NATURAL GAS COOLING SYSTEMS

SYNOPSIS

This Tech Data Bulletin discusses the theoretical concepts of gas-fueled cooling systems, alternative system designs, and the applicability of these systems and designs to Air Force requirements.

INTRODUCTION

Utility companies have been searching for an alternative source of power to meet increased demand for electrical services and address growing environmental concerns. Also, many power distribution utilities are required by generating companies to pay a costly penalty based on their monthly peak load. To offset these pressures by optimizing operations, many utilities have adopted demandside management (DSM) programs. Some of these programs involve designing rates that protect base electric consumption and penalize peaking requirements. Penalties invoked on power distribution utilities are usually passed on to consumers. Since peak load demands during cooling seasons are primarily due to cooling loads (Reference 1), direct load control (DLC) strategies serve to reduce these peaks by altering the cycle of the units so that load peaks occur during a non-peaking period. This has proven very successful, economically (Reference 2), in spite of the disadvantages (customer comfort is not well addressed, and consumers are still charged high rates due to the peak penalties imposed on the utility).

The revived use of natural gas cooling helps consumers avoid the problems associated with electric cooling. Natural gas cooling provides an efficient and reliable solution to some of the problems faced by utilities and consumers as well. The advantages of natural gas cooling include: low energy costs; elimination of peak demand charges; and uninterrupted consumer comfort. Consumers are charged for what they actually use, regardless of the time of day. In some parts of the country natural gas prices are lower than electric prices, particularly in the summer. Some electric utilities encourage gas cooling to lower peak load demands. Natural gas cooling is also an environment-friendly alternative, although it does not provide a complete answer to environmental problems. Gas-fueled cooling systems emit CO2 and, in some cases (primarily engine-driven cooling systems), use chlorofluorocarbons (CFCs) as refrigerant. However, the efficiency of gas-fueled cooling systems makes them relatively environment-friendly in comparison to other cooling systems which use different types of fuel with their own environmental problems.

Discussions of the state of the technology, applications, and field test results follow.

GAS COOLING TECHNOLOGY

Three types of gas cooling systems are available in the market today: absorption, engine-driven, and desiccant. Each has been successfully field tested and has accumulated many hours of continuous operation (References 3-5).

ABSORPTION SYSTEMS. Gas-fired absorption cooling systems rely upon a cycle of condensation and evaporation. The cooling process is similar to that of an electric chiller, but with some essential differences. These differences make absorption systems more economical and environment-friendly (e.g., the use of gas for fuel, and elimination of CFC/hydrochlorofluorocarbon (HCFC) as refrigerants). Absorption cooling systems use water as a refrigerant, a safer and cleaner alternative, and have fewer moving parts, thus reducing noise, vibration, and maintenance. An absorption system uses a heat source instead of a mechanical compressor, unlike a conventional electrical system.

There are two types of gas-fired absorption cooling systems. The single-effect system (Figure 1) is called "singlestage" to indicate that refrigerant vapor is generated in a single step. In contrast, the double-effect absorption chiller (Figure 2) uses two generators to recover and reuse more of the heat used to separate the refrigerant from the absorbent, increasing refrigerant vapor production by 30 to 40 percent over single-effect units. The additional heat exchanger in the double-effect cycle also increases heat recovery. The double-effect absorption chiller is more efficient than the single-effect chiller.

A uniform standard for rating coefficients of performance (COPs) is under development by the gas industry. Currently, individual companies produce COPs unique to their own systems. Absorption cooling units can be driven by any heat source of sufficient temperature (200F for single-effect; 300F for double-effect). Lower temperatures decrease efficiency. Absorption chillers are commercially available in different sizes, ranging from 3 to 1,660 tons. These characteristics of absorption chillers make them appropriate for use in residential, commercial, and industrial sectors.

