Chiller Performance Evaluation Report

TR-111981

Final Report, December 1998

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REPORT SUMMARY

This report presents the analysis-results of a research project that monitored a new packaged chiller designed for R-407C, a nonchlorinated refrigerant. During the test period, R-22 and R-507 (both chlorinated refrigerants) were tested in the chiller for comparison purposes.

Background
The University Union Board—a governing body made up of students—at California State Polytechnic University, Pomona, needed to replace an old centrifugal chiller. Based on an evaluation study and previous field tests indicating R-407C might be a leading replacement for R-22, they chose a newly developed packaged chiller using nonchlorinated R-407C. The chiller, tailored for mid-size air conditioning applications, was designed, in part, as a response to the phaseout of chlorinated refrigerants. It was built using leading edge and emerging technologies, such as single-pass counter-flow circuits in the evaporator and condenser to maximize the impact of R-407C's glide characteristics.

Objectives
To identify the tested chiller's energy-efficiency with each of three refrigerants: R-407C, R-22, and R-507.

Approach
A governing body made up of Cal Poly students established the following general criteria for chiller selection: the new chiller (1) could be 20% (160-tons versus 200-tons) smaller than the original unit due to energy conservation measures; (2) should use a nonchlorine refrigerant; and, (3) should have good energy-efficiency at low-load conditions. The selected chiller was installed and operated for approximately 22 months using three different refrigerants (R-407C, R-22, and R-507). Separate test instrumentation recorded operating data on a two-minute interval basis; subsequently, the hourly values were derived to identify the chiller's performance. Collected operating data consisted of chilled- and condenser-water flows, associated water-temperatures, and the electric consumption by each of the chiller's four screw compressors.

Results

With R-22 refrigerant, the tested chiller provided the best economy in operating performance regardless of water conditions. At high-load output, the chiller's performance was about 12% less efficient using R-407C; at low-load output, chiller performance was as much as 47% less efficient using either R-407C or R-507. A projection of the integrated part load values (IPLV) were 0.79 kW/ton and 0.92 kW/ton for R-22 and R-407C operations, respectively—about 16% less efficient overall while using R-407C.

EPRI Perspective

Refrigeration and air-conditioning play an important role in modern life. They not only offer comfortable and healthy living environments but also are necessary to survive severe weather. Man-made products contributing to human comfort, however, can have serious side effects: for example, ozone depletion and global warming. These concerns are the biggest driving force for technical innovation in the field of refrigeration and air-conditioning. Based on these observations, EPRI plans to demonstrate and evaluate new refrigerant systems as they become available.

TR-111981

Interest Categories
Commercial HVAC

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EXECUTIVE SUMMARY

This report presents the analysis-results of a research project sponsored by the Electric Power Research Institute (EPRI). The project consisted of monitoring a packaged chiller designed for a non-chlorinated refrigerant (**R-407C**) even though, during its test period **R-22** and **R-507** were also employed for a short period of time for comparison purpose.

The packaged chiller was installed and operated at the University Union building located on the campus of the California State Polytechnic University, Pomona. The University Union Board -- a governing body made up of students – needed to replace an old centrifugal chiller and they opted for a newly developed packaged chiller using an environment-friendly refrigerant. The board's decision was based on an evaluation study and previous field tests in the United States, Canada and Europe that have indicated that R407C might be a leading replacement for R-22.

VaCom, Inc. manufactured the new chiller and its trade name is 'EcoCHILL.' This chiller was designed and built using the latest refrigeration technologies. Some of its main features are that it has four screw compressors, a unique single-path counter-flow design of the evaporator and condenser section and a two-stage process for sub-cooling of the refrigerant. In addition, to further enhance its performance a microprocessor controls all the EcoCHILL operating functions.

The general chronology of the project is as follows:

- In 1995 the University Union board decided to replace the old centrifugal chiller.
- In 1995 the board commissioned an evaluation study.
- In 1995 the board requested design/build bids from local contractors
- In 1996 the new package chiller was installed and started its operation.
- From Feb-96 to Apr-97 the chiller was operated using R-407C.
- From May-97 to mid Oct-97 the chiller was operated using R-22.
- From mid-Oct-97 to late Nov-97 the chiller was operated using R-507.

Separate test instrumentation provided by EPRI recorded operating data on a two-minute interval basis and subsequently the hourly values were derived to identify the EcoCHILL performance. Some of collected operating data consisted of chilled- and condenser-water flows, associated water-temperatures and the electric consumption by each of the four screw compressors.

Table 1 presents the evaluated refrigerants, their corresponding data collection periods and the number of hours used to derive the chiller performance with each of the refrigerants used during the test period.

Table E-1

Run No.	Refrigerant	Data Collection From	Data Collection To	Total Hours Used in the Analysis
1	R-407C	Feb-96	Apr-97	1940
2	R-22	May-97	Oct-97	1095
3	R-507	Oct-97	Nov-97	251

Figure E-1 shows the EcoCHILL performance results.

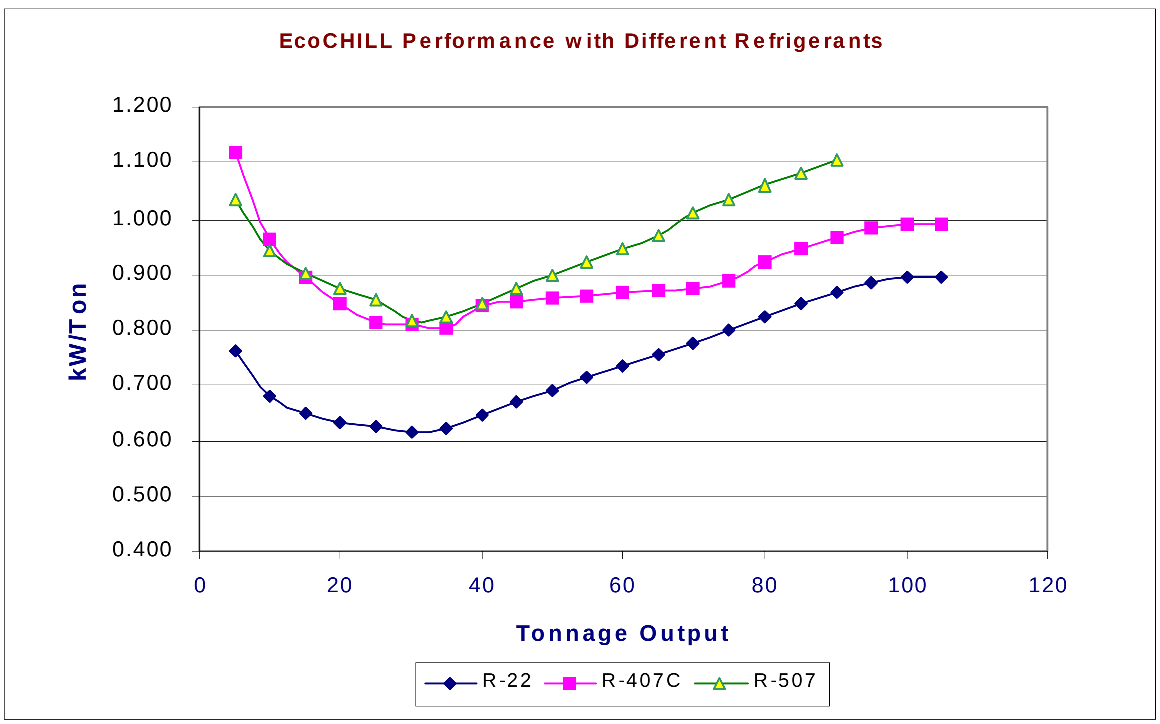


Figure E-1
Chiller Performance with R-22, R407C, and R507

In conclusion, at high-load output the EcoCHILL performance is about 12% less efficient using R-407C than when it is using R-22; at low-load output the chiller performance can be as much as 47% less efficient using either R-407C or R-507 than when it is using R-22 at ARI conditions. A projection of the IPLV's are 0.79 kW/ton and 0.92 kW/ton for the R-22, and the R-407C operations respectively; about 16% less efficient overall while using the R-407C.

1

INTRODUCTION

Background

The Electric Power Research Institute (**EPRI)** directed ASW Engineering Management to analyze the performance of a new package chiller manufactured by VaCom, Inc. The chiller was operated for approximately 22 months using three different refrigerants (R-407C, R-22 and R-507). The objective was to identify the chiller's energy-efficiency with each of the three refrigerants. This report presents ASW's findings and associated backup information.

The chiller was installed at the University Union Building which is located on the campus of the California State Polytechnic University (Cal Poly), Pomona. When the student-owned University Union Building needed to replace a 20-year old centrifugal chiller, the University Union Board -- a governing body made up of Cal Poly students – established the following general criteria for the selection of their new chiller:

1. The new chiller could be 20% (160-tons versus 200-tons) smaller than the original unit due to the implementation of many energy conservation measures (e.g., lighting system retrofit, etc.).

2. The new chiller should use a non-chlorine refrigerant.

3. The new chiller should have good energy-efficiency at low-load conditions.

After an evaluation study, the board decided to purchase and install a newly designed '**EcoCHILL**' manufactured by VaCom, Inc.

The EcoCHILL is a high-efficiency, parallel screw chiller tailored for mid-size air-conditioning applications. One of the objectives for manufacturing this chiller was to respond to the phaseout of chlorinated refrigerants. It was built utilizing leading edge and emerging technologies, such as single-pass counter-flow circuits in the evaporator and condenser to maximize the impact of the glide characteristics of R-407C.

Project Participants

The chiller research project was a partnership between the following participants:

1. The board of the University Union Building, who purchased and installed the EcoCHILL.

2. VaCom, Inc. who put the design teams together and built the prototype EcoChill.

3. Carlyle Compressor Company, whose screw compressors were used in the EcoCHILL chiller.

4. Standard Refrigeration, a heat exchanger manufacturer who designed and built the evaporator and condenser based on R-407C products developed in their UK division.

5. Allied Signal, who donated the R-407C refrigerant.

Project Timeline

The general timeline of the project was as follows:

1. The EcoCHILL was installed in December of 1995 and was in full operation by January of 1996.

2. Chiller operating data was collected from Feb-96 to Apr-98 when the chiller was operating with R-407C.

3. Interim performance report; March 1997.

4. Chiller operating data was collected from May-97 to Oct-97 when the chiller was operating with R-22.

5. Chiller operating data was collected from Oct-97 to Nov-97 when the chiller was operating with R-507.

6. Data analysis started from day one and continued until Nov-97.

7. The final report was completed on April 15, 1998.

2

PROJECT DATABASE

Background

Information about the University Union Building is presented in this section for the purpose of providing a general understanding of the cooling requirements when the EcoCHILL was in operation during the test period.

Generally speaking, this section presents the following information:

- Outdoors peak design parameters for the City of Pomona, Calif.
- A site plan of the campus.
- General information about the University Union Building.
- The EcoCHILL equipment design parameters.
- Cooling plant general layout.
- Information about the existing air-handling units.
- Historic electric-energy consumption.

