**PERFORMANCE AND EVALUATION OF GAS ENGINE
DRIVEN ROOFTOP AIR CONDITIONING EQUIPMENT
AT THE WILLOW GROVE (PA) NAVAL AIR STATION**

INTERIM REPORT - 1992 COOLING SEASON

**P. R. Armstrong
D. R. Conover**

May 1993

**Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Richland, Washington 99352**

MASTER

SP

Abstract

In a field evaluation conducted for the U.S. Department of Energy (DOE) Office of Federal Energy Management Program (FEMP), the Pacific Northwest Laboratory (PNL)^(a) examined the performance of a new U.S. energy-related technology under the FEMP Test Bed Demonstration Program. The technology was a 15-ton natural gas engine driven rooftop air conditioning unit. Two such units were installed on a naval retail building to provide space conditioning to the building. Under the Test Bed Demonstration Program, private and public sector interests are focused to support the installation and evaluation of new U.S. technologies in the federal sector. Participating in this effort under a Cooperative Research and Development Agreement (CRADA) with DOE were the American Gas Cooling Center, Philadelphia Electric Company, Thermo King Corporation, and the U.S. Naval Air Station at Willow Grove, Pennsylvania. Equipment operating and service data as well as building interior and exterior conditions were secured for the 1992 cooling season. Based on a computer assessment of the building using standard weather data, a comparison was made with the energy and operating costs associated with the previous space conditioning system. Based on performance during the 1992 cooling season and adjusted to a normal weather year, the technology will save the site \$6,000/yr in purchased energy costs. An additional \$9,000 in savings due to electricity demand ratchet charge reductions will also be realized. Detailed information on the technology, the installation, and the results of the technology test are provided to illustrate the advantages to the federal sector of using this technology. A history of the CRADA development process is also reported.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

Preface

The federal government is the largest single energy consumer in the United States with consumption of nearly 1.5 quads/yr (1 quad = 10^{15} Btu) and cost valued at nearly \$10 billion annually. The U.S. Department of Energy's (DOE) Federal Energy Management Program supports efforts to reduce energy use and associated expenditures within the federal sector. One such effort, the Test Bed Demonstration Program, seeks to evaluate new energy-saving U.S. technologies and secure their more timely adoption by the federal government.

Through the results of a test bed project, federal agency decision makers can receive more "hands on" information with which to validate the decision to utilize a new technology in their facilities. Energy-saving technologies regularly emerge in the marketplace. This program seeks to identify those technologies, determine which have the broadest application for the federal sector, and then shorten the deployment time for those that prove beneficial to the federal market.

Recent initiatives within the federal government have focused on the use of natural gas for both economic and environmental reasons. It is therefore fitting that the technology selected for evaluation in the first test bed demonstration, and the subject of this interim report, is natural gas engine driven cooling equipment.

The project began with the solicitation of interested parties willing to participate in the installation and evaluation of gas cooling technologies. The search for a suitable federal site within the service areas of the responding utilities then commenced. By early 1992 the field had been narrowed to one manufacturer, Thermo King Corporation, and three utilities.

The Philadelphia Electric Company (PECO), one of the three interested utilities, determined that a naval facility within its service area had recently (fall 1991) installed two of the Thermo King units. This provided an opportunity to more quickly implement the first test bed demonstration, which became critical with the 1992 cooling season approaching.

Discussions were initiated with the site—the Naval Air Station at Willow Grove, Pennsylvania—and other interested parties who had responded to the solicitation. These included the American Gas Cooling Center (AGCC), PECO, and the Thermo King Corporation. Based on an evaluation of the building, utility costs, and past building performance, it was determined that the installation offered a good opportunity to evaluate the performance of the subject technology. A Cooperative Research and Development Agreement involving the foregoing parties, DOE, and PNL, was formalized to evaluate the technology.

As part of the agreement, the American Gas Association Laboratories, who had performed similar efforts on the equipment at other non-federal installations, was tasked to design the data acquisition system on behalf of PECO and AGCC. At the beginning of the 1992 cooling season the data acquisition system was installed and commissioned. Operation of the units was monitored during the 1992 cooling season, the monitored data were analyzed, and the results are reported herein.

Executive Summary

Through a Cooperative Research and Development Agreement (CRADA), the U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP), Pacific Northwest Laboratory (PNL), the American Gas Cooling Center (AGCC), Philadelphia Electric Company, Thermo King Corporation (TK), and the Naval Air Station at Willow Grove (NASWG) are evaluating the performance of a new U.S. cooling technology that has been installed for the first time at a federal facility.

The gas engine driven cooling technology selected for the Test Bed Demonstration Program is a 15-ton natural gas engine driven rooftop air conditioning unit manufactured by Thermo King Corporation. The equipment is air cooled and serves a single zone for both heating and cooling. It is factory assembled, charged with R-22 (an HCFC refrigerant), and requires single point connections of electrical power (for the supply air fan motor) and natural gas. The unit's cooling capacity is 190,000 Btuh at ARI Standard 360 rating conditions. The unit's heating capacity is 216,000 Btuh output at 265,000 Btuh input. Variable engine speed allows for cooling operation in three stages and cylinder unloading provides an additional stage for light load conditions.

Two of the Thermo King units were installed to serve the base exchange (BX) at NASWG. The retail sales area of the building covers 12,500 ft² and was previously conditioned by two rooftop units using #2 fuel oil for heating and direct expansion refrigeration for cooling. To evaluate the new technology, the building and the new gas engine driven units were instrumented and monitored.

Data collected during the demonstration included outdoor and indoor temperature and humidity, gas and electric consumption of the equipment, refrigerant pressures and temperatures, and operating time associated with different stages of the units. The measurements, generally averaged and recorded at the end of each 15-minute scan interval, were used to evaluate the equipment performance and energy use, and to diagnose operational problems. Additional measurements were taken to provide redundant measures of performance and for monitoring system diagnostics.

The relation between cooling load and ambient temperature, and the relation between equipment coefficient of performance ($COP = \text{cooling effect}/\text{input energy}$) and load were characterized based on the recorded data. A number of problems associated with the operation of the equipment, and possible solutions, were also identified.

The input load was fairly well correlated with outside temperature. However, one unit used almost twice as much fuel as the other unit. A small difference in the room temperature setpoints of the two units may have caused the load imbalance. Each of the two

units has its own thermostat, even though both units serve the same retail area of the BX. This area would normally be considered a single zone. It might be more appropriate to control both units from a single thermostat with multiple-temperature sensors to ensure load balance.

The linear regression of input load with outside temperature indicated a daily gas consumption of 3,960 kBtu per Fahrenheit degree above a mean daily temperature of 60°F on days that the BX was open. The cooling capacity of each unit is varied to meet load by changing engine/compressor shaft speed and (for the lowest stage) by unloading two of four compressor cylinders and changing indoor fan speed. Thus a unit can operate in one of four cooling stages designated C1 through C4. The nominal capacities are 25,000^(a) Btuh in stage C1, 84,000 Btuh in stage 2, 143,000 Btuh in stage 3, and 190,000 Btuh in stage C4.

The coefficient of performance for unit 1 was computed from air-side sensible and latent loads and gas input energy rate. COP was relatively constant in each cooling stage, ranging between 0.5 and 0.6 in C1, between 0.8 and 1.0 in C2, between 0.65 and 0.75 in C3 and between 0.5 and 0.6 in C4. The overall daily COP was found to track the stage 1 (C1) COP on most days but improve, because of the influence of C2 and C3 COPs, on higher load days.

The measured COPs were compared to the COPs quoted by Thermo King (Appendix B, p. B.29, of this report). The C1 COP was almost double the quoted value,^(b) the C2 COP was very close to the quoted value, and the C3 and C4 COPs were both about 10% less than the quoted values.

The *seasonal* COP is, in simplest terms, the sum of the part-load COP and part-load operating time products divided by the total operating time. The seasonal COP for unit 1 is substantially lower than the integrated part-load value (IPLV) quoted, due mainly to longer operation in stage 1 and shorter operation in stage 2 relative to the IPLV shares of operating time assumed by the manufacturer.

-
- (a) Two values of the first stage nominal capacity are possible depending on whether one or both sections of the evaporator are selected. With one section (25% of face area) selected the nominal capacity is 26,000 Btuh; with both it is about 40,000 Btuh.
- (b) The quoted COP was based on use of 1/4 of the evaporator coil by means of a control valve that can be used to stop flow through the other 3/4 of the coil in C1. This valve was disabled (as is standard in all units manufactured after 4/92) in unit 1. Hence the full coil was used, resulting in higher capacity at about the same shaft power (due to higher refrigerant flow but lower suction pressure) and higher COP.

The units consumed 190 MBtu (HHV) of natural gas and provided 115 MBtu of cooling effect during the monitoring/analysis period. They are expected to consume 370 MBtu of gas and provide 225 MBtu of cooling in a normal cooling season.

The new and unique nature of the equipment required extra care and support from experienced local service people. However the added cost, in terms of lost performance, was relatively minor. There were only two shutdowns that were directly related to the equipment. These were attributable to removal and replacement of the engine starter on one unit and a unit shutoff due to refrigerant pressure. Service for this installation will probably not be a problem in future years because the local service people are now familiar with the new technology. The growing market penetration that is currently underway nationally should ensure the availability of qualified local service in the future.

There appear to be opportunities for improving the seasonal performance of the equipment by modifying the staging control sequence. There may be further opportunities for improving seasonal performance and reducing aggregate annual engine starts in multi-unit applications by coordinated and integrated control of the units. A multi-zone Rooftop Unit (RTU) configuration with the two RTUs feeding a single air distribution system would be appropriate at the Willow Grove BX.

The annual energy costs for cooling, based on the loads and performance measured during the 10-week monitoring period and weather normalized to the full cooling season in a normal year, are \$2,450 to operate the compressors and condenser fans in the two units. The annual energy costs to operate the compressors and condenser fans in comparable electric powered units would be \$1,040 in energy charges and \$14,380 in demand and ratchet charges. Maintenance of the TK units is expected to cost about \$400/yr more than the maintenance of comparable electric powered units.

The units will use about the same amount of source energy^(a) for cooling as comparable electric powered units. The operation of electric motor and gas engine driven units is very similar and the level of comfort provided by the two types of units is indistinguishable.

(a) Source energy is defined here as the energy input to the power plant in the case of electricity, or the energy input to the regional gas transmission system in the case of natural gas, to provide a given amount of energy at the customer's meter. By this definition, source energy includes transmission and distribution losses and generation losses, but does not include energy input required for fuel extraction, processing, and transportation to get the fuel to the region.

The cost of fuel for heating is assumed to be the same for a comparable gas heating/ electric cooling RTU as for the subject unit. Continued monitoring through the 1992-1993 heating season will provide field performance data in the heating mode, which will be presented in the final report.

The net savings for the gas engine driven unit is the difference between the present value of savings, \$148,023, and the increased total investment of \$26,642. This gives a net LCC savings, expressed as a present value, of \$121,381. The savings-to-investment ratio is 5.56 assuming the previous electric units had to be replaced anyway at the time of the retrofit.

In cases where the existing electrical equipment is not worn out, the savings-to-investment ratio would be less, but it is still positive (0.88), even for the hypothetical case of replacing brand new electric equipment, given the rate structure and load distributions at Willow Grove.

Other regions where climate and energy rates favor the gas cooling technology are being determined by PNL staff.

A gas engine driven unit is generally cost effective in areas with high (e.g., > 15 cents/kWh blended) electric rates, moderate (e.g., < 70 cents/therm) gas rates, and annual cooling loads that result in present value electric energy/operating costs that are at least twice the comparable electric unit's replacement cost minus any utility rebate. Annual operating cost is primarily a function of annual full load equivalent operating hours (cooling) and gas and electric rate structures.

Acknowledgments

The authors wish to acknowledge the participation, review, comments, and support provided to this project by the CRADA participants and others associated with the project. These include K. Dean DeVine, Federal Energy Management Program; Jim Edmond, NASWG; Bob Ellis, Thermo King; Terry Falvey, Northern Division, NAVFAC; Jack Flanigan, PECO; Chuck Karr, Thermo King; Robert McNulty, PECO; Commander Mike Strand, NASWG; Rich Sweetser, AGCC; and Jim Verna, PECO.

Contents

Abstract	iii
Preface	v
Executive Summary	vii
Acknowledgments	xi
1.0 Introduction	1.1
2.0 Conclusions and Recommendations	2.1
2.1 Savings Potential at NASWG	2.1
2.2 Savings Potential in Federal Sector	2.2
2.3 Conditions for Implementation	2.2
3.0 Background	3.1
3.1 Facility Description	3.1
3.2 Description of the Previous Rooftop Units	3.3
3.3 Description of Gas Engine Driven Rooftop Units	3.4
3.4 Analysis That Supported Gas for Cooling	3.7
3.5 Technology Assessment Methodology	3.8
4.0 Field Performance Monitoring	4.1
4.1 Data Acquisition System	4.1
4.2 Measurements for Field Performance Evaluation	4.3
4.3 Acquired Data	4.9
5.0 Observed Performance and Operation	5.1
5.1 Cooling Loads	5.1
5.2 Efficiency	5.3

5.3 Control and Seasonal Performance	5.6
6.0 Annual Performance and Life-Cycle Cost	6.1
6.1 Normal Year Loads	6.1
6.2 Equivalent Electric Powered Unit	6.3
6.3 Energy Costs	6.4
6.4 Life-Cycle Cost Comparison	6.7
7.0 References	7.1
Appendix A - Summary of Activity Leading to the Cooperative R&D Agreement (CRADA) and the Joint Statement of Work (JSOW)	A.1
Appendix B - Description of Thermo King Equipment	B.1
Appendix C - Acquired Field Data	C.1
Appendix D - Glossary of Terms and Abbreviations	D.1

Figures

3.1 Floor Plan of Base Exchange	3.2
3.2 Base Exchange: View from the East	3.2
3.3 Base Exchange: East Wall Detail	3.3
3.4 Cut-Away View of the Thermo King Equipment	3.6
3.5 Thermo King Unit 1: View from the South	3.6
4.1 Data Acquisition System	4.2
4.2 Location of Thermostat Controls in Relation to TK Units and Air Distribution Systems	4.5
4.3 Sensor Locations in Refrigerant Loop	4.6
4.4 Sensor Locations in Air-Side Loop	4.7
5.1 Daily Average Fuel Input and Temperature as a Function of Time	5.2
5.2 Relation Between Daily Gas Load and Ambient Temperature	5.2
5.3 Average Daily COP by Cooling Stage	5.4
5.4 Measured COPs Versus Rated COPs	5.4
5.5 Unit 1 Measured Part-Load Operating Times Versus Those Used by the ARI Standard to Compute Seasonal COP	5.5
6.1 Comparison of Normal-Year and 1992 Ambient Temperature Distributions	6.2
6.2 Energy Requirements for Electric and Natural Gas Alternatives	6.5
6.3 Monthly Energy Costs for Electric and Natural Gas Alternatives	6.5
6.4 Distribution of Monthly Energy Costs for the Electric Alternative	6.6

Tables

3.1 Capacity and Related Operating Parameters	3.5
3.2 Life-Cycle Cost of HVAC Options Considered for the BX in 1990	3.7
4.1 Sensor Specifications	4.8
6.1 Available Climate Data	6.2
6.2 Energy-Related Costs	6.7
6.3 Comparison of Present-Value Costs	6.8

1.0 Introduction

The purpose of the Test Bed Demonstration Program is to accelerate the deployment of advanced energy technologies through government and private sector partnerships that install and evaluate technology performance in the federal sector. Through the results of a test bed project, federal agency decision makers have more "hands on" information with which to validate a decision to utilize that technology in their facilities. Energy-saving technologies emerge regularly in the marketplace. This program seeks to identify those technologies, determine which have the broadest application for the federal sector, and then shorten the deployment time for those that prove beneficial to the federal market.

Beginning in 1989 activities were initiated to develop a Test Bed Demonstration Program that could facilitate the introduction of new technologies into the federal sector. The first major program activity was to develop the overall concept and description of the program. Four concurrent activities were then undertaken, including development of the criteria for interagency and cooperative agreements. Another of those concurrent activities was to identify candidate technologies for test bed demonstrations. This was done through a series of meetings with government and industry representatives. A number of technologies were originally suggested and the scope of these options was narrowed through these discussions. Specific criteria associated with energy, cost, and environmental challenges in the federal sector were also identified.

Based on discussions and meetings with Department of Defense officials, five technology alternatives were identified and ranked. The technology receiving the highest ranking was natural gas engine driven chillers. The reasons for this decision were the clean air aspects of the technology; potential energy savings; and potential cost savings. No limitation on equipment size was specified. Through selection of a target technology the groundwork for the first (pilot) test bed demonstration project was complete.

A solicitation of interested parties to participate in this first test bed demonstration project was made available in mid-1991 to utilities and manufacturers. The solicitation explained the purposes of the program and highlighted the benefits to be derived from such a public- and private-sector partnership. A search was undertaken to identify a federal site that was within the service area of the responding utilities, had a facility infrastructure that was broadly representative of the federal sector, and a building that was appropriate for the technology.