GAS ENGINE-DRIVEN CHILLERS. A gas engine-driven chiller (Figure 3) uses a natural gas-fueled engine instead of an electric motor (References 3, 6, and 7). The natural gas-fueled engine offers variable speed capability, higher low-land cooling efficiency, efficient waste heat recovery, and low operating costs. Field tests have demonstrated that gas engine-driven chillers can reduce energy costs by as much as 30 percent (Reference 7). Cooling is achieved using a conventional vapor compression cycle. The main components of a gas engine-driven cooling system include the engine, compressor, expansion valve, condenser, and evaporator (Figures 3 and 4). The steps in the cooling cycle are shown in Figure 4 (Reference 3).

The variable speed capability of engine-driven chillers increases the efficiency of the unit. Electric motor COPs are higher than for gas-fueled units. However, the process of obtaining COPs figures for motor units does not include electric generation, transmission, and distribution losses. Most conventional electric chillers operate at a fixed speed, regardless of the load. If the system is partially loaded, conventional systems spend most of the energy moving the motor and compressor, rather than the refrigerant (Reference 9). The variable speed of gas engines enables gas cooling systems to closely track changing cooling loads. Cooling needs change constantly due to changes in the position of the sun, building occupancy, wind speed, process requirements, and other random factors (Reference 1).

DESICCANT COOLING SYSTEMS. Two cooling processes are used in commercial air conditioning: latent cooling and sensible cooling. Latent cooling is the process of reducing air humidity by cooling the air enough to condense the moisture. Sensible cooling is the process of lowering the air temperature. Most air conditioners perform the two cooling processes simultaneously. If an application requires low humidity levels, conventional systems cool the air until sufficient moisture is removed, and then reheat the air to comfort levels (Reference 3).

Desiccant systems work directly to remove moisture from the air without cooling it (Figure 5), allowing independent, direct control of humidity levels. Desiccant systems are normally combined with a separate chiller. This combination allows independent control of humidity and cooling. Desiccant cooling systems offer several advantages (Reference 3).

- They reduce mold, mildew, and bacteria growth by eliminating condensation and reducing humidity in ducts. This in turn reduces maintenance costs and improves air quality.
- They reduce operating costs, since comfort cooling levels in low humidity conditions can be achieved at a higher chiller temperature set-point, resulting in significant energy cost savings.
- Because comfort levels can be achieved at higher temperature set-points, use of desiccant cooling systems permits downsizing of chillers. This could yield significant cost savings. In some cases, reducing chiller sizes could lower the initial investment to less than that of conventional electric chillers.
- In some cases, where existing chillers cannot meet cooling requirements, adding a desiccant system can extend the chiller's capacity to meet the cooling load.

The main component of a desiccant dehumidifier is the desiccant material used to dry the air. The desiccant captures moisture as air comes in contact with it. The air temperature is cooled by a separate chiller.

There are several methods of sensible cooling; Figure 5 shows three techniques. The first uses a recuperative heat exchanger and/or separate chiller to cool the warm, dry air released from the desiccant system. The second method employs a direct evaporative cooler that cools the air by evaporation. This approach is usually inadequate for all cooling requirements. The third approach uses an indirect evaporative cooler with a separate cool air stream to cool the dry air through an air-to-air heat exchanger (Reference 3).

COGENERATION APPLICATIONS

Gas-driven chillers can be used where cogeneration is required. All gas-driven chillers can produce cooling as well as heating through waste heat recovery. Some system configurations can provide electric power generation in addition to cooling and heating (trigeneration).

COGENERATION. Gas-driven chillers compete with high-efficiency electric alternatives and off-peak "cool-storage" technologies (Reference 8). Gas-driven chillers avoid the complications of off-peak ice storage equipment and control systems; eliminate peak electric demand penalty charges; and provide superior partial-load performance, due to variable speed capability (References 4-8). In addition, if a simultaneous need for cooling and steam/hot water arises, gas cooling systems can meet the need partially or fully, depending on the size of the application.

Desiccant dehumidification can increase the capability of chillers, as refrigerant compressors work harder in a humid atmosphere (Reference 8). Conventional systems use more energy than necessary to simply remove moisture from the air, as the cooling coils must operate at lower temperatures than required for sensible cooling. The compressor in a conventional system operates at a higher compression ratio, which requires more energy in the form of shaft horsepower. Using a desiccant dehumidifier with a separate chiller can provide a more efficient cooling system, since the cooling system can operate at higher temperature set-points (Reference 8).

