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Within the Department of Defense (DOD) chillers are used for a variety of applications. Industrial, commercial, and residential buildings use chillers for industrial process cooling, computer system cooling, as well as for human comfort/space cooling. This TechData Sheet covers commercial comfort cooling applications in the 30-to 1,500-ton range. The purpose of this TechData Sheet is to assist activity personnel in making energy conscious decisions when selecting a chiller for their application. Variables affecting the chiller selection include: equipment cost, installation cost, chiller efficiency, size, utility availability, utility costs, and location constraints. These variables must be considered together when selecting the appropriate chiller.

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Naval Facilities Engineering Service Center
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Selecting the Correct Chiller for Your Specific Needs

Within the Department of Defense (DOD) chillers are used for a variety of applications. Industrial, commercial, and residential buildings use chillers for industrial process cooling, computer system cooling, as well as for human comfort/space cooling. This Techdata Sheet covers commercial comfort cooling applications in the 30- to 1,500-ton range. The purpose of this Techdata Sheet is to assist activity personnel in making energy conscious decisions when selecting a chiller for their application. Variables affecting the chiller selection include: equipment cost, installation cost, chiller efficiency, size, utility availability, utility costs, and location constraints. These variables must be considered together when selecting the appropriate chiller.

Chiller Size and Efficiency

For commercial applications (i.e., human comfort/space cooling) ranging from 30 to 1,500 tons, five types of chillers are considered. Table 1 is a list of the five types of chillers including size ranges and full load efficiencies.

Chiller Cycles

Vapor Compression Cycle

Each chiller, with the exception of absorption chillers, uses a conventional vapor compression cycle. The main components of the vapor compression cycle are the compressor, condenser, expansion valve, and evaporator (see Figure 1). The mechanical compressor compresses the vaporized refrigerant from a low pressure/low temperature state to a high pressure/high temperature state. The high pressure/high temperature vapor enters the condenser where heat is removed, allowing the vapor to condense to a high temperature liquid. Waste heat is rejected to the cooling water or air. The expansion valve reduces the pressure of the liquid refrigerant. The refrigerant enters the evaporator where heat is transferred to the refrigerant from the chilled water. This heat boils the refrigerant at the lower temperature and pressure.

Table 1. Types of Chillers

Chiller	Size Range (tons)	Full Load Efficiency	
		kW/ton	COP*
Electric Centrifugal (water-cooled)	100 to 1,500	0.49 - 0.68	---
Electric Reciprocating (water-cooled)	30 to 400	0.80 - 1.00	---
(air-cooled)		1.40 - 1.60	---
Electric Screw (water-cooled)	40 to 1,100	0.61 - 0.70	---
(air-cooled)		1.10 - 1.30	---
Absorption (direct-fired)	30 to 1,500	---	0.95 - 1.04
(indirect-fired)			0.70 - 1.19
Natural Gas Engine Driven	30 to 1,500	---	1.00 - 2.24

