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Advanced Gas Cooling Technology Demonstration Program at Air Force Installations, Fiscal Year 1996

by
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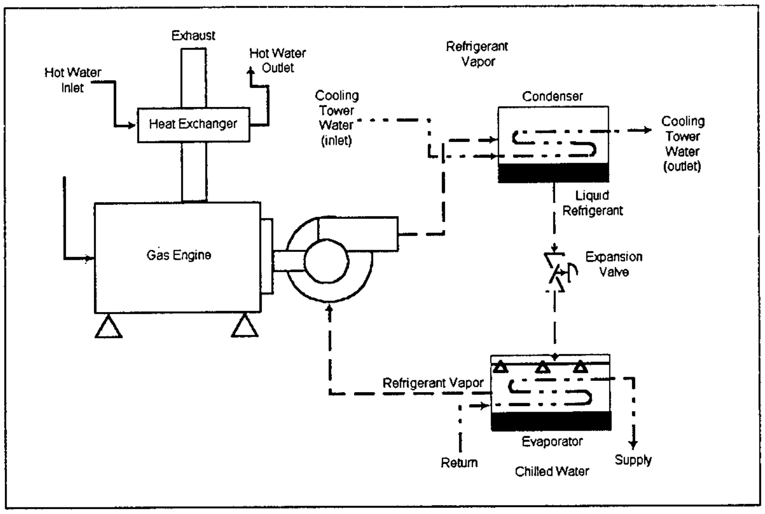

Approximately one-third of all energy consumption and two-thirds of total energy expenditures at Department of Defense fixed facilities are electricity related. Electrical energy costs can be reduced by conserving electrical energy or by replacing electrical consuming devices with alternate fuel-driven mechanisms, e.g., by natural gas cooling. Use of state-of-the-art gas cooling technologies can reduce an installation's electric demand, provide domestic hot water, and lessen environmental impacts normally attributed to electric-driven chillers.

This study evaluated absorption chillers, engine-driven chillers, and desiccant dehumidification systems as possible alternatives to electric cooling equipment at Air Force facilities. Site candidates were screened, economic costs/benefits analyses of applying gas cooling technologies at specific locations were done, and new equipment was purchased, installed, and tested at approved sites. Recommendations were made regarding the use of gas cooling technologies at Air Force facilities as a whole.

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Foreword

This study was conducted for the Headquarters, Air Force Civil Engineer Support Agency (HQ AFCESA), under Military Interdepartmental Purchase Request (MIPR) No. N94-92, Work Unit WL4, "Evaluation and Application of Gas Cooling Technologies." The technical monitor was Freddie Beason, and the contract monitor was Rich Bauman, AFCESA/CESE.

The work was performed by the Utilities Division (UL-U) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Timothy W. Pedersen. Chang W. Sohn is Acting Chief, CECER-UL-U; Martin J. Savoie is Acting Operations Chief, CECER-UL; and Gary W. Schanche, CECER-UL, is the associated Technical Director. The USACERL technical editor was William J. Wolfe, Technical Resources.

Dr. Michael J. O'Connor is Director of USACERL.

Contents

1 Introduction

Background

Approximately one-third of all energy consumption and two-thirds of total energy expenditures at Department of Defense (DOD) fixed facilities are electricity related. Summer air-conditioning loads account for 30 to 60 percent of the total energy expenditures. Natural gas is another major energy resource available to DOD fixed facilities, even though it accounts for only 38 percent of the fuel consumed and only 20 percent of the total energy expenditures (Cler 1995).*

The apparent high cost of electricity is a result of peak cooling loads that can occur over short periods of time and can cause high fluctuations in the utility load profile. Utility companies must therefore operate their expensive and inefficient peaking plants to meet this demand. This extra cost is passed to the consumer in the form of time-of-day and seasonal variation rates, seasonal variations in demand charges, and/or a ratchet clause.

Peak cooling requirements at DOD facilities generally occur when utility rates are highest. This portion of an installation's total bill can exceed 50 percent. Use of state-of-the-art gas cooling technologies to replace existing electric-driven cooling devices can offer many benefits, including reducing the installation's electric demand, providing domestic hot water, and lessening environmental impacts normally attributed to electric-driven chillers.

These energy costs at DOD fixed facilities can be reduced by conserving electrical energy or by replacing electrical consuming devices with alternate fuel-driven mechanisms. Absorption chillers, engine-driven chillers, and desiccant dehumidification systems are all being evaluated as possible alternatives to electric cooling equipment.

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*Cler, Gerald L., *Evaluating Gas-Fueled Cooling Technologies for Application at Army Installations*, Technical Report (TR) 96/14/ADA304704 (U.S. Army Construction Engineering Research Laboratories [USACERL], February 1996).

Objectives

The overall objective of this study was to determine the applicability of gas-cooling technologies to Air Force facilities as a whole. Task objectives that combine to meet this overall objectives were to:

1. Screen site candidates for locations that would benefit from application of gas cooling technologies
2. Analyze the economic costs and benefits of applying gas cooling technologies
3. Assist in purchase, installation, and acceptance testing of new equipment at approved sites
4. Monitor equipment performance for 1 to 2 years
5. Make recommendations regarding the use of gas cooling technologies at Air Force facilities as a whole.

Approach

Candidates for gas cooling technologies include facilities such as hospitals, dormitories, and other installation facilities that require large cooling loads and hot water capabilities. This study investigated potential implementation sites, developed the equipment purchase documentation, and procured the equipment for installation in the following tasks:

1. Potential sites were screened for candidacy by taking into consideration the electric and natural gas rate structures, cooling and hot water load profiles, and site-specific operating conditions. This process produced a list of economically viable demonstrations sites. USACERL and the Air Force Civil Engineer Support Agency (AFCESA) performed site visits to these installations to determine the appropriate gas cooling technology for funding and to gather site-specific information on the design and estimated installation costs of the proposed system.
2. Equipment purchase documentation was developed for the sites identified as good candidates for gas cooling technology. This document included equipment purchase, installation, start-up, acceptance testing, and first year warranty and maintenance information.
3. Equipment purchase, installation, and acceptance testing were completed for approved sites. Standard documentation was used as the basis for an Invitation for Bid (IFB). This IFB was advertised for each implementation site identified. On contract award, USACERL and AFCESA personnel were available to assist in the design review stage and will be available to inspect the installed systems. USACERL representatives were also available to

supervise and evaluate the acceptance testing results for the installed system.

4. Monitoring equipment was specified for each facility to record data for 1 or 2 years. The data will be used to determine the applicability of the particular technologies to Air Force facilities as a whole. Both technical and economical aspects of system performance are to be monitored.

These tasks were programmed to occur in FY96 and FY97. This report details tasks to date.

Payoff

Installations that use gas cooling technologies will realize environmental and economic benefits. The environmental benefit stems from the fact that these technologies use refrigerants with less potential to deplete the ozone than older cooling technologies. Absorption and desiccant chillers are free of ozone-depleting CFC and HCFC compounds while engine-driven chillers typically use HCFCs or HFCs with low or no ozone-depleting potential. The economic benefits of gas cooling are varied. Gas chiller equipment costs are higher than conventional electric-driven vapor-compression equipment. To help offset this cost differential, areas with large electric-to-gas cost ratios are the first to be considered for gas cooling technology. This will minimize the payback period for the incremental cost of the project. Some applications reduce costs in other areas by providing energy for the production of domestic hot water and/or boiler makeup water. The use of these applications can increase the overall cost effectiveness of the system.

2 System Characteristics

Absorption Chillers

Absorption chillers were first developed over 100 years ago. The first patent for this technology was issued in 1859; further technological advances occurred into the 1950s. Absorption cooling systems were fine-tuned for commercial use by large manufacturers in the 1950s and 1960s but their popularity declined in the late 1970s due to the inexpensive cost and abundance of electricity. Absorption chillers rely on a cycle of condensation and evaporation to produce cooling that is similar to the vapor-compression cycle. However, in absorption chillers, the mechanical compressor of the vapor-compression cycle is replaced by a heat source. This heat source is either direct-fired via a burner or indirect-fired via steam, hot water, or waste heat from other processes.

Figure 1 shows a single-effect, or single stage, lithium bromide/water absorption chiller. The components that make up the cycle are:

- *Evaporator.* As the building chilled water circulates throughout the evaporator, it releases heat to the low pressure liquid refrigerant. The refrigerant boils and is transferred to the absorber.
- *Absorber.* The cold low pressure refrigerant vapor entering the absorber is absorbed by the lithium bromide (absorbent) to form a liquid solution of lithium bromide/water. This solution is then pumped up to the condenser pressure using a liquid pump. Heat is released to the cooling tower water during the absorption process.
- *Generator.* The generator is the most energy-intensive step of the absorption chiller. The heat input from the burner boils off the refrigerant, which flows to the condenser. The resulting concentrated lithium bromide solution is pumped back to the absorber. Sometimes the lithium bromide solution is passed through a liquid-to-liquid heat exchanger as a preheater for the lithium bromide/water solution before entering the generator.
- *Condenser.* The hot liquid refrigerant enters the condenser where it is cooled and condensed to a liquid. Again, heat is released to the cooling tower water and the hot liquid refrigerant is expanded into the evaporator.

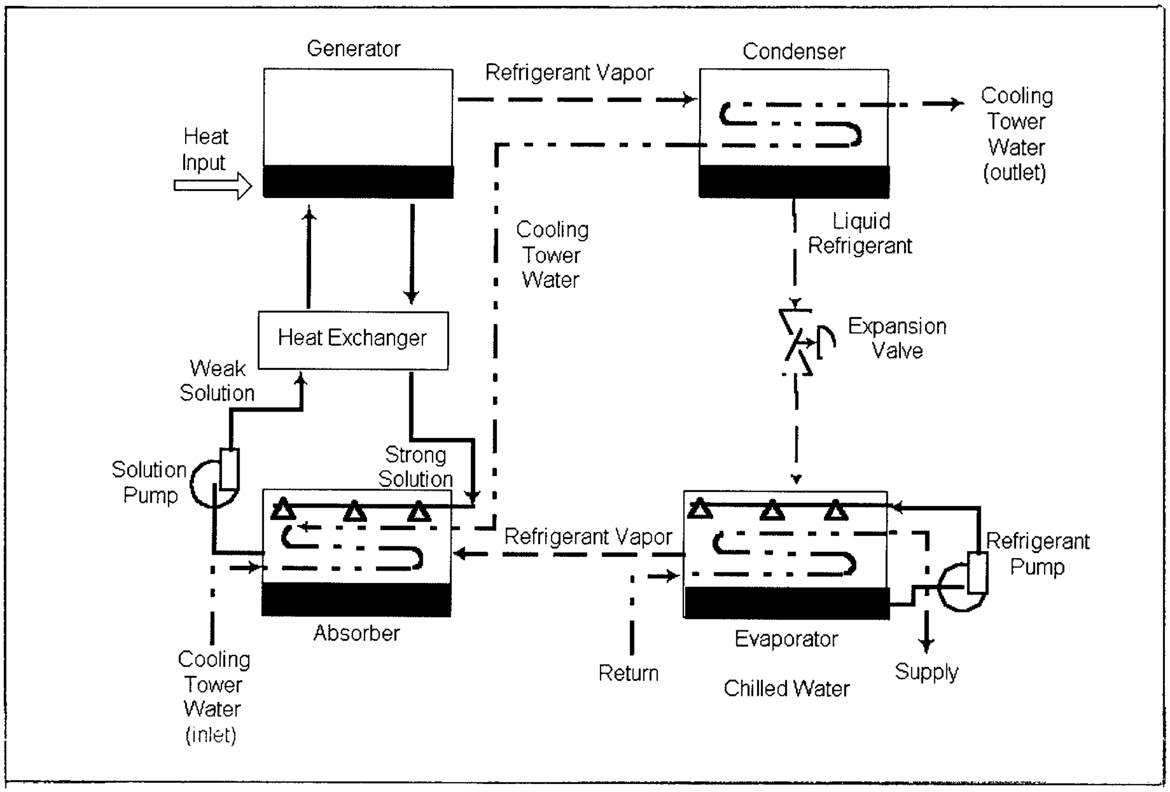

Figure 1. Single-effect lithium-bromide/water absorption chiller.