Design Parameters

Table 2-1 presents the 'Peak' design parameters for the City of Pomona, Calif.:

Table 2-1

Latitude	Elevation	Summer Design DB/WB (*)	Outdoor Daily Range	Winter Design DB	Heating Degree Days
34.1	740	100 DB/70 WB	36	35	1,971

(*) From ASHRAE

Site Plan

Figure 2-1 shows a site plan of the campus of the California State Polytechnic University, Pomona and the relative location of the University Union Building.

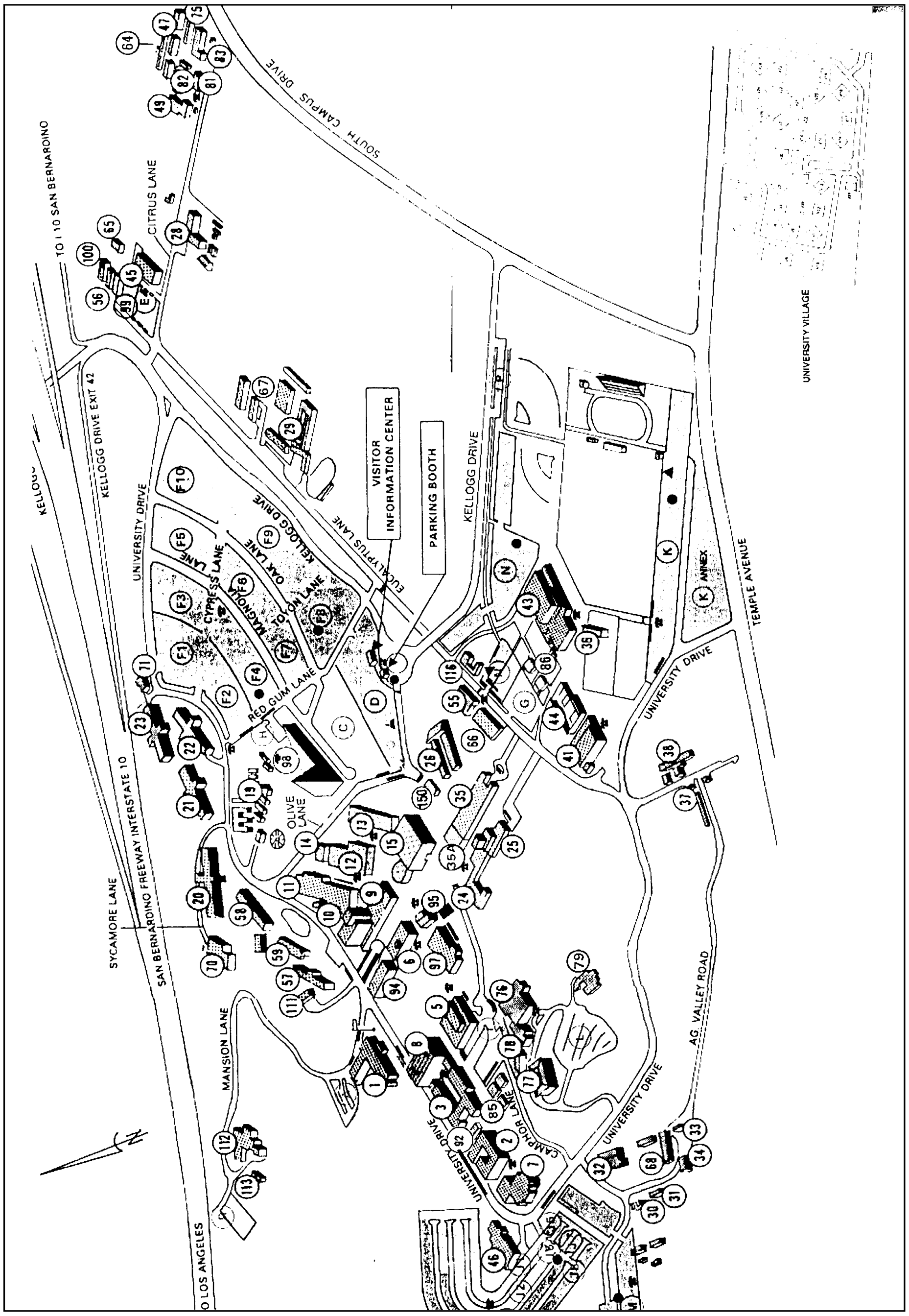


Figure 2-1
Campus of the California State Polytechnic University, Pomona

Building Information

The University Union Building was built in 1973 and has two stories. The building has a rectangular shape and encompasses approximately 68,000 square feet of conditioned space. The building has a maximum capacity of approximately 1,500 people.

The building exposures are NE, NW, SE and SW. Some of the exposures of the first floor are underground due to the sloping land surrounding the building. Most of the windows have overhangs and have tinted-glass.

The air conditioning is provided by a cooling plant located in a mechanical room on the first floor, at the SE corner of the building. The cooling tower serving the cooling plant is located within the same mechanical room. Two air-handling units provide the air circulation for the entire building.

Building Elevation

Figure 2-2 below shows the main entrance of the University Union Building.

Figure 2-2
University Union Building

Building Occupancy

The general occupancy of the building is as follows:

1. Several offices which are occupied by approximately 25 people
2. Lecture rooms with a capacity of 80 to 100 people
3. A multipurpose room with a capacity of 400 people
4. An art gallery
5. A cafeteria with a capacity of 100 people
6. A game room and several small lounges

Building Operating Hours

Generally speaking, the building's operating hours is from 7 a.m. to 11 p.m. during weekdays. The operating hours of the offices is from 8:00 a.m. to 5:00 p.m. The lecture rooms and multipurpose room are occupied on an as-needed basis.

During the school year, the lecture rooms are used twice per week for campus club meetings from 11 a.m. to 2 p.m. A few offices as well as the multipurpose room are occupied on Sunday by a church group from 8 a.m. to 6 p.m. during the school year and until 2 p.m. during the summer. The art gallery is open from 11 a.m. until 3 p.m. on weekdays and a few evenings per week from 6 p.m. until 8 p.m.

Cooling Plant

The cooling plant consists of the new EcoCHILL and the original ancillary equipment. Table 2-2 presents the designed engineering parameters of the EcoCHILL.

Table 2-2

Mark	Max. Tons	Max. kW	CHW - GPM	CHWR	CHWS
CH-1	160	145.3	350	55	44

Mark	CW – GPM	CWTT	CWFT	Voltage	Remarks
CH-1	612	95	85	480/3/60	Four screw compressors

Central Plant Operations

The operating staff reported the following information about the operation requirements of the cooling plant:

1. Winter Operations - The chiller is only needed for a few hours, one or two days per week if the outdoor temperature is above 65° F. or if there is a high level of occupancy.

2. Spring Operations - The chiller operating requirements for the months of April and May are similar to winter operations. The June operating requirements are similar to the summer months.

3. Summer Operations - The chiller typically operates from 7:30 a.m. until 6 p.m. During the summer months there is a low level of occupancy.

4. Fall Operations – The chiller requirements for the month of September are typically from 7 a.m. until 11 p.m. During October and November, the chiller operates less time depending on the outdoor temperatures and the level of occupancy.

Cooling Plant Layout

Figure 2-3 shows the general layout of the equipment in the cooling plant.

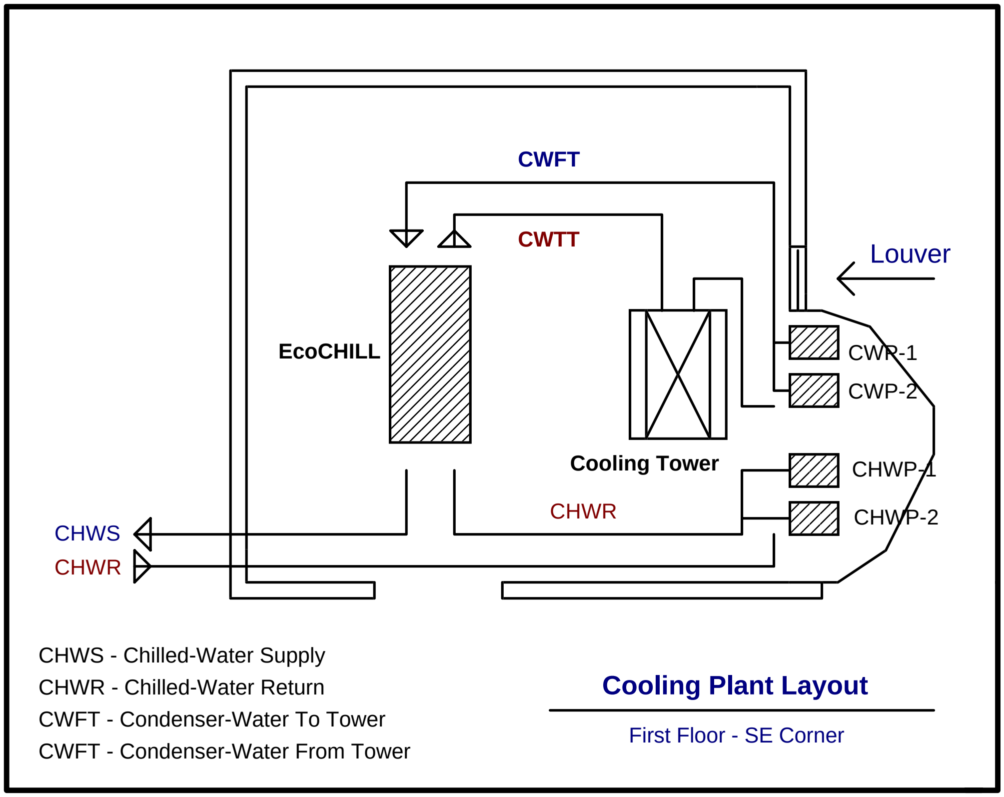


Figure 2-3
Cooling plant layout

Additional Information

1. The EcoCHILL was installed where the old centrifugal chiller was located.

2. The original cooling tower that served the 204-ton centrifugal chiller remained in place to serve the new EcoCHILL. The original chilled- and condenser-water pumps were also retained.

3. A variable-speed drive was added to control the operation of the cooling tower fan-motor.

Air Systems

The air circulation requirements of the building are met by two air-handling units that are located in a mechanical room on the upper level of the building. The air-handling units are double-duct units that were converted to variable-air- volume by installing a variable-speed drive for each fan-motor and modifying the double-duct mixing boxes.

The return-air dampers were modified to take advantage of nearly 100% outside-air intake. The units were not provided with return/relief fans to effect the economizer cycles. Therefore, during maximum outside-air intake, the air is relieved through the building's doors.

Table 2-3 presents the specific information about the air-handling units:

Table 2-3

MARK	AREA SERVED	TYPE	CFM	HP
S-1	Lower Level	Double Duct / VAV	29,000	50
S-2	Upper Level	Double Duct / VAV	36,600	60

Additional Information

1. The staff reported that during peak weather and occupancy conditions, the air-handling units deliver the maximum supply-air to the building.

2. Electric-strip heaters in the air-handling units are use to meet the heating requirements of the building. The total electric load of these heaters is 270 kW (921 MBH).