In early 1992, during the course of the search, the interest of some utilities and manufacturers changed and they could no longer consider participation. This left three manufacturers and three utilities still interested in participating in the first test bed. The Philadelphia Electric Company (PECO) identified a federal site that had installed equipment

from one of the three manufacturers that remained interested. The other two utilities also identified candidate sites, but these were found unsatisfactory. One was a postal facility where the private sector building owner did not feel the subject equipment size was appropriate for the building. The other, a presidential library, would not have been ready for test initiation by the summer of 1992. Another possibility in Philadelphia was considered but found unsuitable due to the historic nature of the subject structure and its inability to accommodate the equipment. Although additional search efforts could have been undertaken to identify another federal site, the site proposed by PECO was determined to be most appropriate to serve as the first project under the Test Bed Demonstration Program. This decision was driven in large part by time, considering the desire to have the equipment installed and operational for evaluation during the summer of 1992.

The site selected for the first FEMP test bed demonstration project was the Naval Air Station in Willow Grove (NASWG), Pennsylvania. The building selected for application of the gas engine driven air-conditioning technology was a retail facility known to its customers as the base exchange (BX). The equipment installed was Thermo King (TK) natural gas engine driven rooftop heating and air conditioning equipment as submitted by Thermo King in its response to the solicitation. Two 15-ton units were installed on the roof to supply the heating and cooling to approximately 12,500 ft² of the 16,000 ft² structure. These units were already installed in the building,^(a) having been the first such sales in the federal sector. Other organizations responding to the solicitation and participating in the project were the Philadelphia Electric Company and the American Gas Cooling Center. Together with DOE these organizations were interested in forming a partnership to determine how the equipment would perform in the federal sector.

These organizations were contacted and a draft Cooperative Research and Development Agreement (CRADA) and Joint Statement of Work (JSOW) were prepared for consideration by each of the parties. The CRADA and JSOW documents formalize the partnership by which each organization would jointly sponsor and participate in the monitoring and evaluation of the performance of the Thermo King equipment. After review, comment, and negotiation these documents were finalized. A key concept and portion of these documents addresses the in-kind services which each organization brought to the project. Rather than DOE supporting the entire project, each organization supported certain specific project activities. This resulted in the cost and value of the project being shared by DOE and the other four participants.

(a) The existing equipment, installed in 1983, used electricity for cooling and fuel oil for heating. The facility engineer initiated a project to explore replacement alternatives because of the high cost to operate and maintain the equipment.

The purpose of the Willow Grove test bed demonstration project is to evaluate the performance and economics of natural gas engine driven^(a) rooftop air conditioning equipment within the federal sector. Included in the evaluation is energy use and cost, operation and maintenance, reliability, and building space temperature and humidity. With this information it was hoped that any benefits of the equipment could be identified and subsequently communicated to others in the federal sector. As delineated in this interim report, \$13,000 in energy costs will be saved during a normal (weather) year at NASWG.

The primary tasks in the NASWG test bed included planning, data acquisition system design and installation, data acquisition and analysis, and reporting of results. The planning activity was led by PNL and NASWG. This included all activities necessary to define the project and the methodology by which the equipment would be evaluated. Considerable support for this activity came from the PECO and the AGCC who contracted with the AGAL to provide the data acquisition system. The data acquisition system (DAS) was installed by AGAL with additional measurements recommended by PNL. NASWG staff assisted with the DAS installation and PECO provided the necessary gas metering devices.

Beginning in early June of 1992 operating data were logged by the DAS every 15 minutes and downloaded to computer systems at PNL for classification and analysis. Concurrent with the initiation of data acquisition, a media presentation was conducted at Willow Grove and the activities to be conducted during the test period presented to the press. The preliminary results of the test, which are the subject of this report, were determined in late 1992. During the test period, and under the terms of the CRADA, Thermo King provided service and maintenance at no cost to NASWG. The results of the first summer of operation were presented at a workshop for federal facility managers and energy and procurement officials on December 11th in Washington, D.C. This outreach activity was sponsored by the AGCC as part of its project support.

The purpose of this interim report is to present the information gathered during the first summer of equipment operation at NASWG. Section 2 provides the conclusions and recommendations derived from the activity at NASWG. Background on the facility and the project is provided in Section 3. The manner in which the equipment was monitored in the field is presented in Section 4 and Section 5 presents the observations and analysis results for the monitoring period. Normal year performance is estimated from the measured performance results in Section 6 and a life-cycle cost analysis is presented. References are included in Section 7. Appendix A summarizes the CRADA and joint statement of

(a) The terms "gas powered" and "gas engine driven" are used interchangeably in this report to refer the TK air-conditioning units. Note, however, that "gas powered" equipment generally includes a variety of technologies, including gas-fired absorption machines and gas-fired desiccant cooling technologies.

work development histories. Appendix B provides information on the Thermo King equipment and the acquired field data are presented in Appendix C. Terms and abbreviations are defined in Appendix D.

2.0 Conclusions and Recommendations

Based on the results of the NASWG installation, certain conclusions about the equipment performance can be drawn and then applied to the entire federal sector. In addition, recommendations for application of the equipment at other federal sites can be provided as well as consideration for continued equipment evaluation. Section 2.1 describes the savings potential at NASWG. The savings potential in the federal sector is estimated in Section 2.2. Conditions which should be considered in implementing this technology at other federal sites are presented in Section 2.3.

2.1 Savings Potential at NASWG

The annual energy cost is \$2,450/yr to operate the compressors and condenser fans in the two TK units. This is based on the building loads and equipment performance measured during the 10-week monitoring period during the summer of 1992 and weather data normalized to the full cooling season in a normal year as described in Section 5. The annual energy costs to operate the compressors and condenser fans in comparable electric powered units would be \$1040/yr in energy charges and \$14,380/yr in demand and ratchet charges. Maintenance of the TK units is expected to cost \$400/yr^(a) more than the maintenance of comparable electric powered units.

The TK units will use about the same amount of source energy^(b) as comparable electric powered units. The only real differences between the electric and gas powered units

(a) The estimate is based on *engine maintenance only* because refrigeration subsystem and air-side maintenance activities are the same as for electric motor driven units. According to *GTC-1 Installation, Operation and Maintenance Manual*, publication #TIC 40267-1, January 1993, p. 11, one engine maintenance call per year is required for complete tune-up, renewal of filters, 40 quart oil change and engine winterization. Actual maintenance costs will be reviewed in the future and presented in the final report.

(b) Source energy is defined as total energy that must be supplied to the source power plant or regional gas transmission system to provide a specified end-use service. This definition considers transmission, distribution, and generation losses but does not consider extraction, processing and transmission losses outside the region of interest.

result from the operating characteristics of the electric motor or natural gas engine as a source of compressor shaft power. The service (level of comfort) provided by the two types of units is indistinguishable.^(a)

The net savings for the gas powered unit is the difference between the present value of non-investment savings, \$148,023, and the increased total investment of \$26,642. This gives a net savings, expressed as a present value, of \$121,381 for the gas powered alternative over a 15-year life cycle. The savings-to-investment ratio is 5.56, assuming the previous electric units had to be replaced anyway at the time the TK units were installed. In cases where the existing electrical equipment is not worn out, the savings-to-investment ratio would be less, but it is still positive (0.88) even for the hypothetical case of replacing brand new electric equipment given the rate structure and load distributions at Willow Grove.

2.2 Savings Potential in Federal Sector

An assessment extrapolation is being developed from the 1989 Commercial Buildings Energy Consumption Survey (CBECS). This will identify the number of candidate sites and affected building area for this technology.

Based on the savings attributable to the NASWG installation and the site-specific climate and energy rate structures of each potential federal site, an estimate of total federal energy and cost savings potential will be developed and included in the final report.

2.3 Conditions for Implementation

In the analysis of the retrofit economics for other sites, it is important to determine—by simulation or by monitoring existing equipment with simple run-hour clocks^(b) and

-
- (a) The noise level of the units was not considered objectionable by the NASWG. No incremental effect of ozone depletion would be found since the TK unit uses R-22, an HCFC refrigerant which is common to electric rooftop equipment as well. A short-term reduction in fossil fuel emissions may result from replacement of electric power as the energy source by natural gas; however, in the long term central plant emissions are expected to be as low, per electric cooling ton-hr delivered, as the per-ton-hr emissions resulting from gas powered air conditioners.
 - (b) A run-hour clock connected to each cooling stage control line will give a good indication of part load distribution. The readings should be logged at least weekly. A daily log of the readings, together with daily outdoor maximum and minimum temperature, will facilitate extrapolation of the part-load distribution to a normal weather year.

logs—the distribution of part-load hours for a typical cooling season. This is imperative where the gas powered alternative is expected to be only marginally attractive or where there is reason to believe that the existing equipment is significantly oversized or undersized. A feasibility study can then be completed using the normal year energy analysis developed and presented in Section 6 of this report.

A gas powered unit is generally cost effective at a site with high (e.g., > 15 cents/kWh blended) electric rates, moderate (e.g., < 70 cents/therm) gas rates, and annual cooling loads that result in present value electric energy/operating costs that are at least twice the electric unit's replacement cost minus any utility rebate. Annual operating cost is primarily a function of annual full load equivalent operating hours (cooling) and gas and electric rate structures. Gas powered units should be considered as replacements for aging electric units that are inefficient or unreliable as well as for new construction.

3.0 Background

The building selected for the inaugural test bed demonstration had recently installed the new equipment and was just being readied for its first cooling season since the retrofit. This installation was the first application of the TK gas engine driven cooling technology in the Federal sector.

3.1 Facility Description

The base exchange (BX) at NASWG is a 15,277 ft² single story masonry structure built in 1983. The retail sales area, covering 12,500 ft², was previously heated and cooled by two conventional rooftop units using #2 fuel oil as the heating fuel and direct expansion refrigeration with electrically driven reciprocating compressors for cooling. The aggregate capacity of these units was 225,000 Btuh heating and 380,000 Btuh cooling. The storage area, covering 3,200 ft² (with an additional 3,000 ft² mezzanine above), was heated by #2 fuel oil fired unit heaters and was not cooled. The snack shop, covering 210 ft², was cooled and heated by a split DX system of 17,000 Btuh nominal cooling capacity with electric resistance heaters of 3 kW capacity. Figure 3.1 provides a layout of the structure and Figure 3.2 depicts the BX from a distance sufficient to make the two TK units just visible on the roof.

The structure is uninsulated with concrete "T" walls and roof. The exterior wall finish is white and the roof is black (tar and pea gravel). A small portion of the front (east facing) wall, as shown in Figure 3.3, consists of display windows. The rest of the walls are windowless.

The BX is occupied from 0700 to 1700 Tuesday through Friday, 0800 to 1600 Saturday and Sunday; it is closed on Monday. The average number of occupants is estimated to be 10 and the peak (daily) number is estimated to be 35. Lighting is provided by fluorescent fixtures for 98% of the floor area with the balance covered by incandescent and high pressure sodium fixtures.

Figure 3.1. Floor Plan of Base Exchange

Figure 3.2. Base Exchange: View from the East

Figure 3.3. Base Exchange: East Wall Detail

3.2 Description of the Previous Rooftop Units

No data are available on the performance of the conventional rooftop units that were used prior to 1992 nor on their electrical consumption. However, the main purpose of this particular project is to compare current state-of-the-art conventional technology (energy efficient electric rooftop unit) with a current state-of-the-art alternative technology (gas engine-driven rooftop unit). This is because selection of a replacement technology should be based on a comparison of currently available candidate technologies. Information on the field performance or nominal performance of the 10-year old units could be used as a "reality check" but is not directly relevant to the comparative analysis. The field performance that would be realized using state-of-the-art conventional technology is addressed in Section 6, Economic Analysis.

3.3 Description of Gas Engine Driven Rooftop Units

The existing rooftop units were replaced in early 1992 by new units manufactured by TK. The two TK units are identical even though the units they replaced were of different sizes. The nominal characteristics of the TK units are given below.

Condenser. A 5-row coil with a face area of 15 ft², tube diameter of 3/8 in., and fin spacing of 12 per inch is provided to reject heat from the condensing refrigerant. The engine driven condenser fan is 24 inches in diameter and provides 9000 cfm of air flow with the engine running at 2400 rpm.

Evaporator. The 6-row evaporator coil has a face area of 13 ft², tube diameter of 3/8 in., and fin spacing of 9 per inch. An 11-ton expansion valve is provided for the upper (75%) section of the evaporator and a 3-ton expansion valve is provided for the lower (25%) section of the evaporator. Both are external equalizer type with a superheat setting of 20 ± 5°F.

Compressor. The 4-cylinder V-configuration compressor displaces 30 in³, and cylinder unloading is provided on two cylinders. The unit holds a charge of approximately 30 lbm of R-22 (an HCFC refrigerant).

Engine. A 4-cylinder in-line engine displacing 163 in³ produces 40 hp at 2400 rpm. An 18 inch diameter fan provides 4000 cfm through the radiator at 2400 rpm engine speed and the refrigerant subcooler rejects heat to this airstream.

Maintenance. The unit requires biannual preventive maintenance with an oil change every spring. Replacement or refacing of valves, seats, and guides is recommended by the manufacturer at 10,000-hour intervals and engine rebuilding is recommended at 20,000-hour intervals.

Thermostat. A Honeywell T7400 programmable microprocessor-based thermostat is used to control the two heating and four cooling stages, the economizer, and night setback and temperature recovery operation of each unit. The thermostat uses proportional-plus-integral control to determine the required heating or cooling stage and the cycling rate that will minimize deviations from the setpoint. The room temperature sensor can be internal or external, and multiple sensors can be used to provide a spatial average room temperature. The thermostat also provides intelligent outside air control and ramped setpoint recovery.

The heating and cooling stages are enumerated in Table 3.1, where the heating or cooling capacity and related operating parameters are given for each stage.

Table 3.1. Capacity and Related Operating Parameters

Stage	Mode	Capacity	Engine Speed	Supply Air Fan	
				(rpm)	(hp) ^(a)
H1	Heating	108	n.a.	860	1
H2	Heating	216	n.a.	1760	5
C1	Cooling	28	1000(b)	860	1
C2	Cooling	84	1000	1760	5
C3	Cooling	143	1500	1760	5
C4	Cooling	190	2400	1760	5
(a) Fan power depends on distribution system flow-pressure characteristic. The nominal values for the standard motor are shown. The units installed at NASWG are equipped with the standard motor.					
(b) With two of four compressor cylinders unloaded.					

A cut-away view of the TK 15-ton natural gas engine driven rooftop air conditioner, showing the main mechanical components, appears in Figure 3.4. Additional details about the TK units are presented in Appendix B as provided by Thermo King Corporation.

One of the two TK rooftop units (Unit 1) installed at NASWG is pictured in Figure 3.5. The engine, compressor, and condenser are located in the left-hand end of the unit. The louvered panel on the left end is removable for service. Condenser and engine radiator air enter through this panel and from below the left-hand section. The burners, heat exchanger, induced-draft fan, and unit controls are located in the center section. Combustion air intake louvers are visible on the burner service access panel. A removable panel on the opposite side of the center section provides access to the controls. The supply-air fan, evaporator coil, and economizer dampers are located in the right-hand section of the unit. Service access is from the opposite side. The outside air intake hood is visible on the right end of the unit.

The roof curb supports the center and right-hand sections of the unit. The return air duct connects to the bottom of the right-hand section. The supply-air duct connects under the center section.

Figure 3.4. Cut-Away View of the Thermo King Equipment

Figure 3.5. Thermo King Unit 1: View from the South

3.4 Analysis That Supported Gas for Cooling

The decision to replace the existing rooftop units with gas engine driven rooftop units was based on a life-cycle cost (LCC) analysis of five different HVAC plant options (Falvey, 1990). These options are listed in Table 3.2 along with the option of replacing the worn-out existing RTUs with current conventional technology (essentially identical) RTUs. The lowest LCC option was replacement with natural gas engine driven RTUs.^(a)

Table 3.2. Life-Cycle Cost of HVAC Options Considered for the BX in 1990

Option	Initial Cost	Annualized Operating Cost	Life-Cycle Cost
Similar RTUs & unit heaters	\$51,330	\$14,682	\$154,450
Heat by Steam from Central Plant & Cool by Electric Chillers	\$96,369	\$16,273	\$210,644
Heat by Steam from Central Plant & Cool by Gas Chillers	\$107,705	\$8,019	\$176,109
Co-generation with Absorption Chillers	\$189,419	\$3,657	\$215,104
Double-effect Absorption Chiller/Heaters	\$92,119	\$7,875	\$159,294
Natural Gas-fired RTUs	\$77,972	\$6,148	\$130,416

(a) Note that the natural gas-fired RTUs have the lowest life-cycle cost even though the annual operating cost estimate is conservatively high.

3.5 Technology Assessment Methodology

The overall approach of the project was to measure field performance of the TK 15-ton natural gas engine driven rooftop air conditioning equipment, extrapolate the data to normal weather year conditions, and compare to normal year performance of current conventional technology on both an energy and LCC basis.

To measure field performance, the units were instrumented and a data acquisition system and phone line for remote data upload were installed as described in Section 4.

To assess performance, the average COP in each of four cooling stages was determined from measured air-side temperature and humidity differences and fuel input rates as described in Sections 5.1 through 5.3.

To extrapolate performance to normal weather year conditions, a cooling degree-day base temperature was determined from the correlation between measured daily cooling plant input energy and daily mean temperature. Normal year energy use was taken to be the product of energy use during the monitoring period and the ratio of normal-year cooling degree-days (CDD) to CDD experienced during the monitoring period.