The COP for indirect-fired, double-effect absorption chillers ranges from 1.2 to 1.46. Boiler efficiency is not included in the energy consumption calculations. Direct-fired, double-effect absorption chillers have a lower COP, ranging from 0.90 to 1.10. Boiler efficiency is not considered since the generator is directly-fired and the efficiency is accounted for during the COP calculations. Generator temperatures required for double-effect chillers approach 300 °F with steam pressures of 120 psig.* Consequently, direct-fired units must be fueled by natural gas or oil.

Absorption chillers can reach 10 percent capacity while maintaining relatively good efficiencies. Part loads are achieved by varying the flow of steam or firing rate of the burner, which changes the production of concentrated absorbent. To enhance part load performance, some units use multiple capacity burners.

Gas Engine-Driven Chillers

Gas engine-driven chillers have been successfully marketed in the United States since the 1960s. Gas shortages in the mid 1970s and an increase in market

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* °F = (°C × 1.8) + 32; 1 psi = 6.89 kPa.

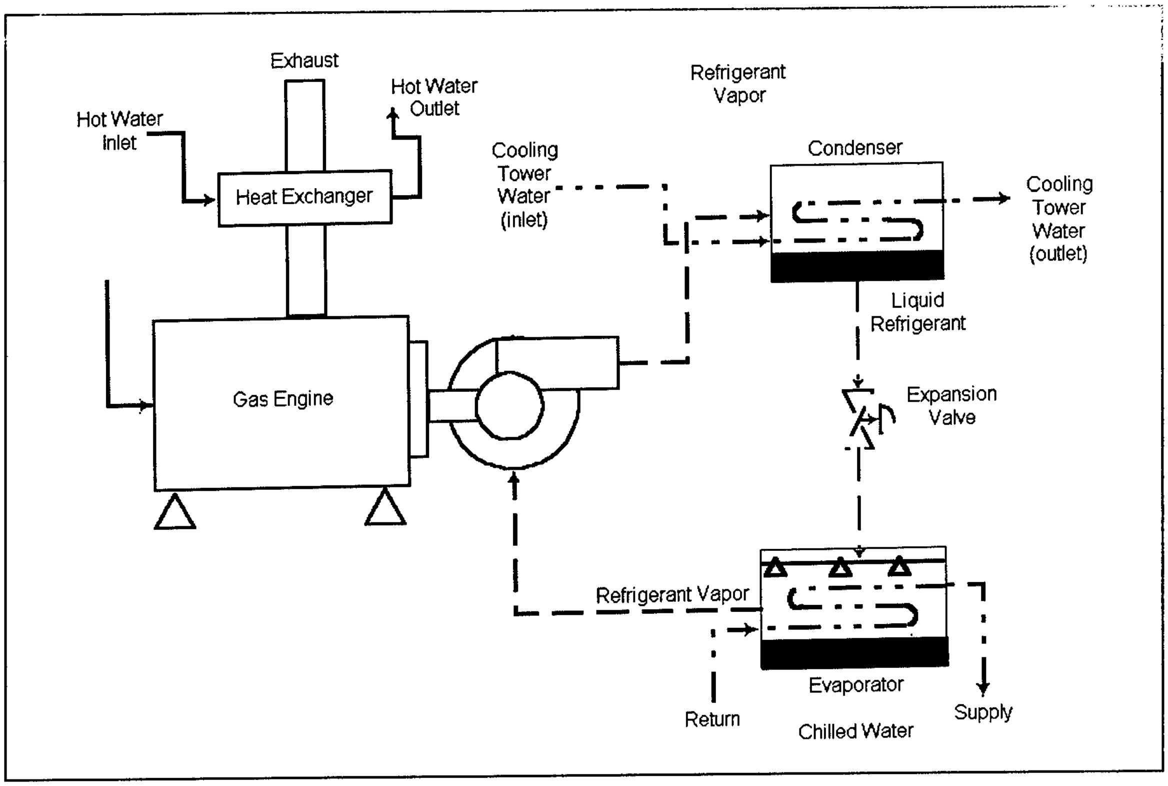

Figure 2. Gas engine-driven chiller.

shares moving toward electric cooling systems have virtually destroyed the market for gas engine-driven chillers. However, the reliability on properly maintained systems was high.

An engine-driven chiller is similar to an electric chiller except that the motor that would drive the chiller is replaced by a gas engine. An open drive configuration is required since the engine must be housed outside the compressor casing. The waste heat from the engine could be used for service water heating or as the steam provider for an absorption chiller unit. Other than those minor changes, an engine-driven chiller operates in the same manner as conventional vapor compression cycle. Figure 2 shows a gas engine-driven chiller. The components that make up the cycle are:

- *Evaporator.* As the building chilled water circulates throughout the evaporator, it releases heat to the low pressure liquid refrigerant, causing it to boil.
- *Compressor.* The engine-driven compressor pulls the refrigerant vapor from the evaporator and compresses it to a higher temperature and pressure.
- *Condenser.* The high temperature and pressure refrigerant enters the condenser where the cooling water or air cools the refrigerant, causing it to condense to liquid form.

- *Expansion Valve.* The liquid refrigerant is then passed through an expansion valve into the evaporator. This reduces the pressure and temperature of the refrigerant.

The performance of engine-driven chillers is primarily a function of the gas-engine efficiency and the compressor COP. The efficiency for a gas engine ranges from 0.27 to 0.33 while the compressor COP ranges from 4.5 to 6.5. The lower efficiency value is for a reciprocating type compressor and the higher value is for a screw type compressor. A combined COP for the chiller plant will run from 1.22 to 2.15.

In general, the COPs for engine-driven chillers are slightly higher than those for absorption chillers. The increase in performance translates into cooling towers that are smaller than those required by absorption chillers yet larger than those required by electric chillers. It is important to keep in mind that an engine-driven chiller requires more maintenance than a comparable absorption or electric-driven unit.

The ability to operate an engine-driven chiller at off loads by modulating the engine speed results in good part-load performance. A screw compressor maintains good part-load performance down to 10 percent because of its ability to operate at variable displacements. A reciprocating compressor offers good off-load performance down to about a 50 percent load. At that point, the engine speed must remain constant and further reduction in load is accomplished by unloading the cylinders. It is in this regime where part-load performance degrades rapidly.

Desiccant Dehumidification System

Desiccant systems use either absorption or adsorption processes to dehumidify the air. Common desiccants are lithium chloride, silica gel, and molecular sieve. As the air passes through the desiccant, the latent heat load is converted to a sensible heat load resulting in warm, dry air. This air is then cooled to the desired process air temperature.

In comparison, a conventional vapor-compressor chiller cools the air to be conditioned below its dew point thereby causing the moisture in the air to condense in the evaporator. The evaporator temperature must be low if it is to be used for applications requiring low humidity levels. This results in a lower COP. The process air is then too low for application purposes and must be reheated to the desired levels.

There are two basic types of desiccant cooling systems:

1. *A "Standalone" Desiccant System.* The process air enters the desiccant section where the moisture is absorbed or adsorbed by the desiccant. This results in warmer, dryer air. The air is then cooled by evaporation to the desired temperature. Two slight variations on this system occur when process air is recirculated or vented.

2. *A "Latent-Load Reducer" Desiccant System.* This is sometimes referred to as a "hybrid system" since it combines the components of a vapor-compression system with a desiccant system. This allows the system to meet both sensible and latent cooling loads. The desiccant system removes the latent load while the vapor compressor system meets the sensible load. A combination of heat exchangers and a vapor compression system meets the sensible load requirement. Energy is saved since no overdrying or reheating is required. The required vapor compression system can be smaller because the latent cooling load is processed under the desiccant system.

Both types of desiccant cooling systems operate on the same physical concepts. The process involving the "standalone" system is the least complicated:

1. Process Air Side

- *Desiccant Wheel.* The airstream enters the supply air side and is heated and dehumidified by the desiccant wheel.
- *Heat Exchanger.* The air leaving the desiccant wheel is further cooled in a heat exchanger. The heat is lost to the air on the regeneration side of the system.
- *Humidifier.* A second evaporator cooler creates a sensible cooling effect before the air stream discharging to the space.

2. Regeneration Air Side

- *Humidifier.* The regeneration air is cooled by evaporation and is transferred to the heat exchanger.
- *Heat Exchanger.* The air from the humidifier is heated by energy transferred from the process air side of the heat exchanger.
- *Reactivation Air Heater Coil.* The air is further heated to a high enough temperature to reactivate the desiccant in the wheel.
- *Desiccant Wheel.* The air entering the desiccant wheel is hot enough to remove the moisture from the desiccant. The discharge air is now cooler and more humid.

The COP for a desiccant system ranges from 0.7 to 1.5. The performance calculation for desiccant systems is not as straightforward as it is for other systems. Difficulty arises because the desiccant system converts latent load to sensible load and then the sensible load must be removed via heat exchanger and/or an electric vapor-compression system. The electric consumption for process and reactivation fans and wheel drives must also be considered in the performance calculations.

Data Gathering

Equipment information and data used in the feasibility analyses for each site were compiled from electric-driven, gas engine-driven, and absorption chiller and desiccant dehumidifying system manufacturers. The data were curve-fitted or averaged to provide accurate information about the various sizes and types of chillers currently on the market. Specific information included chiller capacity, budget equipment and installation costs, equipment performance, maintenance and operating costs, and the required utility services. This information is constantly updated to reflect current information.

Equipment Capacity

Though there is overlap in the electric chiller size category, small chillers are usually reciprocating, medium chillers are screw-type, and larger chillers are centrifugal. The overlap usually occurs in the medium to large size range.

Gas engine-driven chillers cover the same capacity ranges as the electric-driven chillers, but are typically limited in the number of available capacities. As this technology advances, the voids in available capacities are rapidly filling. As with the electric-driven chillers, small capacity chillers are reciprocating, medium capacity are screw, and the larger capacities are centrifugal.

Absorption chillers are available in a wide variety of capacities and are either direct or indirect-fired, and single or double-effect. Chillers with capacity greater than 100 tons[*] come in an array of configurations while smaller chillers have somewhat limited configuration options.

Desiccant dehumidifying systems are available in a variety of capacities. Desiccant systems are typically used in buildings with high ventilation air requirements or moisture-control problems.

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[*] 1 ton (refrigeration) = 3.516 kW.

Budget Equipment and Installation Costs

Budget equipment and installation costs were taken from a variety of manufacturers and were reduced to a usable form. No one specific manufacturer is associated with the information.

The information was general and based on two assumptions: (1) installation costs included only the chiller and not associated equipment, and (2) the installation does not require any rework and is rather straightforward. This information is generic. Any on-site information available should be used in a supplemental form.

Two main considerations in developing cost correlation include capacity and performance. Capacity is generally inversely proportional to the unit cost per unit of cooling while performance is directly proportional to unit cost per unit of cooling. The data represents electric, gas engine, and absorption chillers and desiccant dehumidifying systems. Since there are large variations between applications, it is virtually impossible to develop curves representing true installation costs. This data is used for a first-cut estimate of project costs. If the review shows that it is cost effective to implement gas cooling technology, a detailed budget cost should be developed and a more detailed cost analysis should be done.

