ALTERNATIVES TO ELECTRIC AIR CONDITIONING SYSTEMS

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ABSTRACT

The rapid escalation of electricity prices has created an opportunity to re-introduce gas-fired air conditioning systems to the commercial building market. In 1985 Gas Research Institute initiated a program to develop an advanced gas engine-driven water chiller. The packaged system has been designed, fabricated and tested. A field experiment unit has been operating since August, 1986, and seven field test units have been operating since April, 1987. The performance of the system has been outstanding. The system should be an economically attractive alternative to electrically-driven chillers in most of the United States.

INTRODUCTION

Most large commercial buildings in the United States require air conditioning (cooling) to provide a comfortable environment for tenants and occupants. In addition to the loads imposed on buildings during the summer, including solar gains and high ambient temperatures, the air conditioning system must also handle the heat generated by lighting, personnel, and office equipment. These internal loads dominate in large buildings, especially where there are large internal zones relative to exposed wall zones.

The mechanical equipment that provides cooling will vary significantly, depending on the building configuration, owner/engineer preference, and local conditions. For the most part, however, the cooling system will utilize an electric motor-driven vapor compression device. Electric systems are ubiquitous, due to their inherent simplicity, reliability, flexibility, and efficiency. The availability of low cost electric power has equally supported the concept of an engine-driven chiller. (Each prime mover has a shaft that rotates the refrigerant compressor, is replaced with an engine.)

There are, of course, alternative cooling systems that utilize other energy sources, such as natural gas or steam. In the early days of air conditioning, these systems accounted for nearly 20% of the installed capacity. That share has fallen in recent years because of the steadily declining cost of electricity and the increase in compressor/motor performance a critical factor in the reduction in alternative cooling capacity.

In the last two decades, the energy environment has undergone a tremendous transition, especially in the electric utility sector. Prior to 1970, the electric industry consistently lowered its cost to generate electricity with large central power plants and economies of scale production. Regulations influenced by Three Mile Island and soaring interest rates have pushed the cost of new generating capacity beyond the range of many consumers. Certain utilities have experienced "rate shock". (Each prime mover has a shaft that rotates the refrigerant compressor, is replaced with an engine.)

Gas-fueled cooling systems. Engine-driven compression cooling packages and desiccant dehumidification systems are now available for commercial buildings. Engine-driven chillers compete directly with electric air conditioning systems and will be discussed further.

Gas ENGINE-DRIVEN COOLING

The concept of an engine-driven chiller is very fundamental. The electric motor, which drives the refrigerant compressor, is replaced with an engine. (Each prime mover has a shaft that rotates and transmits power.) Gas engine-driven chillers can capitalize on the advances in compressor technology that have made electric air conditioning so attractive. The relative prices of natural gas and electricity will determine the best choice. A gas engine chiller may have a COP of 5.5. The gas engine chiller, because its engine is approximately 30% (HHV) efficient, will have a COP of 1.6. If the electric/gas price ratio is greater than 3.3, the gas chiller will cost less to operate. This simple substitution is much more complex in reality.

40-90% increases in electricity prices, as new plants are brought on-line. Simultaneously, the natural gas industry has seen a reversal in its pricing, as increased competition with oil and "open access" have stabilized the market. The reversal in pricing has created a unique opportunity to market gas-fired cooling systems. Figure 1 illustrates these trends.

GAS COOLING SYSTEMS

Gas-fueled air conditioning systems have been synonymous with absorption chillers. Carrier, York, Trane, and A & K Service manufactured a line of units in the early 1970s based upon a single-effect cycle, which achieved a coefficient of performance (COP) of 0.8. These packages, with the exception of York, are still available. The Japanese have developed direct-fired double-effect absorption chillers that are 40% more efficient than the single-effect predecessors (COP of 0.9-1.0). Hitachi, Yaskawa, and Sanyo are currently marketing products in the United States. Absorption chillers are penetrating certain regions of the United States, and they have been increasingly employed with cogeneration systems, which have large amounts of waste heat to drive the chiller. Unfortunately, the large heat transfer surface required for the absorption process imposes a high first cost penalty and many engineers are hesitant to install these packages.

