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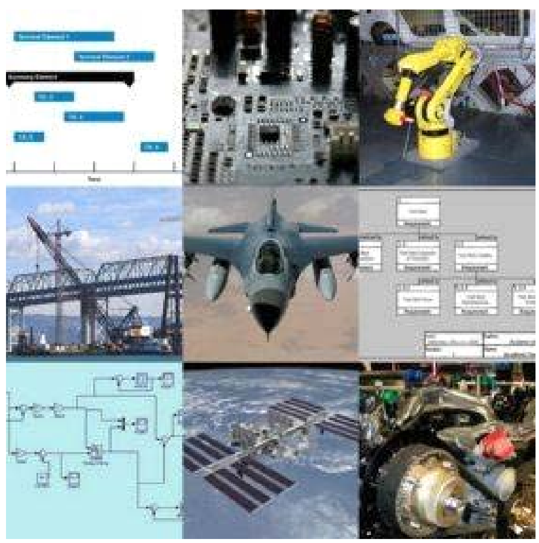

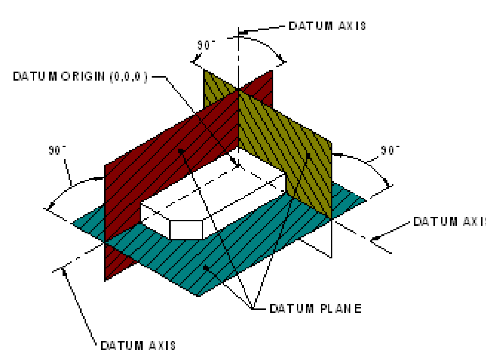

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An Introduction to Solar Cooling Systems

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1. INTRODUCTION. The state-of-the-art of solar cooling has concentrated primarily on the developmental stages of systems in the last few years. Various methods have been researched, and some demonstrated, but only a few systems have been installed for other than research purposes. Solar cooling systems are attractive because cooling is most needed when solar energy is most available. If solar cooling can be combined with solar heating, the solar system can be more fully utilized and the economic benefits should increase. Solar cooling systems by themselves, however, are usually not economical at present fuel costs. Combining solar heating and cooling systems is not easy because of the different system requirements. This can best be understood by summarizing the different solar cooling techniques. As with solar heating, the techniques for solar cooling consist of passive systems and active systems. The passive systems are not part of this course. For active solar cooling systems the three most promising approaches are the heat actuated absorption machines, the Rankine cycle heat engine, and the desiccant dehumidification systems. A brief summary of these systems is given here and a more detailed explanation can be found in other sources in the literature.

2. ABSORPTION COOLING. Absorption cooling is the most commonly used method of solar cooling. An absorption refrigeration machine is basically a vapor-compression machine that accomplishes cooling by expansion of a liquid refrigerant under reduced pressure and temperature, similar in principle to an ordinary electrically operated vapor-compression air conditioner. Two refrigerant combinations have been used: lithium bromide and water, and ammonia and water. There have been a number of proposed solid material absorption systems also. Figure 1 shows a typical lithium bromide (LiBr) absorption cooler. In the absorption cooler, heat is supplied to the generator in which a refrigerant is driven from a strong solution. The refrigerant is cooled in the condenser and allowed to expand through the throttling valve. The cooled, expanded refrigerant receives heat in the evaporator to provide the desired cooling, after which the refrigerant is reabsorbed into the cool, weak solution in the absorber. The pressure of the resulting strong solution is increased by pumping and the solution is available to repeat the process.