The relationship between capacity and cost may prompt a quick decision to install a single large capacity chiller to meet the load demand rather than two smaller capacity chillers. This approach is rarely cost effective. It is important to consider the fraction of installed capacity at which the chiller plant will typically operate. Rarely is a chiller operated at its rated capacity more than a few hundred hours per year. Two or more smaller chillers may result in more efficient operation, lower life-cycle costs and lower operating costs. In some cases, a hybrid chiller plant makes economic sense. A hybrid plant is a combination of electric- and gas engine-driven chillers and sometimes leads to lower life-cycle and operation costs. The plant's operation would be cycled to take advantage of the off-demand portion of the electric utility bill. The installation of more than one chiller will also ensure continued service during scheduled and unscheduled maintenance.

Equipment Performance

One goal of this study was to do a cost comparison of electric and gas chiller technologies and analyze the results. Such a comparison must account for the unique characteristics of each of these technologies.

The performance of absorption chillers is independent of capacity, but dependent on whether the chiller is steam- or direct-fired, and single- or double-effect. It is important to remember that the boiler efficiency and parasitic power requirements must be accounted for when calculating economic cost comparison of indirect-fired absorption chillers.

Air-cooled, engine-driven chillers usually do not exceed 250 tons in capacity. Water-cooled, engine-driven chillers have higher performance ratings, but they do come with additional costs. A cooling tower will be required causing maintenance and installation costs to rise. This additional cost is usually outweighed by the lower operational cost of these machines. In general, water-cooled equipment should be considered for equipment exceeding 100 tons capacity. This capacity limit will continue to decrease with advances in cooling tower technology. As with absorption technology, it is important to consider parasitic power consumption when performing an economic cost comparison.

Maintenance and Operation Costs

Regularly scheduled maintenance is the only way to ensure the proper operation and performance of equipment throughout its useful life. All types of chillers have some common maintenance activities, including: required annual checkout and calibration of all controls, regular tube cleaning, periodic check of refrigerant and oil levels and ancillary equipment, and periodic service of the pumps and fans associated with the condensers and evaporators. Additionally, absorption chillers require regular checks on the inhibitors. The quality of the refrigerant and absorption fluids must also be checked.

Gas engine-driven chillers require slightly more maintenance. Routine maintenance includes changing oil, changing oil and air filters, checking belts and fluid levels, changing spark plugs and wires, and adjusting valves, ignition timing, and carburetor settings. Additionally, the engine will require periodic valve maintenance, also referred to as “top end overhaul.” Depending on usage and maintenance practices, the engine will require a complete overhaul on a 5 to 10-year (15,000 to 45,000-hour) cycle. Appendix A shows a sample maintenance schedule for different types of engines.

Since the majority of facilities in the United States have electric-driven chillers, personnel are already familiar with the maintenance procedures. The introduction of gas cooling technology into these facilities will require retraining of personnel or the purchase of maintenance agreements. The costs of these agreements are usually a function of the chiller capacity. These agreements are not exclusive to gas engine-driven chillers and can also be purchased for electric-driven chillers.

As expected, the maintenance cost of gas engine-driven chillers is somewhat more expensive than that of an electric-driven or absorption chiller or desiccant dehumidifying systems. Annual maintenance costs are based on the annual equivalent full load hours of operation, maintenance costs, and chiller capacity. The maintenance costs of gas engine-driven chillers are approximately 1.5 to 3 times higher than their electric counterparts with the cost of absorption units and desiccant dehumidifying systems falling somewhere in between.

Water-cooled chillers require water purchase, treatment, and disposal. Generally the makeup water requirements for an electric-driven chiller are lower than its gas cooling technology counterparts. The cost of makeup water (gal/t-h) for an absorption chiller is 50 to 60 percent more than for the electric chiller.* A gas engine-driven chiller requires a 10 percent cost increase, based on the maintenance and treatment of makeup water and the required quantity of water for each type of technology.

Equipment Commissioning and Instrumentation:

Equipment commissioning is vital to ensure the equipment operates in conformity with the design intent. The process of commissioning starts at the beginning of the design phase and ends when the equipment is turned over to the customer. The need and scope of commissioning is identified in the beginning, but remains flexible throughout the design. It is important to remember that each project is unique and warrants special consideration. Available resources and other project-specific considerations have a direct impact on the design and construction time and costs.

The commissioning for this demonstration program requires a simulated load be induced on the gas cooling equipment. These considerations are highlighted before the start of the design phase and emphasized throughout the remainder of the project. The load is derived from local boilers or rented mobile hot water or steam generators. In all cases, additional piping is required. Some facilities have opted to use additional heat exchangers and pumps in addition to the extra piping. Once the project is constructed, it the responsibility of the contractor to verify the equipment is capable of performing at the level dictated in the specification. This includes meeting the COP at full- and part-load conditions as well as the IPLV value. If the equipment fails to meet acceptable performance, the necessary corrective action will be performed. The commissioning procedure will then be repeated until all specified levels of performance are achieved. The commissioning is scheduled to be conducted just before turning the equipment over to the customer. Commissioning in itself will not replace any other aspects of the design and construction process, but should reveal defects that in turn can be addressed before equipment acceptance. The results are a piece of equipment

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* 1 gal = 3.78 L.

proven to operate in the field, that meets the manufacturer's specifications and the customer's needs and expectations.

As part of the commissioning procedure, it is necessary to monitor and record operating parameters, which become inputs to a USACERL-developed spreadsheet (Appendix B) that generates relevant economic results. Some equipment manufacturers have installed the capability to collect the necessary information and store it in a format easily accessible for downloading from a remote computer. Others require additional equipment to perform the same function. The data points required to successfully perform equipment commissioning is a function of equipment type. The monitoring equipment specified in the demonstration program will be used in the commissioning process as well as performance monitoring through the first year of the equipment life. USACERL will perform remote monitoring to analyze the effectiveness of gas cooling equipment at each of the demonstration sites. The results will be detailed in a subsequent report. Appendix C includes a sample instrumentation scheme used at a specific site where the gas cooling equipment required additional hardware to monitor its performance.

Economic Evaluation

The data discussed in the previous sections are used as inputs to a USACERL-developed evaluation spreadsheet. Some site-specific information is required to complete the spreadsheet. Additional information includes utility rates, cooling loads, and, if heat recovery from an engine-driven chiller is being considered, boiler efficiency. Spreadsheet output summarizes the economic results and indicates the relative costs, benefits of each cooling technology, and gives a breakdown of annual operating costs for each technology. It includes the cost of natural gas, electric energy and demand, maintenance, and makeup water. Appendix B includes a sample spreadsheet.

3 Environmental Issues

DOD Fixed Facility Energy Consumption

The Defense Utility Energy Reporting System (DUERS) was commissioned to obtain energy consumption, inventory, and cost data from each of the services. DEIS tracks all purchased and nonpurchased energy consumption excluding nuclear. The major commands (MAJCOMs) use this information to evaluate trends and determine progress toward meeting energy reduction goals. The majority of energy consumed by the services is made up of natural gas and electricity, and all three branches of the Armed Services consume approximately the same amount of energy for their fixed facilities. The proportions of fuel types used are roughly the same, except for the Air Force, which consumes more natural gas and less fuel oil than the other two services. Using the 1985 data as a baseline, all services have reduced overall energy consumption. However, all three services have increased the amount of electricity consumed leading to an increase in energy costs. Natural gas consumption has remained relatively stable.

DOD Fixed Facility Energy Costs

Facilities in each branch of the armed services consume nearly equal amounts of natural gas and electricity. Despite energy conservation efforts, energy costs are escalating—the reverse of what one might expect. In fact, fuel costs are only one part of the overall cost associated with implementing new technology at DOD facilities. Electricity costs account for nearly 70 percent of the total facility costs while natural gas accounts for less than 20 percent. In fact, electricity cost over four times that of natural gas on a per unit of energy cost. Clearly, other less expensive options should be considered with electricity when available. The use of new natural gas technologies could reduce DOD operating costs by increasing the efficiency of existing gas systems, converting more expensive fuel technologies to natural gas, applying overall new technologies, and developing electrical generation capabilities. All economic analysis must be made on life-cycle cost basis, including capital equipment investments and operations and maintenance costs.

Environmental Impact of Gas Cooling Technology

Several environmental issues must be discussed when evaluating any new or existing cooling technology. The most obvious is the impact of refrigerants on the ozone layer. The impact of natural gas combustion products, in particular carbon dioxide (CO_2) on global warming is of equal concern, but usually does not receive as much attention.

Some believe the release of chlorofluorocarbons (CFCs) is a major contributor to the destruction of the ozone layer located in the stratospheric region of the atmosphere. As these molecules make their way to the stratosphere, they deplete ozone (O_3) through a catalytic reaction. This concern has led to a congressional mandate to eliminate the use of CFCs, particularly in chiller applications. New chillers are usually shipped with either hydrochlorofluorocarbons (HCFCs), which have a significantly lower ozone depletion potential, or hydrofluorocarbons (HFCs), which have a no ozone depletion potential. However, a large portion of existing chillers are charged with CFCs and the problems associated with these units are not eliminated.

On a daily basis, solar radiation penetrates the earth's atmosphere, heating it to a given level. This energy is reradiated back into the atmosphere thereby creating a cooling effect. Equilibrium between these two modes of energy transfer is what allows earth to remain habitable. Various factors contribute to the rate at which this energy is radiated and reradiated through the earth's atmosphere. Much research has been conducted in this process. In recent years, some scientists have come to believe there is an imbalance between these energy transfer modes and that, as a result, the earth is warming. They believe this warming effect is caused by an increase of CO_2 in the atmosphere produced by combustion processes. These combustion processes include those associated with the internal combustion engine, various manufacturing processes and combustion processes used for electricity generation. The release of refrigerants in the atmosphere is also thought to contribute to this warming effect. This presumed temperature increase in the earth's atmosphere has been termed by scientists and politicians as the "Greenhouse Effect."

Alternative Refrigerants

The ozone depletion and global warming concerns has changed the criteria used in the selection of refrigerants. At one time, a refrigerant was selected based on its thermodynamic properties, flammability limits, toxicity levels, molecular stability, and cost. These new concerns have added considerations associated with a refrigerant's ozone depletion potential and global warming potential to the list of selection criteria. Significant strides have been made in developing and implementing refrigerants with zero ozone depletion potential so that, in the future, the contribution of refrigerants to ozone depletion will no longer be an issue. The issue of global warming is a more complex problem; a solution is not as easily determined. Because of this, a Total Equivalent Warming Impact (TEWI) has been developed and can be calculated for each type of cooling technology. These values can also be used to help determine which cooling technology is appropriated for a given site. The TEWI is the sum of the Equivalent Warming Impact from direct effects and the Equivalent Warming Impact from indirect effects. Direct effects are those attributed to the intentional or unintentional leakage of refrigerants that have nonzero global warming potential. Indirect effects are those associated with the combustion of fossil fuels to drive the chiller and its auxiliary components. The determinations of the TEWI value for the available cooling technologies, along with sample calculations, are detailed in USACER TR 96/14

4 Sites

Screening of Air Force Facilities

Initial site screening identified a number of Air Force bases where gas cooling technologies could be considered for replacement of failed or aging chillers. System installations at these sites were found to be technologically and economically viable solutions to existing problems. A technologically viable solution was one that resulted in a system capable of providing the necessary cooling capacity for the given scenario. A solution was considered economically viable if it had a simple payback less than 10 years and was based on the incremental capital, maintenance and utility cost differential between the gas cooling option and an electric-driven chiller. The projects are in various phases of execution. Each project is discussed individually.

Andrews Air Force Base, MD

Andrews Air Force Base (AFB) submitted utility rate and chiller operation information for a retail store (Bldg. 1683) located on base. A preliminary screening of the project to replace an existing 200-ton, 24-year-old chiller with a new gas engine-driven chiller resulted in a simple payback greater than 20 years. The long payback did not make Andrews AFB an economically feasible project.

