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Gas-Fueled Engine-Driven Air Conditioning and Refrigeration Systems for Commercial Buildings

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GAS-FUELED ENGINE-DRIVEN AIR CONDITIONING AND REFRIGERATION SYSTEMS FOR COMMERCIAL BUILDINGS

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Abstract

Since 1985, the author has been involved in 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. The engine chiller has subsequently been redesigned to improve performance, increase capacity, and reduce the footprint, and is undergoing field tests at seven sites to verify performance and reliability.

The engine chiller has produced 142 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 modified 454 cubic inch engine, 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. Further, the engine can be operated above design speeds for short periods to provide additional peaking capacity.

The engine chiller was experimentally installed at a 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 new design 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 5000 hours of operation.

Market assessments and economic analyses have demonstrated that a huge potential for gas-fueled engine-driven cooling systems exists, especially in regions of the United States that have high electric demand charges. The superior part-load performance of the engine chiller, coupled with its minimal electric requirements, makes it an ideal peaking unit. Gas-fueled cooling systems can significantly reduce peak electric demand growth for utilities and minimize investment in new generating capacity.

The development program has been expanded to a range of gas engine-driven cooling systems from 20-ton DX packages to 500-ton liquid chillers. Additionally, an integrated engine chiller/desiccant dehumidification system is being developed which should greatly improve occupant comfort while reducing energy costs.

INSTALLATIONS FRIGORIFIQUES ET DE CLIMATISATION A MOTEUR A GAZ POUR LE TERTIAIRE.

RESUME : Depuis 1985, l'auteur s'occupe d'un programme de mise au point d'un refroidisseur d'eau à moteur à gaz de 527 kW pour immeubles du tertiaire. Le système monobloc a été conçu, construit et exploité de façon satisfaisante en laboratoire et dans un hôpital de 450 lits. On a ensuite remanié la conception du refroidisseur à moteur à gaz pour améliorer sa performance, augmenter sa puissance et réduire sa surface au sol ; on le soumet actuellement à des essais dans des conditions réelles de service dans 7 sites pour apprécier sa performance et sa fiabilité.

Le refroidisseur à moteur à gaz a une production de 500 kW avec un COP de 1,4 dans les conditions de charge totale de l'ARI. En option, la chaleur du moteur peut être récupérée pour alimenter un refroidisseur à absorption, fournissant 123 kW de froid supplémentaires et faisant passer le COP du système à 1,75. L'installation est composée d'un moteur modifié de 7 440 cm^3, d'un compresseur à double vis et d'un dispositif perfectionné de régulation par microprocesseur. Le refroidisseur à moteur à gaz, en tirant parti du matériel de compression de vapeur disponible et de moteurs d'automobile bon marché peut être d'un coût très compétitif, inférieur à environ 114 dollars/kW froid. L'aptitude du moteur à fonctionner à vitesse variable améliore sensiblement la performance du compresseur à charge partielle. De plus, le moteur peut fonctionner, pendant de courtes périodes, à des vitesses supérieures à celles prévues pour fournir une puissance de pointe supplémentaire.

Un essai du refroidisseur à moteur à gaz a été fait dans un hôpital de Manchester, New Hampshire, pour évaluer le fonctionnement réel du système et les méthodes d'installation. Le COP moyen du système de refroidisseur, y compris le groupe à absorption, a été voisin de 2,0. Les résultats préliminaires de cette expérience sur les lieux d'utilisation ont été pris en considération dans une nouvelle conception qui a simplifié radicalement le groupe et amélioré sa performance. Le nouveau modèle a fait l'objet de sept essais expérimentaux sur les sites d'utilisation au cours de l'été 1987. Les refroidisseurs prototypes ont été installés dans divers immeubles du tertiaire, tels que hôtels, bureaux, habitations et usines. Les appareils ont présenté une disponibilité d'ensemble de 96 % avec plus de 5 000 h de fonctionnement.

Des études de marché et des analyses économiques ont montré qu'il existait un grand potentiel pour les systèmes frigorifiques à moteur à gaz, en particulier dans les régions des Etats Unis dont les demandes en électricité sont élevées. La performance élevée à charge partielle du refroidisseur à moteur à gaz et ses faibles besoins en électricité en font un appareil idéal pour les heures de pointe. Les systèmes frigorifiques à gaz peuvent beaucoup réduire la croissance de la demande de pointe en électricité pour les appareils et minimiser l'investissement pour des puissances supplémentaires de production.

