ALTERNATIVES TO ELECTRIC AIR CONDITIONING SYSTEMS

BRUCE B. LINDSAY
Project Manager, Space Conditioning
Gas Research Institute
Chicago, Illinois

MICHAEL D. KOPLOW
Director, Engine Technology
TECOGEN Incorporated
Waltham, Massachusetts

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 gain 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 widespread acceptance of electric air conditioning.

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 40% of the installed capacity. That share has fallen to 7% in the Eighties. The steadily declining cost of electricity and the increase in compressor/motor performance was 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", 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 Arkla Servel manufactured a line of units in the early Sixties based upon a single-effect cycle, which achieved a coefficient of performance (COP) of 0.70. 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 0.92-1.0). Hitachi, Yazaki, 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-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. An electric 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 1.6-1.7. If the electric/gas price ratio is greater than 3.33, the gas chiller will cost less to operate.

This simple substitution is much more complex in reality.

Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

1. 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 shaft speed.
3. Gas engines are typically larger than electric motors and subject to vibration and torque fluctuations.
4. Oil and spark plug 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 makes 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 required for an installation.
3. Waste heat from the engine can be recovered for domestic water heating, process applications, and additional cooling capacity, if integrated with absorption or desiccant equipment.

TECOCHILL CH-150

In 1985 the Gas Research Institute initiated a program to develop a nominal 150 ton gas-fueled engine-driven water chiller for commercial buildings. The packaged 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 Elliot 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 2.0. The preliminary results of the field experiment were integrated into a new design that radically simplified the package and improved its performance.

The engine chiller has produced 150 tons of cooling at a COP of 1.4 at ARI full load conditions. The heat from the engine may be recovered to drive an optional absorption chiller package, providing an additional 35 tons of cooling and increasing the system COP to 1.75. The system is comprised of a 454 cubic inch G.M. engine, modified for stationary duty, a Howden twin screw compressor, and advanced microprocessor controls. The engine chiller, by capitalizing on available vapor compression equipment and low cost automotive engines, can meet a highly competitive cost goal of less than $400/ton. The engine's ability to vary speed greatly improves the performance of the compressor at part load. The engine chiller has an ARI Integrated Part Load Value (IPLV) of 1.7. Figure 3 exhibits the part load curve for the engine chiller. Further, the engine can be operated above design speeds (up to 3600 rpm) for short periods to provide additional peaking capacity.

The engine chiller incorporates an advanced microprocessor-based controller that monitors compressor and engine functions. The system permits the engine to start and "warm up" prior to loading the compressor. The controller can be connected by modem to remote sites for monitoring and operation. This feature and the internal diagnostics capability reduce nuisance outages and can significantly reduce maintenance costs. In addition, the low cost engine can be replaced, rather than repaired, further reducing down time.

The new design, shown in Figure 4, was tested in a seven unit field test during the summer of 1987. The prototype chillers were installed in a variety of commercial buildings, including hotels, office buildings, apartment buildings, and manufacturing facilities. The units have demonstrated a fleet availability of 96% with over 9,200 hours of operation. The average COP ranged from 1.09 to 1.86, depending upon the load profile and outdoor temperatures. Minor design problems were identified and the packages were modified. The microprocessor-based controller permitted remote monitoring and operation as well as serving as the data acquisition system during the field test. Site owners have reported a high degree of satisfaction.

Bleyle of America, located in Shenandoah, Georgia, is one of the field test sites. The manufacturing firm produces fine women's apparel. The engine chiller replaced an external chilled water supply that had experienced poor availability, forcing Bleyle to utilize electric rooftop cooling systems. The high latent loads from the steam presses and personnel were easily met by the engine chiller while avoiding nearly 110 kW of electric demand.

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 gas 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 centrifugal chiller. All cities above the line have shorter paybacks. 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 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 peaking 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 reducing 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 reheat. 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 cal 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/ice storage system are being developed, which should greatly improve occupant comfort while reducing energy costs.

Gas engine-driven rooftop packages are under development by TECOGEN Inc., and American Gas Association Laboratories. TECOGEN is integrating a 3.0 liter General Motors engine with a Carrier compressor and air handling package. AGA 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.