TRIGENERATION. Gas cooling systems can operate efficiently at partial cooling loads as low as approximately 50 percent (Reference 8). Gas engine chillers are usually designed as open drive engine/compressor (Figures 3 and 6), which refers to the total isolation of the engine from the refrigerant compressor. The use of open drive allows the engine to be used to drive a generator in addition to the compressor.

Trigeneration is accomplished by inserting an electric generator between the engine and compressor or at the opposite end of the engine driving the compressor (Figure 6). Either configuration allows control of the system so that the engine can simultaneously provide cooling, electric power generation, and waste heat recovery. The amount of cooling and electric power generation can be controlled so that the engine is fully loaded for increased efficiency.

A preferred configuration uses a double-shafted induction motor/generator between the engine and compressor. Combining this configuration with ice-storage technology allows another approach to peak load shaving. Peak load shaving is achieved in two ways: from ice generated and stored overnight to meet cooling requirements during the day; and from using the system fully as an electric generator during peak load hours. Induction generators are efficient when fully loaded, although the power factor rapidly deteriorates under poor electric load profiles (Reference 8). Other alternatives include the use of waste heat recovery to drive absorption chillers. Also, engine heat can be used to regenerate liquid desiccant systems in conjunction with cogeneration and trigeneration systems (Reference 8).

CASE STUDIES

Several field tests of gas-driven chillers have been conducted recently (References 4, 5, and 8). Most were concerned with improving the design aspects of gas cooling systems. Other studies performed with the guidance and support of the Gas Research Institute (GRI) indicate that the use of gas-driven chillers could result in paybacks in less than three years in most US cities (References 4-6).

A study by GRI (Reference 6) concluded that the owner of a building in Chicago could cut operating costs substantially by replacing an electric motor-driven system with a natural gas engine-driven system. Savings in operating costs would result primarily from reduced electric charges, which account for one-third of total air conditioning costs. In the Chicago area, electric demand charges are $13.34 per kW. In this study, the building owner could save over $4000 per year on energy charges.

In another study, a trigeneration system was installed in the Palm Springs Ramada Resort (Reference 8). The results of this study were concerned with the performance of the system under various loading profiles. The system was installed to supply the cooling requirements of the resort, and generate electric power as needed to keep the engine fully loaded. The system was designed to support a base cooling load of approximately 15 tons, while remaining horsepower could be directed to provide electricity. During cogeneration of cooling and electric power, engine waste heat could be recovered for the laundry, pool, and spas. Some preliminary performance data are listed in Table 1.

APPLICATIONS

Gas-driven chillers can be used in various environments on U.S. Air Force bases. Depending on the application, a choice of one of the three available gas cooling technologies may provide a cleaner, more efficient alternative than conventional cooling systems. The added flexibility of gas cooling systems can help the Air Force meet various needs through cogeneration and trigeneration. Further, most available gas cooling systems do not require any additional infrastructure needs (other than the installation of gas lines) than those required by conventional systems. In some cases, they require only minor site modifications.

The three technologies discussed herein may be easily applied to support Air Force buildings and housing facilities. Applications and case studies of gas-driven chillers have shown their effectiveness in supplying thermal loads (and electric power generation through trigeneration) in commercial, industrial, and residential sectors.

The Air Force is currently working with the US Army Corps of Engineers Construction Engineering Research Laboratory installing natural gas cooling technology equipment at various Air Force locations. The program originated in 1993 when Congress appropriated funds for the express purpose of developing demonstration projects for natural gas technologies throughout the Department of Defense. For a specific installation to be feasible the following criteria is needed: a high ratio of electric (peak demand) to low natural gas costs; hot water load to utilize recovered heat; high chiller equipment utilization; and the installation's acceptance of the equipment's higher maintenance and operation costs. In any project of this nature it is very important to work through a life cycle cost analysis which includes the capital cost of the equipment as well as the maintenance and operation costs. Since most natural gas cooling equipment has a higher capital and maintenance cost than its electric driven competition the energy savings over the life of the equipment becomes the most important cost variable.