*COP = Coefficient of Performance

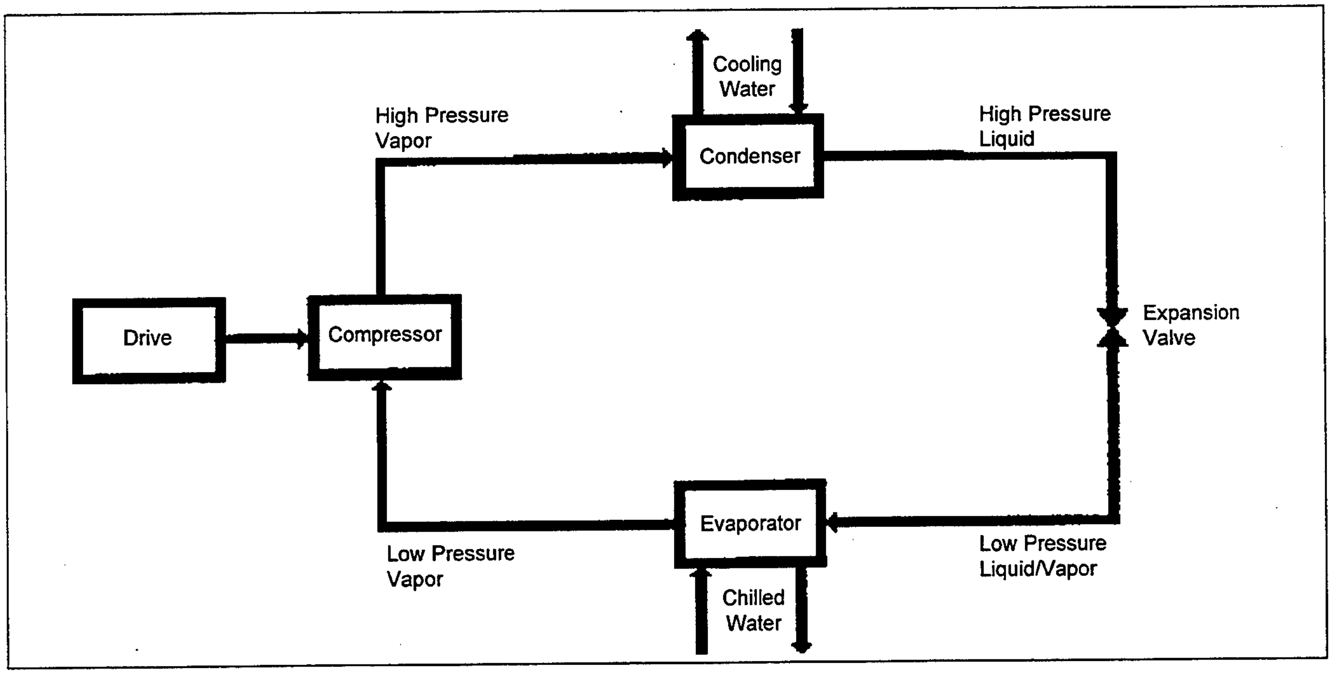

Figure 1. Conventional vapor compression system.

Absorption Thermal Compression Cycle

Absorption chillers do not use a mechanical compressor; instead they use a thermal compressor consisting of a generator, pump, and absorber. See Figure 2. The thermal compressor requires heat and work to operate. Heat is required by the generator to boil the refrigerant from the solution. The heat energy can be provided directly from natural gas or indirectly from steam or hot water. Work is required by the pump to raise the pressure of the solution from the lower evaporating pressure to the higher condensing pressure. Unlike mechanical compressors, which use fluorinated hydrocarbons as the refrigerant, the absorption thermal compressor uses water as the refrigerant and lithium bromide as the absorbent.

CHILLER TYPES

Centrifugal Chillers

Electric centrifugal chillers account for approximately 80 percent of chiller sales in the United States. Although centrifugal chillers are available in sizes down to 100 tons, they are used for applications over 300 tons. The centrifugal compressor compresses the refrigerant vapor by spinning it from the center of the impeller wheel outward so that centrifugal forces compress the vapor. Multiple impellers may be used to compress the vapor in stages. The compressor is driven by either a constant speed direct drive system or a gear drive system. Variable speed motors can be used but greatly increase the initial cost.

Centrifugal chillers can use hydrochlorofluoro carbon (HCFC)-123, hydrofluoro carbon (HFC)-134a, or HCFC-22 refrigerants. Selecting the refrigerant depends on the size and application of the chiller.

Chillers using HCFC-123 have the highest efficiency (0.49 kW/ton) at full load but cannot reach low temperatures. HCFC-123 can be used in most space cooling applications. HFC-134a and HCFC-22 refrigerant chillers can reach 0.55 kW/ton at full load and can be used for low temperature applications - ice rink, ice storage plant, etc. Also, the size of the chiller may effect which type of refrigerant can be used.

Centrifugal chillers are best used in high, constant load applications. Chiller efficiency drops rapidly below 60 percent of full load. At low part load the centrifugal fan may stall, resulting in noise and vibration problems as well as the potential for permanent damage. Centrifugal chillers can be either air- or water-cooled. Water-cooled chillers are more efficient.

Reciprocating Chillers

Reciprocating chillers are positive displacement machines that use pistons to compress refrigerant vapor. An electric motor turns a crankshaft, which drives the pistons. The chillers may include multiple compressors to meet larger loads and increase part load efficiency. Adjustable speed drives are being applied to reciprocating compressors, reducing energy consumption 20 to 30 percent. Most reciprocating chillers are used in rooftop applications and use HCFC-22 refrigerant. Depending on the application, reciprocating chillers can be either air or water cooled. Water-cooled chillers are more efficient but have a higher initial cost.