TECOGEN has fabricated a 500-ton liquid chiller based on a dual centrifugal compressor chiller package from Carrier. Each 250-ton compressor will be driven by a 454 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

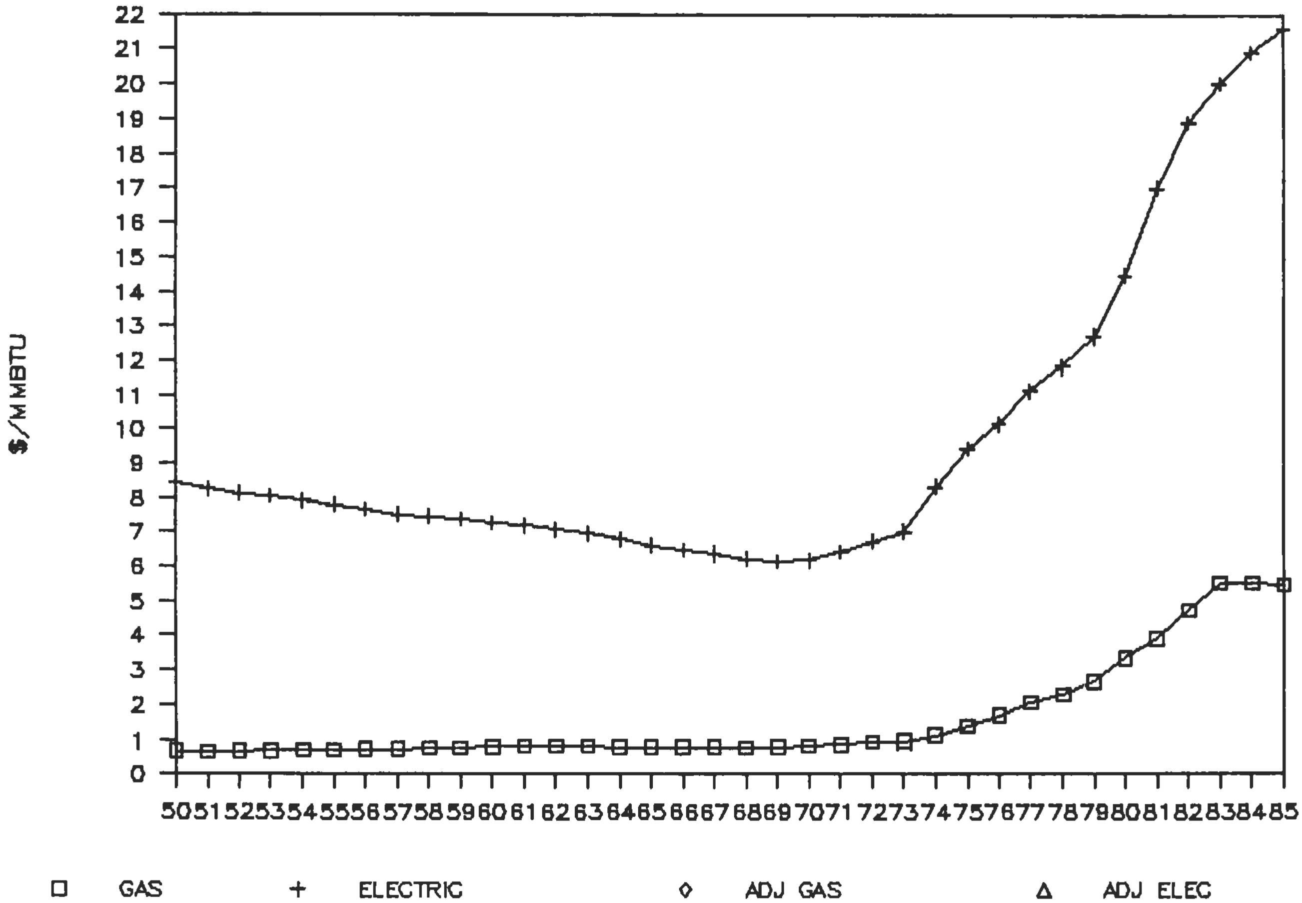


Figure 2. Engine-Driven Chiller with Absorption

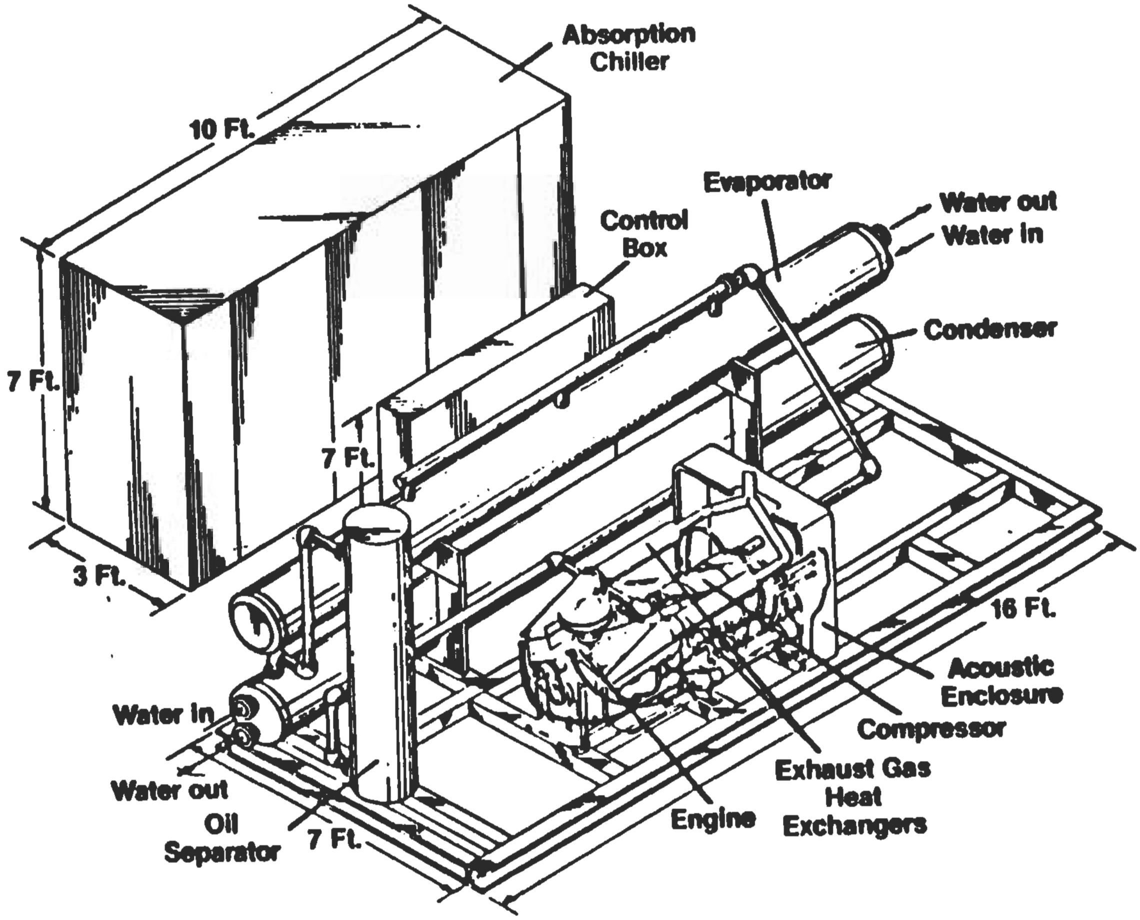
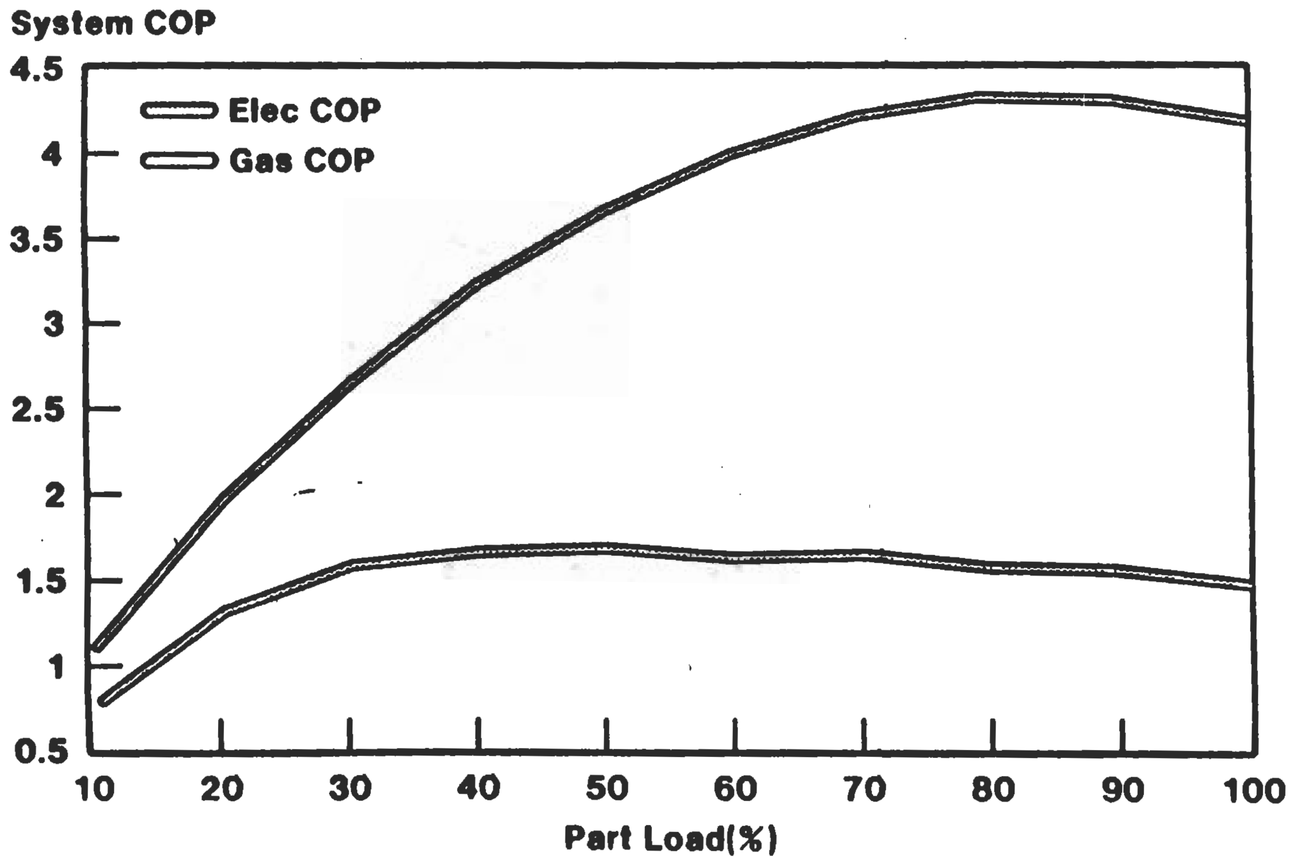