3. Mechanical cooling and heating does not take place simultaneously.

4. The chilled-water cooling coils in the air-handling units are 3-way valves.

3

CHILLER INFORMATION

Background

VaCom, Inc manufactures the EcoCHILL and their main objective was to design a piece of equipment that took advantage of the latest refrigeration technologies. To accomplish this objective, VaCom, Inc. put together a design-build team that consisted of the following firms:

1. Carlyle Compressor Company, whose screw compressor were used in the EcoCHILL chiller.

2. Standard Refrigeration, a heat exchanger manufacturer, designed and built the evaporator and condenser, which were based on R-407C products developed in the UK division.

3. Allied Signal, who donated the R407C refrigerant.

Previous field tests in the United States, Canada and Europe have indicated that R-407C may be a leading replacement for HCFC-22. For this reason, the EcoCHILL design was based on the R-407C refrigerant, which is an HFC blend of R-32, R-125 and R-134a. R-407C shows similar efficiency and pressure characteristics as HCFC-22 and requires about the same heat-exchanger surface area. As a zeotropic blend, R-407C exhibits about a 10°F glide; or put in other words, the refrigerant temperature shifts 10° during the constant-pressure phase-change in the evaporator and condenser section.

To determine the relative energy-efficiency of the R407C in the EcoCHILL, it was decided that the EcoCHILL would be operated for a period of time using R407C, HCFC-22 and HCFC-507 refrigerants.

EcoCHILL Features

The main features of the EcoCHILL are listed below:

1. Four screw compressors in a parallel configuration to ensure redundancy and better than normal low-load operating energy-efficiency.

2. Screw compressors are available 'off-the-shell' at a relatively low cost and can be replaced in a single-day.

3. A unique single-path counter-flow design allows the evaporator and condenser to minimize the impact or even take advantage of refrigerant glide to maximize heat exchanger performance.

4. A two-stage process for sub-cooling increases cooling capacity, provides stable control with floating head pressure and thereby, improves the chiller's energy-efficiency. In this process, a heat exchanger first sub-cools the liquid refrigerant by applying cool suction gas from the evaporator, and a direct-expansion economizer further sub-cools the refrigerant using an intermediate port of the compressor.

5. To effect the floating head pressure in the EcoCHILL, a variable-speed drive was installed in the cooling tower fan-motor.

6. A microprocessor controls all functions of the EcoCHILL and provides user information, both locally and remotely over a phone line. The microprocessor controls compressor sequencing to achieve optimum part-load energy-efficiency. Cooling tower 'approach' control is also achieved by means of a variable-speed drive. In addition, a leak detection system is provided via refrigerant-sensors connected to the microprocessor.

EcoCHILL

Figures 3-1 and 3-2 show the EcoCHILL installation at the University Union Building:

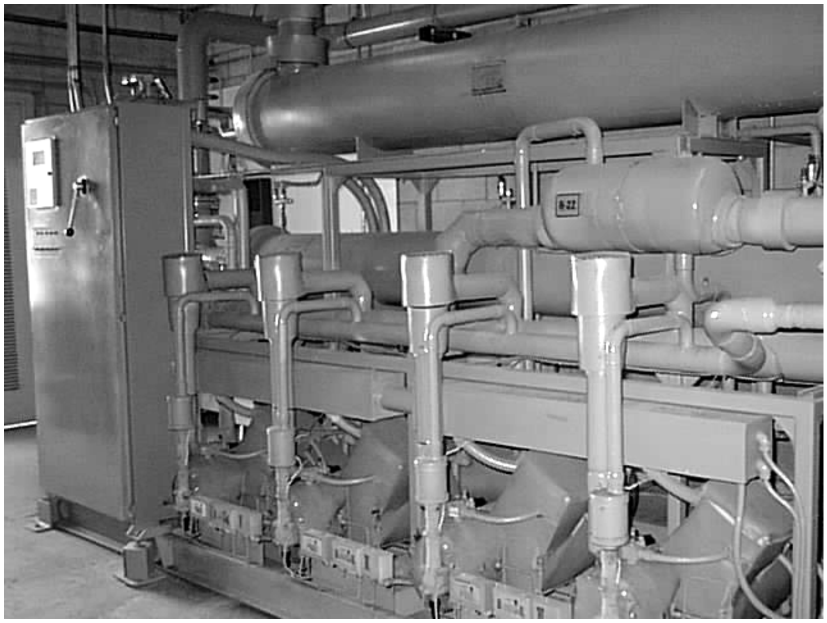


Figure 3-1
Multiple compressor chiller

Figure 3-2
Prototype chiller

Monitoring System

'On-going' operating data was retrieved on a daily basis by ASW to perform the analysis presented in this report. Figure 3-3 shows a system-piping diagram and the instrumentation installed to record the operating data.

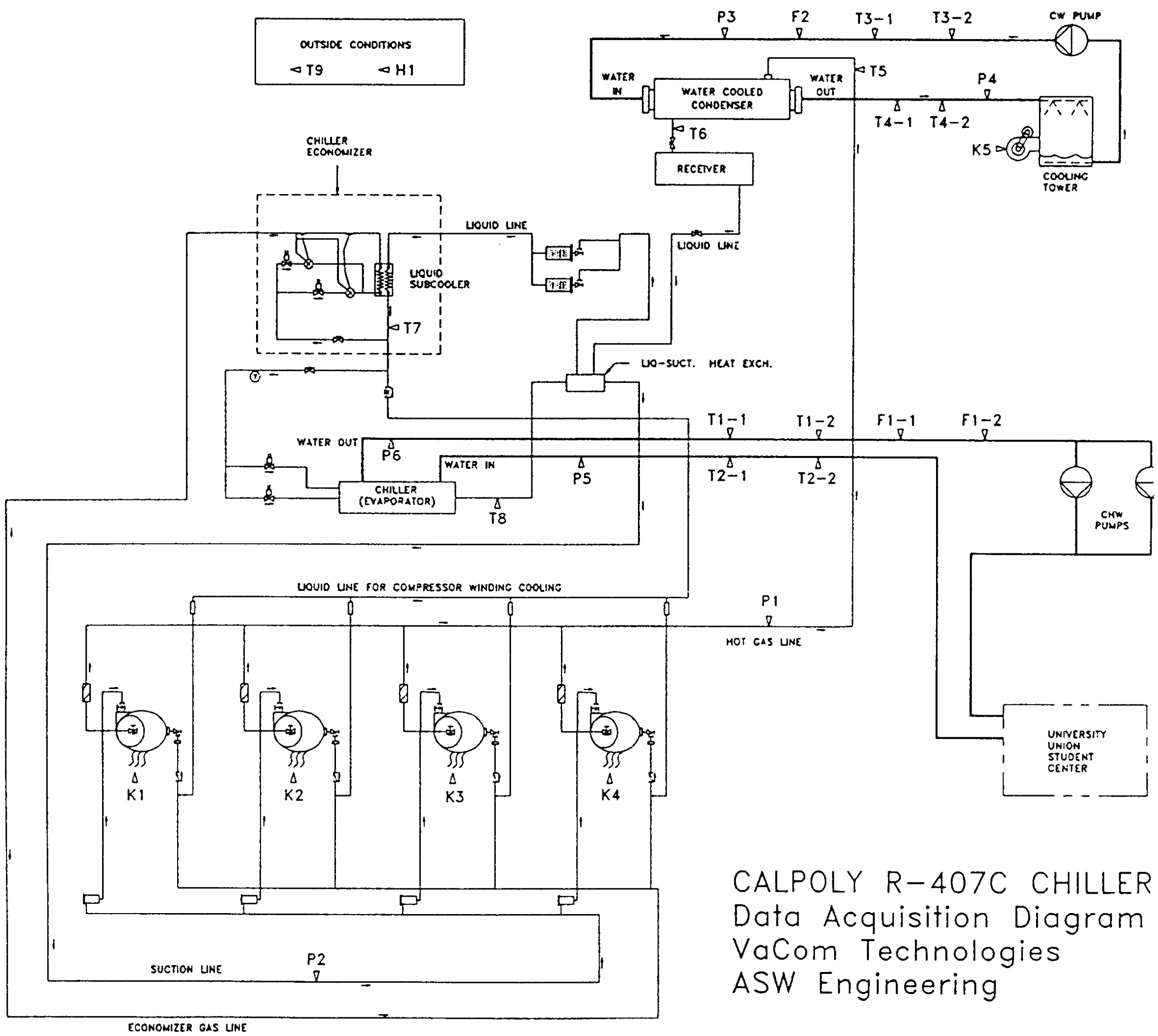


Figure 3-3
Data acquistion system schematic

Table 3-1 shows a list of the monitoring sensors and associated shop calibration data.

Table 3-1

Cal-Poly Chiller Monitoring System Shop Calibration Data *Operator:* *ALS* *Date:* *1-3-96 thru 1-5-96*

Sensor Code	Description	Type	Data Loc.	Calibration Range	Reference "Low"	System "Low"	Reference "Mid"	System "Mid"	Reference "High"	System "High"
T1-1	Chilled water supply 1	RTD	1	+32 / +59 °F	31.91 °F	31.88 °F	45.42 °F	45.39 °F	58.96 °F	58.89 °F
T1-2	Chilled water supply 2	RTD	2	+32 / +59 °F	31.91 °F	31.93 °F	45.42 °F	45.43 °F	58.96 °F	59.00 °F
T2-1	Chilled water return 1	RTD	3	+32 / +59 °F	31.91 °F	31.92 °F	45.42 °F	45.41 °F	58.96 °F	58.80 °F
T2-2	Chilled water return 2	RTD	4	+32 / +59 °F	31.91 °F	31.89 °F	45.42 °F	45.42 °F	58.96 °F	58.89 °F
T3-1	Cond. water from tow. 1	RTD	5	+59 / +104 °F	58.97 °F	58.93 °F	81.43 °F	81.44 °F	103.93 °F	103.90°F
T3-2	Cond. water from tow. 2	RTD	6	+59 / +104 °F	58.97 °F	58.88 °F	81.43 °F	81.44 °F	103.93 °F	103.88°F
T4-1	Cond. water to tower 1	RTD	7	+59 / +104 °F	58.97 °F	58.84 °F	81.43 °F	81.41 °F	103.93 °F	103.94°F
T4-2	Cond. water to tower 2	RTD	8	+59 / +104 °F	58.97 °F	58.95 °F	81.43 °F	81.42 °F	103.93 °F	103.85°F
T5	Condenser inlet	RTD	9	+122 / +176 °F	121.97 °F	121.91 °F	148.97 °F	148.95 °F	175.98 °F	175.64 °F
T6	Condenser outlet	RTD	10	+59 / +122 °F	58.97 °F	59.02 °F	90.46 °F	90.45 °F	121.97 °F	121.82°F
T7	Sub-cooler outlet	RTD	11	+32 / +104 °F	34.12 °F	34.03 °F	68.45 °F	68.41 °F	97.92 °F	97.84 °F
T8	Chiller outlet	RTD	12	+23 / +59 °F	22.96 °F	23.02 °F	40.96 °F	40.93 °F	58.94 °F	58.86 °F
T9	Outside air	RTD	13							
H1	Outside relative humidity	RH	14							
F1-1	Chilled water flow	Turb	15							
F1-2	Chilled water flow	PW	16							
F2	Condenser water flow	PW	17							
K1	Compressor 1 power	PWR	18							
K2	Compressor 2 power	PWR	19							
K3	Compressor 3 power	PWR	20							
K4	Compressor 4 power	PWR	21							
K5	Cooling tower fan	PWR	22							
P1	Comp. discharge press.	Pres	23	0 / 500 psig	0.0 psig	0.0 psig	144.4 psig	144.5 psig	297.1 psig	297.6 psig
P2	Comp. suction press.	Pres	24	0 / 100 psig	0.0 psig	0.0 psig	51.7 psig	52.1 psig	101.3 psig	101.9 psig
P3	Condenser pressure in	Pres	25	0 / 30 psig	0.0 psig	0.0 psig	14.5 psig	14.6 psig	30.1 psig	30.3 psig
P4	Condenser pressure out	Pres	26	0 / 30 psig	0.0 psig	0.0 psig	14.8 psig	14.9 psig	30.6 psig	30.7 psig
P5	Evaporator pressure in	Pres	27	0 / 60 psig	0.0 psig	0.0 psig	29.6 psig	29.9 psig	58.4 psig	58.7 psig
P6	Evaporator pressure out	Pres	28	0 / 60 psig	0.0 psig	0.0 psig	31.0 psig	31.3 psig	60.6 psig	60.9 psig