Absorption chillers are not the only gas-fired cooling systems. Engine-driven compression cooling packages and desiccant dehumidification systems are now available for commercial buildings. Engine-driven chillers compete directly with electric air conditioning systems and will be discussed further.

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The compressor choices are limited to an open drive, which has mechanical seals that are subject to wear.

2. The compressor is typically designed to operate with electric motors at 1800 rpm or 3600 rpm. The gas engine may have to be coupled with a gearbox to increase or decrease the shaft speed.

3. Gas engines are typically larger than electric motors and subject to vibration and operation. This feature and the internal diagnostics capability reduce nuisance outages and can significantly lower life cycle costs.

4. Oil and wear point changes, timing adjustments, valve wear, and coolant replacement add considerable cost to the chiller's operation.

Despite these obstacles, the engine chiller possesses certain attributes that make it very attractive:

1. The engine can vary its speed and load, which permits the chiller to modulate very effectively. The part load performance of the gas engine chiller is superior, relative to electric systems.

2. The engine can operate above rated capacity for short periods, reducing the total capacity requirement for an installation.

3. Waste heat from the engine can be recovered for domestic water heating, process heat recovery, and additional cooling capacity, if integrated with absorption or desiccant equipment.

Figure 3 exhibits the part load curve for the original prototype design that was experimentally and operated satisfactorily in the laboratory and in the field experiment were integrated into the chiller system. The heat from the engine can be recovered for domestic water heating, process heat recovery, and additional cooling capacity, if integrated with absorption or desiccant equipment.

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In 1987 the Gas Research Institute initiated a program to develop a nominal 150 ton gas-fueled engine-driven water chiller for commercial buildings. The package system has been designed, fabricated, and operated satisfactorily in the laboratory and in a 450-bed hospital. Figure 2 illustrates the original prototype design that was experimentally installed at a new hospital in Manchester, New Hampshire, to evaluate actual system operations and installation procedures. The chiller system, including the absorption package, exhibited an average COP approaching 3.0. The preliminary results of the field experiment were integrated into a new design that radically simplified the package and improved its performance.

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The engine chiller incorporates an advanced microprocessor-based controller that monitors compressor and engine functions. The system permits the engine to "wake up" prior to leading the compressor. The controller can be commissioned by nodem to create sites for monitoring and operation. This feature and the internal diagnostics capability reduce nuisance outages and can significantly lower life cycle costs.

In addition, the low cost engine can be replaced, rather than repaired, further reducing down time.

Prospects for Gas Cooling

Market assessments and economic analyses have demonstrated that a huge potential for gas-fueled engine-driven cooling systems exists, especially in regions of the U.S. that have high electric demand charges. Demand charges can constitute approximately half the operating cost for an electric chiller. Figure 5 illustrates the difference in operating costs for an electric and a gas-cooled 150 ton chiller in the Chicago area based on current rates. Figure 6 exhibits the cities within the United States with attractive economics. The cities are plotted by the electric demand and energy charges of the city's major utility. The diagonal line represents a three year payback for the incremental investment above an electric chiller. The cities above the line have shorter payback periods. Several gas utilities offer rebates of $100-$280/ton to commercial customers that install gas cooling systems, further reducing the first cost premium.

Although the engine chiller will be competitive (on life cycle costs) with electric chillers in the new construction market, the real opportunity for penetration is in the replacement market. Commercial building developers are particularly interested in a cost-effective, reliable, low-cost alternative to electric systems. The engine chiller incorporates a variety of features that make it particularly useful to these developers.
sensitive to first costs, almost to the exclusion of other considerations. Owners, on the other hand, are more willing to consider the long-term operating costs. If the owner has two or more electric chillers, which is typical of many installations, he can replace one electric chiller with the gas chiller and operate the units in the most advantageous strategy. The superior part-load performance of the engine chiller, coupled with its minimal electric requirements, makes it an ideal peak unit. In regions with high energy costs, it may be beneficial to base load the gas chiller and peak with the electric chiller.