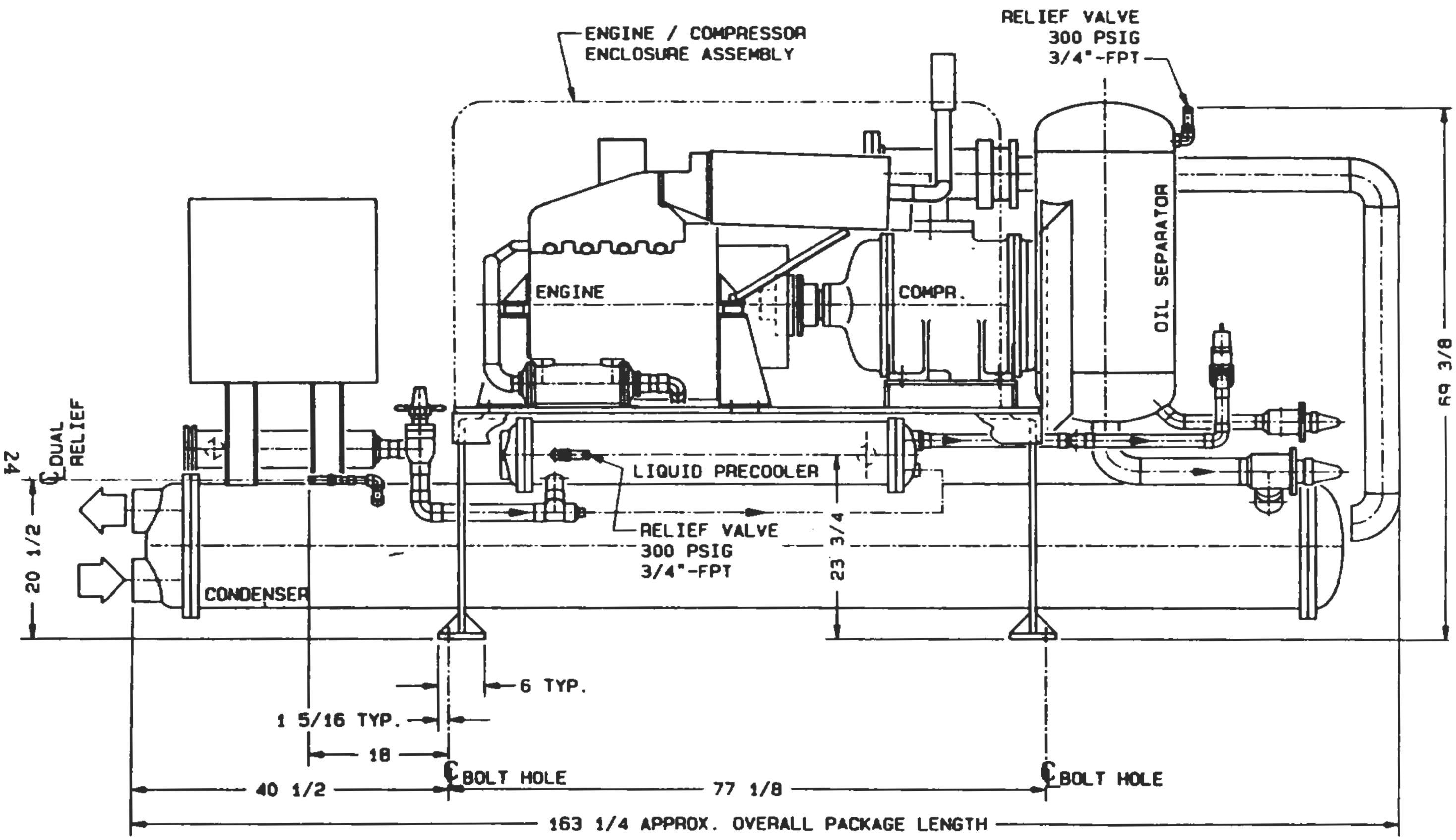
Figure 3. Part Load Performance (COP)
Electric vs. Gas Engine