4

ANALYSIS AND RESULTS

General

Data of the facility chiller plant was remotely collected and analyzed to determine operating performance and efficiency of the new chiller machine using three different air conditioning refrigerants. The refrigerants were installed sequentially over a timeframe of about one-and-a-half years. The evaluated refrigerants and their corresponding data collection periods were as follows:

Run No.	Operating Refrigerant			Data Monitoring Time-Frames		
	Name	Type	Description	Refrigerant Operation	Data-Analysis Period	Hours
1	R-407C	HFC-Blend, zeotropic	R-32/125/134a (23/25/52)	Feb'96-Apr'97	Feb'96-Nov'96	1940-hrs
2	R-22	HCFC	Pure Compound	May'97-Oct'97	May'97-Sep'97	1095-hrs
3	R-507	HFC-Blend, azeotropic	R-125/143a (45/55)	Oct'97-Nov'97	Oct'97-Nov'97	251-hrs

Data Collection

Operating data was recorded on a two-minute interval basis, and subsequently transformed to hourly values for quantification and analysis. The primary measurements included chilled water temperatures and flow for determination of tonnage production, and the electric consumption of each compressor. Secondary operating measurements included condenser water temperatures and flow, outside dry-bulb temperature and relative humidity.

For R-407C, the first refrigerant installed, monthly analyses were performed which included printouts of hourly operation, summarized by day, and by month. For R-22 and R-507, only monthly summaries showing the overall daily operations were printed. For each refrigerant, all pertinent hourly data and results were forwarded into databases for evaluation of their respective performances. The appendices under this report cover include the 'monthly data summaries' for each refrigerant and results of the performance analyses; Appendix-A: R-407C, Appendix-B: R-22, and Appendix-C: R-507. (Due to the volume of material, the daily printouts generated for refrigerant 407C only are provided under separate cover as Appendix-D.).

Evaluation

Also included in the appendices of each refrigerant is the analysis of performance and results. The operating characteristic of the chiller was determined separately for each of the subject refrigerants. The operating characteristic is defined in terms of the amount of electric power consumption (kWh) which is needed, at the varying conditions of chilled water supply (CHWSt) and entering condenser water (ECWt) temperatures, to provide a specific amount of cooling output (tonnage). The characteristics were developed via multiple regression techniques to include the primary independent variable and secondary independent parameters (i.e. kWh f % Full-Load Tons, ECWt, CHWSt).

Due to the multiple-compressor configuration of this chiller, a separate characteristic was determined for a 'single-compressor', a 'two-compressor' and a 'three-compressor' mode of operation for each of the refrigerants. The 'four-compressor' operation could not be evaluated due to insufficient and suspect data. The manufacturer rates for each of the four compressors 40-tons at ARI conditions. As previously mentioned operation above 120-tons (the three-compressor operation) was briefly evidenced and only during the R-22 refrigerant phase.

Beyond these 'operating' results, which are shown based on the actual conditions encountered, the appendices also present a transition of the findings to project the results at common (normalized) parameters for purposes of comparison. The common water temperatures employed are according to test standard of the Air-Conditioning and Refrigeration Institute (ARI, Std.550), wherein, a chilled-water supply temperature (CHWSt) of 44ºF and an entering-condenser water temperature (ECWt) of 85ºF are specified at full-load conditions. Additionally, the ARI standard identifies 'relief' (a relaxing) of the ECWt requirement for less than full-load operations (i.e. a linear reduction from 100%/85ºF to 0%/60ºF); this provides for a more realistic representation of overall equipment efficiency in applications where reduced condensing temperatures are realized and can be taken advantage of. For the purpose of performance comparisons regarding this application, however, and rooted in the equipment operation, a full-load value of 120 tons is used with a linear ECWt relief down to a minimum value of 65ºF at loads of 20% (24 tons) and less. The limited amount of temperature data obtained below this value was insufficient for inclusion in the analysis, and therefore performance cannot be accurately predicted by the derived equations at these lower ECW temperatures.

Analysis Results

An overview of the data and the resultant evaluations of the chiller performance are summarized in the Tables 4-1, 4-2, and 4-3[1] for the refrigerants R-407C, R-22, and R-507 respectively.

First, as Item 1. In these tables, the equations of performance derived for each mode of the chiller compressors' operation is identified. The equations comprise of a constant and the coefficients of named variables for a polynomial equation. The operating performance is defined, as the energy needed (kWh) to provide an amount of cooling (% Full-Load Tons/compressors on-line) under varying temperatures of chilled-water supply (CHWS) and entering condenser-water (ECW).

Shown next in each table, Item 2. Summarizes particulars of the actual analyzed data as used to evaluate the performances, and also shows the accuracy of the derived results as compared with the actual data. This is shown in A) for the number of compressors on-line, in B) for the months of data-fit basis, and in C) for any months of additional data collected beyond the period of the performance analysis.

Finally, and to provide a single, uniform operating level for refrigerant comparison, Item 3 presents results of the derived performances at the ARI water temperatures of 44°F CHWS / 85°F ECW and at 88% rated full-load (FL) tonnage per compressors on-line; where 88% represents the approximate maximum load experienced just prior to the starting of an additional compressor for the 407C and R-22 refrigerants; as stated, 'system' loading at 100% of the on-line compressors did not occur.

Following each table, for complete results and later comparison, the graphs of Figures 4-1, 4-2, and 4-3 show for each refrigerant respectively (R-407C, R-22, and R-507), the entire derived performance characteristic and resulting efficiency of the chiller as projected from application of the performance equations to the aforementioned ARI conditions. Performance and efficiency are shown for operation at both (1) constant CHWSt/ECWt water conditions of 44°F/85°F, and (2) at a constant CHWSt of 44F with a varying ECW temperature relief. The projected performances are shown only up to 105 tons, beyond which, effects of the aforementioned suspect-data of the fourth-compressor operation may have influenced the determinations at the higher load performances for both the R-407C, and the R-22 refrigerant operations.

[1] See Tables 4-1 through 4-3 and associated figures at the end of this section

Refrigerant-407C:

As the refrigerant of primary interest, the R-407C was initially installed in the new chiller. Operating data was collected over a period of approximately fourteen months. Data from the first nine months of the operation were evaluated to determine performance of the chiller; about 1950 hours of suitable data. This operating period, from February through October, provided the climate basis to impose a complete range of load and conditional parameters on the system. Based on the data, the 'single-compressor' mode accounted for about 20% of the operating time, the 'two-compressor' mode about 33%, and the 'three-compressor' operating mode about 47%.

Referring to Table 4-1, the average operating levels were at about 22 tons (55% of 40 tons FL) during the 'single-compressor' operation, 50 tons (62.5% of 80 tons FL) during the 'two-compressor' operation and 75 tons (62.5% of 120 tons FL) during the 'three-compressor' operation. The corresponding average operating efficiencies, expressed in terms of 'kW/ton' were 0.91, 0.84, and 0.94 respectively for each of the compressor operating modes. Overall, from data of the analysis period, the chiller averaged an efficiency of 0.91 kW/ton.

Accuracy of the derived performances expressed in terms of kW- 'average error' and 'standard deviation of error' (i.e. 'AVG-kWerr' / 'STD-kWerr') are 0.0/1.2 kW, 0.1/1.7 kW, and -0.1/2.4 kW for the three operating modes respectively. Fit accuracy to the overall chiller operation is -.01 AVG-kWerr / 1.9 STD-kWerr. This represents about a 3.8% coefficient of variance for the overall fit at the average operating level of 50 kW.

At the selected uniform operating levels as previously identified (i.e. 88% FL-ton/compressor, 44ºF CHWS, and 85ºF ECW), the resulting derived efficiencies are 0.938, 0.964, and 1.026 kW/ton respectively for each mode of compressor operation. Figure 4-1 presents the complete projected results of the chiller performance as derived with the refrigerant 407C installed.

For completeness, it can be noticed that the data-fit accuracy's during the 'follow-on' period of months are not in keeping with those of the data-analysis period; rather, they demonstrate an overall -0.7 AVG-kWerr / 5.4 STD-kWerr; a 15.8% coefficient of variance. After additional investigation, the reason for this poorer fit was determined to be caused by changes in the staging and sequencing of the compressors. We were able to establish, however, that the original control of the chiller operation as occurred during the 407C data analysis period, had been resumed through the subsequent operating periods with the refrigerants R-22 and R-507 installed.

Refrigerant-22:

To provide for a comparison of the new chiller's performance while using an 'industry standard' refrigerant, a decision was made to install R-22. Operating data for this refrigerant was subsequently collected over a period of about five months. This operating period, from May through September, also provided a good range of load and conditional parameters on the system; about 1100 hours of data. The 'single-compressor' operating mode constituted about 10% of the operation, the 'two-compressor' mode about 42%, and the 'three-compressor' mode about 48%.

Referring to Table 4-2, the average operating levels were at about 24 tons (60% of 40 tons FL) during the 'single-compressor' operation, 53 tons (66% of 80 tons FL) during the 'two-compressor' operation, and 84 tons (70% of 120 tons FL) during the 'three-compressor' operation; these slightly higher averages than those encountered during the 407C run are attributable to the lack of spring data. The corresponding average operating efficiencies, expressed in terms of 'kW/ton' were 0.82, 0.80, and 0.90 respectively. From data of the analysis period, the chiller averaged an overall efficiency of 0.85 kW/ton; better than 407C, while operating at a lower average CHWS temperature, but at a slightly higher average load (the average of ECW temperatures were about equal).

Accuracy of the derived performances expressed in terms of kW- 'average error' and 'standard deviation of error' (i.e. 'AVG-kWerr' / 'STD-kWerr') are -0.2/1.3 kW, -0.3/1.1 kW, and -0.1/2.1 kW for the three operating modes respectively. With regard to the overall chiller operation, the fit accuracy is about -.01 AVG-kWerr / 1.6 STD-kWerr. This represents about a 2.9% coefficient of variance for the overall fit at the average operating level of 56 kW.