Gas-fueled cooling systems can provide significant benefits to electric utilities and ratepayers. Commercial cooling may account for up to 40% of a utility's peak demand. As capacity margins are consumed, gas cooling may actually reduce peak electric demand growth for utilities and defer investment in new generating capacity.

**SPECIAL APPLICATIONS**

Humidity is a prominent concern in commercial buildings especially in critical environments, such as hospitals or computer centers. In conventional electric air conditioning systems, the customary approach to reduced humidity levels utilizes low temperature water to supercool the incoming air stream. Water moisture condenses out at the lower dewpoint, reducing humidity, but the air stream must be reheated to temper the air. This approach is very expensive, in that the compressor requires greater energy to produce the lower temperature water and energy is required for the terminal reheating. The engine chiller has the ability to produce low temperature chilled water, plus the benefit of hot water recovery, which can be applied to dehumidification processes.

The recovered hot water from the engine chiller can also be used to regenerate a desiccant material. Desiccants adsorb moisture from the conditioned air stream, reducing humidity levels. The "wet" desiccant is cycled out of the air stream, heated, and exposed to a purge air stream to remove the moisture. The drier air eliminates the need for low evaporator temperatures, allowing the compressor to operate more efficiently, providing only sensible cooling. The synergy of the desiccant/engine chiller system has great potential to maintain higher comfort levels at equal or lower costs relative to conventional electric systems.

**FUTURE PRODUCTS**

The development program has been expanded to a range of gas engine-driven cooling systems from 15-ton direct expansion rooftop packages to 500-ton liquid chillers. Additionally, an integrated engine chiller/desiccant dehumidification system and an engine chiller/free storage system are being developed, which should greatly improve occupant comfort while reducing energy costs.

Gas engine-driven rooftop packages are under development by TELEDEN Inc. and American Gas Association Laboratories. TELEDEN is integrating a 3.0 liter General Motors engine with a Carrier compressor and air handling package. ARA Labs is integrating a Hercules engine with a Thermo King compressor. The package capacities are 25 and 15 tons respectively. The concept is illustrated in Figure 6.

TELEDEN has fabricated a 300-ton liquid chiller based on a dual centrifugal compressor chiller package from Carrier. Each 150-ton compressor will be driven by a 1.8 cubic inch General Motors engine. A COP of 1.8 is targeted and the first cost premium should be very low. The engines can vary speed from 2200 rpm to 3000 rpm and the engine-compressors can be operated individually to provide extremely attractive part load operation. The 500-ton chiller is shown in Figure 8.

The 150-ton engine-driven chiller package will be commercially available in 1988. Forty units have been ordered for 1988 delivery by a consortium of gas utilities. The 500-ton package and engine-driven unitary packages should be available in 1990.
Figure 1. Electric and Natural Gas Pricing

$/mmBTU

GAS + ELECTRIC 0 ADJ GAS ADJ ELEC
Figure 2. Engine-Driven Chiller with Absorption
Figure 3. Part Load Performance (COP)
Electric vs. Gas Engine
Figure 5. Typical Operating Costs
Electric vs. Gas Engine
Figure 6. Sensitivity to First Cost

Electric Energy Cost ($/kWh)

Demand Charge ($/kW)

Base Case Assumptions:
- First Cost Premium: $30/ton
- Gas Engine: COP=5.5; 30 days:0.19 kW/t; Maint:$0.015
- Else: Cond: COP=6.5; Aux:0.75 kW/t; Maint:$0.005
- Hours: 1700; Operating: 2400
- Gas: $4/MMBTU
- Demand Reset: 4 Month

Summer, 1985 Rates, Large Commercial Buildings. No Taxes or Surcharges Included
- Ratchet Charges Applicable

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988
Figure 7. Engine-Driven Rooftop HVAC Package
Figure 8. 500 Ton Engine-Driven Chiller