Le programme de développement a été étendu à une série de groupes frigorifiques en détente directe et à moteur à gaz, de 70 kW froid à des refroidisseurs de liquide de 1 750 kW froid. De plus, un système de déshumidification par déshydratant intégré au refroidisseur à moteur à gaz est en cours de mise au point qui devrait nettement améliorer les conditions de confort tout en réduisant les dépenses énergétiques.

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INTRODUCTION

Rapidly escalating electricity prices have forced commercial building owners to investigate the potential for cooling systems that utilize alternative energy sources. Electrically-driven air conditioning compressors, the most commonly selected technology, add significantly to the peak demand of most facilities and are a major contributor to operating costs. In many regions of the United States, gas-fired absorption chillers have been effective substitutes, but the high first cost, parasitic requirements, and performance of these systems have limited their application. Gas-fueled engine-driven chillers have been packaged that capitalize on the advantages of state-of-the-art refrigeration, but perceptions of poor reliability and high first costs have limited their penetration as well.

GRI DEVELOPMENTS

In 1985 a program was initiated to develop a nominal 150-ton gas-fueled engine-driven water chiller for commercial buildings. The packaged system has undergone several revisions. The early prototype was designed, fabricated, and operated satisfactorily in the laboratory and in a 450-bed hospital. The engine chiller has subsequently been redesigned to improve performance, increase capacity, and reduce the footprint, and is undergoing field tests at seven sites to verify performance and reliability.

Figure 1 illustrates the initial concept for the engine-driven chiller with absorption bottoming. Figure 2 shows the field test unit design.

The engine chiller produced 142 tons of cooling at a coefficient of performance (COP) of 1.4 at ARI full load conditions. The heat from the engine was recovered to drive an absorption chiller package (which is optional), providing an additional 35 tons of cooling and increasing the system COP to 1.75. The system is comprised of a 454-cubic-inch engine modified for stationary duty, a twin screw compressor, and advanced micrioprocessor controls. By capitalizing on available vapor-compression equipment and low-cost automotive engines, the engine chiller 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 operates within a speed range of 1000-3200 rpm. Below 1000 rpm, the compressor slide valve is engaged and the chiller is therefore able to modulate from zero to 100% load. The variable speed capability permits the engine chiller to achieve an ARI Integrated Part Load Value (IPLV) of 1.7. Electrically driven systems have employed adjustable speed drive to obtain the benefits of speed modulation, but at an additional $100/ton cost. In addition to improved performance, the engine can be operated above design speeds (up to 3600 rpm) for short periods to provide additional peaking capacity. Performance deteriorates, but the building can respond to unanticipated short-term loads.

The engine chiller was experimentally installed at a hospital in Manchester, New Hampshire, in late 1986 to evaluate actual system operations and installation procedures. The chiller system, including the absorption package, exhibited an average COP approaching 2.0. The prototype supplemented a 500-ton electric centrifugal chiller that operated primarily at partload. The hospital reports significant energy cost savings and trouble-free operation. The preliminary results of the experiment were integrated into a new design that radically simplified the package and improved its performance.

The new design 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 sites, participating utilities, and applications are summarized in Figure 3. The chillers were the primary source of cooling for the buildings, and some were equipped to recover engine waste heat for domestic water. The units have demonstrated a fleet availability of 96% with over 9200 hours of operation through December 31, 1987. The average COP ranged from 1.05 to 1.89, being highly dependent upon specific site conditions and operating methods. Figures 4 through 6 show the hours of operation, load profile, and average COP for each site.

The engine chiller incorporates an advanced microprocessor controller that monitors engine and compressor functions and provides diagnostic capabilities. The controller features a modem, permitting remote monitoring and operation of the chiller, which should reduce downtime and maintenance costs. The controller also served as the data acquisition system for the field test program.

MARKET OPPORTUNITIES

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. Paybacks of less than three years for the incremental cost above conventional electric chillers are anticipated in New York, San Diego, Chicago, Los Angeles, Boston, San Francisco, and Cleveland. These cities are also expected to have high replacement rates for chillers in the future and are viewed as ideal market areas. Figure 7 compares the annual operating costs for electric and gas engine chillers in the Chicago area for two operating scenarios.

The superior part-load performance of the engine chiller, coupled with its minimal electric requirements, makes it an ideal peaking unit. The gas chiller can operate in parallel with an electric chiller to take advantage of special gas and electric rate structures. This is especially advantageous in replacement situations.