To estimate normal weather year performance of the current conventional technology, the hypothetical energy consumption during the monitoring period that would have resulted if the engine was replaced by an energy efficient motor was estimated. Normal weather year energy use was then taken to be the product of energy use during the monitoring period and the ratio of normal-year CDD to CDD experienced during the monitoring period. Normal year weather and performance estimates are developed in Sections 6.1 through 6.3.

To compare LCCs, the FEMP/NIST LCC program (NIST 1986) and fuel escalation data (NIST 1992) were used as described in Section 6.4. The Code of Federal Regulations (10 CFR Part 465) requires that all energy improvements be justified by comparing the LCCs of all reasonable alternatives.

During the evaluation period service records were also maintained.

4.0 Field Performance Monitoring

Effective assessment of the performance of the TK units involved monitoring numerous operating characteristics of the equipment, building, and exterior environment. This necessitated the design and installation of a data acquisition system and the collection of operating data.

4.1 Data Acquisition System

Two data loggers were installed to monitor the performance of the two TK units. The Campbell Scientific CR10 is the basic unit of both loggers, but the logger for TK Unit 1 has a high resolution analog extension module that provides additional analog channel capacity for thermocouples, thermopiles, resistance temperature detectors (RTD) and other low level inputs. The capabilities of the data logger that are germane to this particular test bed demonstration are summarized below.

The logger has six differential analog input channels, any of which can be configured as two single-ended channels. The analog extension module provides an additional 32 differential input channels. The basic accuracy of the logger is 0.2% of full scale range (FSR) when operated between -25°C and +50°C. Sampling takes 2.6 ms per channel in fast single-ended mode, 4.2 ms in fast differential mode, 8.6 ms in fast differential thermocouple mode, and 25.9 ms in 60 Hz rejection (70 dB) differential mode. Each channel can be configured to one of five input ranges: ± 2500 mV, ± 250 mV, ± 25 mV, and ± 7.5 mV. The analog input resistance is 20×10^{10} ohm. The logger has 8 status inputs and two eight-bit, 2000 Hz pulse inputs. The clock is accurate to ± 1 minute per month.

The logger and instrumentation specifications and the data logging programs were developed by AGAL and were used for monitoring similar TK units in previous field monitoring work. The loggers for the NASWG installation were installed by AGAL on behalf of PECO and AGCC. Transducers for measuring outside and room air conditions, engine fuel and supply fan power inputs, and refrigerant-side conditions and heat transfer rates were also installed by AGAL. Air-side instrumentation, added by PNL to TK Unit 1, included thermopiles to measure supply-return air temperature difference, outside-return air temperature difference, and outside-mixed air temperature difference, and a tipping bucket gauge to measure condensate flow rate at the drain of the evaporator coil. The loggers were programmed by AGAL to scan the PNL-added instrumentation as well as the original AGAL instrumentation.

Each logger communicates remotely via an RS-232 serial port, a modem, and a dedicated phone line. Polling stations were set up at AGAL, NASWG and PNL with PNL being

the primary site for uploading and archiving the data. The PNL polling was performed nightly by a PC running a batch program that calls executable programs for uploading data from the NASWG CR10 loggers (and two other types of loggers used in other projects) in a predetermined sequence.

Figure 4.1 shows the data acquisition system installed on the north side of Unit 1.

Figure 4.1. Data Acquisition System

4.2 Measurements for Field Performance Evaluation

Most of the measurements are used to evaluate performance (e.g., efficiency as a function of conditions) and to diagnose operational problems with the system being monitored. Additional sensors provide redundant measures of performance and monitoring system diagnostics. In the case of the gas powered rooftop air conditioning units monitored at NASWG, the measurements can also be organized in terms of the units' major subsystems: engine, refrigerant circuit, air circuit, controls, and conditioned building space.

Engine/Compressor. The monitored conditions that affect engine performance are barometric pressure and ambient temperature and humidity. Outside air temperature and relative humidity sensors are located on the BX roof at the southeast corner of Unit 1. The engine performance is not measured directly, but the flow of natural gas to the engine is measured to assess the aggregate engine/compressor performance. Compressor output is measured in terms of refrigerant mass flow rate and the pressures and temperatures of the refrigerant at the compressor's inlet and exhaust ports. Diagnostic points include manifold pressure, exhaust temperature and engine speed (RPM).

Refrigerant Loop. The cooling effect is measured on the refrigerant and air sides of the evaporator coil. Refrigerant heat rates involve sensible heating and cooling of the refrigerant in its liquid and vapor states as well as latent heat transfer associated with refrigerant boiling and condensation. The refrigerant mass flow rate is measured downstream of the condenser where the refrigerant is normally in a liquid state. The latent heat picked up by the refrigerant is determined from the evaporator pressure and the sensible heat from the temperature of the leaving refrigerant minus the saturation temperature. The latter is a function of evaporator pressure. The latent heat rejected by the refrigerant is determined from the condenser pressure and the sensible heat from the superheating and subcooling temperatures measured, respectively, at the desuperheater inlet and the condenser outlet.

Air-Side Measurements. A redundant measure of the cooling effect is obtained on the air side of the evaporator coil. The latent load is inferred from the flow of water, which condenses on the cold air-side surfaces of the coil as it drains from the condensate pan through a tipping-bucket gauge. The sensible load is determined from the change in air temperature; the change is measured by a thermopile connected between the mixed air and supply air plenums of the unit. The outside air fraction is determined from the outside air, return air, and mixed air temperatures. The mixed air humidity is determined from the outside air humidity, return air humidity and outside air fraction. The mixed air conditions are needed to develop a weather and load-normalization model that can be used to extrapolate the unit's monitored performance to a standard cooling season. One-time air flow measurements were made at each of the two supply fan speeds by a hot-wire anemometer. Each measurement was based on the average of 30 traverse points evenly

distributed across the upstream face of the evaporator coil with the unit in fan-only (no cooling) mode of operation. Four replications were made of each air flow measurement.

Conditioned Zone. The air temperature and humidity in the conditioned zone are measured in the vicinity of the two thermostats that control the two rooftop units. The location of these thermostats in relation to the TK units and supply and return air points is shown in Figure 4.2.

Controls. The control signals for cooling stages 1 through 4 and heating stages 1 and 2 are monitored to provide a means of disaggregating the measured performance and conditions by mode of operation.

The sensor locations in relation to the mechanical subsystems of the rooftop unit are shown schematically in Figures 4.3 and 4.4. Sensor specifications are enumerated in Table 4.1.

Figure 4.2. Location of Thermostat Controls in Relation to TK Units and Air Distribution Systems

Control Panel
(Status Channels)
S25, 26, 27, 28, 29, 30
S31, 33, 56, 58

Logger
C21, C22
B50
T51

Transducer Function Legend
V - Volumetric flow rate
M - Mass flow rate
E - Electric power
S - Status
A - Absolute pressure
P - Gauge pressure
T - Temperature
ΔT - Differential temperature
H - Relative humidity
X - Position
R - Shaft rotation speed
C - Calibration test point
B - Battery voltage

Figure 4.3. Sensor Locations in Refrigerant Loop

Figure 4.4. Sensor Locations in Air-Side Loop

Table 4.1. Sensor Specifications

Physical Quantity ^(a)	Point Description	Input Type ^(a)	Sensor Range	Normal Range	Unit ^(a)	Sensor Type	Sensor Manufacturer	Sensor Model
T	Refrigerant discharge	DE	-340..1112	0..250	°F	Pt RTD	Hy-Cal	RTS-64-T-100-3-12-X1
T	Refrigerant subcool	DE	-340..1112	0..150	°F	Pt RTD	Hy-Cal	RTS-64-T-100-3-12-X1
T	Refrigerant suction	DE	-340..1112	0..50	°F	Pt RTD	Hy-Cal	RTS-64-T-100-3-12-X1
T	Engine exhaust	DE	-20..1000	0..1000	°F	TC, type J	Omega Engng	TJ38-CASS-116-12
T	T.C. reference	SE	-13..122	-13..122	°F	Thermistor	Campbell Scientif	10TCRT
H	Outside air	SE	0..100	0..100	%RH	Polymer	General Eastern	RHT-2-I-OA
T	Outside air	SE	-20..140	-20..100	°F	Pt RTD	General Eastern	RHT-2-I-OA
H	Supply air	SE	0..100	0..100	%RH	Polymer	General Eastern	RHT-2-I-R
T	Supply air	SE	-20..140	50..140	°F	Pt RTD	General Eastern	RHT-2-I-R
H	Return air	SE	0..100	0..100	%RH	Polymer	General Eastern	RHT-2-I-R
T	Return air	SE	-20..140	60..80	°F	Pt RTD	General Eastern	RHT-2-I-R
H	Room air	SE	0..100	0..100	%RH	Polymer	General Eastern	RHT-2-I-S
T	Room air	SE	-20..140	60..80	°F	Pt RTD	General Eastern	RHT-2-I-S
A	Barometer	SE	0..25	14.5..15	psia	strain gage	Setra	C280E
P	Intake manifold vac	SE	0..10	0..5	psig	strain gage	Setra	C239
A	Gas supply	SE	0..25	14.5..15	psia	strain gage	Setra	C280E
P	Compressor suction	SE	0..250	50..200	psig	strain gage	Setra	C207
P	Compressor discharge	SE	0..500	150..350	psig	strain gage	Setra	C207
M	Refrigerant mass flow	SE	0..60	5..45	ppm	Inertial	Micromotion	D-40-119
E	Total electric power	SE	0..6000	0..4000	W	Hall effect	Ohio Semitronics	WOE-23ET/80K
X	Outside air damper opening	SE	0..2400	0..2400	mV	pot	Honeywell	Q181A-1007
R	Engine RPM	P	0..5000	0..2600	rpm	magnetic	Transwire	XP160-SPI53-ISO
T	Gas ACFH	P	0..1000	0..300	cfh	PD lobe	Roots	8C-175psig-050932-101caxx
S	Cooling step 1	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Cooling step 2	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Cooling step 3	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Cooling step 4	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Heating step 1	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Heating step 2	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
S	Engine enable	IN	1=ON	0..900	s	LED Relay	Stevens Engng	RH2B-UL-AC24V
E	Electric power pulse	P	0..1500	0..1000	Wh	Hall effect	Ohio Semitronics	WOE-23ET/80K
DT	Return-outside air	DE	+/-200	+/-25	°F	TP, type T	C.S. Gordon	T24-2-505
DT	Mixed-outside air	DE	+/-200	+/-75	°F	TP, type T	C.S. Gordon	T24-2-505
DT	Supply-return air	DE	+/-200	+/-75	°F	TP, type T	C.S. Gordon	T24-2-505
V	Condensate drain	P	0..10	0..1	pps	tip bucket	Texas Data	501

(a) T = temperature, DT = differential T, H = humidity, S = contact status, M = mass flowrate, E = electric power, A = absolute pressure, P = gauge pressure, R = rotational speed, V = volumetric flowrate
 (b) DE = differential, SE = single-ended, P = pulse count, IN = integrated ON-time
 (c) °F = degree Fahrenheit, psig = lbf per inch² absolute, psia = lbf per inch² absolute, pps = pulse per second, psia = lbf per inch² absolute, psig = lbf per inch² gauge, %RH = percent relative humidity, mV = millivolt, rpm = revolution per minute, W = watt, Wh = watt hour, cfm = ft³ per hour, s = second; all units apply to both the Sensor range and Normal range columns.

4.3 Acquired Data

During the course of the 1992 summer cooling season a considerable body of performance data was compiled. Service and maintenance data were gathered as well as the electronically recorded time-series data used to characterize equipment performance and operating conditions. A tabular listing of daily summary data, showing calculated average values of measured conditions and performance variables by operating mode, is presented in Appendix C. The results of the analysis of the data and what they convey about equipment performance are presented in Section 5.

5.0 Observed Performance and Operation

The gas powered air conditioning units were monitored starting June 18, 1992, and monitoring will continue to the end of the 1993 cooling season. This continued monitoring will be used to assess heating season performance as well as assess performance during an additional cooling season. The data used in the 1992 cooling season analysis were limited, for the most part, to the period from July 11 through September 14, 1992. Because of operational problems early in the monitoring period and data format problems late in the monitoring period, cooling data from June 18 to July 11 and from September 14 to 18 are not directly usable.

5.1 Cooling Loads

The simplest measure of cooling load is input energy to the compressor and condenser fan. (The supply fan energy is only a weak function of cooling load, since it runs continuously during occupied hours.) The daily average input rates (based on 1040 Btu/scf) to the two units are shown in Figure 5.1 along with the daily mean temperature history. The input load is clearly correlated with outside temperature. Notice, however, that Unit 2 uses almost twice as much natural gas as Unit 1.

The load imbalance problem was observed in early July during a site visit and was attributed to a small difference in the thermostat setpoints within the building. The thermostats are set by the building manager to satisfy employees' comfort needs. However, even if the same nominal setpoint is used on both thermostats, a small setpoint difference can result in a large load imbalance because the two units serve the same zone. It might be more appropriate to control both units from a single thermostat to ensure load balance. On the other hand, there may be significant load differences between the north and south ends of the retail area that would make single thermostat control unsatisfactory. This problem needs to be resolved before the 1993 cooling season. An energy load simulation of the building will determine if two separate zones are needed. If not, a single thermostat can be used and the staging sequence can be modified to control both units feeding a single air distribution system.

Figure 5.2 shows the daily gas loads for Units 1 and 2 combined as a function of ambient temperature. Data for Mondays are not shown because the BX is closed Mondays and the cooling loads are therefore lower (as expected) on Mondays. The regression line ($r^2 = 0.7$) indicates a load of 165 kBtuh per Fahrenheit degree above a mean daily temperature of 60°F on business days.

Figure 5.1. Daily Average Fuel Input and Temperature as a Function of Time

Figure 5.2. Relation Between Daily Gas Loads and Ambient Temperature

5.2 Efficiency

The coefficient of performance (COP) for Unit 1 was computed from air-side sensible and latent loads and gas input energy rate. Note that the compressor and condenser and engine fan energy inputs are included in this definition but that the supply air (indoor) fan energy is not. Figure 5.3 shows the average daily COP in each cooling stage. The COP is relatively constant in each cooling stage (C1 through C4), ranging between 0.5 and 0.6 in C1, between 0.8 and 1.0 in C2, between 0.65 and 0.75 in C3 and between 0.5 and 0.6 in C4. Also shown is the average daily load and overall daily average COP. The overall daily COP tracks C1 COP on most days but improves on higher load days because of the influence of C2 and C3 COPs.

The measured COPs are compared to the COPs quoted by the manufacturer in Figure 5.4. The middle bar in each group reflects COPs measured during the period after Unit 1 had been purged of noncondensibles, was properly charged with refrigerant, had its evaporator coil splitter solenoid disabled, and was subject to large daily cooling loads that minimized engine starts/stops and other operational transients. In this period the C1 COP was almost double the quoted value, the C2 COP was very close to the quoted value, and the C3 and C4 COPs were about 10% less than the quoted values. The average COPs over the longer period were about 10% lower than the COPs measured in the shorter period and show the effects of imperfect maintenance and control as well as the effect of transient operation that is more prevalent later in the cooling season.

The seasonal COP is, in simplest terms, the sum of the part-load COP and part-load operating time products divided by the total operating time. Figure 5.5 shows the part-load operating times for Units 1 and 2 along with the ARI standard operating times used by the manufacturer to compute seasonal COP for typical applications. The seasonal COPs at Willow Grove are substantially lower than the integrated part-load value (IPLV) quoted, due mainly to longer operation in C1 and shorter operation in C2 relative to the IPLV shares of operating time assumed by the ARI standard.

Figure 5.3. Daily Average COP by Cooling Stage

Figure 5.4. Measured COPs Versus Rated COPs

Figure 5.5. Unit 1 Measured Part-Load Operating Times Versus Those Used by the ARI Standard to Compute Seasonal COP

5.3 Control and Seasonal Performance

In the foregoing analysis, a number of allusions have been made to the effect that control and operation have on seasonal performance. These effects are discussed below.

Coordination. Unit 2 provided more cooling than Unit 1 throughout most of the test period. There was no indication, however, that this was due to a significant difference in load between the areas served by the two units. Rather, the cooling load imbalance was most likely caused by the thermostat location or a slight difference in setpoint. Connecting the two distribution systems to form a single-zone distribution system would likely not result in a noticeable degradation in temperature and humidity conditions.

A single zone system would have three benefits in this application.

First, redundancy would be provided. If one of the two units failed (as happened) the loss of capacity would be spread over the entire zone with no resulting "hot spot."

Second, equal wear of the two units would be ensured. The units could be operated in an alternating lead-lag arrangement for light loads and in tandem for heavy loads.

Third, improved efficiency could be realized. Many times Unit 1 cycled between stage 1 and 2 cooling while Unit 2 cycled between stage 2 and 3 cooling. The aggregate load could have been met by operating both units at stage 2, the most efficient stage. Similarly, many times Unit 1 cycled between off and stage 1 cooling while Unit 2 cycled between stage 1 and stage 2 cooling. The aggregate load could have been met by operating one of the units at stage 2, the most efficient stage, most of the time.

Design Considerations. Because of the high first cost, it is important not to oversize the gas powered unit. The part-load efficiency considerations—discussed below—provide additional incentive to make sure that the equipment size is no greater than needed.

Capacity Control. First stage cooling is effected by running the engine at low speed (1000 rpm), unloading two of the four compressor cylinders, and closing a solenoid valve to restrict refrigerant flow to the lower 1/4 of the evaporator coil. A better^(a) approach might include one or more of the following features.