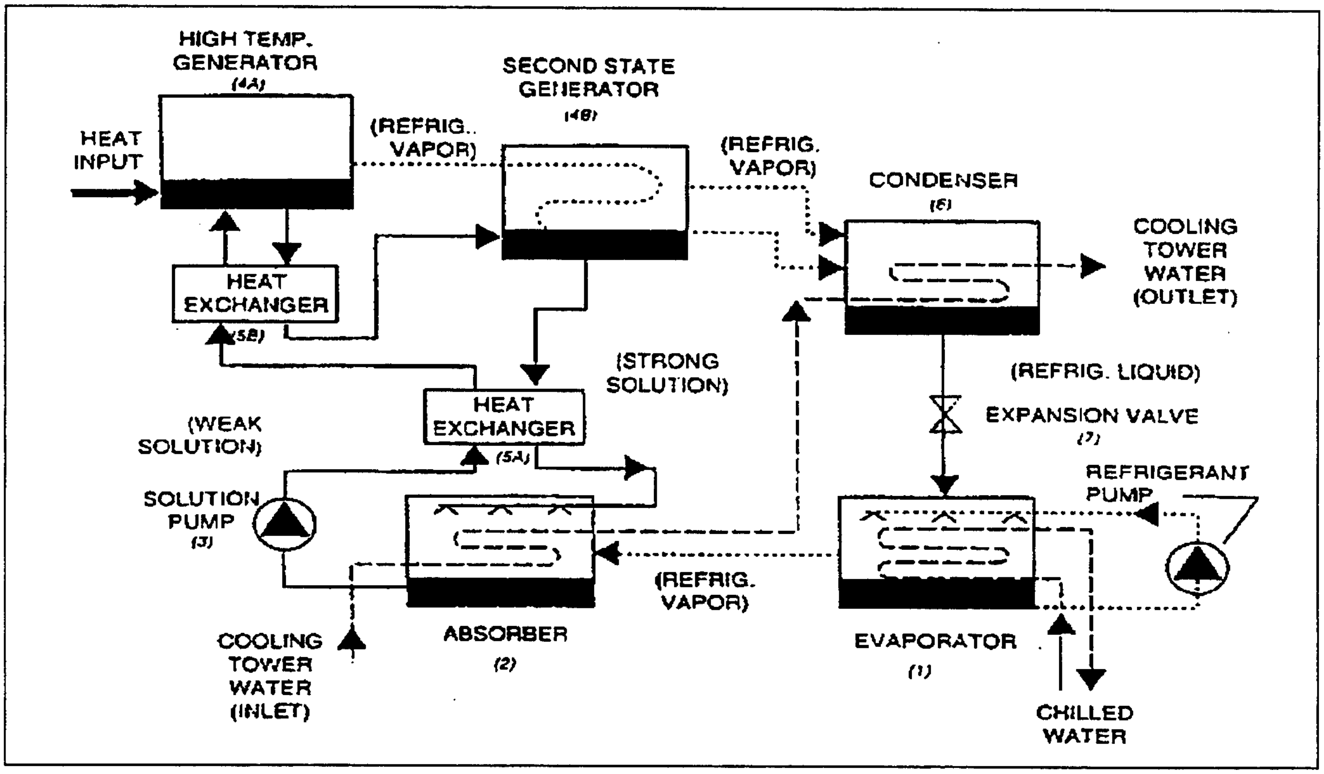

Figure 2. Absorption thermal compression system.
(Printed with permission from the American Gas Cooling Center.)

Screw Chillers

Screw chillers have been used for years, but only in industrial and refrigeration applications. Within the past few years, screw chillers have been used for commercial space cooling. Increased rotor and housing tolerances and combined smaller and lighter design then centrifugal chillers, have made screw chillers a good replacement option for centrifugal, reciprocating, and other chillers.

Like reciprocating chillers, screw chillers are positive displacement machines. Mesh rotors compress the refrigerant by twisting the refrigerant to a smaller volume. Screw chillers are available in single- and double-screw configurations. Single-screw machines use liquid refrigerant to seal the compressor, whereas, double-screw and some single-screw machines use large amounts of lubricant oil to cool the compressed gas, seal the rotor, and lubricate the bearings. Screw chillers use either HCFC-22 or HFC-134a refrigerants. Like reciprocating chillers, screw chillers can be either air- or water-cooled, depending on the application. Although screw chillers full load efficiencies are below centrifugal chillers, its part load efficiencies are comparable to centrifugal chillers.