At the selected uniform operating levels as previously identified (i.e. 88% FL-ton/compressor, 44ºF CHWS, and 85ºF ECW), the resulting derived efficiencies are 0.939, 0.926, and 0.952 kW/ton respectively for each mode of operation; at these conditions, about equal with 407C for the 'single-compressor' operation, but better for the 'two-' and 'three-compressors' operation. Figure 4-2 presents the complete projected results of the chiller performance as derived with the refrigerant R-22 installed.

Refrigerant-507:

The refrigerant 507 was installed for only a brief period until it became evident that it was not performing as well as either of the two previous refrigerants. The operating data for this refrigerant was limited to about one and a-half months between mid-October through late-November; about 251 hours of data. The 'single-compressor' operating mode constituted about 43% of the operation, the 'two-compressor' mode about 13%, and the 'three-compressor' mode about 44%.

Referring to Table 4-3, the average operating levels were at about 14 tons (35% of 40 tons FL) during the 'single-compressor' operation, 38 tons (48% of 80 tons FL) during the 'two-compressor' operation, and 56 tons (46% of 120 tons FL) during the 'three-compressor' operation; considerably lower averages than either prior run due to the fall-season operating period. The corresponding average operating efficiencies, expressed in terms of 'kW/ton' were 1.36, 0.96, and 1.01 respectively. During this analysis period, the chiller averaged an overall efficiency of 1.15 kW/ton.

Accuracy of the derived performances expressed in terms of kW- 'average error' and 'standard deviation of error' (i.e. 'AVG-kWerr' / 'STD-kWerr') are -0.0/0.5 kW, 0.0/0.7 kW, and 0.0/1.3 kW for the three operating modes respectively.

At the uniform operating levels previously identified (i.e. 88% FL- ton/compressor, 44ºF CHWS, and 85ºF ECW), the resulting derived efficiency is 0.947 for the 'single-compressor' mode of operation; just slightly worse than the 407C operation. We could not project comparative results for either the 'two-, or 'three-compressor' operations; at the stated load/parameters, both projections would exceed the maximum anticipated compressors kW limits. Figure 4-3 presents the complete projected results of the chiller performance as derived with the refrigerant R-507 installed.

Comparison of Chiller-Refrigerant Performances

Differences in Chiller Performance Characteristics between Refrigerants

The graphs in Figures 4-4 and 4-5[2] compare the overall differences in the chillers' performance while utilizing the different refrigerants; R-22 is selected as the common reference. On these graphs the operating water conditions are at a constant 44ºF of CHWS with a decreasing ECW temperature from 85ºF (as previously employed in accordance with ARI ECW relief). At points where the individual compressor's performance overlapped due to staging control (refer to prior graphs), the values were averaged to provide some smoothing of the characteristics for purpose of clarity.

R-407C vs. R-22:

Figure 4-4 compares the projected performance and resulting efficiency of the chiller while using the refrigerant 407C to those results obtained while using the refrigerant R-22. On an absolute basis, the comparison shows that the chiller operating with the R-407C refrigerant will require anywhere from between 1.8 to 10 kW more energy than the R-22 refrigerant throughout the identified cooling load range of 5 to 105 tons. Across the loading range this equates to a nominal decrease in chiller efficiency while using the 407C refrigerant by as much as 47% at the lower loads, and leveling out to around 12% less efficiency at loading of approximately 75 tons, and higher.

Projection of the chiller IPLV's for each operation (using a straight-line extrapolation of the identified performances up to 120 tons full-load) are 0.92 kW/ton while using R-407C, and 0.79 kW/ton for the R-22 operation. This comparison indicates about a 16% less efficient overall operation for the R-407C refrigerant.

R-507 vs. R-22:

Likewise, Figure 4-5 presents comparison for the refrigerant 507 chiller operation. As shown, it is projected that the chiller will require between 1.4 to 23 kW more power in the loading range from 5 to 95 tons. This represents a decrease in chiller efficiency of approximately 36% at lower loads to about 28% at loads above 80 tons when compared with the R-22 chiller performance.

[2] See Table 4-4 and associated Figures 4-4 and 4-5 at the end of this section.

Annual Energy Use Comparisons

In Table 4-4 the annual chiller power consumption and difference due to refrigerant use is projected based on the derived performances. The first comparison is calculated based on the averaged operating loads and water conditions (of the values 'forwarded to the databases'; ref. appendices) as experienced during the year of operation with the refrigerant 407C installed. The annual averaged values are calculated for each mode of the chiller operation; 'single-', 'two-', and 'three-compressors'. In the subsequent comparisons, the ECW temperature and then, the CHWS temperature are modified toward the ARI standards in order to illustrate the incremental impacts on the absolute, and the relative, consumption of power among the refrigerants.

Comparison 1: As stated above, this first comparison presents projected annual power consumption using the annual averaged operating conditions during the 407C phase of operation (i.e. at compressors' average loading, and CHWS/ECW temperatures).

Table 4-4 shows that, under these conditions, the R-22 chiller operation would use about 91,500 kWh annually. With refrigerant 407C, the additional energy use is 8.8% higher at about 99,500 kWh. Using the refrigerant 507 the projected energy consumption is 114,800 kWh; a 25.5% increase over the R-22 operation. Based on this simple model, the weighted overall average chiller efficiencies are 0.82 kW/ton for the R-22, 0.90 kW/ton for R-407C, and 1.03 kW/ton for the R-507 operation.

Comparison 2: Next, to illustrate change/variance in annual power consumption due to changes in the ECW, these water temperatures are modified to bring them in accordance with the ARI relief allowance as based on percentage of the chiller full-load (taken as 120 ton). Since these temperatures are lower than the actual averaged ECW temperatures encountered, the overall annual power consumption is also accordingly less. However, though the absolute energy consumption of both the 407C, and the 507 operation have each decreased by about 8000 kWh annually (at -7.9% and -7.3%, respectively), the greater 12.1% energy reduction for the R-22 chiller operation has effectively increased the relative differences in energy consumption of both the 407C, and 507 chiller operations to 13.9%, and 32.4% respectively when compared with the R-22. Therefore, as the result of the approximate 5°F overall reduction in the ECW temperature of this comparison, the 407C and 507 refrigerants responded at only about 63% of the percentage reduction identified for the R-22 chiller operation. The resulting overall weighted averages of the chiller efficiency for this operating model are 0.72 kW/ton for R-22, 0.82 kW/ton for the R-407C, and 0.96 kW/ton for the R-507 operation.

Comparison 3: The last comparison illustrates the relative changes in energy consumption when, at last, the CHWS temperature is set in accordance with the ARI requirement of 44ºF. Since this constitutes a decrease to the actual CHWS averages encountered during the actual operation (nominally, about 4.5ºF less than experienced)., the overall annual energy consumption increases.

The projected results show that the relative energy consumption of the 407C has again widened, as compared with the R-22 chiller operation, to 17.0%, and the 507 refrigerant operation has slightly decreased to about a 30.1% of greater energy use. Further, though the incremental energy use of the R-22 chiller operation increased by about 4%, energy use with the 407C increased by almost 7% while incremental increase of the R-507 showed only a 2% increase. The overall, weighted average chiller efficiencies for this operating model are 0.75 kW/ton for R-22, 0.88 kW/ton for the R-407C, and 0.98 kW/ton for the R-507 operation.

Conclusions

The annual performance of the EcoCHILL machine, as operated with the refrigerant 407C installed, yielded an overall efficiency of 0.91 kW/ton. The best sustained chiller efficiency averaged at about 0.69 kW/ton during operation at favorable water temperatures of 51ºF CHWS / 68ºF ECW, and between 35 to 45 tons of the 'one- and 'two-compressor modes of operation.

Comparison of the chiller performance to results obtained with the installation of the refrigerant R-22 show that, at ARI conditions, the chiller with the 407C refrigerant installed is anywhere from as much as 47% (at low-loads) to 12% (at higher-loads) less efficient. Similar comparison using the R-507 refrigerant shows chiller efficiency ranging between 36% to 28% less efficient from lower- to higher-load operation.

From the standpoint of annual energy consumption, and when operated at the annual average conditions as encountered during the 407C refrigerant installation period, the comparison projects that, at 99,561 kWh, the 407C refrigerant chiller operation would consume about 8.8% more energy than the R-22 refrigerant operation, projected at 91,501 kWh. The corresponding projection for the 507 refrigerant, 114,800 kWh represents a 25.5% increase in energy consumption over the R-22 chiller operation. Results of the corresponding overall weighted averages of the chiller efficiency for this comparison were 0.82 kW/ton for the R-22, 0.90 kW/ton for R-407C, and 1.03 kW/ton for the R-507 operation.

Further, however, but at the ARI water conditions for the average encountered compressor loads, it is projected that the 407C chiller operation would consume 17.0% more energy annually than the comparable R-22 operation, while the projected operation using the 507 refrigerant would consume 30.1% more energy. The weighted average operating efficiencies were 0.75 kW/ton for the R-22, 0.88 kW/ton for R-407C, and 0.98 kW/ton for the R-507 operation.

With the R-22 refrigerant, the chiller responded more favorably to changes in both the lowering of ECW and CHWS temperatures than it did with the 407C refrigerant. Though on a par with the 407C results for lowering of the ECW temperature, results of the chiller operation with the 507 refrigerant showed less incremental energy increase when the CHWS was lowered than occurred with the R-22 refrigerant.

From on these comparisons, it is concluded that the EcoCHILL machine operating with the R-22 refrigerant provides the best economy in operating performance regardless of water conditions. Based on the average compressor loads and operating times encountered during the annual 407C refrigerant chiller operation, the study concludes that chiller operation will range between 8.8% to 17.0% less efficient for the 407C refrigerant, and 25.5% to 30.2% less efficient for its operation with the 507 refrigerant; where conditions are first at the average encountered CHWS and ECW temperatures, and then at the ARI standard temperatures (the averaged nominal differences amounting to about a 5ºF overall decrease in the ECW temperature and about a 4ºF overall decrease in CHWS temperature.).

On a final note regarding the analysis, it can be noted that '100% full-load values' could not be established. This was primarily due to the 'staging' nature of this chiller machine and the fact that only the 'total system tons' were available from the measurements obtained. This, therefore, obviated calculation of IPLV’s according to the ARI standard for comparisons.