Columbus Air Force Base, MS

The T34/T38 training facility at the Columbus AFB currently is cooled by two, 329-ton, CFC-12 chillers, each of which can provide enough cooling to handle the design day load by itself. Failure to provide the necessary cooling will render the facility useless and result in costly delays in pilot training. A feasibility analysis was conducted based on data submitted by base personnel. Replacement of the worse of the electric chillers with a gas engine-driven chiller would give Columbus AFB greater resource capability and reduce the cost of cooling. A 250-ton gas engine-driven chiller was selected to replace one aging electric-driven chiller. The favorable 1:6 per unit cost of gas to electricity ratio and a high demand charge made installation of a gas engine-driven chiller even more attractive. The project had a simple payback period of 3 years. Based on this information, an architect/engineer (A/E) firm was contracted to begin design. After the 95 percent design review, the base decided not to accept the additional operation and maintenance workload, and terminated the project via a formal letter to AFCESA. This letter expressed the Base Civil Engineer's decision not to accept the additional operation and maintenance workload associated with the proposed gas engine-driven chiller. The design cost of this project was $30,600. The Columbus AFB point of contact (POC) is Tom Waller, tel.: (601) 434-7403.

Davis-Monthan Air Force Base, AZ

Davis-Monthan AFB currently had a 23-year-old, 400-ton, gas engine-driven chiller and a 24-year-old, 400-ton, electric-driven chiller at a facility where the peak cooling load was estimated at 350 tons. Both of these were candidates for replacement with one or two gas engine-driven chillers. During the summer of 1994, the gas engine-driven chiller experienced a bearing failure. The backup electric-driven chiller was brought up to speed and consumed an estimated $25k in demand charges before the gas engine-driven chiller was repaired. Assuming one of the chillers would be replaced to become the primary cooling provider, an analysis was conducted comparing an electric-driven chiller to a gas engine-driven chiller and a gas-fired absorption chiller. It was determined that ignoring heat recovery opportunities, installing a gas engine-driven chiller had a payback from 4.3 to 5.6 years.

AFCESA had done a previous feasibility study that showed an increase in the existing chilled water distribution system to be an economically beneficial alternative. An A/E performed a load analysis to determine the final chiller capacity if the base decided to expand the distribution system. Upon review of the study, it was decided that both aging chillers would be replaced with two, 650-ton, gas engine-driven chillers and the base would pay to expand the chilled water distribution system. No heat recovery options were available at this site. Ignoring heat recovery opportunities, installing the 650-ton gas chillers has an incremental simple payback of 7.8 years. This project has been designed and awarded with construction activities scheduled to begin in the 2d quarter of FY97, at a:

- total design cost funded by AFCESA: $72,000 (3400—FY94)
- total construction cost funded by AFCESA: $1,621,000 (3080—FY94).

The opportunity to replace a 250-ton, CFC-11 chiller at the DMAFB hospital with a gas engine-driven chiller was also identified. The plant was assumed to have approximately 2200 Effective Full Load (EFL) hours of cooling for a 12-month period. A feasibility study similar to the previous one resulted in a gas engine-driven chiller being more favorable with a payback of the incremental investment in 4.5 to 5.6 years.

The site visit revealed the age of the 250-ton hospital chiller to be no more than 5 years. The newness of this chiller resulted in the elimination of the hospital as a possible candidate. It was also determined that a study of the hospital's heating and cooling facilities as a whole should be conducted by the base to optimize the configuration of exiting and future equipment installations. The Davis-Monthan AFB POC is Steve Weleck, tel.: (520) 228-4253.

Dobbins Air Reserve Base, GA

Dobbins ARB submitted utility rate and chiller operation information for the Wing Headquarters. A preliminary screening of the project to replace an existing 15-year-old, 60-ton chiller with a new gas engine-driven chiller resulted in a simple payback greater than 20 years. The long payback does not make Dobbins ARB an economically feasible project.

Dover Air Force Base, DE

Dover AFB submitted utility rate and chiller operation information for a retail store (Bldg. 266) and the Flight Simulator Building (Bldg. 206). A preliminary screening of the retail store (Bldg. 266), which was being cooled by an aging 225-ton chiller, resulted in a payback greater than 20 years. This study considered replacing the existing unit with a new gas engine-driven chiller. Since the payback was longer than 10 years, it was not considered to be economically feasible. The Flight Simulator Building (Bldg. 206) was being cooled with a 130-ton centrifugal chiller and a 25-ton DX unit. The payback analysis looked at replacing both units with a single 155-ton, gas engine-driven chiller. The resulting payback was greater than 20 years. Therefore Dover AFB was not considered as a gas engine-driven chiller demonstration site.

Dyess Air Force Base, TX

Dyess AFB submitted utility rate and chiller operation information on a 120-ton central chiller with service to four dormitories and one administrative building. The existing chiller is over 10 years old and is in average condition. A preliminary screening of the project to replace the existing 120-ton electric chiller with a new gas engine-driven chiller resulted in a simple payback greater than 10 years. The long payback did not make Dyess AFB an economically feasible project. The total project management cost funded by AFCESA was $13,600.

Keesler Air Force Base, MS

The U.S. Army Corps of Engineers (USACE) Engineering and Support Center in Huntsville, AL completed negotiations with the contractor to install a two-wheel desiccant unit at the Gaude Lanes Bowling Center located at Keesler AFB, MS. This unit will dehumidify 4400 cfm* of outside air prior to the air being

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* 1 cfm (cu ft/minute) = 0.028 m^3/minute.

introduced into the existing HVAC system. Estimated completion date is 2d quarter of FY97. The total project management cost funded by AFCESA was $13,600 (3400 [type of Air Force O&M funds] for FY94). The Keesler AFB POC is Gene Baker, tel.: (601) 377-5852.

MacDill Air Force Base, FL

At the 6th Medical Group Hospital, the 18,000 cfm desiccant unit has been operating since the beginning of June 1996, removing moisture from the 100 percent outside air being supplied to hospital operating suites. Work is in progress to connect the unit to a direct digital control (DDC) system that will monitor the unit's performance, which at present is checked remotely by modem.

Some additional project refinements may still be required: water softening for the evaporative cooler water and some adjustment of the controls to ensure the air supplied is not *too* dry at any time. The installation is somewhat unusual in that there is a pre-cooling coil upstream of the desiccant wheel, as well as a post-cooling coil. The post-cooling coil is typically required for final sensible cooling and/or some final dehumidification when the outdoor humidity is very high. A pre-cooling coil, usually not provided, was reportedly installed to provide some measure of "insurance" for the user should the desiccant unit not remove moisture as it should.

However, if the desiccant unit is capable of removing some (or all) of the moisture that the pre-cooling coil is now removing, some energy cost savings may be realized by reducing the load on the chiller and increasing the dehumidification load on the desiccant unit. It is recommended that consideration be given to deactivating the pre-cooling coil during a period when the operating suites are not in use to see if the sensible and latent loads can be met by the desiccant unit and post-cooling coil only. If so, consideration should be given to closing the pre-cooling coil valve under more stringent outdoor weather conditions to see if, or under what conditions, use of the pre-cooling coil is really necessary. It may be that the pre-cooling coil is only necessary is when either the post-cooling coil or desiccant unit is not functioning properly. The MacDill AFB POC is Jim Zaccari, tel.: (813) 828-5340.

McChord Air Force Base, WA

McChord AFB submitted utility rate and chiller operation information on a 175-ton central chiller with service to two administrative buildings. The existing chiller is 13 years old and in need of repair. A preliminary screening of the project to replace the existing 175-ton electric chiller with a new gas engine-driven chiller resulted in a simple payback greater than 20 years. The long payback does not make McChord AFB an economically feasible project.

Patrick Air Force Base, FL

Patrick AFB submitted utility rate and chiller operation information on an aging, 120-ton electric chiller at the NCO Club. The payback to replace the existing electric chiller with a gas engine-driven chiller is less than 10 years. The site visit revealed evidence of interior damage due to high levels of humidity within the building. It was recommended that a gas engine-driven chiller be installed to produce the chilled water. To reduce moisture damage, it was also recommended that a desiccant system be installed to service the redesigned air handlers. This hybrid system would meet the cooling load and increase the comfort level of the indoor space. There is also a design in place, currently at 30 percent, to replace the chiller, cooling tower, and air handlers. The statement of work for the design would be modified to reflect the installation of the hybrid system. Based on a review of the maintenance requirements for the gas engine-driven chiller, Patrick AFB decided not to participate in the Natural Gas Cooling Program. The Patrick AFB POC is Mark Brennan, tel.: (407) 494-7198.

Scott Air Force Base, IL

Scott AFB submitted utility rate information for Buildings 44, 1600, and 1601. The base also submitted operational characteristics for each chiller. Buildings 1600 and 1601 are two different mechanical buildings that serve the same space. The first analysis considered replacing 800 tons of cooling with a single unit. The payback for this scenario was greater than 10 years. A second scenario was investigated that replaced the 800 tons of cooling with two 400-ton units. The payback for the second scenario was also greater than 10 years. In both cases, the units were assumed to be used for base-loading purposes.

Bldg. 44 has an old 250-ton and two newer electric chillers that provide chilled water to several administrative buildings. Replacement of the old chiller with a new gas engine-driven chiller showed a payback of 8 years. Based on this analysis, a site visit was conducted. Bldg. 44 had sufficient room and easy access for the installation of the proposed chiller. However, there was some discrepancy between the chiller performance data provided to USACERL and the data measured by base personnel. Further analyses were suspended until more accurate data could be obtained. The Scott AFB POC is Roger Lee (618) 256-4115.

Tinker Air Force Base, OK

Tinker AFB is installing direct-fired, double-effect, absorption units as replacement units for three existing steam turbine-driven chillers in Bldg. 3001. This facility supports the energy requirements for depot industrial operations, a computer center and administrative space. The plant had eight, 1500-ton, steam turbine-driven chillers for a total capacity of 12,000 tons. Due to a reduction in required capacity, the new chillers will be rated at 1000 tons.

Minimal changes to the existing auxiliary structures are required. Commissioning for the new system will include technical support from USACERL and will occur in FY97. The total construction cost funded by AFCESA was $1,900,000 (3080—FY93). The Tinker AFB POC is Brad Brachur, tel.: (405) 734-7222.

Travis Air Force Base, CA

Travis AFB currently has four centrifugal chillers located in the hospital energy plant. Two of these are 384-ton units and the other two are 768-ton units. One 768-ton unit is being replaced via an emergency commodities purchase through Base Contracting. The remaining units are approximately 18 years old.

Electricity is provided by Pacific Gas and Electric (PG&E) in anticipation of switching to Western Area Power Administration (WAPA) power in the near future. PG&E's electric schedule was straightforward—made up of a power rate and a monthly demand charge. WAPA's electric schedule is two-tiered; a higher power rate is applied to conditions where the load factor is above 70 percent. Information supplied by the base indicated the load factor was typically greater than 70 percent during the summer months so the higher utility rates were used in the analysis. WAPA also had a monthly demand charge.

The analyses was divided into two scenarios. The first was to replace the existing 768-ton chiller with a single gas engine-driven chiller of comparable size. A gas engine-driven chiller is a prime candidate for replacement of the existing unit if for some reason PG&E power is used instead of WAPA. Payback is less than 10 years. Since this is unlikely, the cost of power supplied from WAPA should be used to determine the payback. If indeed the hospital is continually operating above the 70 percent load factor, the payback for a gas engine-driven chiller is greater than 10 years. If the hospital is continually operating below the 70 percent load factor, the paybacks increase to over 20 years with and without heat recovery. Operation that is not consistently above or below the 70 percent load factor will yield paybacks somewhere between the two extremes.

The second scenario considered replacing an existing 384-ton chiller with a single gas engine-driven chiller of comparable size. As with Scenario 1, a gas engine-driven chiller is a prime candidate for replacement of the existing unit if for some reason PG&E power is used instead of WAPA. The payback for installing a 384-ton gas engine-driven chiller is improved by 3 to 4 years over the installation of the 768-ton unit. With respect to the load factor, the payback trends for the smaller chiller follow the trends set by the larger unit.