Gas-fueled cooling systems can significantly reduce peak electric demand growth for utilities and minimize investment in new generating capacity. Several electric utilities are offering special inducements to commercial building owners to install thermal storage systems which shift the cooling load to off-peak periods. The engine-driven chiller can accomplish the same task and avoids the possibility that the off-peak system is operated on-peak. A west coast utility currently offers a first cost subsidy of $280/ton for gas-fired cooling systems up to 200 tons capacity. Some natural gas utilities offer inducements of $100/ton. These programs can actually make the engine chiller the lowest first-cost option.

FUTURE DEVELOPMENTS

Industry development programs have been expanded to a range of gas engine-driven cooling systems from 15-ton DX packages to 500-ton liquid chillers. Additionally, an integrated engine chiller/desiccant dehumidification system is being developed which should greatly improve occupant comfort while reducing energy costs. The engine chiller can incorporate either an electric generator to provide emergency power or ice storage systems to decrease total equipment capacity. These options are now under review at GRI.

The 150-ton engine-driven chiller package will be commercially available in 1988. Sixty units have been ordered, with 30 of them scheduled for delivery in 1988, to a consortium of gas utilities. The 500-ton chiller and engine-driven unitary packages should be available in 1990. Purdue University is being considered as a site for field testing the 500-ton chiller beginning in late 1988. The integrated engine-chiller/desiccant system could be available in 1990.

The participation of major HVAC and refrigeration firms and the success of the early commercial units should ensure the rapid acceptance of gas cooling technologies. The continued support of the natural gas industry, will make engine-driven cooling systems a viable alternative for commercial building owners.

FIGURE 1

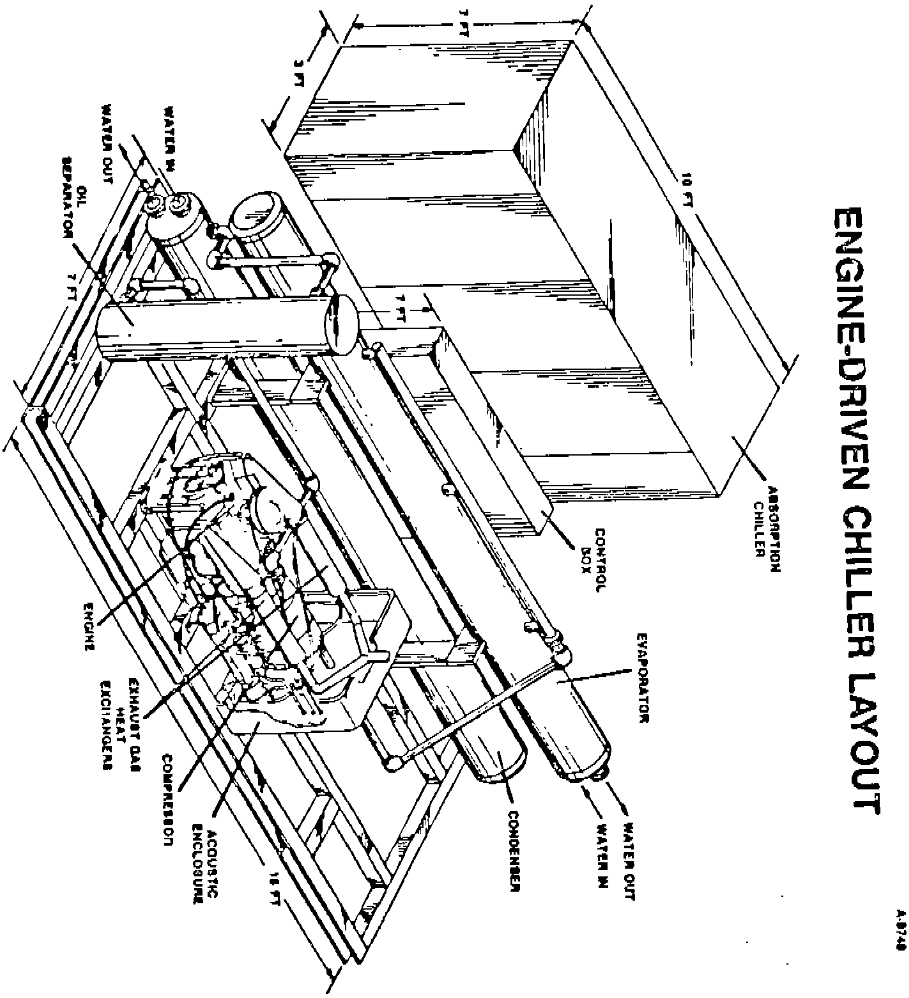
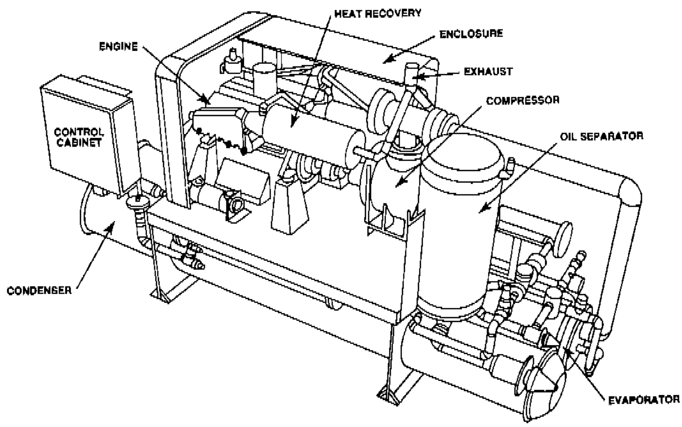