Table 4-1

CAL POLY CHILLER STUDY: **STUDENT UNION BUILDING**	REFRIGERANT INSTALLED: **R-407C**

SUMMARY OF OPERATIONAL DATA and PERFORMANCE RESULTS

1. DERIVED PERFORMANCE EQUATIONS: KW f %FULL-LOAD TONS/#COMPRESSORS OPER, CHWSt, ECWt

	CHILLER OPERATING MODE			
VARIABLE	1-CMPSR	2-CMPSRs	3-CMPSRs	4-CMPSRs
	(FL=40T)	(FL=80T)	(FL=120T)	(FL=160T)
k=	*-3.120*	*-3.256*	*-59.580*	-
CHWSt=	*-0.406*	*-0.767*	*-0.799*	-
ECWt=	*0.343*	*0.593*	*1.247*	-
ECWT^2=	*0.000*	*0.000*	*0.000*	-
%FLtons=	*35.360*	*58.896*	*286.872*	-
%FLtons^2=	*-8.080*	*3.450*	*-839.318*	-
%FLtons^3=	*0.000*	*0.000*	*1278.720*	-
%FLtons^4=	*0.000*	*0.000*	*-628.301*	-

2. OPERATIONAL AVERAGED HOURLY DATA SUMMARY and DERIVED PERFORMANCE ACCURACIES:

A. BY NUMBER OF OPERATING COMPRESSORS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
#CMPSRS	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
1	392	62.8	47.9	72.6	22.1	18.9	0.907	*0.0*	*1.2*
2	643	71.2	49.7	75.9	49.5	41.5	0.840	*0.1*	*1.7*
3	905	80.2	47.5	79.7	75.3	71.5	0.940	*-0.1*	*2.4*
4	-	-	-	-	-	-	-	-	-
TOT/AVG=	1940	73.7	48.3	77.0	55.8	50.7	0.913	*-0.01*	*1.93*

B. BY MONTH OF DATA EVALUATION BASIS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
'96 FEB	79	67.2	51.2	67.5	30.8	21.9	0.740	*-0.4*	*2.2*
MAR	54	61.5	49.4	66.7	30.9	22.7	0.740	*-0.7*	*2.9*
APR	316	70.2	50.9	75.2	42.8	34.3	0.810	*0.6*	*1.6*
MAY	376	71.1	51.2	76.2	49.9	41.1	0.840	*0.1*	*1.6*
JUN	198	74.6	47.3	78.7	57.4	53.2	0.950	*0.6*	*2.2*
JUL	216	78.6	46.3	82.0	74.2	73.1	0.980	*0.1*	*2.1*
AUG	231	81.7	46.4	83.2	77.1	77.9	1.020	*-0.3*	*2.3*
SEP	252	74.7	46.2	77.3	60.8	57.3	0.960	*-0.1*	*2.2*
OCT	239	72.3	45.3	73.6	49.3	45.3	1.010	*-0.9*	*1.5*
TOT/AVG=	1961	73.6	48.2	77.0	55.4	50.4	0.912	*-0.01*	*1.92*

C. BY MONTH OF ADDITIONAL DATA COLLECTED

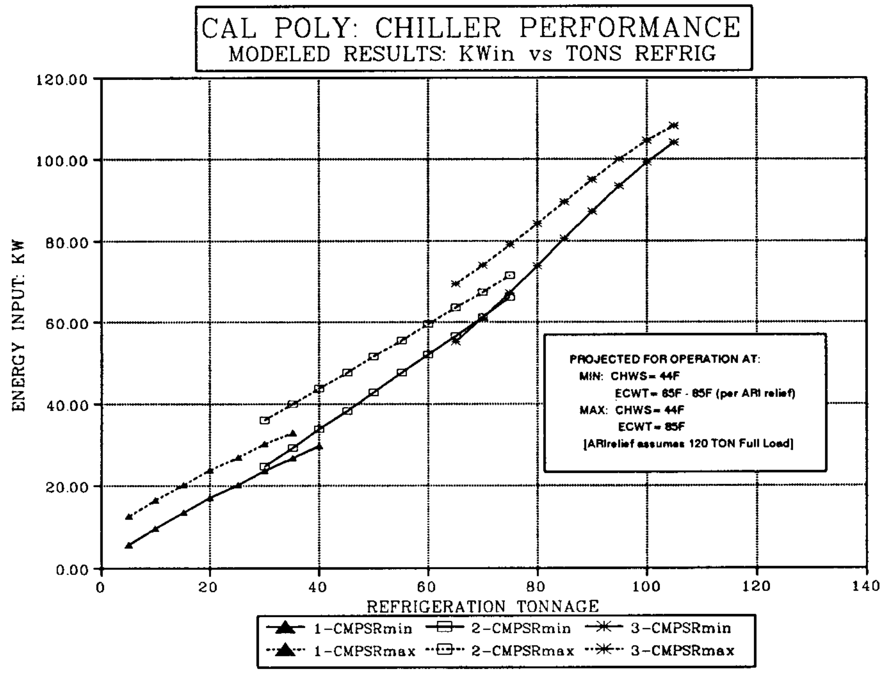
	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
'96 NOV	77	71.7	46.6	70.0	35.1	28.4	0.870	*0.4*	*3.1*
DEC	0	(no oper)	0.0	0.0	0.0	0.0	0.000	0.0	0.0
'97 JAN	15	64.8	53.2	70.5	11.3	13.1	1.260	*-6.8*	*2.6*
FEB	27	69.5	51.5	70.4	27.0	23.9	1.080	*-4.2*	*6.8*
MAR	166	72.2	50.1	70.9	39.6	31.7	0.890	*-1.0*	*6.1*
APR	135	71.9	47.4	71.9	54.3	44.3	0.870	*0.4*	*4.6*

3. RESULTS OF DERIVED PERFORMANCE @88% NOMINAL F.L. per #COMPRESSORs AT ARI WATER TEMPERATURES:

		OPERATING CONDITIONS			OPERATING LEVELS		
#CMPSRS			CHWSt	ECWt	TONS(*)	KW	KW/TON
1	-	-	44.0	85.0	35.2	33.0	0.938
2	-	-	44.0	85.0	70.4	67.9	0.964
3	-	-	44.0	85.0	105.6	108.4	1.026
4	-	-	-	-	-	-	-

*- @88% nominal F.L.

'DBSMRY-1'



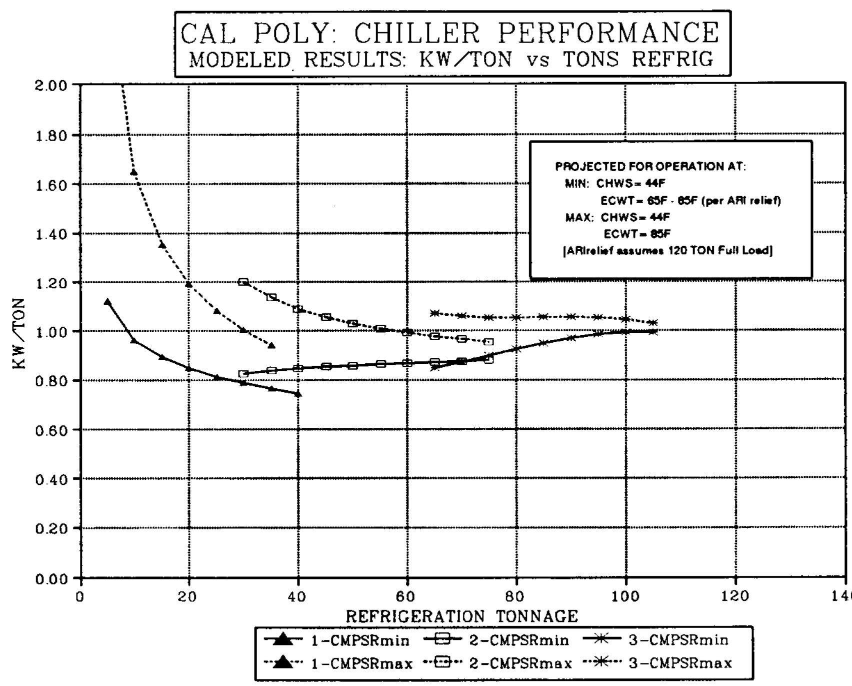


Figure 4-1
Chiller Performance with Refrigerant-407C Installed

Table 4-2

CAL POLY CHILLER STUDY: **STUDENT UNION BUILDING** REFRIGERANT INSTALLED: **R-22**

SUMMARY OF OPERATIONAL DATA and PERFORMANCE RESULTS

1. DERIVED PERFORMANCE EQUATIONS: KW f %FULL-LOAD TONS/#COMPRESSORS OPER, CHWSt, ECWt

	CHILLER OPERATING MODE			
VARIABLE	1-CMPSR	2-CMPSRs	3-CMPSRs	4-CMPSRs
	(FL=40T)	(FL=80T)	(FL=120T)	(FL=160T)
k=	-17.347	-50.350	215.109	-
CHWSt=	-0.465	-0.281	-0.410	-
ECWt=	0.594	1.017	-6.110	-
ECWT^2=	0.000	0.000	0.049	-
%FLtons=	24.529	26.536	189.986	-
%FLtons^2=	-1.514	23.376	-627.245	-
%FLtons^3=	0	0	1044.049	-
%FLtons^4=	0	0	-536.6991	-

2. OPERATIONAL AVERAGED HOURLY DATA SUMMARY and DERIVED PERFORMANCE ACCURACIES:

A. BY NUMBER OF OPERATING COMPRESSORS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
#CMPSRS	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
1	107	66.9	43.6	69.9	23.9	18.1	0.820	*-0.2*	*1.3*
2	460	75.4	44.4	74.6	53.0	41.7	0.800	*-0.3*	*1.1*
3	528	80.5	44.1	80.4	83.8	75.7	0.900	*-0.1*	*2.1*
4	-	-	-	-	-	-	-	-	-
TOT/AVG=	1095	77.0	44.2	76.9	65.0	55.8	0.850	*-0.19*	*1.57*

B. BY MONTH OF DATA EVALUATION BASIS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
'97 MAY	221	77.7	44.4	76.9	78.4	66.0	0.860	*0.1*	*1.9*
JUN	174	73.8	44.4	75.6	61.6	51.2	0.850	*0.2*	*1.6*
JUL	255	75.7	44.2	74.3	46.7	37.0	0.790	*0.0*	*0.6*
AUG	193	79.5	44.1	79.0	68.9	62.2	0.880	*-0.3*	*1.6*
SEP	252	78.1	43.9	78.9	71.3	64.0	0.880	*-0.8*	*2.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
TOT/AVG=	1095	77.0	44.2	76.9	65.0	55.8	0.850	*-0.19*	*1.52*

C. BY MONTH OF ADDITIONAL DATA COLLECTED

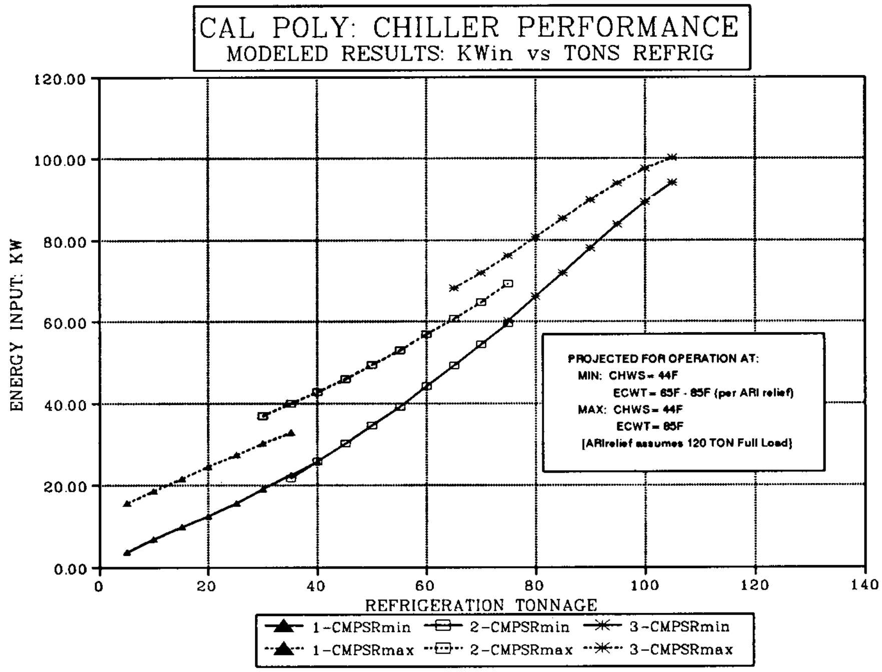
	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
'97 OCT	149	75.1	43.7	76.8	68.0	59.2	0.840	*-1.0*	*1.7*
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-

3. RESULTS OF DERIVED PERFORMANCE @88% NOMINAL F.L. per #COMPRESSORs AT ARI WATER TEMPERATURES:

		OPERATING CONDITIONS			OPERATING LEVELS		
#CMPSRS			CHWSt	ECWt	TONS(*)	KW	KW/TON
1	-	-	44.0	85.0	35.2	33.1	0.939
2	-	-	44.0	85.0	70.4	65.2	0.926
3	-	-	44.0	85.0	105.6	100.6	0.952
4	-	-	-	-	-	-	-

*- @88% nominal F.L.