Utah Air National Guard, UT

Utah Air National Guard was MIPRed funds for the design and construction of two, 60-ton, gas engine chillers. These chillers will replace existing 50-ton units at the Squadron Operations Building (#40) and the Squadron Administration Building (#50). Heat recovery options are being installed on each unit and will operate as a source for domestic hot water. A contract was awarded in FY96 to an A/E firm for the design of two gas engine-driven chillers and the associated heat recovery systems. The construction contract was also awarded in FY96 with construction to begin the 2d quarter of FY97. A payback study conducted for the 60-ton gas engine-driven chiller shows an incremental simple payback result of 6.6 years with heat recovery, versus a payback of 9.9 years without heat recovery. An additional contract was awarded by the base for inspection services at a:

- total design cost funded by AFCESA of $26,400 (3400—FY94)
- total construction cost funded by AFCESA of $399,600 (3080—FY95)
- total inspection services cost funded by AFCESA of $14,100 (3400—FY94).

The Utah ANG POC is MAJ Leon Jones, tel.: (801) 595-2291.

Warner Robins Air Force Base, GA

The central energy plant at Warner Robins AFB is being expanded to accommodate a larger chilled water capacity. The project will install two, 1310-ton gas engine-driven chillers at the central energy plant. The base will fund a large portion of the plant modifications to support the new chillers. The design and construction contracts have been awarded. Construction is scheduled to begin the 2d quarter of FY97. Heat recovery units will be installed as a steam preheat. A payback study was conducted for the 1310-ton gas engine-driven chillers resulting in incremental simple paybacks of 5.5 years with heat recovery versus 7.2 years without heat recovery. The total design cost funded by AFCESA: was $74,000 (3400—FY94); the total construction cost funded by AFCESA: $2,987,000 (3080—FY94) + $133,000 (3400—FY94). The Warner Robins AFB POC is Richard Eunice, tel.: (912) 926-3533, x 134.

Wright-Patterson Air Force Base, OH

A site visit was conducted at Wright-Patterson AFB hospital in October 1995. It appears the hospital is a good candidate for a hybrid electric and gas engine-driven cooling application. The existing facility has three chillers, of which only two can operate due to electrical feeder limits. The Air Force has been provided with the various options afforded to them by implementing the hybrid configuration and the associated construction factors. The base will conduct a noise impact and space availability survey before beginning the project.

Current DOD Natural Gas Cooling Demonstration Program

A survey of natural gas cooling systems in DOD facilities, as of November 1996, has been conducted. Table 1 gives a global summary of DOD installations with natural gas cooling system demonstrations, categorized by individual branches of the Armed Services: Army, Air Force, Navy, and Marine Corps. The table shows 42 major DOD installations that have various types of systems currently either in operation or under design and construction. Including the number of DOD installations under evaluation, more than 50 DOD installations are actively participating in the natural gas cooling demonstration program.

Table 1. Summary of current demonstration program.

Installation	Facility Type	Project Funding	Type of NG Cooling	NG Cooling Equip Type	Total No of Units	Tons per Unit (if Eng or Absorp)	CFM per Unit (if Desic)	Total Tonnage (if Eng or Absorp)	Total CFM (if Desic)	In Operation	Under Construction	In Plan/Design
Army												
Fort Riley, KS	Irwin Army Community Hospital	Congressional	Engine	Chiller	2	300		600		Yes	No	No
Fort Dix, NJ	Air Warfare Mobility Center	Congressional	Absorption	Chiller	1	340		340		No	Yes	No
Fort Eustis, VA	McDonald Hospital	Congressional	Engine	Chiller	1	350		350		No	Yes	No
Fort Bliss, TX	New Dining Facility	Congressional	Engine	Chiller	1	50		50		No	Yes	No
Fort Polk, LA	Bldg 1941 - Central Energy Plant	Congressional	Engine	Chiller	1	570		570		No	Yes	No
Fort Hamilton, NY	Daycare Center	Congressional	Engine	Chiller	1	25		25		No	Yes	No
	Barracks Building	Congressional	Engine	Chiller	1	125		125		No	Yes	No
Fort Huachuca, AZ	Hospital Building 45001	Congressional	Absorption	Chiller	2	145		290		No	Yes	No
Fort Jackson, SC	Central energy plant	Congressional	Engine	Chiller	2	700		1400		Yes	Yes	No
Barnes Bldg, Boston, MA (Fort Dix project)	Downtown office building		Engine	Chiller	1	700		700		No	No	Yes
Fort Sam Houston, TX	Single family detached residential bldg	FEMP	Engine	Heat pump	1	3		3		Yes	No	No
Fort Campbell, KY	Building 3214 (3rd Battalion)	FEMP	Engine	Chiller	1	250		250		Yes	No	No
	Building 6944	FEMP	Engine	Chiller	1	360		360		Yes	No	No
	Building 6921A	FEMP	Engine	Chiller	1	570		570		Yes	No	No
	Building 6711	FEMP	Engine	Chiller	1	360		360		No	Yes	No
	Building 6726	FEMP	Engine	Chiller	1	360		360		No	Yes	No
	Building 6732	FEMP	Engine	Chiller	1	300		300		No	Yes	No
	Building 6910	FEMP	Engine	Chiller	1	320		320		No	Yes	No
	Building 6929	FEMP	Engine	Chiller	1	320		320		No	Yes	No
	Building 6936	FEMP	Engine	Chiller	1	160		160		No	Yes	No
	Building 6938	FEMP	Engine	Chiller	1	320		320		No	Yes	No
	Building 3213	FEMP	Engine	Chiller	1	140		140		No	Yes	No
	Building 6718	FEMP	Engine	Chiller	1	140		140		No	Yes	No
	Don F Pratt Memorial Museum	FEMP	Desiccant	Dehumid unit	1		4000		4000	No	No	Yes
Aberdeen Proving Ground, MD	Burger King	FEAP	Desiccant	Dehumid unit	1		2000		2000	Yes	No	No
Fort Myer, VA	Barracks/O-Club	Army R&D	Desiccant	Dehumid unit	1		5000		5000	No	Yes	No
Fort Benning, GA	Martin Army Community Hospital (Operating unit)	FEMP	Desiccant	Dehumid unit	1		5000		5000	No	Yes	No
Redstone Arsenal, AL	Rocket Propellant Testing Facility	FEMP	Desiccant	Dehumid unit	1		10000		10000	No	No	Yes
White Sands Missile Range, NM	Data Reduction Facility, Bldg 1526											
Radford AAP, VA												

Installation	Facility Type	Project Funding	Type of NG Cooling	NG Cooling Equip Type	Total No of Units	Tons per Unit (if Eng or Absorp)	CFM per Unit (if Desic)	Total Tonnage (if Eng or Absorp)	Total CFM (if Desic)	In Operation	Under Construction	In Plan/Design
Fort Gordon, GA												
Fort Gillem, GA	New Gymnasium, Bldg 700											
Fort McPherson, GA	FORSCOM HQ											
Fort Knox, KY												
McAlester AAP, OK	Health Clinic/Safety Office											
Scranton AAP, PA	Administration Building											
Air Force												
Robins AFB, GA	Central Energy Plant	Congressional	Engine	Chiller	2	1310		2620		No	Yes	No
Davis-Monthan AFB, AZ	Central Chiller Plant	Congressional	Engine	Chiller	2	650		1300		No	Yes	No
Utah ANG, UT	Admin. Buildings	Congressional	Engine	Chiller	2	55		110		No	Yes	No
MacDill AFB, FL	6th Medical Group Hospital	FEMP	Desiccant	Dehumid unit	1		18000		18000	Yes	No	No
Keesler AFB, MS	Bowling alley	FEMP	Desiccant	Dehumid unit	1		5000		5000	No	Yes	No
Youngstown-Warren Air Reserve Station, OH	AirliFort Wing Headquarters	Congressional	Engine	Chiller	1	140		140		No	No	Yes
Tinker	Central Energy Plant	Congressional	Absorption	Chiller	3	1000		3000		No	Yes	No
Navy												
Naval Air Station, Jacksonville, FL	Allegheny Circle Housing Area	Congressional	Engine	Heat pump	10	3		30		No	Yes	No
	Building 919 - Data Processing											
Naval Air Station Joint Reserve Base, Fort Worth, TX	Carswell Housing Area	Congressional	Engine	Heat pump	7	3		21		No	Yes	No
National and Naval Hospital, Bethesda, MD	Hospital	Congressional	Absorption	Chiller	1	1000		1000		Yes	No	No
Naval Training Center, Great Lakes, IL	Building 237 - Medical and Dental Clinic	Congressional	Absorption	Chiller	2	268		536		Yes	No	No
	Building 1405 - Administrative Support Office	Congressional	Absorption	Chiller	1	400		400		No	Yes	No
Naval Air Station, Miramar, CA	Building 515 - Electronics/Hydraulics Maintenance Training	Congressional	Absorption	Chiller	1	180		180		Yes	No	No
Naval Air Station, Willow Grove, PA	Base Exchange (BX)	FEMP	Engine	RooFortop A/C unit	2	15		30		Yes	No	No
	Multipurpose Library	FEMP	Engine	Split system A/C unit	1	15		15		Yes	No	No
	Building 180 - AircraFort Intermediate Maintenance Department	Congressional	Absorption	Chiller	1	80		80		No	Yes	No

Installation	Facility Type	Project Funding	Type of NG Cooling	NG Cooling Equip Type	Total No of Units	Tons per Unit (if Eng or Absorp)	CFM per Unit (if Desic)	Total Tonnage (if Eng or Absorp)	Total CFM (if Desic)	In Operation	Under Construction	In Plan/Design
	Building 180 AircraFort Intermediate Maintenance Department	FEMP	Desiccant	Dehumid unit	1		5000		5000	No	Yes	No
Fleet Combat Training Center, Damneck VA	Building 543 - Guided Missile School	Congressional	Absorption	Chiller	1	210		210		No	Yes	No
Submarine Base New London, Groton, CT	Building 488 - Bachelor Enlisted Quarters	Congressional	Absorption	Chiller	1	175		175		No	Yes	No
Naval Education and Training Center, Newport, RI	Building 95 - Officers Club	Congressional	Absorption	Chiller	1	130		130		No	Yes	No
Naval Air Weapons Station, Point Mugu, CA	Building 50 - Laboratory	Congressional	Absorption	Chiller	1	100		100		No	Yes	No
Navy Public Works Center, Naval Air Station, Pensacola, FL	Environmental Building	FEMP	Desiccant	Dehumid unit	2		1590		3180	Yes	No	No
Naval Hospital, Camp Pendleton, CA	Naval Hospital	Congressional	Absorption	Chiller	1	800		800		No	No	Yes
Naval Air Station, Atlanta, GA	Bldg 1 - AircraFort Intermediate Maintenance Dept	Congressional	Engine	Chiller	2	50		100		No	No	Yes
	Bldg 2 - Training Facility	Congressional	Engine	Chiller	1	75		75		No	No	Yes
	Bldg 5 - Hangar	Congressional	Engine	Chiller	1	30		30		No	No	Yes
	Bldg 550 - Medical Clinic	Congressional	Engine	Chiller	1	80		80		No	No	Yes
Naval Air Weapons Station, China Lake, CA	Building 5 - Michelson Laboratory	Congressional	Engine	Chiller	2	750		1500		No	No	Yes
Fleet Industrial Supply Center, Norfolk, VA	Building W-143	Congressional	Engine	Chiller	1	250		250		No	No	Yes
	Building W-133											
Naval Construction Battalion Center, Port Hueneme, CA	PWC Building 850	Congressional	Engine	Heat pump	1	3		3		No	No	Yes
Navy Air Depot, Jacksonville, FL	Building 101 - Tube and Hose Shop	FEMP	Desiccant	Dehumid unit	1		5000		5000	No	No	Yes
	AircraFort Maintenance & Repair											
Naval Air Station, Corpus Christi, TX	Building 8 - Admin, Repairs, Maint, Testing											
Fleet Industrial Supply Center, San Diego, CA	Building 1 - Administrative											
Fleet Combat Training Center, San Diego, CA	Building 24 - Training Facility											
Naval Air Station, Whiting Field, Milton, FL	Building 2946 - AircraFort Simulator											
Naval Air Oceana, VA	Building 419 - Enlisted Barracks											