ENGINE-DRIVEN CHILLER LAYOUT
ABSORPTION CHILLER
CONTROL BOX
EVAPORATOR
WATER OUT
WATER IN
CONDENSER
ACOUSTIC ENCLOSURE
COMPRESSOR
EXHAUST GAS HEAT EXCHANGERS
ENGINE
OIL SEPARATOR
WATER OUT
WATER IN
7 FT
3 FT
10 FT
7 FT
7 FT
16 FT

FIGURE 3
150-TON GAS ENGINE-DRIVEN CHILLER
1987-88 FIELD TEST SITES

SITE	START	APPLICATION	TYPE
BUDGET INN	MAY 6, 1987	HT RECOV	HOTEL
BLEYLE	JUNE 5, 1987	ENGINE	MFG
PEPL HQ	JUNE 11, 1987	ENG/ABSORP	OFFICE
GLENVIEW HQ	SEPT 5, 1987	ENGINE	OFFICE
WYNDHAM-BRISTOL	SEPT 11, 1987	HT RECOV	HOTEL
GROSSMONT CENTER	SEPT 25, 1987	ENGINE	OFFICE
S.M.BAY TOWER	APR 18, 1988	ENGINE	APARTMENT
MARTIN BLDG**	JUN 15, 1988*	ENGINE	OFFICE

* - ESTIMATED START UP DATE

** - NON-GRI FUNDED FIELD TEST



Specifications

Output:	150 tons (ARI) Chilled Water @ 44° F 750,000 BTU/HR Hot Water @ 240° F (With Optional Heat Recovery)
Input:	1,260 SCFH Natural Gas 4 kW Electric, 208/230 VAC, 1 PHASE, 60 HZ
Efficiency:*	Mechanical Cooling (Without Heat Recovery) COP = 1.4 at Full Load COP = 1 7 at IPLV Rating (Integrated Part Load Value per ARI 550) Mechanical Cooling With Optional Heat Recovery COP = 1.9 at Full Load COP = 2.2 at IPLV Rating
Acoustic Level:	82 dBA at 20-feet Full Load (With Optional Enclosure)
Controls:	Microprocessor based. Fully automatic start-up, monitoring, load following and shutdown Programmable setpoints 2 level diagnostics. Digital display. Remote monitoring (optional).
Dimensions:	13 5' long x 4' wide x 6' high
Weight:	10,250 lbs dry
Refrigerant:	R22

*COP ratings are based upon fuel higher heating value (HHV).