Proceedings of the Fifth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 12-14, 1988

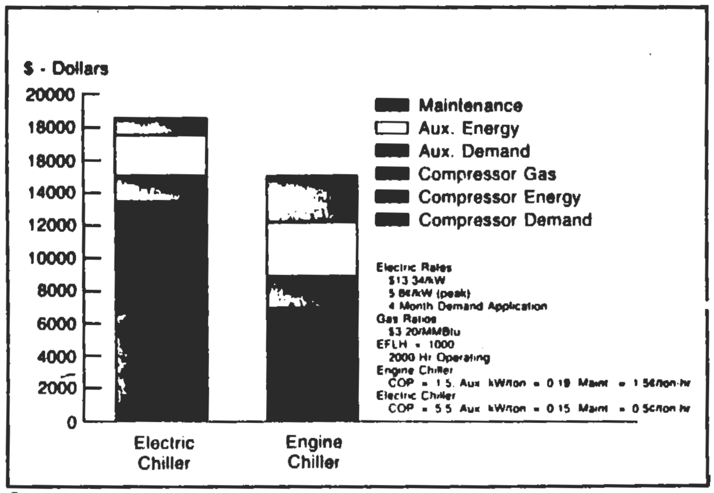
Figure 4. 150 Ton Chiller Field Test Unit Design

12-287.