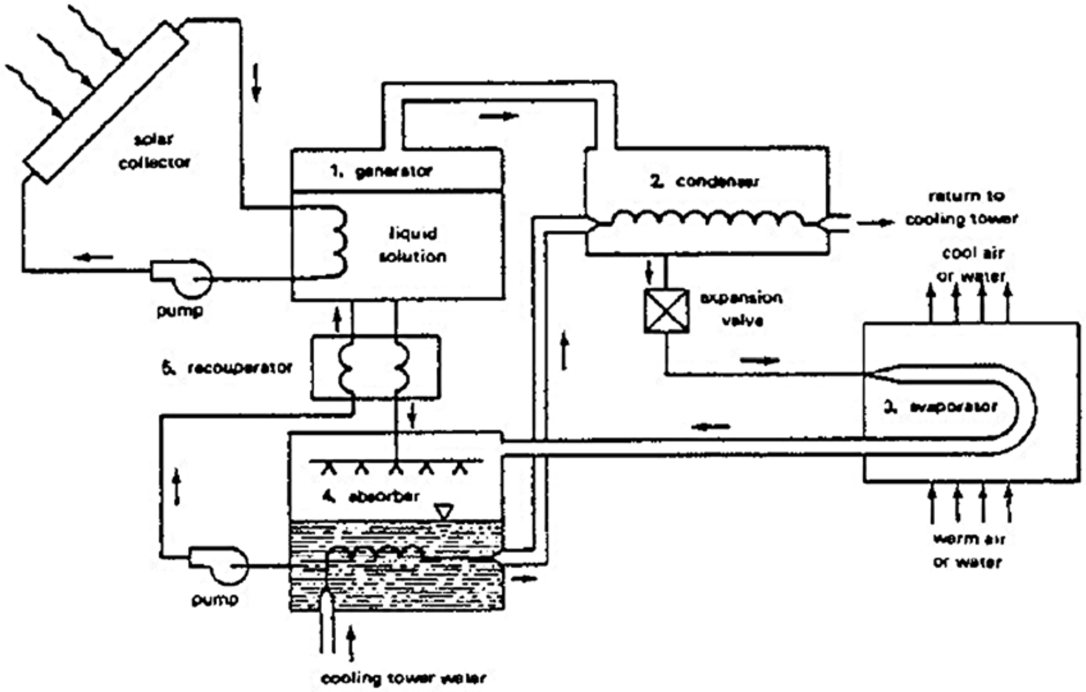

Figure 1

Schematic of Lithium Bromide Absorption Cooler

The performance of the system is governed largely by the temperature difference between the generator and the condenser and absorber units. Since the generator temperatures in solar driven systems are only moderate, it is important to keep the condenser and absorber temperatures as low as possible. The LiBr system is preferred over ammonia systems for solar energy applications because of the lower generator temperatures required. Permissible generator temperatures for a water-cooled LiBr system range from 170 deg. F to 210 deg. F (76 deg. C-99 deg. C) compared to the 205 deg. F to 248 deg. F (95 deg. C-120 deg. C) temperatures required for a water-cooled ammonia absorption system. Most, if not all, of the commercially available absorption units use LiBr and water as the absorbent-refrigerant fluid pair. Because the LiBr will crystallize at the higher absorber temperatures associated with air cooling, these units must be water cooled. A prototype ammonia-water unit, amenable to direct air cooling, has been built by Lawrence Berkeley Laboratories.

A number of equipment requirements and limitations must be considered in the analysis and design of solar powered absorption systems. The first consideration involves the type of collector used. The temperatures required by absorption coolers are obtainable with flat plate collectors but at low collection efficiencies. Collection efficiency is improved with an increased number of glazings and with a selective surface, therefore, it may be cost effective to improve the collector rather than to simply oversize. Concentrating or evacuated tube collectors are usually used in these applications. If concentrating collectors are used, the associated higher costs and potentially increased maintenance for the tracking mechanism must be considered. In general, concentrating collectors operate at higher efficiency at these higher temperatures. However, the higher temperatures are usually not required to operate the space heating system. Therefore, the relative importance of the two thermal loads must be considered when selecting a system. The second consideration involves the means of delivery of the heated fluid to the absorption cooler. Since, in many climates, the cooling load is simultaneous with and often proportional to the solar insolation, it may be desirable to allow the heated collector fluid to bypass the storage unit. Other climates may require a hot storage unit but one of considerably smaller size than the one used for heating purposes. The important requirement is that high temperatures be available during periods of heavy cooling load. A third consideration deals with the problem of reduced efficiency of the absorption cooler under start up and transient conditions. Typical absorption coolers do not reach operating efficiency until after an hour or more of operation time. A machine which is cycled on and off regularly will have a drastically reduced average coefficient of performance when compared to a machine in steady state performance. This problem has been overcome in at least one installation by the use of a cold storage unit. The cold storage unit permits continuous operation of the absorption cooler and thus allows some reduction in the system and cooler size.
A fourth consideration is the need for some means of cooling the absorber and the condenser. A cooling tower or some other low temperature cooling system must be used to obtain reasonable performance. All of the commercially available units require a cooling tower which is another maintenance item. Current research is underway to develop units that do not have a separate cooling tower.