FIGURE 2

Field Test Unit Design - Engine Chiller

ENGINE CHILLER FIELD TEST DATA
LOAD DISTRIBUTION

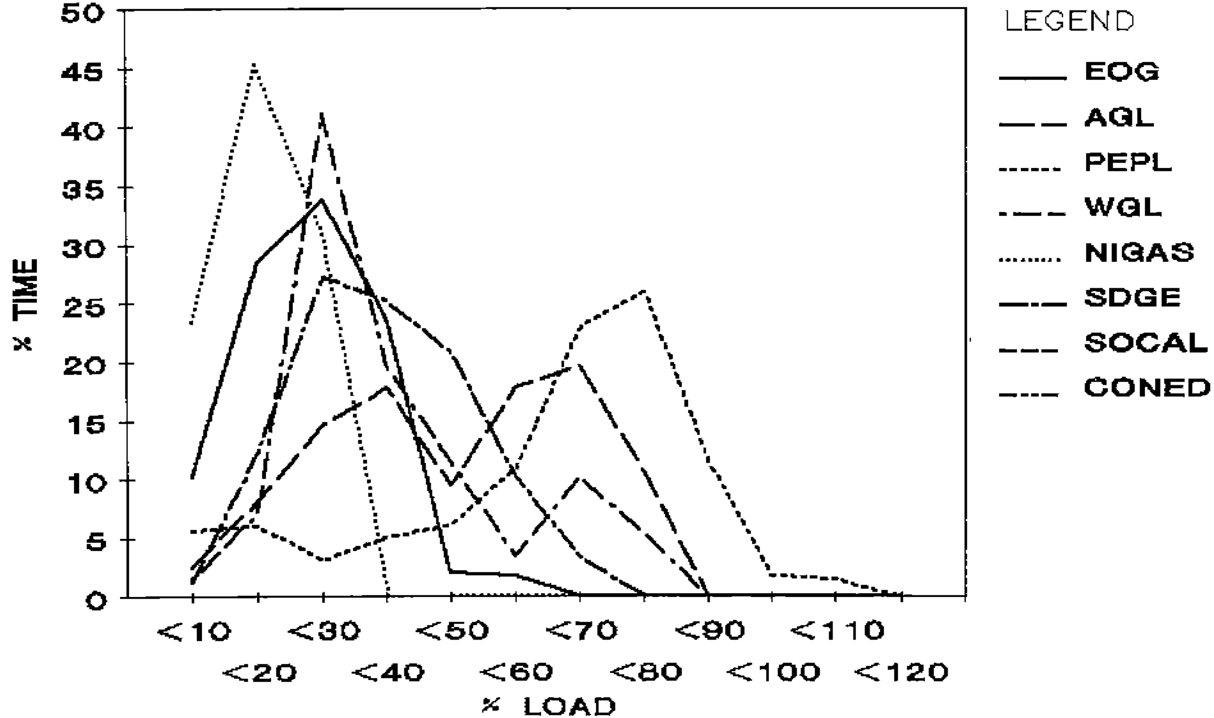
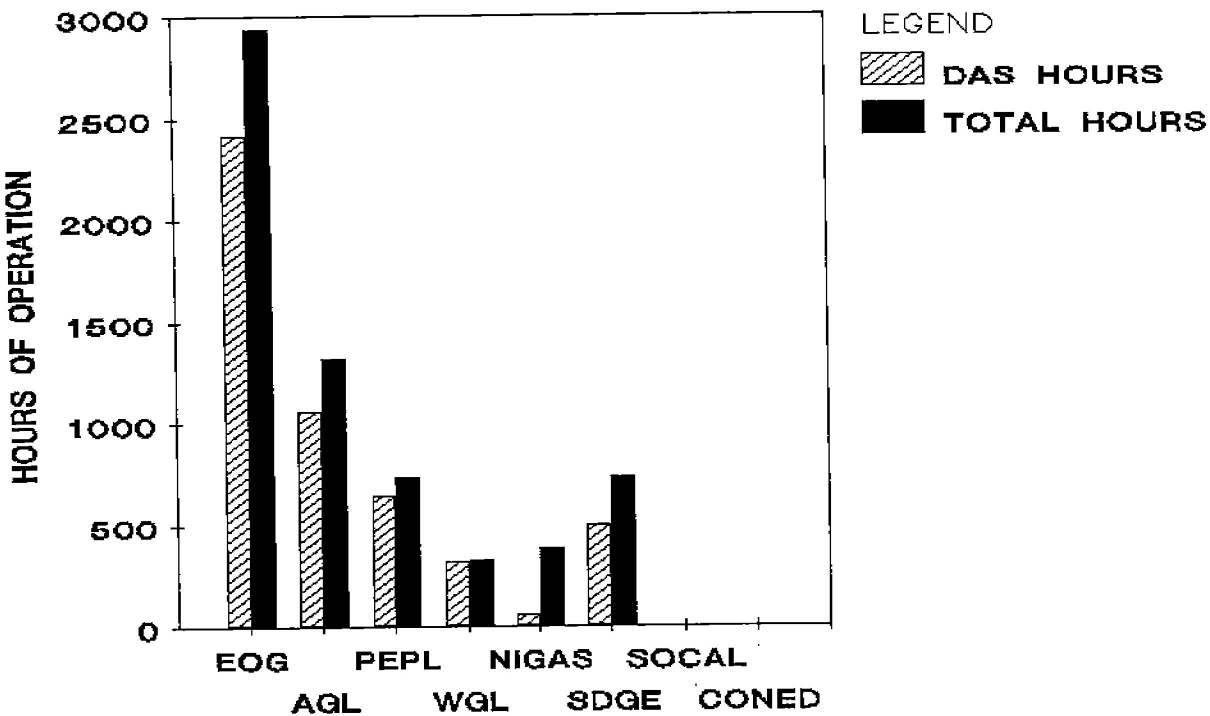