(a) None of these schemes has been evaluated by the authors for life-cycle cost effectiveness. Note that LCC effectiveness depends on economic and load characteristics and that some features may therefore be cost effective for only a small fraction of the market. The drive and coil capacity control arrangements provided on the GTC-1 are simple, reliable, and low in cost. Some alternate schemes considered by TK and the reasons for their rejection are noted.

- Provide a two-speed planetary reduction gear mechanism between the engine and compressor. The low speed ratio would be selected to provide the optimal compressor and engine speeds with the optimal evaporator coil size reduction. The optimal design would probably involve a somewhat lower engine speed, a somewhat larger evaporator coil fraction, and a shaft speed reduction of about one half for 1st, and possibly 2nd, stage cooling.
- Provide a pony motor for the compressor. Replacing the reduction gear with a free wheel and providing a small (about 5 hp) electric pony motor through a second free wheel would result in a performance improvement similar to that achieved with the gear reduction scheme and would also provide a zero-load condition when the engine is started. The condenser fan would have to be driven off the compressor shaft rather than the engine shaft.
- Divide the coil by rows rather than face area.^(a) If the refrigerant is restricted to the first two or three rows during light load operation, the remaining rows can be used for reheat using a heat pipe scheme with the heat source end of the heat pipe being located in the return air stream. This will result in energy savings by matching the latent and sensible cooling loads to provide maximum comfort with minimum cooling effect. An alternative to the heat pipe is to run some of the vapor discharged by the compressor through the reheat rows.
- Eliminate stage 1 cooling. Stage 1 cooling capacity is about 25% of maximum capacity and about 50% of stage 2 cooling capacity. The need for stage 1 cooling from an occupant comfort standpoint is not great, but it serves the very important purpose of reducing engine start/stop cycles. It also provides a light load condition for engine start-up without the need for a clutch. However, providing a clutch would allow for the possibility of letting the engine cycle between stage 2 cooling and idle under certain light load conditions; this would result in better seasonal performance than the current scheme without significantly increasing the number of start/stop cycles.^(b)

(a) A row split coil (e.g., a 3-row coil followed by a 6-row coil) was considered by TK for the purpose of providing reduced coil capacity in stage C1. The scheme was not adopted due to high first cost. The possibility of using downstream rows to extract heat (excess sensible capacity) from the leaving air, and additional upstream rows to precool entering air, and thus increase latent capacity, was not considered.

(b) The increase in first cost and maintenance of a clutch mechanism and control may not be justified by the small improvement in seasonal performance.

Zone Control. The use of zoning with multi-stage rooftop units is effective in certain applications. The BX may be one such application. With a crossover connection and damper between the two existing duct systems, a single unit may be able to meet the entire load most of the time.

The staging and zoning problems observed in the test indicate that the application of gas engine driven rooftop units is not as simple as it is for conventional electric rooftop units. This problem is not peculiar to the subject technology but is common to many energy efficiency measures and new technologies.

6.0 Annual Performance and Life-Cycle Cost

The economic analysis was performed in four steps. First, monitored cooling loads were extrapolated to a normal weather year. Second, performance of a comparable electric chiller was estimated for the monitoring period. Third, input energy requirements of the gas powered unit and the comparable electric powered unit were extrapolated to a normal year cooling season. Fourth, and last, annual energy numbers and other pertinent cost and economic parameters were used to estimate life-cycle costs of the two alternatives.

6.1 Normal Year Loads

Ambient temperatures during the analysis period are compared to normal weather year ambient temperatures in Figure 6.1.

The load is predominantly a sensible cooling load, well correlated with mean daily temperature. The balance point (temperature above which a cooling load exists) is about 60°F. Base 65°F Cooling Degree Days (CDD) tabulated in NAVFAC P-88 (TM 5-785) are 946 CDD for NASWG. The corresponding numbers for nearby locations in Pennsylvania, New Jersey and Delaware are 1104 CDD for Philadelphia IAP, 1104 for Camden, 983 for McGuire AFB, NJ, 945 CDD for Wilmington AP, and 608 CDD for Wilkes Barre-Scranton. Long term historical temperature distributions are tabulated for Newark IAP, McGuire AFB, Wilmington AP, and Wilkes Barre-Scranton, but not for NASWG, Philadelphia or Camden, in NAVFAC P-88 (TM 5-785). The available data indicates annual base-60 and base-65 cooling load potentials as shown in Table 6.1.

From these data it is clear that Wilmington's climate is more (in terms of annual air-conditioning load) like that of Willow Grove than the climate of any other locations (except possibly distant McGuire AFB). The Wilmington climate was deemed sufficiently similar to be used without further adjustment.

Normal-year loads and energy use were extrapolated from the monitoring period by applying a cooling degree-day factor of 1.96. The distribution of load intensity was assumed to be the same for the normal year as it was during the monitoring period. The relative share of light load operations may have been somewhat underestimated as a result. Monthly peak 15-minute demand was assumed to be 100% of connected load for all months with at least one hour at, or over, 80°F and to decrease linearly with peak hourly temperature to 60°F.

Figure 6.1. Comparison of Normal-Year and 1992 Ambient Temperature Distributions

Table 6.1. Available Climate Data

	Base 65°F CDD ^(a)	Base 65°F CDD ^(b)	Base 60°F CDD ^(b)
Willow Grove NAS	946	NA	NA
Philadelphia IAP	1104	NA	NA
Camden	1104	NA	NA
Newark IAP	1024	1168	1835
McGuire AFB	983	1076	1778
Wilmington AP	992	1154	1822
Wilkes Barre-Scranton	608	798	1336
(a) Based on mean of daily max/min temperatures, Chapter 5 of NAVFAC P-89 (TM 5-785).			
(b) Based on one-hour or three-hour temperature readings, Chapter 3 of NAVFAC P-89 (TM 5-785).			

6.2 Equivalent Electric Powered Unit

It was necessary to model the performance of an equivalent electric powered unit for three reasons. First, model-based adjustments are almost always needed in a field performance comparison because the conditions imposed on the test articles in question are different regardless of whether a side-by-side or before-after monitoring protocol is employed. Second, an equitable comparison between gas and electric technologies could not have been obtained from such field monitoring without making substantial adjustments for performance degradation due to equipment age and performance improvements that technology and design evolution have wrought in the years since the previous units were manufactured and installed. And third, there was no opportunity to determine the field performance of the old electric powered rooftop units because they were removed prior to installation of the TK units and before NASWG became involved with the Test Bed Demonstration Program.

To compare electric and gas technologies as equitably as possible and to avoid uncertainties about the field (as opposed to theoretical) performance of a "comparable" electric unit, only the prime movers were modeled. Thus, the comparable electric unit was assumed to be identical to the gas unit in all of its conventional parts—i.e., its compressor, coils and air-side components and controls—and is modeled as a TK unit with the engine replaced by a 30-hp compressor motor and a 2-hp condenser fan motor. The single-speed premium energy-efficient motor efficiencies quoted by Nadel (1991) are assumed, optimistically, to prevail in all four cooling stages, and the engine efficiencies quoted by TK are used to convert natural gas input rates measured in the four cooling stages to corresponding shaft loads.^(a)

With the foregoing assumptions, the energy and demand requirements of the comparable electric units can be readily evaluated for the monitoring period. To complete the life-cycle cost analysis, however, it is necessary to estimate the annual energy requirements of the gas powered units as well as the annual energy and demand requirements of the comparable electric units. The analysis required to make this extrapolation is outlined below.

(a) Note that stage 1 cooling is implemented by cylinder unloading just as it is in the gas powered unit. It might be more realistic to model the comparable electric unit with a small separate hermetic motor/compressor to implement stage 1 cooling. However, introducing the more efficient stage 1 implementation makes analysis of the electric unit's energy consumption much more complex and would not change the life-cycle cost by more than a few percent because monthly ratchet charges (which constitute over 70% of the annual operating cost) would not be affected.

6.3 Energy Costs

Annual operating cost for the electric powered units consists of electric energy, demand, and ratchet penalty costs. The cost of prime mover (motor) maintenance is assumed to be negligible and the other maintenance costs (filter, damper, controls, and supply fan maintenance) are ignored since they will be the same for the gas powered and electric powered units. The PECO rate schedule that applies to NASWG charges \$0.0299 per kWh and \$23.70 per monthly peak demand kW. The load peak for the electric powered units is assumed to coincide with the peak at the PECO meter that measures all electrical energy supplied to NASWG.

The annual operating cost for the gas powered units is considered to consist of natural gas purchases and annual engine service of \$400.00/yr. The PECO natural gas rate schedule that applies to NASWG charges \$6.50/kcf for the first 200 kcf purchased each month and \$5.60 per additional kcf.

The normal weather year monthly refrigeration machine energy requirements are shown, for the electric and natural gas powered alternatives, in Figure 6.2. The electric and gas numbers are in almost constant proportion because the electric motor and gas engine efficiencies are almost independent of shaft speed and load. The corresponding monthly energy costs are shown in Figure 6.3. The electric cost is almost double the gas cost in July and the cost difference is even larger in the other months. The distribution of monthly energy costs for the electric powered alternative are shown in Figure 6.4. The figure shows that demand charges account for more than half, ratchet charges account for over 30%, while energy charges account for less than 10% of the total annual energy cost.

Figure 6.2. Energy Requirements for Electric and Natural Gas Alternatives

Figure 6.3. Monthly Energy Costs for Electric and Natural Gas Alternatives

Figure 6.4. Distribution of Monthly Energy Costs for the Electric Alternative

6.4 Life-Cycle Cost Comparison

The life-cycle cost analysis was performed using the FEMP analysis program BLCC (NIST). The financial parameters for the cost study are as follows:

Analysis Type:	Federal Analysis--Energy Conservation Projects
Study Period:	15 YEARS (1993 THROUGH 2007)
Discount Rate:	4.0% Real (exclusive of general inflation)

The energy related costs for the electric (base case) and gas powered alternatives, are shown in Table 6.2.

The present value costs for the two alternatives are shown in Table 6.3.

The net savings for the gas powered alternative is the difference between the present value of non-investment savings, \$148,023, and the increased total investment of \$26,642. This gives a net savings, expressed as a present value, of \$121,381 for the gas powered alternative. The savings-to-investment ratio is 5.56 assuming the previous electric units had to be replaced anyway at the time the TK units were installed. In cases where the existing electrical equipment is relatively new, the savings-to-investment ratio would be less than 3, but it is still positive (0.88^(a)) even for the hypothetical case of replacing brand new electric equipment given the rate structure and load distributions that apply at NASWG.

Table 6.2. Energy-Related Costs

Energy Type	Units/Year	Price (\$/Unit)	Demand Cost	Total P.V. Cost
Electricity	34,618	\$0.030	\$14,379	\$182,696
Natural Gas	3,875	\$0.634	\$0	\$ 29,114

(a) $\frac{121,381 - 51,330}{77,972} = 0.8842$ where \$121,381 is the net present value

for the replace-on-failure case, \$121,281-\$51,330 is the net present value for the replace-immediately case (assuming no recovery of the \$51,330 recently invested in brand new electric powered air conditioning equipment), and \$77,972 is the initial implementation cost for gas powered equipment.

Table 6.3. Comparison of Present-Value Costs

	Base Case: WGNAS_E	Alternative: WGNAS_NG	Savings From Alternative
Initial Investment Item(s): Cash Requirements as of Occupancy	\$ 51,330	\$ 77,972	- \$ 26,642
Subtotal	\$ 51,330	\$ 77,972	- \$ 26,642
Future Cost Item(s): Annual and non-annual Recurring Costs	\$ 0	\$ 5,559	- \$ 5,559
Energy Expenditures	\$ 182,696	\$ 29,114	\$ 153,582
Subtotal	\$ 182,696	\$ 34,674	\$ 148,023
Total P.V. Life-Cycle Cost	\$ 234,026	\$ 112,646	\$ 121,381

One consideration in the decision to procure the subject technology is the first cost of the equipment versus operating costs. Since many facilities fund capital improvements from one budget and operation, service, and maintenance from another, the long term benefits may not be allowed to be considered. In the above case for NASWG the long term operating expense reduction of \$148,023 would not be considered, or even attainable, if a procurement decision based on lowest first cost were made. Note that the increased first cost is paid back in about two years.

Some utilities offer rebate programs and finalizing assistance that can help address the first cost issue. For instance, the PECO Demand Side Management Program Plan proposes incentives for gas cooling of \$300/kW, or about \$450/ton, cooling capacity. This incentive, had it been in effect at the time of installation, would have resulted in about \$13,500 being available to NASWG to offset the additional \$26,642 for the Thermo King equipment. Where such demand side management or incentive programs exist, financial support for the additional first cost can be found.

7.0 References

ASHRAE, 1991, "A Guide for Analyzing and Reporting Energy Use and Characteristics of Commercial Buildings," American Society of Heating, Refrigeration and Air-Conditioning Engineers, prepared for PNL under contract 001011-A-A2, May 1991.

ASHRAE, 1987, "An Assessment of the Energy Audit Process in Commercial Buildings," SP-56, American Society of Heating, Refrigeration and Air-Conditioning Engineers, December 1987.

ASHRAE, 1989, *Handbook of Fundamentals*. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, Georgia.

Balcomb, J. D., et al., *Passive Solar Design Handbook*, Volume II, DOE/CS-0127/2 (January 1980).

Falvey, T. P., *Natural Gas Cooling at NAS WILGRO. Phase Two—Building 605, Base Exchange*, Public Works Services Directorate, Northern Division, Naval Facilities Engineering Command, Philadelphia, Pennsylvania (May 1990).

NAVFAC P-89, *Engineering Weather Data*, (aka USAF TM-785) 1978, Washington, DC.

NIST, *Comprehensive Guide for Least-Cost Energy Decisions*, National Institute of Standards and Technology, NBS Special Publication 709, 1987, USDOC, Gaithersburg, Maryland.

NIST, *Life-Cycle Costing Manual*, National Institute of Standards and Technology, NBS Handbook 135, 1987, USDOC, Gaithersburg, Maryland.

NIST, *Energy Prices and Discount Factors for Life-Cycle Cost Analysis 1993*, National Institute of Standards and Technology, NIST Interagency Report 85-3273-7 (Annual Supplement to Handbook 135), 1992, USDOC, Gaithersburg, Maryland.

NIST, *A User's Guide to the Federal Building Life-Cycle Cost (FBLCC) Computer Program*, National Institute of Standards and Technology, NBS Technical Note 1222, 1986, USDOC, Gaithersburg, Maryland.

Philadelphia Electric Company, *Demand Side Management Program Plan*, February 28, 1991, Before the Pennsylvania Public Utility Commission, Docket No. I-900005.

TM-785. (see NAVFAC P-89).

7.1 Site data

Monthly BX gas meter readings.

Monthly BX electric meter readings.

Building characteristics data provided by Jim Edmond in ASHRAE (1991) format.

Daily maximum/minimum temperatures from NASWG site weather station for 6/92 through 10/92.

TK, 1990. *GTC-1 Specification*, Thermo-King Corp. (draft—no publication #).

TK, 1991. *Thermo King GTC-1*, Thermo-King Corp. publication #TK 30058-2 (4-91).

TK, 1993. *GTC-1 Installation, Operation and Maintenance Manual*, Thermo-King Corp. publication #TK 40267-1 (1-93).

Appendix A

Summary of Activity Leading to the Cooperative R&D Agreement (CRADA) and the Joint Statement of Work (JSOW)

Appendix A

Summary of Activity Leading to the Cooperative R&D Agreement (CRADA) and the Joint Statement of Work (JSOW)

The federal government is the largest single energy consumer in the United States with consumption estimated to be nearly 1.5 quads (1 quad = 10^{15} Btu) and cost valued at nearly \$10 billion annually. The Federal Energy Management Program (FEMP) supports efforts to reduce energy use and associated expenditures within the federal sector. One such effort, the Test Bed Demonstration Program, seeks to evaluate new energy saving U.S. technologies and secure their more timely adoption by the federal government.

Each year the federal government purchases equipment and products through a procurement process that may not readily recognize or accommodate new technologies. In addition, new technologies are rarely purchased and installed until they have been proven through private sector use. This results in unnecessary federal energy use and operating cost between the time that the technology is commercially available and when it has been "proven" to, and recognized by, federal decision makers.

The Test Bed Demonstration Program aims to demonstrate the field performance of selected technologies implemented within the federal sector and transfer that information to federal decision makers. These "hands on" data provides the federal decision maker with the information needed to justify procurement of the technology in a more timely fashion. This leads to accelerated energy savings and associated environmental benefits. In addition, because the program is limited to U.S. technologies, the U.S. position in the global marketplace may be enhanced.

The program works by using available FEMP resources as leverage to secure public and private interest in jointly evaluating the performance of a new technology. Through a Cooperative Research and Development Agreement (CRADA) a partnership can be created that allows federal and non-federal interests to jointly sponsor such efforts. These partnerships usually involve the manufacturer of the selected technology, a federal site, the utility serving the site, a technology-related research institute, a trade association, and other interested parties. All participants perform certain activities, at their own cost, within the larger program to install and evaluate the technology. This creates a cooperative atmosphere and affords information sharing and economies of scale that might not occur otherwise.

Recent initiatives within the federal government have focused on the use of natural gas for both economic and environmental reasons. It is therefore fitting that the technology selected for evaluation in the first test bed demonstration, and the subject of this interim report, is natural gas engine driven cooling equipment.

