,720	$1,024	$13,404	4.20	$3,979	3.12
	0.58	$29,696	$1,024	$13,404	4.88	($4,425)	2.68
0.09	0.70	$38,640	-	-	-	$62,400	-
	0.65	$35,880	$2,760	$36,128	0.72	$28,272	18.06
	0.62	$34,224	$1,656	$21,677	1.39	$8,895	9.42
	0.60	$33,120	$1,104	$14,451	3.89	($1,257)	3.36
	0.58	$32,016	$1,104	$14,451	4.53	($10,708)	2.89

Table C12. SIR Comparison for 200 Ton Chillers running at an EFLH of 3000. (Example 2)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$21,840	-	-	-	$62,400	-
	0.65	$20,280	$1,560	$20,420	1.28	$43,980	10.21
	0.62	$19,344	$936	$12,252	2.46	$34,027	5.33
	0.60	$18,720	$624	$8,168	6.89	$30,159	1.90
	0.58	$18,096	$624	$8,168	8.01	$26,991	1.63
0.03	0.70	$26,040	-	-	-	$62,400	-
	0.65	$24,180	$1,860	$24,347	1.08	$40,053	12.17
	0.62	$23,064	$1,116	$14,608	2.06	$27,744	6.35
	0.60	$22,320	$744	$9,739	5.78	$22,305	2.26
	0.58	$21,576	$744	$9,739	6.72	$17,566	1.95
0.04	0.70	$30,240	-	-	-	$62,400	-
	0.65	$28,080	$2,160	$28,274	0.93	$36,126	14.14
	0.62	$26,784	$1,296	$16,965	1.77	$21,461	7.38
	0.60	$25,920	$864	$11,310	4.98	$14,451	2.63
	0.58	$25,056	$864	$11,310	5.79	$8,141	2.26
0.05	0.70	$34,440	-	-	-	$62,400	-
	0.65	$31,980	$2,460	$32,201	0.81	$32,199	16.10
	0.62	$30,504	$1,476	$19,321	1.56	$15,178	8.40
	0.60	$29,520	$984	$12,881	4.37	$6,597	3.00
	0.58	$28,536	$984	$12,881	5.08	($1,283)	2.58
0.06	0.70	$38,640	-	-	-	$62,400	-
	0.65	$35,880	$2,760	$36,128	0.72	$28,272	18.06
	0.62	$34,224	$1,656	$21,677	1.39	$8,895	9.42
	0.60	$33,120	$1,104	$14,451	3.89	($1,257)	3.36
	0.58	$32,016	$1,104	$14,451	4.53	($10,708)	2.89
0.07	0.70	$42,840	-	-	-	$62,400	-
	0.65	$39,780	$3,060	$40,055	0.65	$24,345	20.03
	0.62	$37,944	$1,836	$24,033	1.25	$2,611	10.45
	0.60	$36,720	$1,224	$16,022	3.51	($9,111)	3.73
	0.58	$35,496	$1,224	$16,022	4.08	($20,133)	3.20
0.08	0.70	$47,040	-	-	-	$62,400	-
	0.65	$43,680	$3,360	$43,982	0.60	$20,418	21.99
	0.62	$41,664	$2,016	$26,389	1.14	($3,672)	11.47
	0.60	$40,320	$1,344	$17,593	3.20	($16,965)	4.09
	0.58	$38,976	$1,344	$17,593	3.72	($29,558)	3.52
0.09	0.70	$51,240	-	-	-	$62,400	-
	0.65	$47,580	$3,660	$47,909	0.55	$16,491	23.95
	0.62	$45,384	$2,196	$28,746	1.05	($9,955)	12.50
	0.60	$43,920	$1,464	$19,164	2.94	($24,819)	4.46
	0.58	$42,456	$1,464	$19,164	3.42	($38,983)	3.83

Table C13. SIR Comparison for 200 Ton Chillers running at an EFLH of 4000. (Example 2)

Energy Costs ($/kW-h)	IPLV	Energy Costs ($/yr)	Incremental Savings ($/yr)	Discounted Savings	Simple Payback (yrs)	Net Present Value (NPV)	SIR
0.02	0.70	$24,640	-	-	-	$62,400	-
	0.65	$22,880	$1,760	$23,038	1.14	$41,362	11.52
	0.62	$21,824	$1,056	$13,823	2.18	$29,839	6.01
	0.60	$21,120	$704	$9,215	6.11	$24,923	2.14
	0.58	$20,416	$704	$9,215	7.10	$20,708	1.84
0.03	0.70	$30,240	-	-	-	$62,400	-
	0.65	$28,080	$2,160	$28,274	0.93	$36,126	14.14
	0.62	$26,784	$1,296	$16,965	1.77	$21,461	7.38
	0.60	$25,920	$864	$11,310	4.98	$14,451	2.63
	0.58	$25,056	$864	$11,310	5.79	$8,141	2.26
0.04	0.70	$35,840	-	-	-	$62,400	-
	0.65	$33,280	$2,560	$33,510	0.78	$30,890	16.76
	0.62	$31,744	$1,536	$20,106	1.50	$13,083	8.74
	0.60	$30,720	$1,024	$13,404	4.20	$3,979	3.12
	0.58	$29,696	$1,024	$13,404	4.88	($4,425)	2.68
0.05	0.70	$41,440	-	-	-	$62,400	-
	0.65	$38,480	$2,960	$38,746	0.68	$25,654	19.37
	0.62	$36,704	$1,776	$23,248	1.30	$4,706	10.11
	0.60	$35,520	$1,184	$15,499	3.63	($6,493)	3.60
	0.58	$34,336	$1,184	$15,499	4.22	($16,991)	3.10
0.06	0.70	$47,040	-	-	-	$62,400	-
	0.65	$43,680	$3,360	$43,982	0.60	$20,418	21.99
	0.62	$41,664	$2,016	$26,389	1.14	($3,672)	11.47
	0.60	$40,320	$1,344	$17,593	3.20	($16,965)	4.09
	0.58	$38,976	$1,344	$17,593	3.72	($29,558)	3.52
0.07	0.70	$52,640	-	-	-	$62,400	-
	0.65	$48,880	$3,760	$49,218	0.53	$15,182	24.61
	0.62	$46,624	$2,256	$29,531	1.02	($12,049)	12.84
	0.60	$45,120	$1,504	$19,687	2.86	($27,437)	4.58
	0.58	$43,616	$1,504	$19,687	3.32	($42,124)	3.94
0.08	0.70	$58,240	-	-	-	$62,400	-
	0.65	$54,080	$4,160	$54,454	0.48	$9,946	27.23
	0.62	$51,584	$2,496	$32,673	0.92	($20,427)	14.21
	0.60	$49,920	$1,664	$21,782	2.58	($37,909)	5.07
	0.58	$48,256	$1,664	$21,782	3.00	($54,691)	4.36
0.09	0.70	$63,840	-	-	-	$62,400	-
	0.65	$59,280	$4,560	$59,690	0.44	$4,710	29.85
	0.62	$56,544	$2,736	$35,814	0.84	($28,805)	15.57
	0.60	$54,720	$1,824	$23,876	2.36	($48,381)	5.55
	0.58	$52,896	$1,824	$23,876	2.74	($67,257)	4.78