CONCLUSIONS

The gas industry has made great strides in designing efficient cooling systems capable of competing with traditional cooling systems. Case studies have demonstrated that the added capabilities of gas-fueled cooling systems provide higher efficiency, as well as commercial and environmental advantages. The Air Force should take a hard look at using natural gas cooling equipment when economically feasible. For additional information contact Mr. K. Quinn Hart, HQ AFCESA/CESM, e-mail: hartq@afcesa.af.mil.

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This Energy Tech Data Bulletin was prepared by Ali Noureddine, under the direction of David Rhodes, Geo-Marine, Inc. and edited by the Air Force Civil Engineer Support Agency.

TABLE 1

Palm Springs Ramada Resort Trigenerator Performance (Preliminary Results)

ENGINE OUTPUT	**FUEL USE**	**COOLING LOAD**	**TONS PRODUCED**	**kW PRODUCED**	**HEAT RECOVERY**
90 HP	810K BTUH	100%	65	25	390K BTUH
90 HP	812K BTUH	100%	65	30	421K BTUH
90 HP	810K BTUH	25%	20	47.5	390K BTUH
90 HP	882K BTUH	25%	15	54	421K BTUH

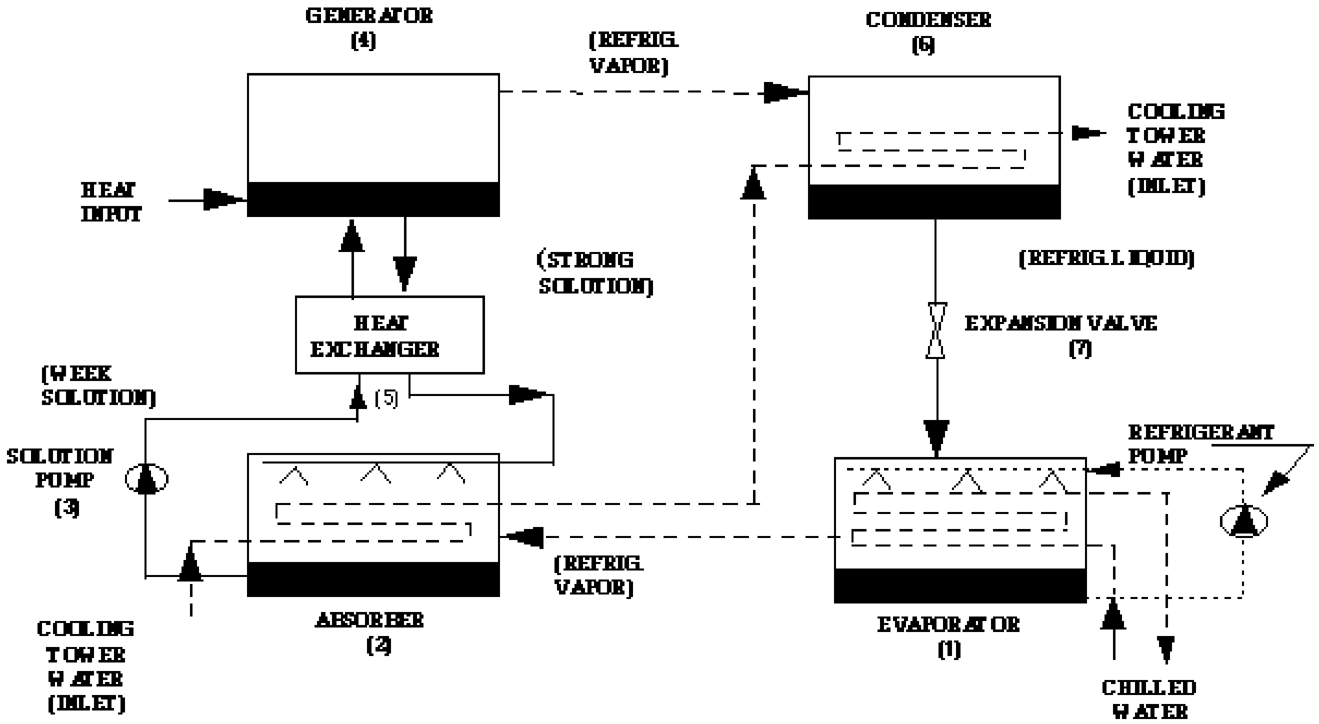

Figure 1. Main Components of a Single-Effect Absorption Chiller. (Source: Reference 3)