The project began with the solicitation of interested parties willing to participate in the installation and evaluation of gas cooling technologies. Responses to the solicitation were received from manufacturers and utilities and communications were initiated to explore potential test bed demonstration arrangements. In addition a search was undertaken to identify a suitable federal site within the service areas of those responding utilities. During the last half of 1991 and in early 1992 the plans of many of the respondents changed, leaving one manufacturer and three utilities still interested in participating in the project.

The equipment offered by the one manufacturer, Thermo King Corporation, was a 15-ton natural gas engine driven rooftop air conditioning unit. The unit is air cooled and serves a single zone for both heating and cooling. It is factory assembled with R-22 (an HCFC refrigerant) and requires single point connections of electrical power and natural gas. The unit's cooling capacity is 190,000 Btuh at ARI Standard 360 rating conditions. The unit's heating capacity is 216,000 Btuh output at 265,000 Btuh input. Variable engine speed and cylinder unloading allow for cooling operation in four stages.

All three utilities still interested in participating in the project were asked in early 1992 to help identify a federal site and building that would be suitable for installation and evaluation of the cooling equipment. Numerous buildings were suggested, including historical buildings associated with Independence National Historic Park in Philadelphia, the James E. Carter Library in Atlanta, and postal service facilities in Baltimore. The Philadelphia Electric Company, one of the three interested utilities, located a naval facility within its service area that had recently (fall 1991) installed two of the Thermo King units. This provided an opportunity to more quickly implement the first test bed demonstration, which became critical with the 1992 cooling season approaching. Efforts were initiated to formalize a CRADA among the participating organizations for a demonstration project at the Naval Air Station, Willow Grove, Pennsylvania (NASWG).

A site visit was made to the Naval Air Station at Willow Grove, Pennsylvania, where two units were installed to serve a retail facility. Discussions were also conducted with other interested parties who had responded to the solicitation. These included the American Gas Cooling Center, Philadelphia Electric Company, and the Thermo King Corporation. Based on an evaluation of the building, utility costs, and past building performance, it was determined that the installation offered a good opportunity to evaluate the performance of the subject technology.

A CRADA, which included a joint statement of work, was developed and forwarded to all parties for review and evaluation. Subsequent to signing the agreement, work was initiated on planning the evaluation methodology and installing the data acquisition system that would monitor and report on equipment and building operation, and climatic conditions. As part of the agreement the American Gas Association Laboratories, who had performed similar efforts on the equipment at other non-federal installations, was tasked to design the data acquisition system on behalf of PECO and AGCC. At the beginning of the 1992 cooling season the data acquisition system was installed and commissioned. Data on the operation of the units was secured during the 1992 cooling season and is continuing during 1993.

Appendix B

Description of Thermo King Equipment

THERMO KING GTC-1

15 TON NATURAL GAS-POWERED ROOFTOP AIR CONDITIONING AND HEATING SYSTEM

Now there is an intelligent, economical alternative to electric-powered rooftop air conditioning/heating units in the 15-ton range. Exclusive from Thermo King...world leader in transport temperature control...the unique GTC-1 features Thermo King's proven, trouble-free components, including compressor and coils. It is custom-engineered to provide a variety of benefits for commercial, industrial and institutional buildings.

- 17 kw average savings over comparable electric units
- All the advantages of clean, efficient natural gas
- Meets existing noise standards
- First cost differential paid back in three years in many installations
- Aluminum construction with stainless steel hardware
- AGA certified
- Backed by our 24 hour/day, 365 day/year nationwide service organization
- Tailored factory leasing program available
- Manufactured in the U.S.A.

THERMO KING CORPORATION
WORLD LEADER IN TRANSPORT REFRIGERATION

GTC-1 Specifications

The Thermo King GTC-1 is a 15-ton, single zone, rooftop air conditioning and heating system with an exclusive engine/compressor power pack fueled by natural gas. The supply air blowers are electric motor-driven. The system is customized for single-story buildings in the 4,000 to 6,000 square foot range. It incorporates the Thermo King-built Model X430 compressor, all-aluminum structural components and stainless steel hardware, and is specially designed to withstand harsh environmental conditions.

GENERAL UNIT DESCRIPTION

Overall unit dimensions -

155" L x 76.5" W x 50.5" W

Overall weight - 2900 lbs (with furnace, economizer, and all fluids)
C.O.P. unit - up to .91 (IPLV)

Cooling capacity - 190,000 BTU/Hr
Heating capacity - 216,000 BTU/Hr

OPTIONS

Cooling only (no furnace)

Economizer (differential enthalpy control, fully modulating with or without building pressure relief).

Engine coolant heat recovery system - available from another manufacturer as an after-market add on. Ask for brochure.

Dual fuel (Propane) capability

Curb kit available at extra cost

230V single phase system

7-1/2 HP blower motor (3 PH only)

460 volt system

Factory Trained Service Organization

The GTC-1 is field-supported by Thermo King's comprehensive network of more than 350 dealers in the United States, Canada and elsewhere throughout the world. All dealerships feature factory-trained technicians, a complete inventory of factory-authorized replacement parts and total service and shop facilities.

ENGINE (HERCULES NG1600)

Type - 4 cylinder in line - 163 cu/in

Horsepower - 31 BHP @ 2200 RPM

Fuel - Natural gas (methane)

Operating speeds - 2200 RPM (high),

1800 RPM (med.), 1200 RPM (low)

Ignition - Solid State Distributorless

12 VDC

Governor - Gear driven

COMPRESSOR (THERMO KING MODEL X430)

Displacement - 30 cubic inches

Number of cylinders - 4

Refrigerant - R22

Compressor drive - direct drive

Compressor/Engine (RPM)	Capacity (BTU/hr)
2200 nominal	180,000
1800 nominal	143,000
1200 nominal	84,000
Unloaded	40,000

ELECTRIC MOTOR

Horsepower - 5 HP at 1725 RPM

Voltage - 230V, 3 phase

14.7 amps and 4.6 KW at high speed

Single phase and alternative voltages available

7-1/2 HP motor available - 3 phase only

SUPPLY AIR BLOWERS

Air flow - 5800 CFM

Fans - 4 10.75" FC

CONDENSER FAN

Air flow - 9000 CFM (maximum)

Fan diameter - 24 inches

Propeller type - engine driven

RADIATOR/SUBCOOL FAN

Air flow - 4000 CFM (maximum)

Fan diameter - 18 inches

Propeller type - engine driven

EVAPORATOR COIL

Net face area - 13.3 square ft.

Tube diameter - 3/8 inch/.020 copper

Number of rows - 6

Fins per inch - 9/.010 /aluminum

All coils are vinyl dipped

CONDENSER COIL

Net face area - 15.5 square ft.

Tube diameter - 3/8 inch/.020 copper

Number of rows - 6

Fins per inch - 12/.010 Aluminum

All coils are vinyl dipped

FURNACE

Induced draft tubular type heat exchanger with intermittent spark ignition.

- Oil retention pans are required with this unit to protect the roofing material. Please contact your local Thermo King dealer for details.

BASIC WARRANTY

- One (1) year on all parts and labor (except consumables)
- Sixty (60) months or ten thousand (10000) operational hours (whichever occurs first), parts and labor on the compressor
- Twenty-four (24) months or two thousand (2000) operational hours (whichever occurs first) parts and labor on the engine

EXTENDED ENGINE WARRANTY (available at extra cost)

- An additional thirty-six (36 months) or three thousand (3000) operational hours (whichever occurs first) labor over and above the basic warranty
- An additional thirty-six (36) months and eight thousand (8000) operational hours (whichever occurs first) on the following parts: cylinder block, crankshaft, camshaft, pistons and connecting rods
- The price for this extended engine warranty is negotiable with your local Thermo King dealer.

PERFORMANCE DATA

The GTC air conditioning unit rating is 15 ton (180,000 BTU/Hr) at ARI conditions, (95F ambient, 80F EDB/67 F EWB to evaporator).

MAINTENANCE

- Unit startup is provided by the TK factory representative and/or the local authorized Thermo King dealer at a nominal charge, as is the 200 hour break-in oil filter change.
- During the first year, the Thermo King dealers or their authorized representative should perform predetermined service at six hundred (600) hour intervals. Local expenses/labor rates determine these costs. The hours in the cooling season in your area determines the number of service calls. Service calls performed specifically for warranty items are not invoiced to the customer.

EXTENDED MAINTENANCE

- Based on the premise that the unit will last at least twenty (20) years, a guaranteed maintenance contract is available through the local Thermo King dealer for years two (2) through whatever time frame the customer requires. With oil and air filter change intervals at three thousand (3000) hours or once annually, whichever occurs first, and spark plug and plug wire life expectancy around four thousand (4000) hours, annual service is anticipated to continue at one (1) service call per six hundred (600) operational hours.

THERMOSTAT

Honeywell T7400 A-1004 (not included)

Thermo King Corporation, 314 West 90th Street, Minneapolis, Minnesota 55420

Telex 29-0450 Phone 612-887-2461 Fax 612-887-2689

Specifications are subject to change without notice.

Printed in U.S.A.

TK 30058-3 (6-92) - LT

THERMO KING
World leader in transport refrigeration

GTC-I SPECIFICATION

MARCH 12, 1990

INDEX / SUMMARY

<u>SECTION</u>	<u>PAGE</u>
1.0 DESCRIPTION - GENERAL	1
2.0 DESCRIPTION - TECHNICAL	2-4
3.0 CONTROL SYSTEM DESCRIPTION	5
4.0 INSTRUMENTATION	7
5.0 APPENDIX	
5.1 Engine Specifications	8
5.2 Engine Lubrication System Schematic	9
5.3 Governor Linkage Schematic	10
5.4 Air Conditioning Component Specifications	11
5.5 Refrigeration Flow Chart	12
5.6 Supply Air Fan Motor Specification	13
5.7 Condenser/Subcooler Fan Specification	13
5.8 Heat Exchanger Coil Data Specification	14
5.9 Control Sequence	15-17
5.10 Typical Electrical Schematic	18
5.11 Unit Dimensional Drawing	19
5.12 Curb Drawing	20
5.13 Curbing Detail	21
5.14 Condenser Drain Pan Drawing	22
5.15 Fan Curve	23
5.16 Rigging Diagram	24
5.17 C.O.P. vs. Capacity	25

(1)

1.0 DESCRIPTION

1.1 General Description:

The Thermo King GTC-I is an engine driven (natural gas fuel), 15 ton packaged, rooftop mounted, air cooled, single zone, heating/cooling air conditioning unit.

Each GTC-I rooftop unit is completely factory assembled, wired, piped, tested, and fully charged with refrigerant 22 and oil. Units require field connection of electrical power and natural gas (both are single point).

The unit features direct expansion cooling, with natural gas heating. The outside air system, return air system, filters, electric supply air fan, and all standard safety and operating controls are factory installed.

1.2 Capacity Ratings:

1.2.1 Cooling Capacity:

Unit cooling capacity at ARI 360 standard conditions, (80/67 EDB/EWB air to evaporator, 95 degrees ambient), is 190,000 Btu/Hr, (15.8 tons).

1.2.2 Heating Capacity:

Unit heating capacity at A.G.A. test conditions is 216,000 Btu/Hr., input is 270,000 Btu/Hr. max. (furnace can be deleted if necessary).

1.3 Physical Data:

1.3.1 Unit Dimensions: 155" x 76" x 50.5", (L x W x H)

1.3.2 Unit Weight: 2600 pounds, including heating system.

2.0 TECHNICAL DESCRIPTION

2.1 Cabinet Construction:

The unit frame is constructed of heavy gauge aluminum, welded and/or bolted as required. Exterior panels are .063 inch thick aluminum. The cabinet and frame are anodized for maximum corrosion resistance. All hardware and hinges are stainless steel.

The unit is insulated with 1" thick fiber glass insulation. Lifting lugs are factory installed on the roof of the unit to facilitate unit rigging.

2.2 Condensing Section:

2.2.1 Power Pack, (direct coupled engine/compressor)

2.2.1.1 Engine: The compressor drive engine is an industrial duty natural gas fuelled engine (propane conversion available). See Appendix I for engine specifications. Starting and ignition systems are 12 VDC. Unit is supplied with a battery.

2.2.1.2 Compressor: The compressor is a Thermo King Model X430; 4 cylinder 30 cu./in. industrial duty, reciprocating, open drive type. The compressor includes a positive displacement oil pump, suction and discharge line service valves, suction strainer, and oil level sight glass.

2.2.1.3 Compressor/Engine Coupling: The engine/compressor coupling is a proprietary Thermo King two plate design that allows tolerance accommodation without applying thrust loads on the compressor or engine crankshaft bearings. Accurate shaft alignment is maintained by flange mounting the compressor to the engine bell housing.

2.2.1.4 Vibration Isolation: The power pack is mounted to a heavy gauge welded steel cradle. The assembly is isolated from the unit frame using a patented elastomeric mounting system. Further isolation is achieved using braided wire line isolators for the suction and discharge lines and engine fuel connection.

2.0 TECHNICAL DESCRIPTION

2.2.2 Refrigeration Components:

2.2.2.1 The refrigerant circuit is fully piped, tested, dehydrated, and charged with oil and refrigerant-22 at the factory.

2.2.2.2 Coils: (Condenser/Radiator/Subcooler) The coils are fabricated from 3/8" O.D. seamless copper tubing, mechanically bonded to corrugated aluminum fins. Each coil is factory leak tested to 400 PSIG.

2.2.2.3 Condenser/Radiator Fans, (1 each): Condenser/radiator fans are propellor type. The fans are mounted on a common shaft and engine driven. The drive system includes an idler pulley for belt tensioning.

2.2.2.4 Refrigeration Circuit Components: Refrigeration circuit components include suction and discharge service valves, wire braided discharge and suction line isolators, receiver with liquid level sight glasses, subcool coil, liquid line filter/drier, manual shutoff valve, spring type high pressure relief valve, liquid line solenoid valve, and two externally equalized thermostatic expansion valves. All copper refrigeration lines are vinyl coated for corrosion protection.

2.3 Evaporator Section:

2.3.1 Evaporator Coil: The evaporator coil is a direct expansion type. The coil is fabricated from 3/8" O.D. seamless copper tubing, mechanically bonded to corrugated aluminum fins. The evaporator is face split and each circuit is fed through an externally equalized adjustable superheat thermostatic expansion valve. The coil headers are seamless copper. Tube sheets are fabricated of heavy gauge aluminum anodized for corrosion protection. Each coil is factory leak tested to 400 PSIG.

2.0 TECHNICAL DESCRIPTION

2.3.2 Drain Pan: The drain pan is constructed of heavy gauge aluminum, anodized for corrosion protection. Condensate drain connections are provided on both sides of the unit. 1.0" I.D. molded rubber "P" traps are supplied for field installation.

2.4 Gas Heating Section:

The natural gas furnace is an induced draft type, with intermittent pilot ignition. The gas valve is a two stage combination type. Furnace elements are tubular aluminized steel. Elements are welded to a heavy gauge stainless bulkhead. The gas burners are in-shot type. The unit is equipped with a fan/limit switch, and two auxiliary high temperature safety limits. The furnace and gas train are all located within the unit cabinet. Gas piping enters the unit at a single point.

2.5 Supply Fan Section:

2.5.1 Supply Fans:

The supply air fans are single inlet, single width, forward curved type. The fan wheel and housing are fabricated from painted cold, rolled steel. The fan wheels are supported by a solid steel shaft, which is mounted to three heavy duty bearings.

2.5.2 Fan Motor:

The fan motor is a heavy duty two speed 1725/860 RPM, 230 VAC, three phase, open drip proof type. It is thermally protected with an external overload.

2.6 Filter Section:

The unit is supplied with an integral aluminum filter rack and 2 in. thick throw-away fiberglass filters. Average efficiency is 30%, (tested per ASHRAE 52-76).

3.0 CONTROL SYSTEM

3.1 General:

The unit is factory equipped with a solid state cooling/heating temperature control system. The customer is supplied with a solid state thermostat for field mounting. The unit is also equipped with refrigeration, electrical, and engine safety/operating controls. (See appendix C for detailed control sequence).

3.2 Temperature Controls:

The temperature controller is a Microprocessor based Honeywell Model T7400/W7401 programmable thermostat. This unit provides four stages of cooling and two stages of heating. The W7401 is integrated with the engine controls to provide automatic stop/starting, and engine speed changes to provide staged cooling. (See appendix C for detailed control sequence).

Furnace staging is by the W7401 controlling a two stage gas valve. First stage of cooling is "low fire", second stage is "high fire".

3.3 Engine Controls (See Control Sequence, Appendix C)

3.3.1 Engine Operating Controls

3.3.1.1 On/Off Switch: Enables or disables this fuel shutoff solenoid and starter.

3.3.1.2 Auto-Thermostat/Manual Control Switch. In the auto position, engine operation is controlled by the thermostat. In the manual position, the engine is disconnected from the W7400 module, but the engine may be started via the manual start switch.

3.3.1.3 Manual Start Switch: With manual control enabled, (3.3.1.2), the engine can be started by enabling the manual start switch on the unit.

3.3.1.4 Starter Control: A magnetic sensor mounted next to the flywheel gear teeth transmits engine RPM to a solid state module mounted in the engine compartment. The module will disable the starter when a pre-set engine RPM is achieved.

3.0 CONTROL SYSTEM

3.3.1.5 Manifold Vacuum Switch: Engine cranking closes the manifold vacuum pressure switch, which enables the gas valve and ignition coil.