Installation	Facility Type	Project Funding	Type of NG Cooling	NG Cooling Equip Type	Total No of Units	Tons per Unit (if Eng or Absorp)	CFM per Unit (if Desic)	Total Tonnage (if Eng or Absorp)	Total CFM (if Desic)	In Operation	Under Construction	In Plan/Design
Marine Corps												
Marine Corps Air Station, Yuma, AZ	Building 663: 2 Barracks & Lounge	Congressional	Absorption	Chiller	1	300		300		Yes	No	No
Marine Corps Air Ground Combat Center, 29 Palms, CA	Building 1748-1859: C&E School		Engine	Chiller	1	300		300		No	Yes	No
	Building to be determined	Congressional	Engine	Chiller	1	100		100		No	No	Yes
Marine Corps Logistics Base, Barstow, CA	Club Street/Eniwetok/Desert View Housing Areas	Congressional	Engine	Heat pump	33	3		99		No	Yes	No
Marine Corps Recruit Depot, Parris Island, SC	Wake Village Housing Area and Quarters 4 & 8	Congressional	Engine	Heat pump	14	3		42		No	Yes	No
Marine Corps Air Station, Beaufort, SC	Capehart Housing Area	Congressional	Engine	Heat pump	10	3		30		No	Yes	No
MCCMC Quantico, VA	District Cooling Plant											

5 Summary and Recommendations

Summary

This closely coordinated study between USACERL and AFCESA has detailed existing gas cooling technologies and their applications to Air Force fixed facilities, including absorption, gas engine-driven, and desiccant chillers. The thermodynamic cycles of each type are discussed individually and the expected COP for each is presented. A description detailing how each system is categorized by capacity and usage is listed for general information purposes.

This work has evaluated and continues to evaluate the effectiveness of gas cooling technologies at Air Force fixed facilities. The benefits are widespread, ranging from reducing total electric consumption (thereby dramatically reducing energy costs associated with peak demands), to lessening the adverse impact on the environment typically associated with chillers.

The approach was to determine which facilities could benefit the most by introducing high technology gas cooling chillers as part of a remodeling, replacement, or expansion project. Congressional funds were used to investigate potential implementation sites, develop the equipment purchase documentation, supervise the equipment installation and acceptance, monitor equipment performance, and document lessons learned.

A detailed description of each of the systems has provided better insight into the capacity, performance, maintenance, and operation costs and economical aspects of each. This wide array of system characteristics makes it impossible to choose the type of chiller best suited for any one facility without performing a first-cut economic and feasibility analysis. Data for this analysis was taken from current manufacturer's information and reduced to a usable form. This information was then fed into an USACERL-developed spreadsheet, which produced the expected payoff and payback information.

Finally, a list of Air Force facilities that were evaluated as part of the feasibility analysis were discussed and the current status of each project documented. To date, two Air Force bases have installed desiccant dehumidification systems and are currently operational. One base is currently under construction for the installation of three absorption units. Three bases have been designed and construction contracts awarded for the installation of gas engine-driven chillers. A fourth base is under design and is expected to begin construction during FY98. The economic analysis has shown gas cooling chillers are not the solution for every facility and every application, but are in some locations a viable option to electric-driven chillers.

Recommendations

Gas cooling technologies continue to be considered for any facility requiring a replacement of existing inefficient equipment, replacement of inoperable equipment, or expansion in capacity. After installation, it is recommended that these facilities be monitored for performance by USACERL representatives to document the actual savings incurred.

To achieve the full benefit of gas cooling technology, it is recommended that the following documents be developed:

1. *Standard Procurement Procedures* to assist an installation purchase new gas cooling technologies. Sometimes additional equipment (cooling towers, pumps, etc.) is required as part of a new procurement. These items must be identified early in the procurement process to avoid unnecessary and costly delays.
2. *Operation and Maintenance Procedures* to ensure longevity of the new equipment. It is particularly important to properly maintain gas engine-driven chillers. Improper maintenance procedures can result in premature engine failure and costly overhauls.
3. *Commissioning Procedures* to guarantee proper installation and setup of a new system. Without these procedures, improper installations can occur. This can lead to equipment failures and lower than expected performance, which will increase the estimated payback period.
4. *Integrated Operating Procedures* to ensure the facility is maximizing the potential of the new system. New systems are usually installed as part of an existing plant. It is important that the plant operators know how the new system's operation is related to the operation of the existing units in the facility. Operation outside of a unit's or an entire plant's design will result in longer payback periods and possible increases in utility costs.

These documents are site-specific and should be produced by people who have intimate knowledge of the equipment, its intended overall operation, and the operation of the existing facility. However, the creation of these documents will not ensure optimal installation and operation of new systems. They must be followed and if necessary, proper training administered.

Abbreviations and Initialisms

A/E	architect/engineer
AFB	Air Force Base
AFCESA	Air Force Civil Engineer Support Agency
CFC	chlorofluorocarbon
CO_2	carbon dioxide
COP	Coefficient of Performance
DDC	direct digital control
DEIS	Defense Energy Information System
DOD	Department of Defense
EFL	equivalent full load
FY	fiscal year
gal	gallon
h	hour
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
IFB	Invitation for Bid
NAVFAC	Naval Facilities Engineering Command
NFESC	Naval Facilities Engineering Service Center
O_3	ozone
SERDP	Strategic Environmental Research and Development Program
t	ton
TEWI	Total Equivalent Warming Impact
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratories

Appendix A: Sample Maintenance Schedule for Gas Engine-Driven Chillers

This will vary as a function of engine manufacturer, size and operation and is only meant to give a general overview of the maintenance required for gas engine-driven chiller. Note that the hours are equivalent full load hours (EFLH) = (operating hours)(average RPM)/(rated RPM)

Walk around inspection (leaks, loose connections, etc.)		Daily
Check Oil Levels		Daily
Check Oil Filter Differential Pressure		Daily
Check Coolant Level		Daily
Check Service Indicator for Air Cleaner		Daily
Check Air Starter (if equipped)		Daily
Clean Dust Collector		Daily
Lubricate Shift Collar on Clutch		Daily
Check/Adjust Clutch (if equipped)		Weekly or 125 hours
Lubricate Clutch Pilot Bearings		Weekly or 125 hours
Scheduled Oil Analysis		Monthly or 750 hours
Replace Engine Oil and Filters		Monthly or 750 hours
Clean Crankcase Breather		Monthly or 750 hours
Inspect Cooling System		Monthly or 750 hours
Measure Cylinder Pressure Blowby		Monthly or 750 hours
Check/Lubricate Carb Linkages		Monthly or 750 hours
Inspect/Replace Spark Plugs		Monthly or 750 hours
Inspect Magneto		Monthly or 750 hours
Check Ignition Timing and Air-Fuel Ratio		Monthly or 750 hours
Drain Water from Gas Pressure Regulator		Monthly or 750 hours
Inspect/Replace Air Inlet (filter) and Exhaust Piping		Monthly or 750 hours

Inspect/Replace Belts and Hoses		Monthly or 750 hours
Lubricate Fan Drive Bearing		Monthly or 750 hours
Inspect/Clean Radiator		Monthly or 750 hours
Inspect Engine Mounts		Monthly or 750 hours
Inspect Damper		Monthly or 750 hours
Inspect Engine Protection Devices		Monthly or 750 hours
Check/Clean Magnetic Pickup		Monthly or 750 hours
Inspect Battery		Monthly or 750 hours
Check Leak Rate on Compressor Shaft Seal		Monthly or 750 hours
Clean Dump HX Strainer		Monthly or 750 hours
Check/Adjust Valve lash and Rotators		Every 2 Months or 1500 hours
Measure Exhaust Valve Take-up		Every 2 Months or 1500 hours
Replace PCV Valve		Every 2 Months or 1500 hours
Replace Distributor Cap		Every 2 Months or 1500 hours
Replace Rotor		Every 2 Months or 1500 hours
Check/Clean Dump HX		Every 2 Months or 1500 hours
Check/Clean Condenser		Every 2 Months or 1500 hours
Check Filter Dryer		Every 2 Months or 1500 hours
Sample Lube Oil		Every 2 Months or 1500 hours
Lubricate Generator Bearing		Every 6 Months or 4000 hours
Check/Clean Magnetic Pickup		Every 6 Months or 4000 hours
Inspect/Lubricate Drive Equipment		Every 6 Months or 4000 hours
Test Ignition Transformers		Every 6 Months or 4000 hours
Rebuild/Exchange Starter Motor		Every 6 Months or 4000 hours
Inspect/Clean Exhaust Bypass		Every 6 Months or 4000 hours
Check Ignition Transformers		Every Year or 8000 hours
Check Magnetic Pickup		Every Year or 8000 hours
Inspect/Clean Alignment on Drive Equipment		Every Year or 8000 hours
Rebuild/Exchange Jacket		Every Year or 8000 hours

Water Pump and Electric Start Motor (if equipped)		
Inspect Alternator		Every Year or 8000 hours
Top End Overhaul		8,000 hours (1200 hp) 19,000 hours (100 hp)
	Rebuild/Exchange Cylinder Head Assemblies	
	Rebuild/Exchange Gas Regulator	
	Rebuild/Exchange Carb	
	Rebuild/Exchange Starter Motor	
	Inspect/Reseal Spark Plug Wires, Magneto and Coupling	
	Replace Bearings in Carb and Governor Linkage	
	Replace Thermostat	
	Replace Coolant Hoses	
	Clean/Flush Coolant System	
	Test Coil Resistance and Rectifiers on Generator	
Overhaul		25,000 hours (1200 hp) 54,000 hours (100 hp)
	Rebuild/Exchange Cylinder Head Assemblies and Cylinder Packs	
	Rebuild/Exchange Oil Pumps	
	Rebuild/Exchange Governor	
	Install New Crankshaft Bearings and Seals	
	Install New Valve Rotators	
	Inspect: Crankshaft, Camshaft, Camshaft Followers and Bearings, Gear Train Gears and Bushings, Rocker Arm Bushings	
	Replace Spark Plug Wires	
	Clean/Test Oil Cooler Core	

Appendix B: Sample of Gas Cooling Spreadsheet

Gas Cooling Analysis

Input Data Sheet

< To Print Tables - ctrl t, To Print Charts - ctrl c >

Notice to Users:

This spreadsheet is designed to assist the user in performing a preliminary feasibility analysis comparing electric, absorption, and engine driven chillers. Calculations are based on user provided data and results rely on this input data. This spreadsheet calculates the approximate equipment & installation costs along with the annual operating and maintenance costs. Additionally, simple payback is calculated, based on the incremental additional cost of the alternative cooling technology and the annual operating cost savings. Part of the development of this tool was supported by the Strategic Environmental Research and Development Program (SERDP)

Input Section

Fill in all shaded boxes

Enter Facility Name: Davis-Monthan AFB, Hospital

Analyst: WTB 12/17/96

Cooling Load

Building Type: Hospital

Peak Load:	250	tons
Annual Hours of Operation:	5,000	hours
Equivalent Full Load Hour Percentage:	45	% (for most air conditioning applications, EFLH = 50 %)
Cooling Peak Load/Ave Load Ratio:	3.89	

Chiller Efficiencies:	Peak	IPLV	COP Ratio		Parasitic Electrical Requirements:		
Existing Electric (kW/ton)	0.95	0.95			Existing Elect	0.210	kw/tn
New Electric (kW/ton)	0.85	0.85	1.12	New/Old Ele	New Elect	0.210	kw/tn
Absorption (COP)	1.00	1.00	0.24	Abs/New Elc	Absorption	0.290	kw/tn
Engine Driven (COP)	1.42	1.68	0.34	Gas/New Elc	Eng Driven	0.240	kw/tn

Monthly Peak Cooling Load (% of peak)

Jan	40	Feb	40	Mar	40	Apr	50
May	60	Jun	100	Jul	100	Aug	100
Sep	90	Oct	60	Nov	40	Dec	40

Notes: 1 therm = 100,000 Btu; k = 1000 (kW = 1000 W); M = 1,000,000 (MBtu = 1,000,000 Btu)
When evaluating steam fired absorption chillers, be sure to account for boiler efficiency when entering chiller COP. This is not done automatically.