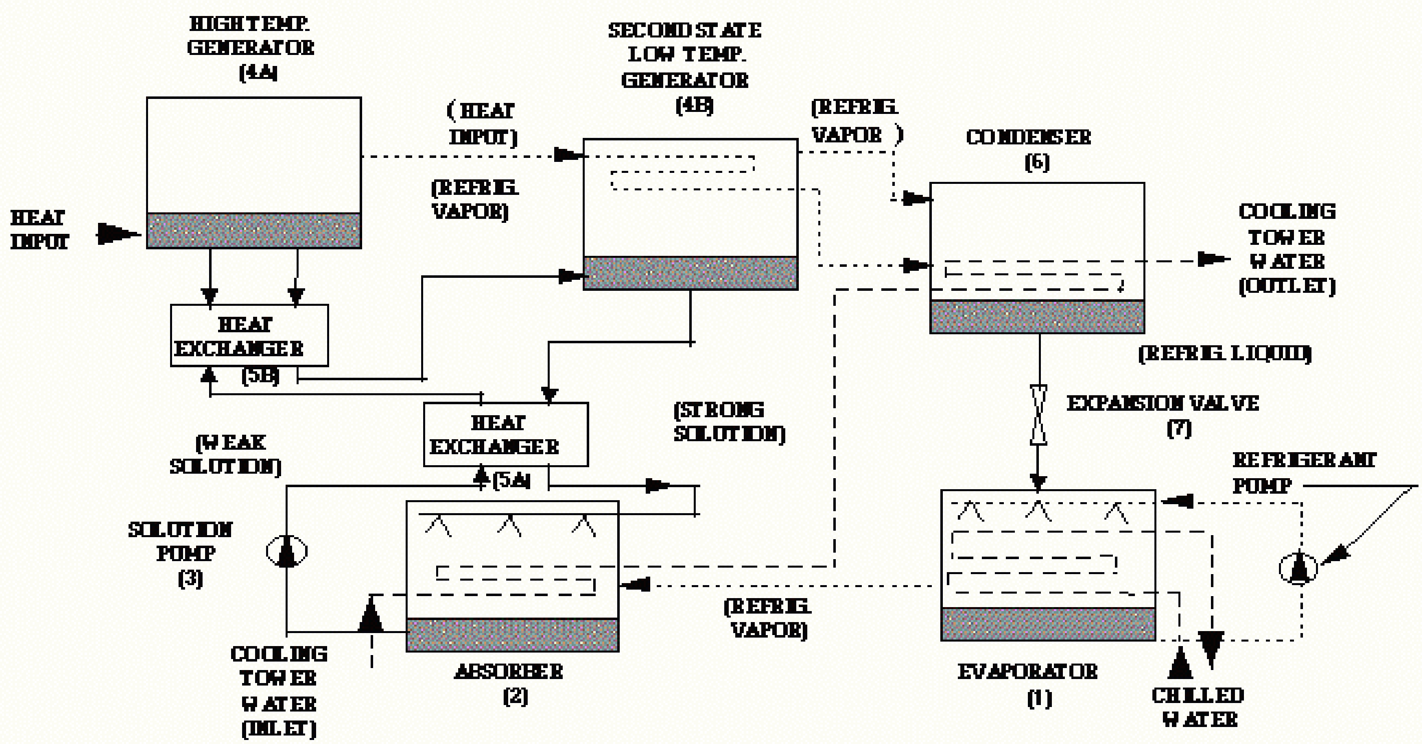

Figure 2. Main Components of a Double-Effect Absorption Chiller. (Source: Reference 3)