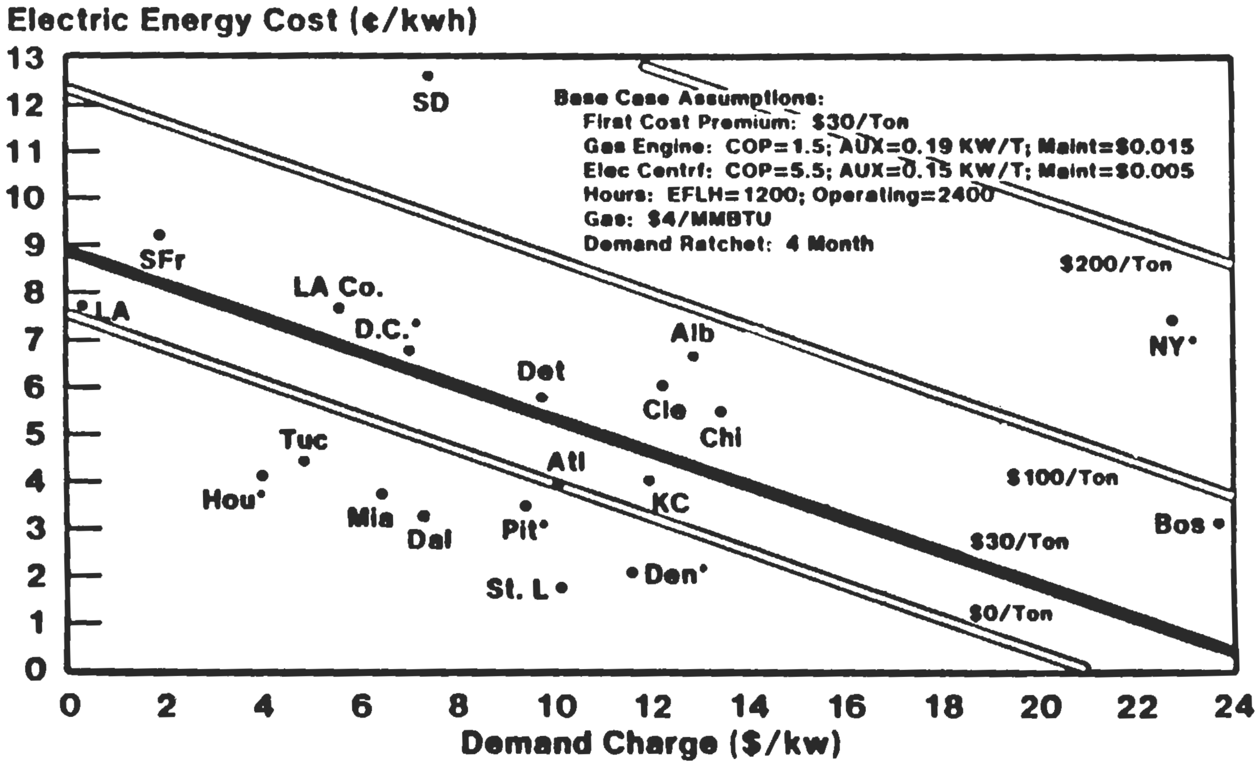
FRONT ELEVATION

Figure 5. Typical Operating Costs
Electric vs. Gas Engine



Operating costs

Figure 6. Sensitivity to First Cost



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