Gas Cooling Analysis

Input Data Sheet

Facility: Davis-Monthan AFB, Hospital

Utility Rates

Notes:
Screw Water Cooled Units (NG and Elect)

Engine waste heat considers both exhaust gases and cooling jacket water
If boiler fuel not gas, convert $/MBtu to $/therm
Can not calculate winter type ratchet charges; input directly??
Must use month format Xxx (i.e Jan, Feb)

Natural Gas Utility Rates:						
Cooling Rate	0.333	$/therm				
Boiler Rate	0.428	$/therm				
Elect/Gas Use Cost Ratio	4.14					
Electric Utility Rates:						
Summer Demand	10.17	$/kW	from	Mar	through	Sep
Ratchet	67	%	from	Jan	through	Dec
Winter Demand	10.17	$/kW	Demand$/Use$ Ratio (hrs)			
Energy	0.047	$/kWh	Smr. El/Gas:	895	Wntr El/Gas:	696

NOTE: Review demand charge calculations to determine appropriate values to enter for number of applicable months.

NOTE: The above rates should include any applicable taxes and surcharges.

Equipment Cost

	Chiller $/ton	Rebate $/ton	Installation $/ton	Maintenance	
Electric (existing)				0.008	$/ton-hr
Electric (new)	250	0	320	0.006	$/ton-hr
Absorption	660	0	335	0.0085	$/ton-hr
Engine Driven					
w/o heat recovery	600	0	360	0.012	$/ton-hr
w/ heat recovery	620	0	380	0.013	$/ton-hr

Heat Recovery

(Engine Driven Chiller only)

				Engine Waste Heat	
Useful thermal energy	500,000	Btu/hr	Engine efficiency	35	%
Summer boiler efficiency	80	%	Recoverable percent	75	%
			Max avail thermal energy	870,536	Btu/hr

Gas Cooling Analysis

Output Data Sheet

Facility: Davis-Monthan AFB, Hospital

Existing Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.95 kW/ton

Chiller IPLV (seasonal efficiency): 0.95 kW/ton (see note below)

Energy Charge (chiller):	250	tons	x	0.950	kW/ton (IPLV)	x	2,250	EFLH	x	0.047	$/kWh		=	$25,116
Energy Charge (parasitic):	250	tons	x	0.210	kW/ton	x	5,000	operating hr	x	0.047	$/kWh		=	$12,338
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)												=	$27,311
												Total Annual Energy Cost		**$64,764**

New Electric Chiller Energy Costs

Chiller Peak Efficiency: 0.85 kW/ton

Chiller IPLV (seasonal efficiency): 0.85 kW/ton (see note below)

Energy Charge (chiller):	250	tons	x	0.850	kW/ton (IPLV)	x	2,250	EFLH	x	0.047	$/kWh		=	$22,472
Energy Charge (parasitic):	250	tons	x	0.210	kW/ton	x	5,000	operating hr	x	0.047	$/kWh			$12,338
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)												=	$24,956
												Total Annual Energy Cost		**$59,766**

Absorption Chiller Energy Costs

Chiller Peak Efficiency: 1.00 COP

Incremental Parasitic Power Consumption: 0.29 kW/ton (see note below)

Chiller IPLV (seasonal efficiency): 1.00 COP -or- 0.120 therms/ton-hr (see note below)

Gas Charge:	250	tons	x	0.120	therms/ton-hr	x	2,250	EFLH	x	0.333	$/therm		=	$22,478
Energy Charge (parasitic):	250	tons	x	0.290	kW/ton	x	5,000	operating hr	x	0.047	$/kWh		=	$17,038
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)												=	$8,848
												Total Annual Energy Cost		**$48,363**

Engine Driven Chiller Energy Costs

Chiller Peak Efficiency: 1.42 COP

Incremental Parasitic Power Consumption: 0.24 kW/ton (see note below)

Chiller IPLV (seasonal efficiency): 1.68 COP -or- 0.071 therms/ton-hr (see note below)

Heat Recovery: 500,000 BTU/hr Boiler Efficiency: 80%

Gas Charge:	250	tons	x	0.071	therms/ton-hr	x	2,250	EFLH	x	0.333	$/therm		=	$13,379
Energy Charge (parasitic):	250	tons	x	0.240	kW/ton	x	5,000	operating hr	x	0.047	$/kWh		=	$14,100
Peak Demand:	(Monthly and annual peak demand estimates are calculated on the following page)												=	$7,322
												Total Annual Energy Cost (without heat recovery)		**$34,802**
Savings with Optional Heat Recovery:	500,000	Btu/hr	x	1 therm/100,000 Btu		x	2,250	EFLH	x	0.428	$/therm	/ 80 % boiler efficiency	=	($6,019)
												Total Annual Energy Cost (with heat recovery)		**$28,783**

EFLH = Equivalent Full Load Hours (for most air conditioning applications, EFLH = 0.5 x annual hours of operation)

IPLV = Integrated Part Load Value. The IPLV should be used for all seasonal energy calculations, since is it represents the seasonal average (non-full load) operating efficiency of the chiller.

therms/ton*hr = 12,000 Btu/hr/ton / (100,000 Btu/therm x COP [Btu/hr Cooling / Btu/hr input])

Direct-fired absorption chillers have significantly higher electric parasitic consumption than electric chillers. This is due to greater condenser flow rates, heat rejection, and pressure drops in the heat exchangers. Engine driven chillers have slightly higher parasitics than electric chillers due to the engine heat rejection.

Gas Cooling Analysis

Output Data Sheet

Facility: **Davis-Monthan AFB, Hospital**

Month	Demand Charge ($/kW)	Existing Electric Chiller Billed Demand (kW)	Existing Electric Chiller Monthly Charge ($)	New Electric Chiller Billed Demand (kW)	New Electric Chiller Monthly Charge ($)	Absorption Chiller Billed Demand (kW)	Absorption Chiller Monthly Charge ($)	Engine Driven Chiller Billed Demand (kW)	Engine Driven Chiller Monthly Charge ($)
Jan	10.17	194	1,976	178	1,806	73	737	60	610
Feb	10.17	194	1,976	178	1,806	73	737	60	610
Mar	10.17	194	1,976	178	1,806	73	737	60	610
Apr	10.17	194	1,976	178	1,806	73	737	60	610
May	10.17	194	1,976	178	1,806	73	737	60	610
Jun	10.17	290	2,949	265	2,695	73	737	60	610
Jul	10.17	290	2,949	265	2,695	73	737	60	610
Aug	10.17	290	2,949	265	2,695	73	737	60	610
Sep	10.17	261	2,654	239	2,426	73	737	60	610
Oct	10.17	194	1,976	178	1,806	73	737	60	610
Nov	10.17	194	1,976	178	1,806	73	737	60	610
Dec	10.17	194	1,976	178	1,806	73	737	60	610
Ave/Sum		224	27,311	204	24,956	73	8,848	60	7,322

Monthly Demand Charge ($/kW) is determined from the utility rate structure or utility contract.
Billed Demand ($) is calculated based on the utility rate structure. If there is no Ratchet associated with the demand charge, the Billed Demand equals the peak metered demand which occured during that month.
If the utility rate structure has a Ratchet clause, the Billed Demand is equal to the greater of either the actual peak metered demand or the peak demand multiplied by the Ratchet percentage.
Monthly Charge ($) is calculated by multiplying the Monthly Demand Charge by the Billed Demand.
The Annual Average/Sum is the average of the monthly Billed Demands and the sum of the Monthly Demand Charges for each of the chiller technologies.
The actual meter demand is the sum of the peak output of the chiller during the month in question plus the full kW rating of the parasitic equipment, i.e. the evaporator and condenser water pumps and cooling tower fan motors.

Gas Cooling Analysis

Output Data Sheet

Facility: **Davis-Monthan AFB, Hospital**

Maintenance Costs							**Maintenance Costs**	**Annual Operating Costs** (Energy + Maintenance)
Electric Chiller Maintenance Costs								
Existing	2250 EFLH	x	250 tons	x	0.008 $/ton-hr	=	$4,500	**$69,264**
New	2250 EFLH	x	250 tons	x	0.006 $/ton-hr	=	$3,375	**$63,141**
Absorption Chiller Maintenance Costs								
	2250 EFLH	x	250 tons	x	0.0085 $/ton-hr	=	$4,781	**$53,144**
Engine Driven Chiller Maintenance Costs								
w/o heat recovery	2250 EFLH	x	250 tons	x	0.012 $/ton-hr	=	$6,750	**$41,552**
w/ heat recovery	2250 EFLH	x	250 tons	x	0.013 $/ton-hr	=	$7,313	**$36,096**

System Installed Cost	Equipment Cost				Installation Cost				**Installed Cost**	**Utility Rebate**	**Cost Premium**	**Incremental Simple Payback**
Electric Chiller Installed Costs												
	250 $/ton	x	250 tons	+	320 $/ton	x	250 tons	=	$142,500		$0	**basecase**
Absorption Chiller Installed Costs												
	660 $/ton	x	250 tons	+	335 $/ton	x	250 tons	=	$248,750		$106,250	**10.6 yrs**
Engine Driven Chiller Installed Costs												
w/o heat recovery	600 $/ton	x	250 tons	+	360 $/ton	x	250 tons	=	$240,000		$97,500	**4.5 yrs**
w/ heat recovery	620 $/ton	x	250 tons	+	380 $/ton	x	250 tons	=	$250,000		$107,500	**4.0 yrs**

Annual Operating Cost = Annual Energy Cost + Annual Maintenance Cost

Installed Cost = Chiller Cost per Ton * Capacity + Installation Cost per Ton * Chiller Capacity

Cost Premium = Installed cost of a specific chiller type - installed cost of an electric chiller

Incremental Simple Payback = Cost Premium/(Electric Chiller Annual Operating Cost - Specific Chiller Annual Operating Cost)

Appendix C: Sample Instrumentation Scheme

Objective

The objective of this project is to develop comprehensive data collection and analysis procedures to provide accurate and thorough data for input to feasibility studies for the replacement of existing cooling technologies with natural gas cooling technologies. The first step is to perform an extensive study of the required input data elements, making sure that important parameters are not overlooked and that inconsequential parameters are not included. The cooling load profile, outdoor temperature and relative humidity, fuel costs, maintenance costs, the chiller's coefficient of performance (COP) (with and without heat recovery), and the local utility rates are the minimum input requirements for a feasibility study. The raw data points necessary to do these calculations were identified from the equations necessary to derive these parameters. The appropriate instruments were then selected from available manufacturers to obtain measurements within tolerances determined through a sensitivity analysis. Finally, the data collection equipment was selected and the collection procedures and schedules were developed. Analysis procedures were designed that consisted of performing error checking routines, calculating the required input parameters using the previously defined equations, and reporting and graphing the results of the calculations.