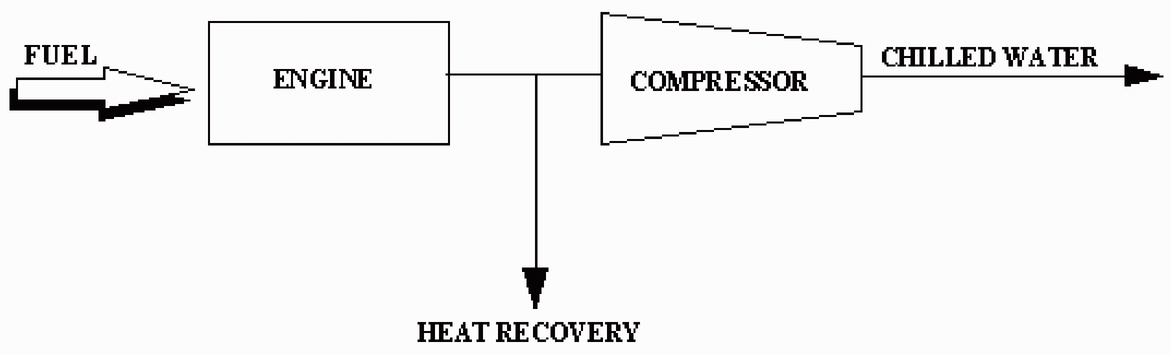

Figure 3. Engine-Driven Cooling System. (Source: Reference 8)