3. RANKINE CYCLE HEAT ENGINE COOLING. Rankine cooling systems are still in development with only a few in operations. In these systems the shaft power produced by a heat engine drives the compressor in a conventional vapor compression-type cooling machine. The thermal energy input to the heat engine can be from a solar collector or from a solar collector and a fossil fuel combustor. The fossil fuel can supplement solar energy, or it can be used alone as the auxiliary energy supply when no solar energy is available. Alternatively, electricity can be used as the auxiliary energy supply by coupling an electric motor directly to the compressor shaft. Another option is a motor-generator using a heat engine for generating electricity when solar energy is available and there is little or no cooling load.

From state-of-the-art considerations, two types of fluid heat engines are primarily feasible in solar cooling units. In one type of engine, the working fluid cyclically changes phase from liquid to gas and back to liquid. The most widely used engine of this type operates on the Rankine cycle. In the other type, the working fluid remains in the gaseous state. These engines operate on various cycles, including the Stirling and Brayton cycles. For relatively low thermal energy input temperatures (less than 400 deg. F), Rankine cycle engines are superior in performance to gas cycle engines. At higher temperatures, gas cycle engines equal or better the performance of Rankine cycle engines.

Relatively low temperatures are attainable with state-of-the-art thermal solar collectors, so the heat engine-vapor compression development projects involve Rankine cycle engines. In a Rankine cycle engine, fluid in the liquid state is pumped into a boiler where it is evaporated and possibly superheated by thermal energy. The vapor generated in the boiler is then expanded through a device such as a turbine, a piston-cylinder (reciprocating) expander, or a rotary vane expander. The expansion process lowers the temperature and pressure of the vapor, and effects a conversion of thermal energy into shaft work. The fluid leaves the expander either in the vapor phase or as a liquid-vapor mixture and flows into a condenser, where it returns to the liquid phase by giving the energy of condensation to cooling water or ambient air. This liquid is then pumped into the boiler, and the cycle is repeated. In some systems under development, the same working fluid is used in both the Rankine engine and the vapor compression chiller, which permits the use of common condenser and the elimination of special seals to maintain fluid separation in the expander-compressor unit. These systems have areas that need development in matching the solar heat engine with the mechanical compressor units of the cooling equipment. Since most compressors are designed for certain speed and torque inputs, the varying operation of a solar heat engine will probably reduce the overall coefficient of performance (COP) of the unit. Also the solar heat engine is at high efficiency at high storage tank temperatures whereas the solar collectors are at low efficiency which will also affect the COP of the system. These systems are designed for large cooling load applications.

4. DESICCANT COOLING. The Rankine engine vapor compression and the absorption cooling units operate on the basis of closed cycles-fixed amounts of working fluid are circulated within sealed equipment; the working fluids do not come in contact with the building air. Desiccant cooling systems, on the other hand, may be designed for open-cycle operation, since the only circulating fluids involved are air and water. The basic concept is to dehumidify air with a desiccant, evaporatively cool the dehumidified air, and regenerate the desiccant with solar-derived thermal energy.