'DBSMRY-2'



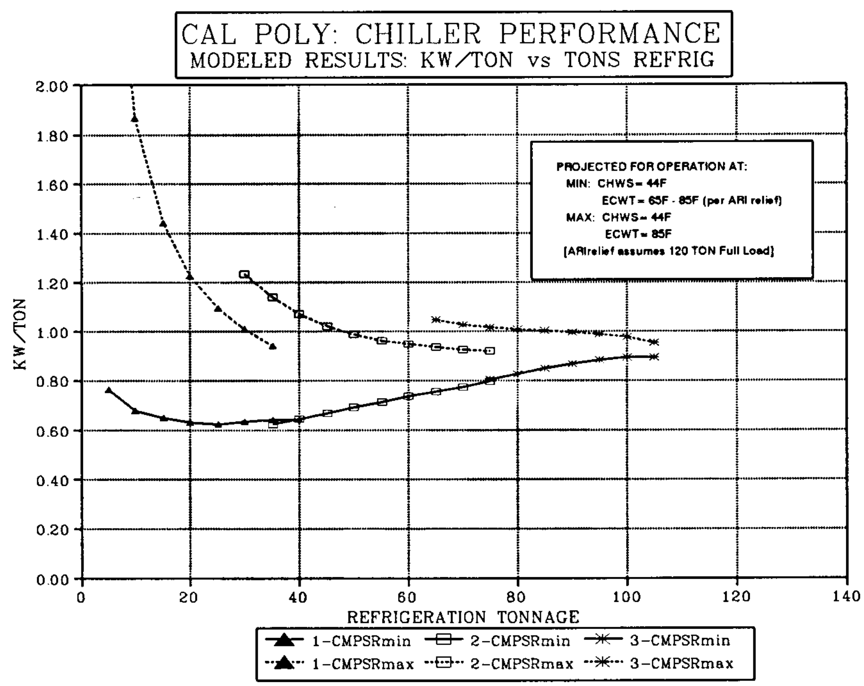


Figure 4-2
Chiller Performance with Refrigerant-22 Installed

Table 4-3

CAL POLY CHILLER STUDY: **STUDENT UNION BUILDING** REFRIGERANT INSTALLED: **R-507**

SUMMARY OF OPERATIONAL DATA and PERFORMANCE RESULTS

1. DERIVED PERFORMANCE EQUATIONS: KW f %FULL-LOAD TONS/#COMPRESSORS OPER, CHWSt, ECWt

	CHILLER OPERATING MODE			
VARIABLE	1-CMPSR	2-CMPSRs	3-CMPSRs	4-CMPSRs
	(FL=40T)	(FL=80T)	(FL=120T)	(FL=160T)
k=	-6.002	-34.232	225.863	-
CHWSt=	-0.202	-0.146	-0.422	-
ECWt=	0.241	0.650	-6.460	-
ECWT^2=	0.000	0.000	0.051	-
%FLtons=	36.019	46.700	85.952	-
%FLtons^2=	-5.092	27.406	40.156	-
%FLtons^3=	*0.000*	*0.000*	*0.000*	-
%FLtons^4=	*0.000*	*0.000*	*0.000*	-

2. OPERATIONAL AVERAGED HOURLY DATA SUMMARY and DERIVED PERFORMANCE ACCURACIES:

A. BY NUMBER OF OPERATING COMPRESSORS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
#CMPSRS	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
1	108	62.7	43.4	71.7	13.9	14.2	1.360	*-0.0*	*0.5*
2	32	68.9	43.9	72.9	38.0	35.6	0.960	*-0.0*	*0.7*
3	111	77.0	43.8	74.9	55.7	56.9	1.010	*-0.0*	*1.3*
4	-	-	-	-	-	-	-	-	-
TOT/AVG=	251	69.8	43.6	73.3	35.5	35.8	1.154	*-0.02*	*0.86*

B. BY MONTH OF DATA EVALUATION BASIS

	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
'97 OCT	170	67.6	43.6	72.7	32.5	32.1	1.180	*-0.1*	*0.9*
NOV	81	74.6	43.7	74.4	41.7	43.5	1.090	*0.2*	*0.9*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
	0	0.0	0.0	0.0	0.0	0.0	0.000	*0.0*	*0.0*
TOT/AVG=	251	69.9	43.6	73.2	35.5	35.8	1.151	*-0.02*	*0.92*

C. BY MONTH OF ADDITIONAL DATA COLLECTED

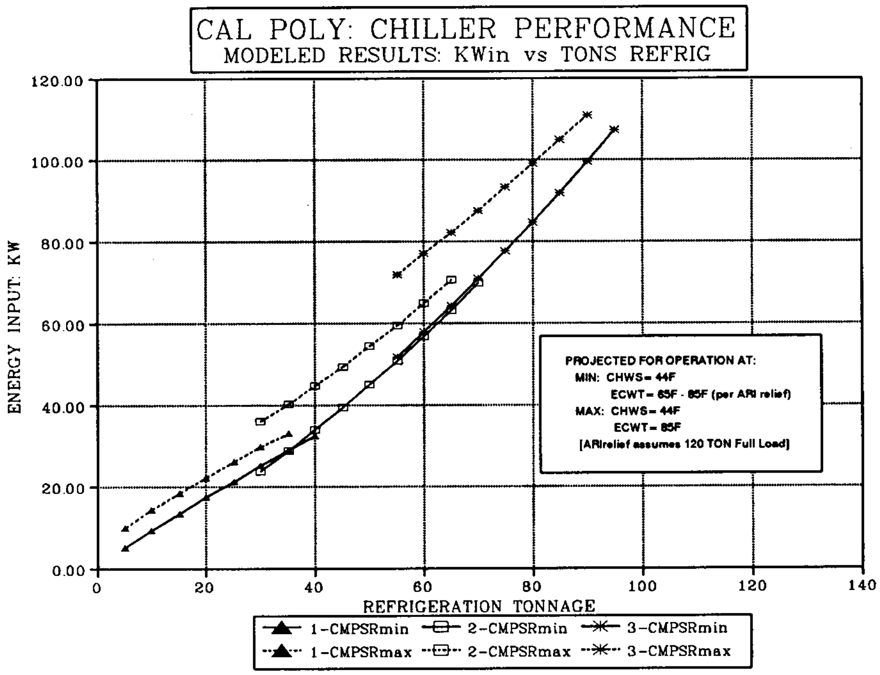
	DATA	AVERAGED OPERATING CONDITIONS			AVERAGED OPERATING LEVELS			FIT ACCURACIES	
MONTH	HOURS	OSA-DB	CHWSt	ECWt	TONS	KW	KW/TON	AVG-KWer	STD-KWerr
-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-

3. RESULTS OF DERIVED PERFORMANCE @88% NOMINAL F.L. per #COMPRESSORs AT ARI WATER TEMPERATURES:

		OPERATING CONDITIONS			OPERATING LEVELS			
#CMPSRS			CHWSt	ECWt	TONS(*)	KW	KW/TON	
1	-	-	44.0	85.0	35.2	33.3	0.947	
2	-	-	44.0	85.0	70.4	na	na	<- Unable to predict this load/temp
3	-	-	44.0	85.0	105.6	na	na	<- Unable to predict this load.
4	-	-	-	-	-	-	-	

*- @88% nominal F.L.

'DBSMRY-3'



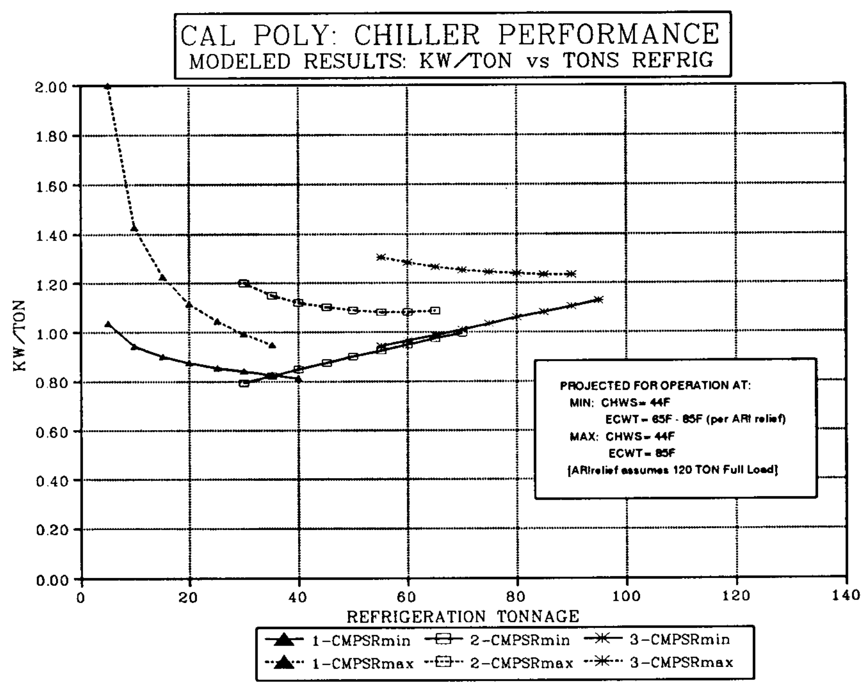


Figure 4-3
Chiller Performance with Refrigerant-507 Installed

Table 4-4

COMPARISON of CHILLER PROJECTED ANNUAL ENERGY USE per REFRIGERANT, under VARING AVERAGE OPERATING CONDITIONS

COMPARE-1: At Actual Average of Conditions (Load, CHWSt, and ECWt) During the 407C Annual Data Collection

#Cmpsr's Running	Total Run Hours	Ton-Load	(%FL)*	CHWSt	ECWt	R-22: Avg-kW	R-22: kW/Ton	R-22: Annual-kWh	R-407C: Avg-kW	R-407C: kW/Ton	R-407C: Annual-kWh	R-507: Avg-kW	R-507: kW/Ton	R-507: Annual-kWh
1	448	20.5	(17.1%)	47.6	72.3	15.6	0.761	6,989	18.3	0.894	8,218	18.9	0.923	8,475
2	690	48.7	(40.6%)	49.6	75.5	37.3	0.766	25,745	40.6	0.833	28,001	46.2	0.948	31,871
3	910	75.1	(62.6%)	47.5	79.6	64.6	0.860	58,767	69.6	0.927	63,342	81.8	1.089	74,454
							Total kWh=	91,501		Total kWh=	99,561		Total kWh	114,800