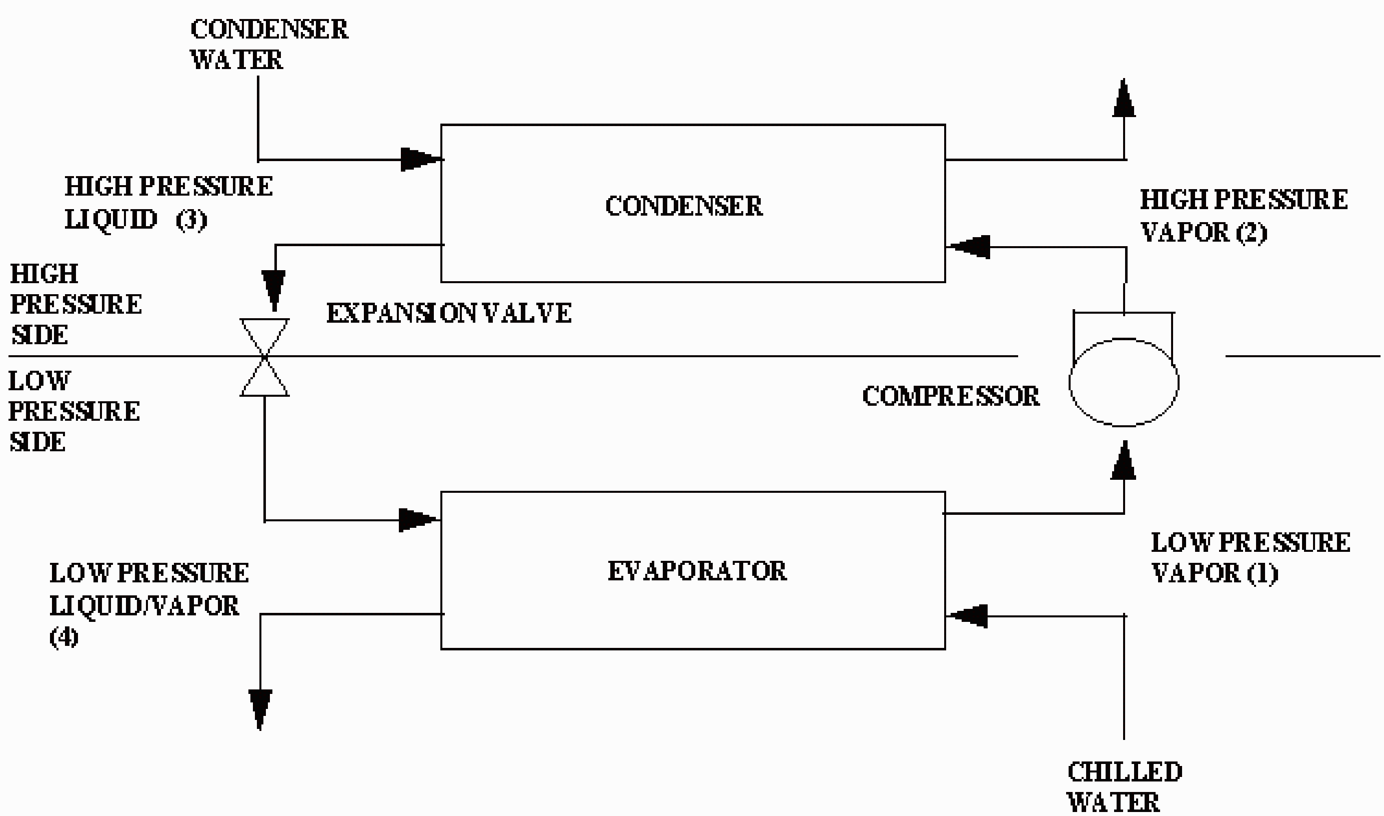

Figure 4. Main Components of a Vapor Compression Water Chiller. (Source: Reference 3)