Absorption Chillers

Absorption chillers have been used in large refrigeration plants since the 1800's. By the turn of the century, absorption cooling found a niche in industrial applications. Presently, with the growing electrical demand and energy costs, direct-fired absorption chillers are being used for commercial space cooling to reduce operating costs.

A natural gas absorption chiller uses a refrigeration system that is similar to a mechanical vapor compression system. Both systems have an evaporator and condenser coil and expand the refrigerant from high to low pressure between the condenser and evaporator. Unlike the mechanical systems, the absorption cycle relies on transferring thermal energy from the heat source to the heat sink via an absorbent and refrigerant fluid. Most absorption systems use a water (refrigerant) and lithium bromide (absorbent) combination as the working fluid. Absorption chillers are available in direct fired (i.e., natural gas) or indirect fired, such as steam or hot water.

Absorption systems are classified as either single, double, or triple "stages" or "effects." "Stages" or "effects" refers to the number of generators in the given system. Direct-fired absorption equipment available in the United States are limited to single- and double-effect, lithium-bromide-water types. Double-effect or two-stage cycles are more efficient and, therefore, more popular. Direct-fired double-effect chiller/heaters are also available. The chiller/heater can produce chilled water for cooling and hot water for space heating or domestic hot water. Chiller/heaters can potentially eliminate the need for boilers and reduce space requirements to heat and cool a facility.

Natural Gas Engine-Driven Chiller

Natural gas engine-driven chillers have been successfully marketed in the United States since the 1960's. Gas shortages in the mid 1970's and an increase in electric cooling market shares virtually destroyed the market for gas engine-driven chillers. Currently, engine-driven chillers are making a comeback by using more reliable engines, which require less maintenance and using HCFC's and other new refrigerants, which are more environmentally friendly than earlier versions.

An engine-driven chiller is similar to an electric chiller except the motor that drives an electric chiller is replaced by a natural gas engine. An open-drive configuration is required since the engine must be housed outside the compressor casing. The waste heat from the engine can be used for domestic hot water or as the steam provider for an absorption chiller unit.

Other than these minor differences, it operates in a conventional vapor compression cycle. A big advantage of engine-driven chillers is their high part load efficiencies, due to the ability of the engine to throttle up and down.

CHILLER SELECTION PROCESS

Activities must consider a variety of variables in selecting the most suitable chiller for their application. Each application is unique and must be evaluated individually. Variables may range from urgency of need to rebates and incentives offered by the utility companies. The following is a guide to the selection process.

Determine Cooling Load Magnitude and Profile

The cooling load magnitude and profile must be investigated to size the chiller and determine when the chiller will operate. The load magnitude and profile can be determined by performing a building load simulation using software or hand calculation (American Society of Heating Refrigerating, and Air-Conditioning Engineers Method), reviewing metered data, or by reviewing design cooling load data for the building. Selecting the same size chiller as the existing or what was designed, may be an insufficient method of sizing the chiller. Often building modifications (i.e., new function, new windows, doors, increased insulation, etc.) will affect the amount of cooling needed. Undersizing the chiller may lead to inadequate cooling during the hottest days and oversizing the chiller may significantly increase the initial cost and decrease the efficiency. Make sure the chiller meets the need. Once the size of the chiller has been determined, review Table 1 to decide which chillers are available in the size needed.

Site Specific Considerations

Each activity will have site specific considerations that will effect the selection of the chiller. Typical questions may include, but are not limited to, the following.

- Will the chiller require a cooling tower or be air-cooled?
- Is the existing chiller water-cooled or air-cooled?
- Which refrigerant best meets the facility's environmental concerns?
- Is there room to remove the existing chiller and replace with the same size or larger chiller?
- Will the chiller run at full load or part load most of the time (check design, building simulation, etc.)
- What is the required delivery time for the chiller?
- What utilities are available at the site?
- Is the chiller inside or outside?
- How will the new chiller interface with the existing HVAC system?
- Who will maintain the chiller?
- Which type(s) of chiller(s) do maintenance personnel know how to maintain?