Raw Data

The raw data points can be divided into two categories; individual chiller data and system data (Table C1). System data includes outdoor air temperature, outdoor relative humidity, cooling tower pump and fan electrical consumption, secondary chilled water supply pump electrical consumption, heat recovery pump electrical consumption, and the local utility rate structures. Individual chiller data consists of the chilled water supply (CWS) temperature, chilled water return (CWR) temperature, chilled water flow, condenser water supply temperature, natural gas flow, chiller electrical consumption, heat exchanger (HEX) supply temperature, HEX return temperature, and HEX water flow.

Table C1. Data collector setup and sensor description.

Symbol	Parameter	Sensor	Range	Vendor
	SYNERGISTICS #1			
T1	CWS #1 Temperature	RTD	Auto	Synergistics
T2	CWR #1 Temperature	RTD	Auto	Synergistics
F1	Chilled #1 Water Flow	Insertion	0-1000 GPM	Data Industrial
G1	Natural Gas Flow #1	Vortex Meter	4-20 ma	Yokogawa
KW1	Engine KW #1	CT	0-25 Amp	Synergistics
T3	HEX Water Supply Temperature #1	RTD	Auto	Synergistics
T4	HEX Water Return Temperature #1	RTD	Auto	Synergistics
F2	Heat Exchanger Flow	Insertion	0-450 GPM	Data Industrial
T5	Outdoor Air Temperature	RTD	Auto	Synergistics
RH	Relative Humidity	RHA-OUT	0-100%	Synergistics
T6	CWS #2 Temperature	RTD	Auto	Synergistics
T7	CWR #2 Temperature	RTD	Auto	Synergistics
F3	Chiller #2 Water Flow	Insertion	0-1000 GPM	Data Industrial
G2	Natural Gas Flow #2	Vortex Meter	4-20 ma	Yokogawa
KW2	Engine KW #2	CT	0-25 Amp	Synergistics
T8	HEX Water Supply Temperature #2	RTD	Auto	Synergistics
T9	HEX Water Return Temperature #2	RTD	Auto	Synergistics
KW3	Chilled Water Pumps KW	CT	0-100 Amp	Synergistics
KW4	Condensor Pumps KW	CT	0-200 Amp	Synergistics
KW5	Cooling Tower Fans KW	CT	0-100 Amp	Synergistics
T10	Condensor Water Temperature	RTD	Auto	Synergistics
	SYNERGISTICS #2			
T11	CWS #3 Temperature	Surf. RTD	Auto	Synergistics
T12	CWR #3 Temperature	Surf. RTD	Auto	Synergistics
KW6	Chiller KW #3	CT	0-2000 Amp	Synergistics
T13	CWS #4 Temperature	Surf. RTD	Auto	Synergistics
T14	CWR #4 Temperature	Surf. RTD	Auto	Synergistics
KW7	Chiller KW #4	CT	0-2000 Amp	Synergistics
T15	Engine Water In Temperature #1	RTD	Auto	Synergistics
T16	Engine Water Out Temperature #1	RTD	Auto	Synergistics
F5	Engine Water Flow #1	Insertion	0-150 GPM	Data Industrial
T17	Engine Water In Temperature #2	RTD	Auto	Synergistics
T18	Engine Water Out Temperature #2	RTD	Auto	Synergistics
F6	Engine Water Flow #2	Insertion	0-150 GPM	Data Industrial

Instrumentation

All of the water temperature readings will be taken with 1000 ohm platinum RTDs obtained from Synergistics, Inc. On new construction, the RTDs will be mounted in stainless steel thermowells that extend at least 3 in. (or to the midpoint) into the pipe. A silver-based heat conducting paste to improve heat transfer to the RTDs will be used in all of the thermowells. On existing systems, surface-mounted RTDs will be use in place of the thermowells. The RTDs will be mounted on a surface free of corrosion and paint. Heat conduction paste will be used between the pipe and the RTD and will be covered with insulation to ensure that the temperature measurements are accurate as possible. An accuracy of ±0.1 °F is expected with proper calibration for all of the 1000 ohm RTDs.

The outdoor air temperature and relative humidity are measured using Synergistics, Inc. models TSA-OUT and TSA-RH. The TSA-OUT is a 1000 ohm RTD package designed to withstand severe environments and the TSA-RH provides a 4-20 ma signal proportional to the relative humidity. Both are shielded from the elements with a vented white plastic cover. The relative humidity sensor is accurate to within ±3 percent over the entire range of the instrument.

Chilled water flow readings will be measured using a Data Industrial Corp. model 225B paddle wheel flow meter with a model 500 flow transmitter used to convert the flow meter signal to a 4-20 ma signal. The model 225B consists of a paddle wheel flow meter and a brass gate valve that allows the flow meter to be removed from the system for maintenance or replacement without shutting down or draining the system. The flowmeters will be calibrated at the factory and verified on-site using measurements taken with a portable ultrasonic flowmeter. The flowmeters are accurate to within ±1 percent of the actual flow for flow rates between 1 and 30 ft per second.

The natural gas consumption will be obtained with a Yokogawa model YF102 vortex flowmeter for each chiller. Temperature and pressure compensating meters with a 4-20 ma or dry contact pulse output will be used where possible. If these compensating factors are not available, corrections for the mass flow will be based on the average pressure and temperature of the natural gas. The gas pressure will be obtained downstream of the building pressure regulator with a calibrated gauge. The average monthly gas temperature will be used to calculate the temperature correction factor, and will be verified by spot pipe measurements. The average Btu content of the fuel will be collected monthly from the natural gas supplier. Corrected gas flow measurements will be accurate to within ±1 percent of the actual flow.

Calibration of all of the temperature sensors will be referenced to a mercury thermometer. Lead wire resistance calculation will be measured by disconnecting the RTD and connecting a decade box set at 1100 ohms, a resistance corresponding to the resistance of a 1000 ohm platinum RTD at a temperature of 45 °F. The temperature difference measured at the data collector will be noted and a correction factor will be calculated and programmed into the data collector to compensate for the lead wire resistance. Chilled water supply and return temperatures require the greatest accuracy. These measurements will be verified by immersing the RTDs in an ice bath. Relative Humidity calibration will be done using calibrated portable relative humidity monitors. This measurement will be spot checked monthly.

Data Collection Equipment

Model C180E data collectors from Synergistic Control Systems will be purchased to collect the chiller data. Each data collector has 15 analog input channels, 16 current transducer channels, 2 potential transducer channels, 16 digital input channels, 8 digital output channels, and 512 KB of memory. The analog channels accept 4-20 ma, 0-5 V, and 1000 ohm platinum RTDs. The optional modem and SYNET package will be used to program the data collectors and to download the data to USACERL.

The 40 VAC transformers will mounted in a separate metal box adjacent to the data collectors. The data collectors will be marked as #1, #2, etc., as necessary. Each data collector is capable of collecting operating data from 2 chillers, the outdoor air temperature, and the relative humidity. Systems with more than two chillers will use combinations of the previously described design, omitting redundant outdoor air temperature and relative humidity measurements. Chiller and data collector numbering designations will be completed in a consistent manner at all installations to simplify the data analysis procedures.

USACERL DISTRIBUTION

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ATTN: CERD-L
ATTN: CERD-M (2)

CECPW 22310-3862
ATTN: CECPW-E
ATTN: CECPW-FT
ATTN: CECPW-ZC

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (11)

US Army Europe
ATTN: AEAEN-EH 09014
ATTN: AEAEN-ODCS 09014
29th Area Support Group
ATTN: AEUSG-K-E 09054
222d BSB Unit #23746
ATTN: AETV-BHR-E 09034
235th BSB Unit #28614
ATTN: AETV-WG-AM 09177
293d BSB Unit #29901
ATTN: AEUSG-MA-E 09086
409th Support Battalion (Base)
ATTN: AETTG-DPW 09114
412th Base Support Battalion 09630
ATTN: Unit 31401
221st Base Support Battalion
ATTN: Unit 29623 09096
CMTC Hohenfels 09173
ATTN: AETTH-SB-DPW
Mainz Germany 09185
ATTN: AETV-MNZ-E
21st Support Command
ATTN: DPW (8)
SETAF
ATTN: AESE-EN-D 09613
ATTN: AESE-EN 09630
Supreme Allied Command
ATTN: ACSGEB 09703
ATTN: SHIHB/ENGR 09705

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DPW 22186

USA TACOM 48397-5000
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Defense Distribution Region East
ATTN: ASCE-WI 17070-5001

Defense Distribution Region West
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HQ XVIII Airborne Corps 28307
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US Army Materiel Command (AMC)
Alexandria, VA 22333-0001
ATTN: AMCEN-F
ATTN: AMXEN-C 61299-7190
Installations: (20)

FORSCOM
Forts Gillem & McPherson 30330
ATTN: FCEN
Installations: (20)

6th Infantry Division (Light)
ATTN: APVR-DE 99505
ATTN: APVR-WF-DE 99703

TRADOC
Fort Monroe 23651
ATTN: ATBO-G
Installations: (20)

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CETEC-ES 22315-3803
ATTN: Water Resources Support Ctr

USA Natick RD&E Center 01760
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ATTN: AMSSC-S-IMI

US Army Materials Tech Lab
ATTN: SLCMT-DPW 02172

USARPAC 96858
ATTN: DPW
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SHAPE 09705
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128
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AMMRC 02172
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ATTN: DRXMR-WE

CEWES 39180
ATTN: Library

CECRL 03755
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USA AMCOM
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ATTN: Facilities Engr (3) 85613

USAARMC 40121
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Military Traffic Mgmt Command
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ATTN: MTE-SU-FE 28461

Fort Leonard Wood 65473
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ATTN: ATZT
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL
ATTN: Australian Liaison Office

Military Dist of WASH
Fort McNair
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ATTN: AMSTA-AR-IMC

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Walter Reed Army Medical Ctr 20307

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US Military Academy 10996
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ATTN: Public Works Center (8)
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ATTN: Naval Facil. Engr. Service Ctr 93043-4328

8th US Army Korea
ATTN: DPW (11)

USA Japan (USARJ)
ATTN: APAJ-EN-ES 96343
ATTN: HONSHU 96343
ATTN: DPW-Okinawa 96376

416th Engineer Command 60623
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US Army HSC
Fort Sam Houston 78234
ATTN: HSLO-F
Fitzsimons Army Medical Ctr
ATTN: HSHG-DPW 80045

Tyndall AFB 32403
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ATTN: Engrg & Srvc Lab

USA TSARCOM 63120
ATTN: STSAS-F

American Public Works Assoc. 64104-1806

US Army CHPPM
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Washington 20330-1260
ATTN: HQ USAF/ILEO

Arlington 22202-2884
ATTN: OASD(ES)

Tyndall AFB 32403-5319
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Langley AFB 23665-2769
ATTN: HQ ACC/CEO

Randolph AFB 78150-4321
ATTN: HQ AETC/CEO

Brooks AFB 78235-5318
ATTN: AFCEE/CMH

Wright-Patterson AFB 45433-7765
ATTN: AFIT/CECM

Wright-Patterson AFB 45433-5746
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Robins AFB 31098-1635
ATTN: HQ AFRES/CEO

Hurlburt Field 32544-5244
ATTN: 16 CES/CEOE

Peterson AFB 80914-4150
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San Antonio 78243-7030
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Scott AFB 62225-5022
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Andrews AFB 20331-5157
ATTN: HQ ANG/CEPD

Bolling AFB 20332-5000
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Hickam AFB 96853-5412
ATTN: HQ PACAF/CECI

9094-5010
ATTN: HQ USAFE/CEO

USAF Academy 80840-2400
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Andrews AFB 20331-4803
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Columbus AFB 39710-6010
ATTN: 14 CES/CC

Davis-Monthan AFB 85707-3844
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Dobbins ARB 30069-4210
ATTN: 94 SPTG/CEC

Dyess AFB 79607-1670
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Keesler AFB 39534-2115
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Patrick AFB 32925-3343
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Travis AFB 94535-2005
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Defense Tech Info Center 22060-6218
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