Figure 7. Engine-Driven Rooftop HVAC Package

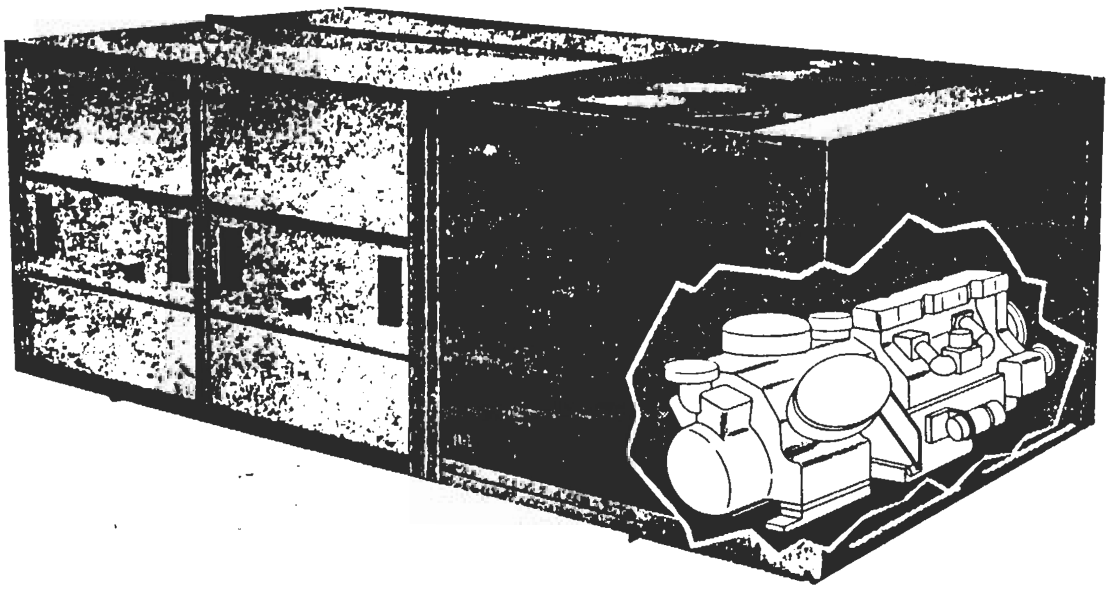
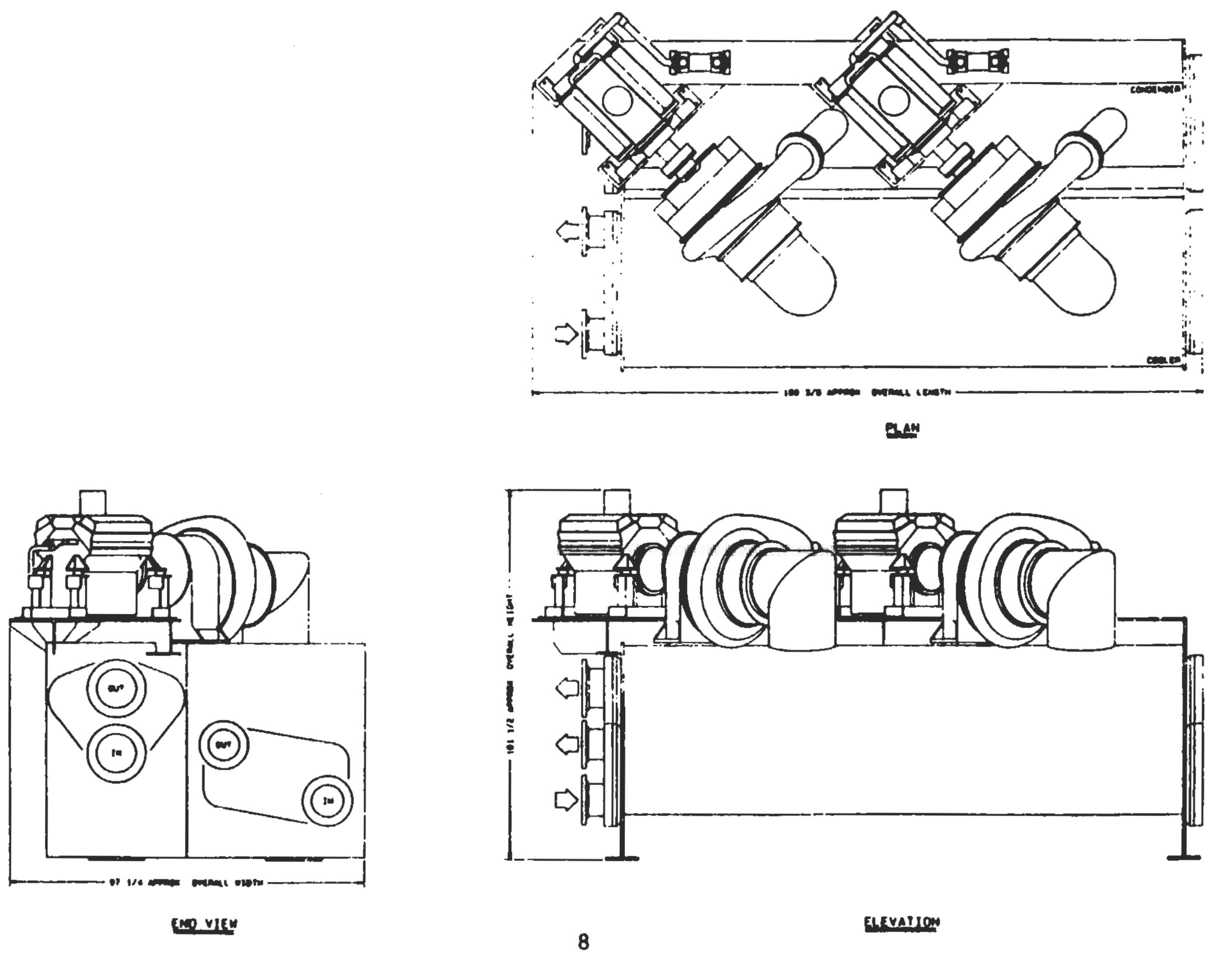


Figure 8. 500 Ton Engine-Driven Chiller

60-288



8