Advantages and Disadvantages

Once the above questions have been answered, selecting the chiller will depend on the specific advantages and disadvantages of each chiller. Each chiller may be more appropriate than another due to its unique features, efficiency, and/or utility used. Table 2 provides some characteristics of each type of chiller. Table 2 should narrow your selection to one or two chillers that meet your individual needs.

ECONOMICS

The economics of replacing a chiller can be quite complicated. Due to developments in chiller technology it can be cost effective to replace an older chiller based on the difference in efficiency and a new chiller. This, of course, depends on several factors, such as cooling load, utility rates, and maintenance costs. There is no magic age of when a chiller should be replaced, however, starting around 15 years it should be evaluated. The example below outlines a method for economic analysis for chiller replacement.

Sample Analysis

An administration building located in the Southeast requires 300 tons of cooling. The existing centrifugal chiller is approximately 25 years old, operates poorly, and requires continual maintenance. The existing HVAC system is operating adequately and no modifications are needed if the chiller is replaced in kind. This example assumes that the above chiller selection process has been used.

The variables in Table 3 were used to evaluate the economics of replacing the existing inefficient chiller with a new high efficiency centrifugal chiller.

The IPLV or Integrated Part-Load Value is an average efficiency. The formula is :

Table 2. Chiller Characteristics

Characteristics	Centrifugal	Reciporcating	Screw	Absorption	Engine
Low initial cost	X	X	X		
High reliability	X	X	X		
Becoming more common			X	X	X
Becoming less common		X			
High full load efficiency	X				
High part load efficiency	X	X	X		X
Eliminates use of harmful refrigerants				X	
Few moving parts	X		X	X	
Smallest physical size/ ton			X		
Low maintenance costs	X		X		
Utility rebates/incentives ($/ton, reduced rates)				X	X
Low electric demand and energy charge				X	X
High electric demand and energy charge	X	X	X		
Good waste heat utilization					X
Available with heating option				X	
Refrigerant surge problem at low part load	X				
Requires increased space				X	
Requires increased cooling tower size/pumps				X	

Table 3. Input Variables

Characteristics	Existing Chiller	New Chiller
Chiller Size	300 tons	300 tons
Annual Hours of Operation	2,500 hrs	2,500 hrs
Chiller Efficiency (Peak/IPLV*)	1.10/1.00 kW/ton	0.60/0.55 kW/ton
Parasitic Loads	0.230 kW/ton	0.210 kW/ton
Material Cost	$0	$250/ton
Installation Cost	$0	$200/ton
Maintenance Cost	$3,750/year	$1,875/year
Monthly Peak Cooling Load (% of Full Load)	Jan 0 Feb 0 Mar 30 Apr 40 May 65 June 85 July 90 Aug 90 Sept 85 Oct 40 Nov 0 Dec 0	
Electric Utility Rates	Energy Cost = $0.030/kWh	Demand Charge = $12.65/kW

*IPLV = Integrated Part - Load Value

$$IPLV = \frac{1}{\frac{P1}{A} + \frac{P2}{B} + \frac{P3}{C} + \frac{P4}{D}} \qquad (1)$$

Where:

- P1 = Percent of total operating hours that the chiller spends at 100% load
- P2 = Percent of total operating hours that the chiller spends at 75% load
- P3 = Percent of total operating hours that the chiller spends at 50% load
- P4 = Percent of total operating hours that the chiller spends at 25% load
- A = kW/ton at 100% load
- B = kW/ton at 75% load
- C = kW/ton at 50% load
- D = kW/ton at 25% load

Note that whatever percentages best represent the load profile of your chiller can be substituted in to make the IPLV more accurate.

Calculations

1. Electric Peak kW = (# of Tons x Peak Eff x Highest Annual % Load) + Parasitic Load

   Existing Chiller = 300 tons x (1.10 kW/ton x 0.90) + 0.230 = 366 kW

   New Chiller = 300 tons x (0.60 kW/ton x 0.90) + 0.210 = 225 kW

2. Billed Demand = (Electric Peak kW x % of Peak) + (# of Tons x Parasitic Load) (March - See Table 4 for complete year)

   Existing Chiller = (366 kW x 0.30) + (300 tons x 0.230 kW/ton) = 179 kW or $2,262/Mo