3.3.1.6 Engine Speed Solenoids: Engine speed is controlled by enabling two electric solenoids. The solenoids control the governor position to regulate speed.

3.3.1.7 Battery Charging Control: The unit is equipped with a solid state battery charger to recharge and maintain the 12 VDC starting battery.

3.3.2 Engine Safety Controls:

3.3.2.1 Oil Pressure Switch: The engine is protected from lubrication failure by a low oil pressure switch. The switch has a 30 second time delay to prevent nuisance trips during engine start up. Switch closure disables the ignition circuit.

3.3.2.2 Coolant Temperature Switch: The engine is protected from overheating by a high coolant temperature switch. The switch has a 30 second time delay to prevent nuisance trips during engine start up. Switch closure disables the ignition circuit.

3.4 Refrigeration Controls/Safeties:

3.4.1 Refrigerant High Pressure:

The compressor circuit has a manual reset high refrigerant pressure switch.

3.4.2 Refrigerant Low Pressure:

The compressor circuit has a manual reset low refrigerant pressure switch.

3.4.3 Low Ambient Compressor Lockout:

The control circuit has an auto reset outdoor ambient temperature switch to prevent compressor operation below 45°F.

3.4.4 High Pressure Relief:

Spring loaded relief valve to prevent unsafe build up of refrigerant pressure.

4.0 INSTRUMENTATION

4.1 Engine Hourmeter:

The control panel mounted hourmeter is a solid state type with LCD readout. It records the number of hours of engine/compressor operation.

4.2 Engine Oil Pressure Gauge:

Analog type; condenser section mounted.

4.3 Engine Coolant Temperature Gauge:

Analog type; condenser section mounted.

5.0 APPENDIX

5.1 White Hercules G1600 Natural Gas Engine:

The White Hercules G1600 is a spark ignition, carburetored natural gas fueled engine that features the following characteristics:

General Information: For further information, consult Hercules Maintenance Manual, Hercules P/N 40-0090202

Fuel	Natural Gas
Number of Cylinders	4
Cylinder Arrangement	No. 1 at pulley end.
Bore	4.0 in.
Stroke	3.25 in.
Displacement	163 cu. in.
Horsepower	40.0 BHP @ 2400
Operating Speeds	2400 RPM - $\pm$ 150 High 1500 RPM - $\pm$ 100 Med. 1000 RPM - $\pm$ 100 Low
Ignition (Electronic)	Capacitive Discharge
Distributor Dwell	26-36° 12 VDC
Distributor Timing	6° BTDC 800 RPM 18° BTDC 1800 RPM
Valve Lash:	
Intake (Cold and Hot)	0.015 in.
Exhaust (Cold and Hot)	0.015 in.
Firing Order	1-3-4-2
Compression Ratio	7.5:1
Oil Pressure (Regulated)	37-40 PSIG, engine at operating temp.
Oil Change Interval	Consult Thermo King Maintenance Manual
Oil Capacity	40 qts. with Remote Tank
Oil Type	Mobil Pegasus 80 Natural Gas Oil
Oil Pump	Gear Type - Positive Pressure
Oil Filter	Full Flow Type, Hercules P/N 40-0000407
Engine Serial Number	Right rear side viewed from pulley end
Engine Rotation	Clockwise, (Viewed from pulley end)
Carburetor	IMPCO Model 100
Carburetor Regulator	Maxitrol full flow type
Spark Plugs	Platinum type Hercules P/N 40-2502307
Air Filter	T.K. P/N 11-5978, dry element type
Cooling System Coolant	50/50 Water Ethylene Glycol Propylene Glycol Optional

(9)

5.0 APPENDIX

5.2 Engine Lubrication System:

Type:	Dry Sump
Capacity	10 Gallons
Oil Specification	Mobile Pegasus 80 Natural Gas Oil

04/14/89 0947399I

5.0 APPENDIX

5.3 Engine Governor Linkage:

ENGINE
LINKAGE

04/14/89 15321553

5.0 APPENDIX**5.4 Air Conditioning Section:****Compressor: Model X430****Displacement 30 C.I.D.****Max. Operating Speed 2600 RPM****Oil Charge 134 oz.****Oil Type (150 SUS) TK P/N 67-404 Synthetic****TK P/N 67-426 Petroleum****Refrigeration R-22****Refrigerant Charge 30 lbs. approximate****High Pressure Cutout (R22)****Opens 400 PSIG****Closes 325 PSIG****Low Pressure Cutout****Opens 10 PSIG****Closes 30 PSIG****Oil Pump Pressure -****Operating Range 15-45 PSIG****Compressor Drive****Direct Drive 6 pin rubber bushing
coupling****High Pressure Relief****- Opens 450 PSIG****(Spring Loaded)****Low Ambient Lockout 45°F cutout****55°F cutin****Expansion Valves:****11 ton (large)****1082A30H59****Type****Superheat Setting****Mounting****Inlet Strainer****External Equalizer****20°F ±5****Flare Connection****Cleanable****3 ton (large)****1082A30H59****Type****Superheat Setting****Mounting****Inlet Strainer****External Equalizer****20°F ±5****Flare Connection****Cleanable**

5.0 APPENDIX

5.5 Refrigeration Schematic:

GTC-1
REFRIGERATION SYSTEM
FLOW CHART

5.0 APPENDIX**5.6 Supply Air Fans and Motor:**

Air Flow	5800 CFM (Max.) 5000 CFM (Min.)
Blower Wheel Diameter	10.75" x 4.00"
Number of Blowers	4
Blower Drive	Belt, T.K. P/N 780604
Horsepower	5 HP
Speeds	1725 RPM High 860 RPM Low
Voltage	208/230V
Phase	3
Frame Size	184T - NEMA Spec
Current Draw (Full Load)	14.07 Amps @ High Speed
Power Draw (Full Load)	4615 Watts @ High Speed

5.7 Condenser/Subcooler Fan:**Condenser Fan:**

Air Flow	9000 CFM (maximum)
Fan Diameter	24 Inches
Number of Blades	10
Fan Drive	Fan is on a belt driven shaft

Radiator/Subcool Fan:

Air Flow	4000 CFM (maximum)
Fan Diameter	18 Inches
Number of Blades	6
Fan Drive	Fan is located on opposite end of condenser fan shaft.

5.0 APPENDIX**5.8 Exchanger Coil Data:****5.8.1 Evaporator Coil:**

Net Face Area	15.46 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	6
Fins Per Inch	9

5.8.2 Condenser Coil:

Net Face Area	15.49 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	6
Fins Per Inch	12

5.8.3 Subcool Coil:

Net Face Area	7.74 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	2
Fins Per Inch	12

5.8.4 Radiator Coil:

Net Face Area	7.74 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	2
Fins Per Inch	12

5.0 APPENDIX

5.9 Control Sequence:

Occupied Cooling Mode:

The supply air fan can be set for auto or continuous duty. When mechanical cooling is not energized, the fan will operate at low speed.

On a call for cooling, unit controller will initiate engine/compressor (power pack) start sequence. After a time delay of four minutes, controller contact Y1 closes, enabling the starter motor solenoid, which cranks the engine. When sufficient engine vacuum is developed, an intake manifold mounted pressure switch will close, energizing the fuel line solenoid valve, allowing natural gas to flow to the engine. After ignition occurs, a control panel mounted solid state module will de-energize the starter motor. (Control senses engine RPM via a magnetic pickup mounted on the engine bell housing).

During first stage cooling, the compressor is unloaded to 50% capacity. A compressor mounted solenoid is energized to unload one bank of cylinders. A normally open liquid line solenoid is energized, to prevent refrigerant flow to the upper 75% of the evaporator coil face. The lower 25% is fed refrigerant by a dedicated expansion valve. Power pack speed is 1000 RPM.

On a continued call for cooling, the second stage of mechanical cooling, contact Y2, is energized. The supply fan motor is switched to high speed and the compressor solenoid is de-energized, fully loading the compressor. Engine speed remains 1000 RPM. The liquid line solenoid is de-energized, and the full face of the evaporator is active.

On a continued call for cooling, the third stage, Y3, will be energized. An engine mounted solenoid is also energized, which changes the engine governor position to increase the power pack speed to 1500 RPM, (medium speed mode).

On a further continued call for cooling, the fourth stage, Y4, will be energized. A second engine mounted solenoid, (high speed), is also energized. Power pack speed is increased to 2400 RPM. The medium speed solenoid is de-energized.

5.0 APPENDIX

Occupied Cooling Mode:

Economizer (Optional):

When outdoor air temperature or enthalpy conditions are suitable, the unit controller will control economizer operation on a call for cooling based on the programmed economizer set point. The economizer can be controlled in the open mode over a range of 16 positions. The economizer will be driven open one position per minute until the thermostat is satisfied or the economizer is in the full open position and mechanical cooling is still required. Note: Maximum economizer setting is 3°F less than the occupied cool set point.

If outdoor air temperature or enthalpy conditions are not suitable for economizer operation, the controller will drive the economizer to the minimum outside air position.

Unoccupied Cooling Mode:

Subject to time of day programming in the thermostat, the control system will reset the cooling setpoint. Unit operation is the same as occupied mode, except supply air fan is energized only during a cooling call. The economizer, (optional), operates at a fixed setpoint 3°F below the unoccupied cool setpoint, (see Occupied Economizer Operation).

The thermostat will not allow the unoccupied cool setpoint to be lower than the occupied cool setpoint.

Occupied Heat:

On a call for heat, contact W1 will close, energizing the furnace vent motor and the supply fan control switch, (bimetal heater switch). The resulting vent motor operation will cause a furnace mounted differential pressure switch to close, powering up the solid state spark ignition controller. The ignition control will simultaneously open the gas pilot valve and supply a continuous spark to the ignitor electrode. When the pilot burner ignites, the pilot flame sensor detects the pilot flame and signals the ignition controller to energize the first stage of the gas valve, which will supply gas to the burners. It will simultaneously discontinue the spark. The main gas valve will not be energized until the flame sensor detects the presence of a pilot flame.

5.0 APPENDIX

If the pilot flame goes out, (with the thermostat still calling for heat), the ignition controller will de-energize the main gas valve and the ignition sequence will be repeated. When the furnace mounted fan switch heats up and closes (after a 20-60 second delay), the supply fan will be energized, (high speed operation).

If the thermostat continues to call for heat, the second stage, W2, will energize a bi-metal heater inside the gas valve. After approximately 60 seconds the internal heater will warp, allowing the gas valve to regulate to a higher pressure, providing furnace high fire operation.

Shutdown sequence is W2 opens to de-energize the second stage of the gas valve. The valve will return to first stage operation after approximately 60 seconds, (time delay for internal bi-metal switch to cool down).

If the thermostat is satisfied, the controller will de-energize contact W1, de-energizing the ignition controller and gas valve, turning the furnace off. Simultaneously the supply fan will go to low speed. The supply fan will continue to operate until the furnace mounted fan switch opens, signalling proper furnace cool down.

The furnace is protected against abnormal operation by three temperature safety. Each is a N.C. bi-metal switch that will open to de-energize the furnace ignition system, controller, and/or the gas valve. The furnace mounted limit control switch senses excessive flue element temperatures. The furnace mounted auxiliary high temperature limit senses furnace's bulkhead temperature. The third is mounted in the filter section and provides limit control in case of a supply fan failure.

The economizer (optional) is held in the minimum outside air position during the occupied heat mode. Maximum occupied heat setpoint is 20°F below economized setpoint (all units).

Unoccupied Heating Mode:

Subject to programming in the thermostat, the control system will reset to an unoccupied heating setpoint. Operation is the same as in the occupied mode. The thermostat will now allow the unoccupied heating setpoint to be higher than the occupied setpoint. The economizer (optional) will be driven fully closed.

5.0 APPENDIX
5.10 Typical Electrical Schematic:

(18)

5.0 APPENDIX

(19)

5.11 Unit Dimensional Drawing: GTC-1

DIMENSIONAL DRAWING

PLAN VIEW

ELEVATION VIEW
(FURNACE SIDE)

ELEVATION VIEW
(CONTROL BOX SIDE)

5.12 Curb Drawing:

5.13 Curb Detail:

TYPICAL CURB INSTALLATION

5.0 APPENDIX

GTC-1 BLOWER PERFORMANCE

5.15 Fan Curve:

B.27

THERMO KING
CORPORATION
MINNEAPOLIS, MINNESOTA, USA

5.0 APPENDIX

5.16 Rigging Diagram

GTC-1

RIGGING DRAWING

B.28

THERMO KING
CORPORATION
MINNEAPOLIS, MINNESOTA

5.0 APPENDIX**5.17 THERMO KING GIC-I C.O.P. VS AIR CONDITIONING CAPACITY**

	1	2	3	4	5	6
	G1600 ENGINE HORSEPOWER REQUIRED (BHP)	SPECIFIC FUEL CONSUMPTION IN BTU/HP HOUR (BSFC)	C.O.P. WITHOUT SUPPLY AIR BLOWER MOTOR	C.O.P. WITH SUPPLY AIR BLOWER MOTOR (5 HP INPUT)	ENGINE EFF. (2545) (BSFC)	% OPERATION
*CAPACITY (BTU/HR) (SHR)						
190,000 0.68	31.0 (2400 RPM)	9464	.65	.63	.27	10
143,000 0.80	19.1 (1500 RPM)	8736	.86	.80	.27	55
84,000 0.88	10.5 (1000 RPM)	8840	.90	.81	.27	30
26,000 1.0	10.0 UNLOADED (1000 RPM)	8840	.31	.25	.27	5
* CAPACITIES ARE AT 95° AMBIENT AND 80°/67°F, EDB/EWB AIR ENTERING EVAPORATOR SHR = SENSIBLE HEAT RATIO						
COP (IPLV)			.77	.69		

TO CALCULATE GAS CONSUMPTION:

Natural Gas Consumption (FT³) = $\frac{\text{BHP} \times \text{BSFC}}{\text{HHV}}$ EXAMPLE: HIGH SPEED OPERATION = (31.0 HP) $\frac{9464 \text{ BTU} \times 1 \text{ FT}^3}{\text{HP} \cdot \text{HR}} = 282 \text{ FT}^3/\text{HR}$

HP - ENGINE HORSEPOWER
BSFC - BRAKE SPECIFIC FUEL CONSUMPTION
HHV - HIGH HEATING VALUE OF LOCAL NATURAL GAS

GTC-I SPECIFICATION

APRIL 1, 1992

REVISION #1

INDEX/SUMMARY

<u>SECTION</u>	<u>PAGE</u>
1.0 DESCRIPTION - GENERAL	1
2.0 DESCRIPTION - TECHNICAL	2-4
3.0 CONTROL SYSTEM DESCRIPTION	5-6
4.0 INSTRUMENTATION	7
5.0 MISCELLANEOUS DATA	
5.1 Engine Specifications	8
5.2 Air Conditioning Section	9
5.3 Fan and Motor Information	10
5.4 Fan and Motor Information	10
5.5 Air Coil Data	11
6.0 UNIT OPERATION/CONTROL SEQUENCE	12-14

<u>DRAWINGS</u>	<u>PAGE</u>
Electrical Schematic	15
Unit Dimensional Diagram	16
Corner Loading	17
Rigging Drawing	18
C.O.P. vs. A/C Capacity Chart	19
Fan Performance Data	20
Curb Drawings and Drain Pan Location	21-24

1.0 DESCRIPTION

1.1 General Description:

The Thermo King GTC-I is an engine driven (natural gas fuel), 15 ton packaged, rooftop or ground mounted, air cooled, single zone, heating/cooling air conditioning unit.

Each GTC-I unit is completely factory assembled, wired, piped, tested, and charged with refrigerant HCFC 22. Units require single point connections of electrical power and natural gas. Engine oil is shipped in packaged form with the unit, requiring field addition before engine startup.

The unit features direct expansion cooling, with natural gas heating. The outside air system, return air system (economizer), filters, electric supply air fan, and all standard safety and operating controls are factory installed.

1.2 Capacity Ratings:

1.2.1 Cooling Capacity:

Unit cooling capacity at ARI 360 standard conditions, (80/67 EDB/EWB air to evaporator, 95 degrees ambient), is 190,000 Btu/Hr, (15.7 tons).

1.2.2 Heating Capacity (optional):

Unit heating capacity at A.G.A. test conditions is 216,000 Btu/Hr. with input of 265,000 Btu/Hr. max.

1.3 Physical Data:

1.3.1 Unit Dimensions: 155" x 76.5" x 50.5", (L x W x H)

1.3.2 Unit Weight: Maximum of 2900 pounds, including economizer, furnace and all fluids.

2.0 TECHNICAL DESCRIPTION

2.1 Cabinet Construction:

The unit frame is constructed of heavy gauge aluminum, welded and/or bolted as required. Exterior panels are .063 inch thick aluminum. The frame is anodized for maximum corrosion resistance. Exterior panels are finished in high solids polyester baked enamel.

The unit is insulated with 1" thick fiberglass. Lifting lugs are factory installed.

2.2 Condensing Section:

2.2.1 Power Pack, (direct coupled engine/compressor)

2.2.1.1 **Engine:** The compressor drive engine is an industrial duty natural gas fueled engine (propane conversion available). See Page 8 for engine specifications. Starting and ignition systems are 12 VDC. Unit is supplied with a battery.