Two basic open-cycle arrangements are feasible: the ventilation mode and the recirculation mode. In the ventilation mode, fresh air is continually introduced into the conditioned space. In the recirculation mode, exhaust air from the conditioned space is reconditioned and returned to the space. Figure 2 illustrates a ventilation system in which a solid desiccant material mounted on a slowly rotating wheel provides the basis for obtaining a cooling effect. The hot desiccant material absorbs moisture from incoming ventilation air and increases the dry-bulb temperature. This dry air stream is cooled in two steps. First, it is sensibly cooled by heat exchange with the building exhaust air. Then it is evaporatively cooled and partially rehumidified by contact with a water spray. The exhaust air from the building is evaporatively cooled to improve the

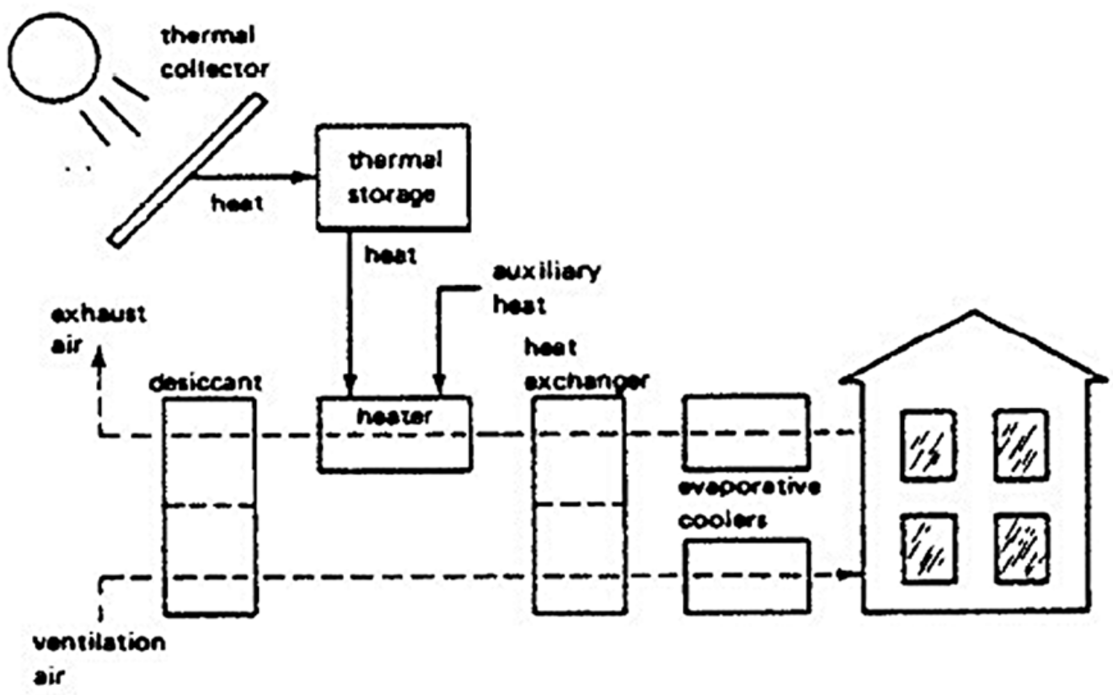

Figure 2

Schematic of Solar Desiccant Cooling

performance of the heat exchanger. After being heated by heat exchange with the incoming air, the exhaust air is further heated by energy from the solar system and/or from an auxiliary energy source. The hot exhaust air passes through the desiccant material and desorbs moisture from it, thereby regenerating it for continuation of the process. Desiccant systems have faced problems of high parasitic power and large space requirements relative to capacity. Because of their bulkiness, the systems may have primary application in the low capacity range (i.e., residential systems) if and when ways can be found to reduce parasitic power requirements to acceptable levels.

The Institute of Gas Technology (IGT) has been investigating design modifications in a prototype 3-ton system. AiResearch is developing a 1-l/2-ton desiccant cooling system around a radial flow design. Illinois Institute of Technology is developing a dehumidifier of a cross-flow design that will provide more compact and efficient operation than

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evaporatively cooled and circulated through the rockbed to cool down the pebbles in the storage unit. During the day, warm air from the building can be cooled by passing it through the cool pebble bed. This method is not very effective in humid geographical areas.

The storage volume can also be cooled using a small refrigeration compressor. Most through-the-wall air conditioners use such compressors to cool the indoor air. This unit acts as the backup or auxiliary cooling system - analogous to the backup heating system. If operated only at night, its capacity can be as small as half that of an independently functioning unit and still meet peak cooling demands. Nighttime operation