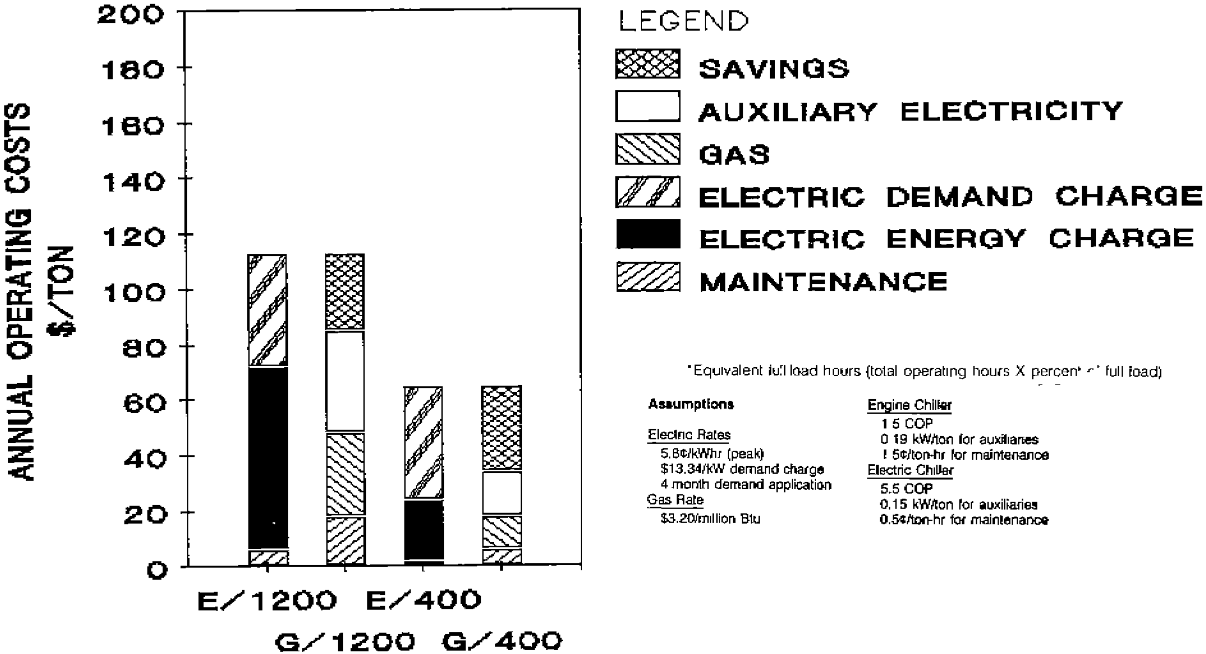
FIGURE 5

FIGURE 4

ENGINE CHILLER FIELD TEST DATA
HOURS OF OPERATION



ENGINE CHILLER ECONOMICS
--CHICAGO AREA--



ELECTRIC AND GAS COOLING/
EQUIVALENT FULL LOAD HOURS

*Equivalent full load hours (total operating hours X percent of full load)

Assumptions

Electric Rates
- 5.8¢/kWhr (peak)
- $13.34/kW demand charge
- 4 month demand application

Gas Rate
- $3.20/million Btu

Engine Chiller
- 1.5 COP
- 0.19 kW/ton for auxiliaries
- 1.5¢/ton-hr for maintenance

Electric Chiller
- 5.5 COP
- 0.15 kW/ton for auxiliaries
- 0.5¢/ton-hr for maintenance

FIGURE 7

FIGURE 6

ENGINE CHILLER FIELD TEST DATA
COEFFICIENT OF PERFORMANCE (COP)