2.2.1.2 **Compressor:** The compressor is a Thermo King Model X430; 4 cylinder 30 cu./in. industrial duty, reciprocating, open drive type. The compressor includes a positive displacement oil pump, suction and discharge line service valves, suction strainer, and oil level sight glass.

2.2.1.3 **Compressor/Engine Coupling:** The engine/compressor direct coupling is a proprietary Thermo King two plate design that allows tolerance accommodation without applying thrust loads on the compressor or engine crankshaft bearings.

2.2.1.4 **Vibration Isolation:** The power pack is mounted to a heavy gauge welded steel cradle. The assembly is isolated from the unit frame using a patented elastomeric mounting system. Further isolation is achieved using braided wire line isolators (vibrasorbers) for the suction and discharge lines and the engine fuel connection.

2.0 TECHNICAL DESCRIPTION

2.2.2 Refrigeration Components:

- 2.2.2.1 The refrigerant circuit is fully piped, tested, dehydrated, and charged with oil and refrigerant HCFC 22 at the factory.
- 2.2.2.2 Coils: (Condenser/Radiator/Subcooler) The coils are fabricated from 3/8" O.D. .020 seamless copper tubing, mechanically bonded to corrugated .010 aluminum fins. Each coil is factory leak tested to 400 PSIG.
- 2.2.2.3 Condenser/Radiator Fans, (1 each): Condenser/radiator fans are propellor type. The fans are mounted on a common shaft and engine driven. The drive system includes an idler pulley for belt tensioning.
- 2.2.2.4 Refrigeration Circuit Components: Refrigeration circuit components include suction and discharge service valves, wire braided discharge and suction line isolators, receiver with liquid level sight glasses, subcool coil, liquid line filter/drier, manual shutoff valve, spring type high pressure relief valve, liquid line solenoid valve, and externally equalized thermostatic expansion valves. All copper refrigeration lines are vinyl coated for corrosion protection.

2.3 Evaporator Section:

- 2.3.1 Evaporator Coil: The evaporator coil is a direct expansion type. The coil is fabricated from 3/8" O.D. .020 seamless copper tubing, mechanically bonded to corrugated .010 aluminum fins. The coil headers are seamless copper. Tube sheets are fabricated of heavy gauge aluminum aladyned for corrosion protection. Each coil is factory leak tested to 400 PSIG. The evaporator is fed through an externally equalized adjustable superheat thermostatic expansion valve.
- 2.3.2 Drain Pan: The drain pan is constructed of heavy gauge aluminum. Condensate drain connections are provided on both sides of the unit. 1.0" I.D. molded rubber "P" traps are supplied for field installation.

2.0 TECHNICAL DESCRIPTION

2.4 Gas Heating Section:

The two (2) stage gas furnace is an induced draft type, with intermittent pilot ignition and in-shot burners. Furnace elements are tubular aluminized steel. Elements are welded to a heavy gauge galvanized steel bulkhead. The unit is equipped with a fan/limit switch, and two auxiliary high temperature safety limits. The furnace and gas train are all located within the unit cabinet. Gas piping enters the unit at a single point.

2.5 Supply Fan Section:

2.5.1 Supply Fans:

The supply air fans are single inlet, single width, forward curved type. The fan wheel and housing are fabricated from painted cold, rolled steel. The fan wheels are supported by a solid steel shaft, which is mounted to three heavy duty bearings.

2.5.2 Fan Motor:

The fan motor is a heavy duty single speed 1725 RPM, 230 VAC, three phase, open drip proof type. It is thermally protected with an external overload.

2.6 Filter Section:

The unit is supplied with an integral aluminum filter rack and 2 in. thick throw-away fiberglass filters. Average efficiency is 30%, (tested per ASHRAE 52-76).

3.0 **CONTROL SYSTEM**

3.1 **General:**

The unit is factory equipped with a solid state cooling/heating temperature control system. The unit is also equipped with refrigeration, electrical, and engine safety/operating controls. (See Pages 13-15 for detailed control sequence). The thermostat is field supplied.

3.2 **Temperature Controls:**

The temperature controller is a Microprocessor based Honeywell Model W7401 controller. This unit provides four stages of cooling and two stages of heating. The W7401 is integrated with the engine controls to provide automatic stop/starting, and engine speed changes to provide staged cooling. (See Pages 13-15 for detailed control sequence). The furnace control is two (2) stage. The recommended mating thermostat is a Honeywell T7400A or T7900B (thermostat is not included with unit).

3.3 **Engine Controls** (See Control Sequence, Pages 13-15)

3.3.1 **Engine Operating Controls**

- 3.3.1.1 **Engine On/Off Switch:** Enables or disables the fuel shutoff solenoid and starter.
- 3.3.1.2 **Auto/Thermostat/Thermostat By-Pass, Auto/start, Auto/Run Switch:** In the auto position, engine operation is controlled by the thermostat. In the manual position, the engine is disconnected from the W7401 module, but the engine will start and run (for cooling checkout).
- 3.3.1.3 **Manual Start Switch:** With manual control enabled, (3.3.1.2), the engine can be started by enabling the manual start switch on the unit.
- 3.3.1.4 **Starter Control:** A magnetic sensor mounted next to the flywheel gear teeth transmits engine RPM to a solid state module mounted in the engine compartment. The module will disable the starter when a pre-set engine RPM is achieved.

3.0 CONTROL SYSTEM

3.3.1.5 **Battery Charging Control:** The unit is equipped with a solid state battery charging system to recharge and maintain the 12 VDC starting battery.

3.3.2 Engine Safety Controls:

3.3.2.1 **Oil Pressure Switch:** The engine is protected from lubrication failure by a low oil pressure switch. The switch has a 30 second time delay to prevent nuisance trips during engine start up. Switch closure disables the ignition circuit.

3.3.2.2 **Coolant Temperature Switch:** The engine is protected from overheating by a high coolant temperature switch. The switch has a 30 second time delay to prevent nuisance trips during engine start up. Switch closure disables the ignition circuit.

3.4 Refrigeration Controls/Safeties:

3.4.1 **Refrigerant High Pressure:**
The compressor circuit has a manual reset high refrigerant pressure switch.

3.4.2 **Refrigerant Low Pressure:**
The compressor circuit has a manual reset low refrigerant pressure switch.

3.4.3 **Low Ambient Compressor Lockout:**
The control circuit has an auto reset outdoor ambient temperature switch to prevent compressor operation below 45°F.

3.4.4 **High Pressure Relief:**
Spring loaded relief valve to prevent unsafe build up of refrigerant pressure.

4.0 INSTRUMENTATION

4.1 Engine Hourmeter:

The control panel mounted hourmeter is a solid state type with LCD readout. It records the number of hours of engine/compressor operation.

4.2 Engine Oil Pressure Gauge:

Analog type; condenser section mounted.

4.3 Engine Coolant Temperature Gauge:

Analog type; condenser section mounted.

5.0 MISCELLANEOUS DATA

5.1 Hercules G1600 Natural Gas Engine:

The Hercules G1600 is a spark ignition, carburetored natural gas fueled engine that features the following characteristics:

General Information: For further information, consult the Thermo King Maintenance/Operating Manual (Yellow Cover), TK #40267.

Fuel	Natural Gas
Number of Cylinders	4
Cylinder Arrangement	No. 1 at pulley end.
Bore	4.0 in.
Stroke	3.25 in.
Displacement	163 cu. in.
Rated Horsepower	31.0 BHP @ 2400 RPM
Operating Speeds	2200 RPM - ± 150 High 1800 RPM - ± 100 Med. 1200 RPM - ± 100 Low
Ignition (Electronic)	Solid State Distributorless
Spark Plugs	Champion RJ88P
Plug Gap	.013-.016"
Valve Lash:	
Intake (Cold and Hot)	0.015 in.
Exhaust (Cold and Hot)	0.015 in.
Firing Order	1-3-4-2
Compression Ratio	7.5:1
Lubrication System	Dry Sump
Oil Pressure (Regulated)	37-40 PSIG, engine at operating temp.
Oil Change Interval	Consult Thermo King Maintenance Manual
Oil Capacity	40 qts. with Remote Tank
Oil Type	Mobil Pegasus 80 Natural Gas Oil
Oil Pump	Gear Type - Positive Pressure
Oil Filter	Full Flow Type - TK P/N 11-7079
Engine Serial Number	Right rear side viewed from pulley end
Engine Rotation	Clockwise, (Viewed from pulley end)
Carburetor	IMPCO Model 100
Carburetor Regulator	Maxitrol full flow type
Air Filter	T.K. P/N 11-5978, dry element type
Cooling System Coolant	50/50 Water Ethylene Glycol
Unit Inlet Gas Pressure	5" - 12" W/C
Oil Pressure Switch	Normally closed, Opens at 15 ± 3 PSIG
Coolant Temperature Switch	Normally open, Open at minimum 190°F, Closed at $225 \pm 5^\circ\text{F}$

5.0 MISCELLANEOUS DATA**5.2 Air Conditioning Section:**

<u>Compressor:</u>	Model X430
Displacement 30 C.I.D.	
Max. Operating Speed	2400 RPM
Oil Charge	134 oz.
Oil Type (150 SUS)	TK P/N 67-404 Synthetic
Refrigeration	R-22
Refrigerant Charge	30 lbs.
High Pressure Cutout (R22)	
Opens	400 PSIG
Closes	325 PSIG
Low Pressure Cutout	
Opens	30 PSIG
Closes	50 PSIG
Oil Pump Pressure	
Operating Range	15-45 PSIG
Compressor Drive	Direct Drive 6 pin rubber bushing coupling
High Pressure Relief	
Opens	450 PSIG
(Spring Loaded)	
Low Ambient Lockout	45°F cutout 55°F cutin
Expansion Valves:	
11 ton (large) Type	External Equalizer
1082A30H59 Superheat Setting	15°F $\pm$ 5
Mounting	Flare Connection
Inlet Strainer	Cleanable
3 ton (large) Type	External Equalizer
1082A30H59 Superheat Setting	15°F $\pm$ 5
Mounting	Flare Connection
Inlet Strainer	Cleanable

(Single expansion valve system planned for units produced after 7/15/92 - check with your local Thermo King representative)

5.0 MISCELLANEOUS DATA**5.3 Supply Air Fans and Motor:**

Blower Wheel Diameter	10.75" x 4.00"
Number of Blowers	4
Blower Drive	Belt
Horsepower	5 HP
Speeds	1725 RPM
Voltage	208/230V (Optional Voltage/ Phases Available)
Phase	3

5.4 Condenser/Subcooler Fan:**Condenser Fan:**

Air Flow	9000 CFM (maximum)
Fan Diameter	24 Inches
Number of Blades	10
Fan Drive	Shaft driven

Radiator/Subcool Fan:

Air Flow	4000 CFM (maximum)
Fan Diameter	18 Inches
Number of Blades	6
Fan Drive	Fan is located on opposite end of condenser fan shaft.

5.0 MISCELLANEOUS DATA**5.5 Air Coil Data:****Evaporator Coil:**

Net Face Area	13.3 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	6
Fins Per Inch	9

Condenser Coil:

Net Face Area	15.49 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	6
Fins Per Inch	12

Subcool Coil:

Net Face Area	7.74 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	2
Fins Per Inch	12

Radiator Coil:

Net Face Area	7.74 sq. ft.
Tube Diameter	3/8 inch
Number of Rows	2
Fins Per Inch	12

6.0 UNIT OPERATION

6.1 Control Sequence (Single Zone Application):

Occupied Cooling Mode:

The supply air fan can be set for auto or continuous duty. When mechanical cooling is not energized, the fan will operate at low speed.

On a call for cooling, unit controller will initiate engine/compressor (power pack) start sequence. After a time delay of four minutes, controller contact Y1 closes, enabling the starter motor solenoid, which cranks the engine. When sufficient engine vacuum is developed, an intake manifold mounted pressure switch will close, energizing the fuel line solenoid valve, allowing natural gas to flow to the engine. After ignition occurs, a control panel mounted solid state module will de-energize the starter motor. (Control senses engine RPM via a magnetic pickup mounted on the engine bell housing).

During first stage cooling, with engine speed at 1200 RPM, the compressor is unloaded to 50% capacity. A compressor mounted solenoid is energized to unload one bank of cylinders.

On a continued call for cooling, the second stage of mechanical cooling, contact Y2, is energized. Engine speed continues at 1200 RPM the compressor unloader is disengaged.

On a continued call for cooling, the third stage, Y3, is energized. An engine mounted solenoid is also energized, changing the engine governor position to increase the power pack speed to 1600-1800 RPM, (medium speed mode).

On a further continued call for cooling, the fourth stage, Y4, will be energized. A second engine mounted solenoid, (high speed), is also energized. Power pack speed is increased to 2200 RPM. The medium speed solenoid is de-energized.

6.0 UNIT OPERATION

Occupied Cooling Mode:

Economizer (Optional):

When outdoor air temperature or enthalpy conditions are suitable, the unit controller will control economizer operation on a call for cooling based on the programmed economizer set point. The economizer can be controlled in the open mode over a range of 16 positions. The economizer will be driven open one position per minute until the thermostat is satisfied or the economizer is in the full open position and mechanical cooling is still required. Note: Maximum economizer setting is 3°F less than the occupied cool set point.

If outdoor air temperature or enthalpy conditions are not suitable for economizer operation, the controller will drive the economizer to the minimum outside air position. Economizer controls use differential enthalpy sensors for maximum free cooling.

Unoccupied Cooling Mode:

Subject to time of day programming in the thermostat, the control system will reset the cooling setpoint. Unit operation is the same as occupied mode, except supply air fan is energized only during a cooling call. The economizer, (optional), operates at a fixed setpoint 3°F below the unoccupied cool setpoint, (see Occupied Economizer Operation).

The thermostat will not allow the unoccupied cool setpoint to be lower than the occupied cool setpoint.

Occupied Heat:

On a call for heat, contact W1 will close, energizing the furnace vent motor and the supply fan control switch, (bimetal heater switch). The resulting vent motor operation will cause a furnace mounted differential pressure switch to close, powering up the solid state spark ignition controller. The ignition control will simultaneously open the gas pilot valve and supply a continuous spark to the ignitor electrode. When the pilot burner ignites, the pilot flame sensor detects the pilot flame and signals the ignition controller to energize the first stage of the gas valve, which will supply gas to the burners. It will simultaneously discontinue the spark. The main gas valve will not be energized until the flame sensor detects the presence of a pilot flame.

6.0 UNIT OPERATION

If the pilot flame goes out, (with the thermostat still calling for heat), the ignition controller will de-energize the main gas valve and the ignition sequence will be repeated. When the furnace mounted fan switch heats up and closes (after a 20-60 second delay), the supply fan will be energized, (high speed operation).

If the thermostat continues to call for heat, the second stage, W2, will energize a bi-metal heater inside the gas valve. After approximately 60 seconds the internal heater will warp, allowing the gas valve to regulate to a higher pressure, providing furnace high fire operation.

Shutdown sequence is W2 opens to de-energize the second stage of the gas valve. The valve will return to first stage operation after approximately 60 seconds, (time delay for internal bi-metal switch to cool down).

If the thermostat is satisfied, the controller will de-energize contact W1, de-energizing the ignition controller and gas valve, turning the furnace off. The supply fan will continue to operate until the furnace mounted fan switch opens, signalling proper furnace cool down.

The furnace is protected against abnormal operation by three temperature safeties. Each is a N.C. bi-metal switch that will open to de-energize the furnace ignition system, controller, and the gas valve. The furnace mounted limit control switch senses excessive flue element temperatures. The furnace mounted auxiliary high temperature limit senses furnace's bulkhead temperature. The third is mounted in the filter section and provides limit control in case of a supply fan failure.

The economizer (optional) is held in the minimum outside air position during the occupied heat mode. Maximum occupied heat setpoint is 2°F below economized setpoint (all units).

Unoccupied Heating Mode:

Subject to programming in the thermostat, the control system will reset to an unoccupied heating setpoint. Operation is the same as in the occupied mode. The thermostat will now allow the unoccupied heating setpoint to be higher than the occupied setpoint. The economizer (optional) will be driven fully closed.