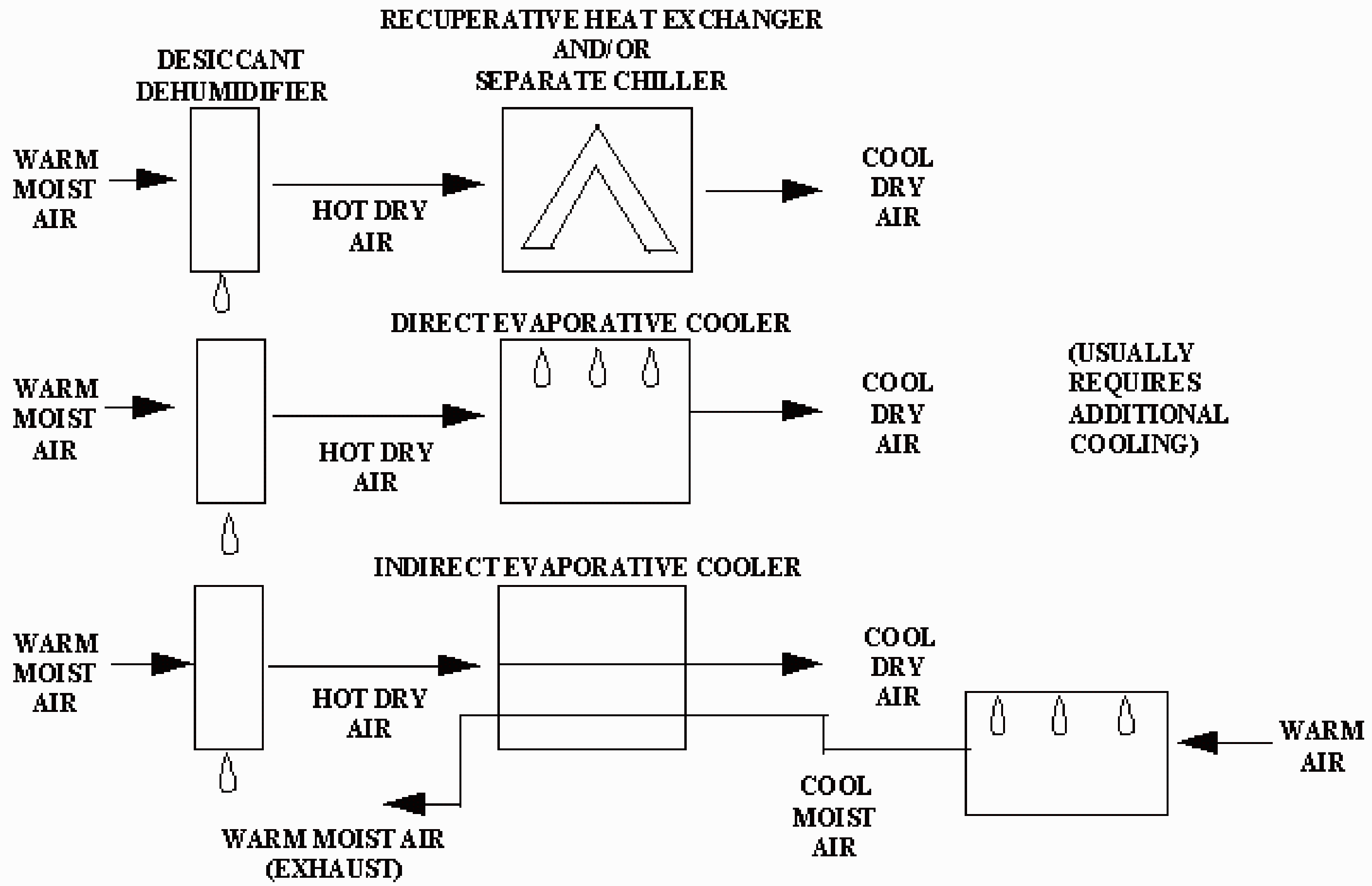

Figure 5. Sensible Cooling Options for Use With Desiccant Systems. (Source: Reference 3)

ENGINE LOADING SEQUENCES

ENGINE	GENERATOR	COMPRESSOR
100%	100%	0%
100%	75%	25%
100%	25%	75%
100%	0%	100%

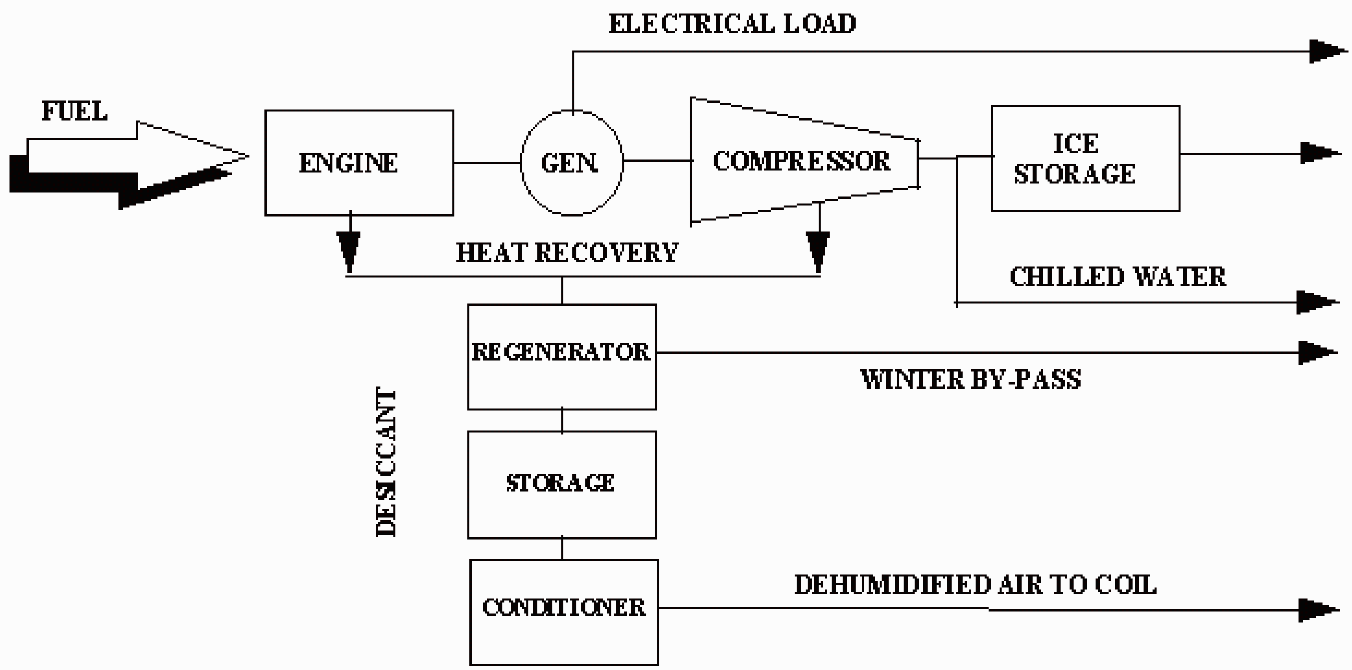

Figure 6. Engine Loading Sequences. (Source: Reference 8)