   New Chiller = 225 kW x 0.30) + (300 tons x 0.210 kW/ton) = 131 kW or $1,651/Mo

3. Energy Costs = # of Tons x IPLV x Operating Hours x Energy Cost

   Existing Chiller = 300 tons x 1.00 kW/ton x 2,500 hr x $0.030/kWh = $22,500/Yr

   Existing Parasitic = 300 tons x 0.230 kW/ton x 2,500 hr x $0.030/kWh = $5,175/Yr

   New Chiller = 300 tons x 0.55 kW/ton x 2,500 hr x $0.030/kWh = $12,375/Yr

   New Parasitic = 300 tons x 0.210 kW/ton x 2,500 hr x $0.030/kWh = $4,725/Yr

4. 1st Year Operational Costs = Energy Cost + Demand Cost + Maintenance Cost

   Existing Chiller = $22,500 + $5,175 + $31,753 + $3,750 = $63,178/Yr

   New Chiller = $12,375 + $4,725 + $21,603 + $1,875 = $40,578/Yr

   New Chiller Cost Savings = $63,178 - $40,578 = $22,600/Yr

5. New Chiller Cost = Material Cost + Installation Cost
   = ($250/ton x 300 tons) + ($200/ton x 300 tons)
   = $75,000 + $60,000
   = $135,000

6. Simple Payback = New Chiller Cost/Cost Savings
   = $135,000/$22,600
   = 5.97 Years

The example shows how chiller replacement can be cost effective based on low efficiency. There is evidence that incorrectly sized chillers is a common problem. Market research done by San Diego Gas and Electric shows that most chillers operate at or near 50 percent load most of the time. In light of this information

Table 4. Yearly Demand Summary

Month	Demand Charge ($/kW)	Existing Chiller Demand (kW)	Existing Chiller Demand ($)	New Chiller Demand (kW)	New Chiller Demand ($)
Jan	12.65	0	0	0	0
Feb	12.65	0	0	0	0
Mar	12.65	179	2,262	131	1,651
Apr	12.65	252	3,188	176	2,220
May	12.65	307	3,882	209	2,647
June	12.65	380	4,808	254	3,216
July	12.65	398	5,040	266	3,359
Aug	12.65	398	5,040	266	3,359
Sept	12.65	380	4,808	254	3,216
Oct	12.65	215	2,725	153	1,935
Nov	12.65	0	0	0	0
Dec	12.65	0	0	0	0
Sum			31,740		21,617

it is worthwhile to consider the sizing and performance of larger chillers. In some cases, it can be cost effective to replace a chiller that is oversized with a smaller one because it will run at a higher efficiency since it will be closer to full load. In other cases there may be two chillers both running at some part load efficiency when they could be replaced with one, running at a higher full load efficiency.

There is a lot of potential savings in chiller replacement but it is not a low cost issue so it must be given careful consideration. Existing energy use, cooling load requirements, and the capabilities of the new equipment must each be carefully considered. The first step is to get a an accurate picture of how the existing equipment is performing.

The percent load profile of a chiller is the best indicator of equipment performance and energy use. A load profile can be generated with a temporary electrical meter on the chiller circuit. Be sure to include any parasitic loads. With a percent load profile and a part load efficiency table for your particular chiller model, available from the manufacturer, a very accurate assessment of chiller operational cost can be made. NFESC can do a performance evaluation and make recommendations on a reimbursable basis.

Energy Savings

Replacing old, inefficient chillers is not the only energy conservation opportunity (ECO) to consider for chilled water systems. There are several common low cost/no cost ECOs, mostly operational. These ECOs are outlined in TechData Sheet TDS-2032-E&U, "Low Cost/No Cost Energy Conservation Opportunities" of October 1996.

Another opportunity for conservation is adjustable speed drives. They can be used on any of the motors in the chilled water system that have a variable load. Refer to TechData Sheet TDS-2011-E&U, "Adjustable Speed Drives" of January 1995 for more information.

A last suggestion for energy conservation would be to investigate centralizing or decentralizing the chilled water distribution.

For more information on chillers, contact **Mr. Darryl Matsui** at (805) 982-3487, DSN: 551-3487, or Internet: dmatsui@nfesc.navy.mil or **Mr. Mike Rocha** at (805) 982-3597, DSN: 551-3597, or Internet: mrocha@nfesc.navy.mil.