Annual Energy Difference vs. R-22 = R-407C: 8,060 kWh more (8.8%); R-507: 23,299 kWh more (25.5%)

[* System Full-Load = 120 tons]

COMPARE-2: At Actual Average of Conditions (Load, and CHWSt only) During the 407C Annual Data Collection; ECWt @ARI per %LOAD

#Cmpsr's Running	Total Run Hours	Ton-Load	(%FL)*	CHWSt	ECWt	R-22: Avg-kW	R-22: kW/Ton	R-22: Annual-kWh	R-407C: Avg-kW	R-407C: kW/Ton	R-407C: Annual-kWh	R-507: Avg-kW	R-507: kW/Ton	R-507: Annual-kWh
1	448	20.5	(17.1%)	47.6	65.0	11.3	0.549	5,047	15.8	0.773	7,096	17.2	0.837	7,688
2	690	48.7	(40.6%)	49.6	70.0	31.7	0.651	21,885	37.3	0.766	25,752	42.6	0.875	29,405
3	910	75.1	(62.6%)	47.5	75.6	58.8	0.783	53,504	64.6	0.860	58,803	76.2	1.015	69,379
							Total kWh=	80,436		Total kWh=	91,651		Total kWh	106,472

Annual Energy Difference vs. R-22 = R-407C: 11,215 kWh more (13.9%); R-507: 26,036 kWh more (32.4%)

[* System Full-Load = 120 tons]

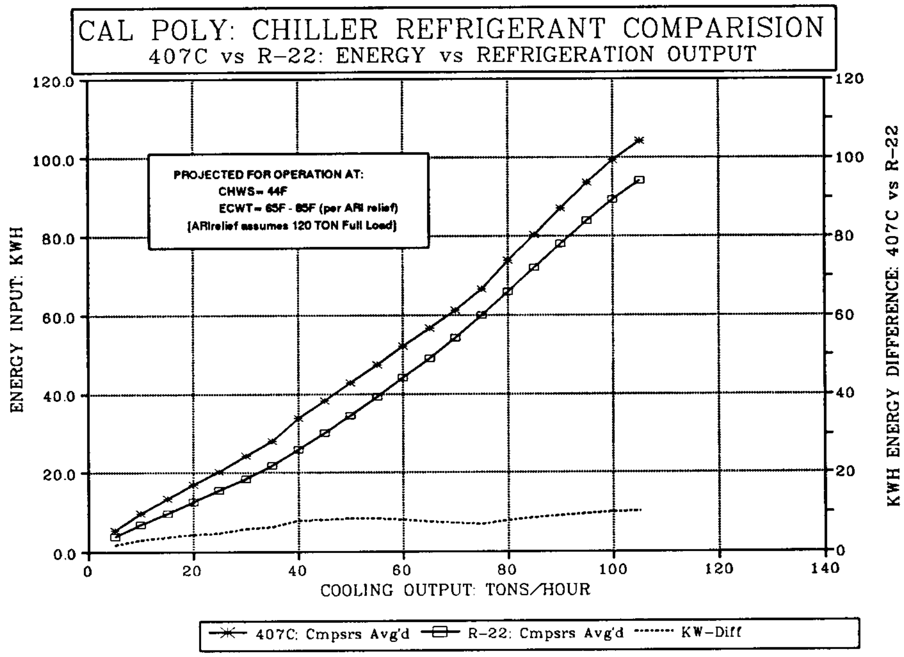
COMPARE-3: At Actual Average of Conditions (Load only) During the 407C Annual Data Collection; ECWt and CHWSt @ARI per %Load

#Cmpsr's Running	Total Run Hours	Ton-Load	(%FL)*	CHWSt	ECWt	R-22: Avg-kW	R-22: kW/Ton	R-22: Annual-kWh	R-407C: Avg-kW	R-407C: kW/Ton	R-407C: Annual-kWh	R-507: Avg-kW	R-507: kW/Ton	R-507: Annual-kWh
1	448	20.5	(17.1%)	44.0	65.0	12.9	0.631	5,798	17.3	0.844	7,751	17.9	0.872	8,013
2	690	48.7	(40.6%)	44.0	70.0	33.3	0.683	22,971	41.6	0.854	28,715	43.4	0.892	29,968
3	910	75.1	(62.6%)	44.0	75.6	60.2	0.802	54,809	67.4	0.898	61,347	77.7	1.035	70,721
							Total kWh=	83,578		Total kWh=	97,813		Total kWh	108,702

Annual Energy Difference vs. R-22 = R-407C: 14,235 kWh more (17.0%); R-507: 25,124 kWh more (30.1%)

[* System Full-Load = 120 tons]

'CMPR-ALL'.xls



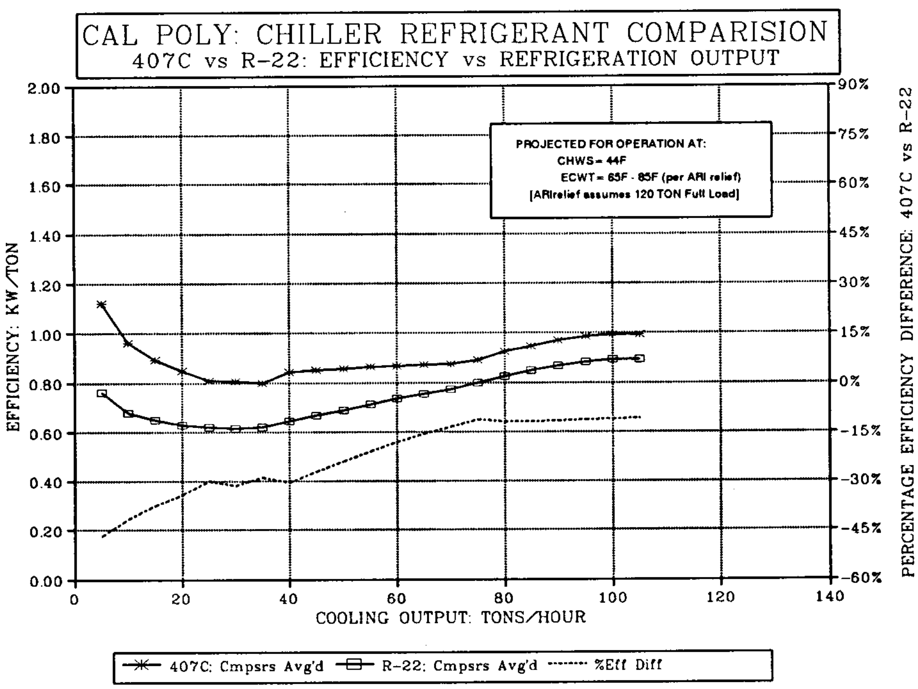
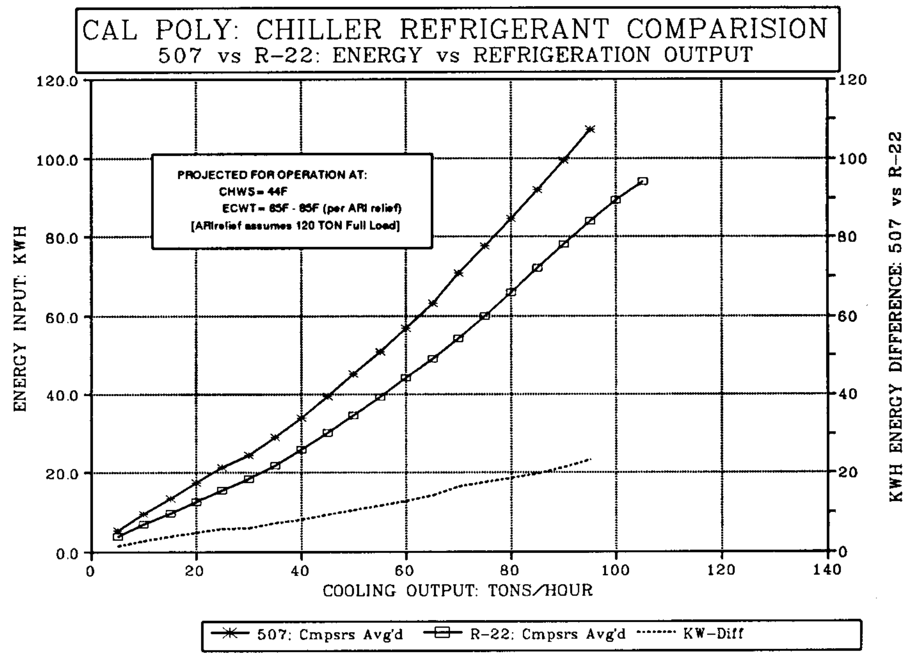


Figure 4-4
Chiller Performance Comparison: Refrigerants R-407C and R-22



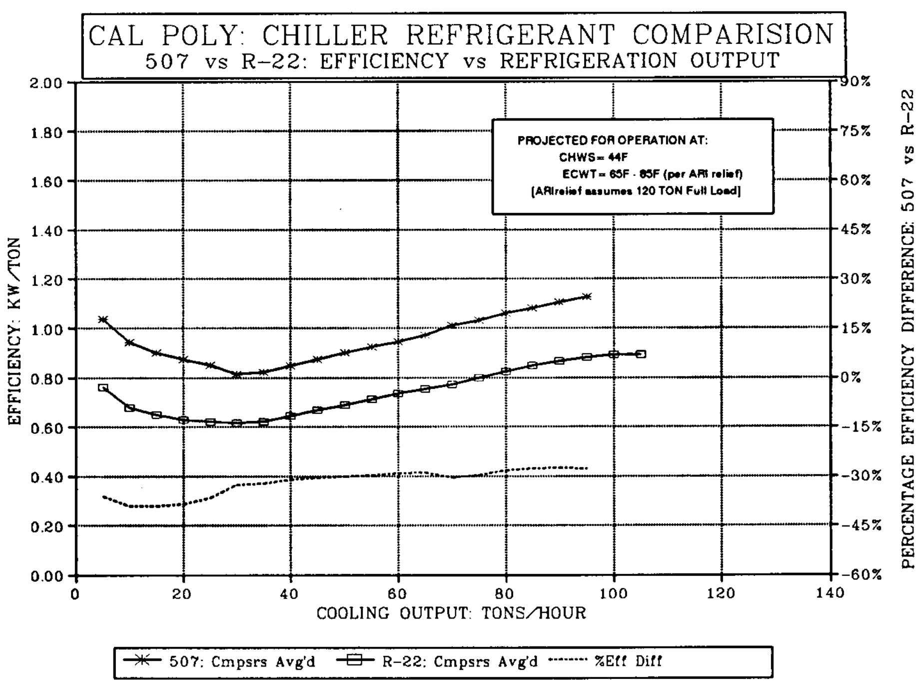


Figure 4-5
Chiller Performance Comparison: Refrigerants R-507 and R-22