GTC-1 DIMENSIONAL DRAWING

PLAN VIEW

ELEVATION VIEW
(FURNACE SIDE)

ELEVATION VIEW
(CONTROL BOX SIDE)

NOTE: THERMO-KING GTC-1 CORNER
WEIGHTS (WITH FURNACE)

GTC-1 CORNER LOADING

5.16 Rigging Diagram

GTC-1

RIGGING DRAWING

GTC-1 COP VS AIR CONDITIONING CAPACITY

Cooling Capacity ① (BTU/Hr) (SHR) ⑥	Engine/Compressor RPM	Fuel Consumption ② MBTU/Hr. (Ft. ³ /Hr.) ⑦	Thermal COP ③	Net COP ④
182,100 (0.68)	2200	324.8 (312.3)	0.56	0.54
152,800 (0.79)	1750	235.9 (226.8)	0.65	0.61
110,600 (.86)	1200	137.6 (132.3)	0.80	0.74
55,200 (1.0)	1200 (Compressor 50% unloaded)	119.2 (109.8)	0.48	0.43
COP IPLV ⑤			0.64	0.59

- ① Rated at 95° ambient, 80/67 EDB/EWB
 ② 1040 BTU/Ft³ HHV Natural Gas Assumed
 ③ Thermal COP = (Net Cooling Cap.) / (Gas Input)
 ④ Net COP = (Net Cooling Cap.) / (Gas Input + Electrical Power)
 ⑤ IPLV = Integrated Part Load Value
 ⑥ SHR = Sensible Heat Ratio
 ⑦ Includes condenser and radiator fan HP

GTC-1 FAN PERFORMANCE DATA

EXTERNAL STATIC PRESSURE (INCHES WATER COLUMNS)									
	0.5	0.75	1.00	1.25	1.50	1.75	2.00		
SCFM	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP	RPM/BHP
4500	1190/2.75	1290/2.9	1370/3.1	1410/3.3	1510/3.9	1580/4.2	1650/4.8		
5000	1300/3.0	1390/3.5	1450/4.0	1510/4.2	1575/4.8	1640/5.0	1705/5.4		
5500	1410/4.0	1480/4.5	1540/4.9	1580/5.1	1630/5.4	1690/5.9	1775/6.4		
6000	1505/5.0	1570/5.3	1600/6.0	1650/6.2	1700/6.5	1790/7.1	-----		
6500	1610/6.3	1650/6.7	1700/7.1	1730/7.5	-----	-----	-----		

STANDARD MOTOR - 5 HP
 OPTIONAL OVERSIZE - 7.5 HP

Appendix C

Acquired Field Data

WNAS1X0.WK1

	Idle (hr)	All (hr)	RHm (%)	Tm (F)	Tr/a (F)	Ts/a (F)	Tm/a (F)	To/a (F)	dT-crx (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)	EngE (s/hr)d	FanO (s/hr)d
06/27	6.09	6.09	45.45	77.7	79.28	76.83	75.42	73.04	-1.39	42.45		50	0.821	94.39
06/28	17.83	17.83	43.11	76.33	76.15	72.69	71.07	68.55	-1.8	248.7	0.003	259	1.963	1491
06/29	17.85	17.85	44.7	76.97	76.59	74.49	72.61	70.92	-1.85	256.7	0.001	267	2.801	1526
06/30	10.47	10.47	49.71	78.63	77.56	76.06	73.64	71.8	-2.39	158.9		166		855.1
07/01	9.21	9.21	62.36	79.5	80.11	77.49	78.46	77.83	0.971	292.9	0.8	303	27.15	1597
07/02	12.77	12.77	43.47	72.51	71.97	67.58	68.39	68.46	0.823	583.1	0.009	594	11.36	3587
07/03	21.59	21.59	50.2	71.2	68.68	62.84	63.04	61.66	0.208	595.5	0.002	611	4.631	3608
07/04	12.36	12.36	57.93	71.86	71.84	69.2	70.78	68.02	1.608	588.8	0.019	613	12.14	3667
07/05	0.00	0.00												
07/06	5.86	5.86	47.16	75.81	78.68	78.94	76.5	73.07	-2.41	24.49		33		41.82
07/07	13.34	13.34	45.86	75.66	75.96	73.73	71.12	67.56	-2.58	185.5		194		1045
07/08	24.00	24.00	45.72	75.67	80.8	78.4	79.69	77.11	1.248	16.4		24		
07/09	13.89	13.89	51.67	77.27	77.78	76.95	75.5	74.14	-1.45	16.67		25		0.36
07/10	13.85	13.85	52.77	76.91	78.41	76.88	75.28	73.34	-1.58	28.39		31		0.361
07/11	14.40	14.40	55.23	76.24	78.08	75.69	74.57	75.51	-1.1	20.08		28	0.347	13.54
07/12	15.72	15.72	58.69	75.21	76.85	74.02	74.6	74.53	0.604	228.2	0.008	237	8.045	1347
07/13	14.05	14.05	63.12	75.62	78.48	76.85	78.44	81.1	1.597	176.8	0.002	185	4.27	1051
07/14	14.05	14.05	62.08	76.37	79.09	76.66	76.65	77.73	*****	77.36		87	1.068	381.5
07/15	12.37	12.37	66.66	76.92	78.41	75.63	76.05	75.39	0.432	459.1		480	1.617	2969
07/16	16.43	16.43	62.14	74.82	75.71	70.83	72.09	69.92	1.284	364.9	0.009	387	8.519	2306
07/17	18.77	18.77	60.06	72.13	72.34	67.54	68.61	68.43	2.119	101.2	0.005	192	7.726	1073
07/18	15.18	15.18	53.14	63.43	64.12	60.74	61.49	62.16	0.965	-82.6	0.004	55	3.293	207.5
07/19	16.58	16.58	61.5	74.79	75.97	71.08	73.67	74.05	2.604	293.2	0.009	304	7.843	1786
07/20	9.35	9.35	61.77	72.36	74.06	71.57	75.8	82.42	4.228	568.1	0.022	583	14.97	3618
07/21	0.46	0.46	58.32	76.05	75.32	70.77	68.87	69.71	-0.9	577		643		3827
07/22	11.05	11.05	52.49	75.54	76.01	72.32	70.9	67.61	-1.41	578.7		614		3674
07/23	12.15	12.15	54.18	75.23	74.56	73.47	70.94	65.46	-2.52	314.8	0.000	329		1891
07/24	23.90	23.90	57.2	73.11	69.92	66.36	63.96	61.25	-2.41	291.5	8E-05	304		1751
07/25	19.17	19.17	56.88	73.32	71.25	68.96	66.55	63.55	-2.42	221.5		233		1315
07/26	13.18	13.18	56.33	74.83	73.4	72.52	70.2	66.4	-2.31	78.53		89		408
07/27	0.00	0.00												
07/28	5.79	5.79	47.16	75.44	76.88	74.63	72.17	65.74	-2.43	421		441		2813
07/29	14.87	14.87	51.33	75.15	75.67	72.54	71.97	69.05	-0.57	307.5	4.523	369	103.3	1505
07/30	15.65	15.65	57.13	74.95	76.99	71.93	73.9	73.07	2.003	456	0.004	476	8.307	2901
07/31	14.37	14.37	61.58	74.97	75.38	71.7	71.55	68.81	-0.13	325.6	0.008	350	5.568	2093
08/01	18.70	18.70	52.72	74.32	74.09	70.09	69.67	68.15	-0.41	204.6	0.003	216	4.813	1242
08/02	17.31	17.31	50.63	74.33	74.4	69.91	70.59	69.17	0.692	224.2	0.004	235	6.644	1343
08/03	18.41	18.41	61.79	72.52	73.45	69.7	72.83	75.5	3.145	564	0.01	578	12.22	3606
08/04	15.08	15.08	61.5	73.54	73.42	69.06	70.68	69.39	1.645	357.7	0.184	376	14.25	2150
08/05	16.92	16.92	53.86	73.81	72.76	68.64	67.5	64.74	0.879	173	0.004	185	5.911	1028
08/06	16.28	16.28	49.56	73.99	73.87	67.71	68.91	65.73	1.225	161.4	2.635	161	5.834	853
08/07	16.05	16.05	47.24	74.21	74.31	68.75	69.41	65.93	0.894	83.65	1.487	163	35.51	685
08/08	15.21	15.21	49.25	74.24	73.54	68.58	68.57	65.6	0.002	131.8	0.008	141	3.946	728
08/09	12.57	12.57	57.54	75.31	75.67	72.96	73.13	73.99	0.186	77.47	0.004	86	2.785	393.1
08/10	2.98	2.98	58.58	71.04	72.23	66.09	71.66	71.34	5.627	573.4	0.026	578	21.79	3543

WNAS1X1.WK1

	C1 (hr)	All (hr)	RHm (%)	Tm (F)	Tr/a (F)	Ts/a (F)	Tm/a (F)	To/a (F)	dT-crx (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)	EngE (a/hr)d
06/27	8.09	8.12	52.92	75.23	76.01	68.39	74.23	76.21	5.882	322.3	88.01	655.9	2013
06/28	4.25	4.27	37.9	77.22	79.97	69.52	81.3	83.33	11.81	279.4	159.8	660.5	3600
06/29	3.23	3.23	45.54	77	79.03	72.04	80.97	89.75	8.914	650.5	144.7	663.3	3303
06/30	1.81	1.81	51.72	76.99	77.16	77.04	76	72.75	-1.02	631.3		644.4	
07/01	4.93	4.86	56.57	76.27	77.76	63.92	80.77	82.87	17.13	504.2	135.3	669	3217
07/02	11.18	11.03	44.02	72.01	72.77	52.64	72.28	73.45	20.34	655.4	157.4	680.7	3651
07/03	2.48	2.36	47.18	71.69	69.62	53.44	66.53	65.83	13.52	668.1	153.8	728.2	3787
07/04	5.63	5.64	58.39	72.52	74.21	63.96	74.91	78.91	11.17	636.4	112.1	653.2	2607
07/05	3.76	3.76	57.45	70.98	70.79	69.38	68.57	68.6	-0.81	586.5		595.2	
07/06	0.07	0.07	46.2	74.7	79.8	80.3	79.5	79.6	-0.79	557.5		578.9	
07/07	2.55	2.56	47.77	72.9	73.59	70.92	70.05	70.02	-0.87	584.7		596.2	
07/08	0.00	0.00											
07/09	0.13	0.14	55.08	77.61	80.85	81.12	81.73	84.89	0.599	597.4		609.8	
07/10	0.14	0.14	51.9	73.34	76.84	69.21	79.06	87.27	10.03	646.6	74.19	666	1764
07/11	2.16	2.17	58.41	74.02	77.13	60.53	78.63	87.14	18.44	397.5	154.2	651.8	3600
07/12	7.91	7.92	57.74	72.78	74.53	59.77	75.28	80.14	15.89	626.9	134.2	642.2	3122
07/13	6.58	6.59	62	72.37	75.38	62.71	78.48	91.95	16.05	400.4	140.5	632.1	3286
07/14	3.52	3.53	61.71	73.62	75.73	60.55	77.53	85.95	17.31	625.2	153.7	632	3600
07/15	4.43	4.46	62.47	74.01	76.3	61.16	77.83	84.04	16.97	370.6	151.3	642.1	3600
07/16	7.51	7.51	59.74	72.81	75.04	58.5	75	76.95	16.87	632.9	154.2	650.5	3600
07/17	5.15	5.15	62.08	72.93	74.3	58.38	73.38	73.26	15.35	633.6	153.8	654.1	3600
07/18	8.74	8.74	59.25	73.13	76.04	59.17	77.28	82.86	18.5	621.5	155.7	635.3	3600
07/19	7.39	7.38	60.93	73.18	75.91	60.14	77.91	86.73	18.13	627.1	156.4	643.1	3605
07/20	8.47	8.23	59.1	72.82	74.81	63.9	75.08	78.79	11.44	616.8	113.8	651.3	2739
07/21	0.21	0.21	58.51	76.1	75.8	71.5	70.4	70.2	-1.1	570.1		586.2	
07/22	3.34	3.35	47.74	73.36	72.53	68.41	67.53	67.46	-0.89	585.7		600.2	
07/23	3.46	3.46	54.63	73.55	72.89	69.25	67.8	63.9	-1.45	587.2		603.2	
07/24	0.10	0.10	57.18	71.6	67.1	58.62	57.88	57.43	-0.96	594.7		619.2	
07/25	3.05	3.06	55.14	74	74.94	73.48	72.42	72.43	-1.05	568		583	
07/26	3.88	3.86	57.32	73.66	74.23	74.35	73.28	70.56	-1.06	577.4		595.9	
07/27	0.55	0.33	61.49	75.37	75.73	76	74.64	71.63	-1.34	607.7		1009	
07/28	0.07	0.07	47.01	74.6	76	74	72.8	72.7	-1.19	556.8		580.5	
07/29	2.29	2.29	52.51	73.59	74.81	72.63	73.1	73.83	0.492	568.8	9.146	585.2	215.7
07/30	8.28	8.28	57.15	72.66	75.64	57.63	76.49	81.64	19.32	628	159.8	644.3	3600
07/31	9.12	9.12	61.4	73	75.29	59.25	75.71	78.88	16.81	531.7	154.9	627.3	3600
08/01	5.27	5.27	45.71	73.28	75	55.88	75.85	80.34	20.54	635.8	160.1	653.8	3600
08/02	6.88	6.65	53.58	73.04	76.14	58.48	77.52	84.18	19.48	632.1	157.9	671.5	3722
08/03	5.61	5.58	60.09	72.79	74.03	60.1	73.62	75.85	13.79	638.3	155.7	663.4	3616
08/04	6.63	6.65	61.53	73.19	75.25	59.57	75.73	80.45	16.51	631.3	154.7	643.1	3565
08/05	7.02	7.02	51.88	72.05	74.13	55.47	74.85	79.55	19.94	634.4	159	651.5	3600
08/06	7.73	7.73	50.34	71.61	75.41	55.71	76.2	80.47	21.08	635.9	161.8	652.4	3600
08/07	7.86	7.86	48.74	71.67	75.28	55.03	75.55	79.45	21.14	636.1	160.4	652.6	3600
08/08	8.29	8.30	53.86	71.81	74.37	55.36	74.62	78.3	19.82	628	157	643	3600
08/09	7.43	7.39	59.05	72.5	74.29	58.09	75.68	82.23	18.02	412.1	154.5	642.3	3636
08/10	6.48	6.38	54.71	71.67	73.49	54.98	72.22	70.43	17.77	566.1	152.2	662.5	3661

WNAS1X2.WK1

	C2 (hr)	All (hr)	RHm (%)	Tm (F)	Tr/a (F)	Ts/a (F)	Tm/a (F)	To/a (F)	dT-crx (F)	Eload (W)	GasLd (kBtuh)	Epuls (W)	EngE (a/hr)d
06/27	3.03	3.03	50.23	76.32	79.98	62.86	80.23	85.15	17.61	3371	164.8	3450	3635
06/28	1.88	1.88	36.83	77.1	81.6	62.99	81.84	85.66	19.12	3389	165.4	3478	3640
06/29	0.92	0.93	47.33	78.55	81.25	80.14	82.41	87.03	2.326	3278	26.9	3332	604.5
06/30	1.19	1.19	55.16	78.45	79.27	80.79	78.87	78.28	-1.89	3273		3322	
07/01	5.75	5.76	58.69	74.91	77.94	64.89	78.02	81.61	13.33	3402	129.8	3455	2910
07/02	0.21	0.21	43.52	72.84	77.93	59.72	78.84	84.51	19.51	3458	163.1	3561	3649
07/03	0.00	0.00											
07/04	1.31	1.31	55.28	74.26	76.58	78.57	77.41	79.96	-1.14	3293		3341	
07/05	2.73	2.73	55.46	72.38	73.86	73.94	71.93	71.86	-2	3295		3343	
07/06	0.07	0.07	46.19	74.8	79.6	80.6	78.7	78.6	-1.86	3170		3314	
07/07	1.38	1.38	46.3	73.98	76.84	77.07	74.92	74.97	-2.12	3282		3341	
07/08	0.00	0.00											
07/09	0.86	0.87	59.68	76.67	78.97	80.79	79.48	81.2	-1.29	3261		3306	
07/10	0.83	0.83	51.15	75.78	78.15	78.89	79.24	83.07	0.401	3300	12.55	3350	294.5
07/11	7.25	7.25	57.93	73.61	77.19	62.83	79.66	91.31	17.07	3421	160.4	3463	3606
07/12	0.31	0.31	60.6	74.02	77.3	79.13	78.96	84.2	-0.16	3269		3350	
07/13	2.73	2.73	61.84	73.55	76.07	68.75	78.23	86.45	9.648	3307	105.2	3367	2407
07/14	3.30	3.31	65.92	75.06	77.68	65.98	81.28	96.17	15.43	3355	155.8	3407	3609
07/15	7.13	7.13	62.84	73.61	77.13	64.08	80.31	93.51	16.43	3355	155.3	3408	3613
07/16	0.00	0.00											
07/17	0.00	0.00											
07/18	0.07	0.07	56.73	72.3	75.8	59.75	76.5	81.4	17.09	3421	156.9	3588	3673
07/19	0.00	0.00											
07/20	1.08	1.09	59.13	75.01	79.11	81.47	81.21	87.76	-0.25	3264		3303	
07/21	0.9	0.90	60.11	76.14	76.43	73.52	71.52	71.42	-1.99	3264		3305	
07/22	2.41	2.42	45.54	74.28	75.75	74.56	72.5	72.29	-2.04	3287		3346	
07/23	1.85	1.85	54.28	74.44	75.99	77.11	73.95	66.91	-3.12	3295		3360	
07/24	0.00	0.00											
07/25	1.74	1.74	54.1	74.6	76.86	76.46	74.35	74.26	-2.08	3260		3311	
07/26	1.54	1.54	55.69	74.76	76.37	77.98	75.92	74.17	-2.03	3268		3318	
07/27	1.75	1.75	62.2	75.31	75.7	77.09	74.72	71.86	-2.34	3269		3316	
07/28	0.62	0.62	52.33	71.61	71.01	68.26	66.1	66.07	-2.17	3275		3315	
07/29	4.38	4.38	54.53	74.35	78.23	67.32	80.26	88.11	13.13	3332	120.2	3377	2736
07/30	0.00	0.00											
07/31	0.41	0.41	63.75	73.84	76.89	63.99	79.14	88	15.34	3361	157.6	3478	3649
08/01	0.00	0.00											
08/02	0.00	0.00											
08/03	0.00	0.00											
08/04	2.02	2.02	60.25	72.77	75.68	60.85	76.27	81.54	15.7	3392	159	3480	3560
08/05	0.00	0.00											
08/06	0.00	0.00											
08/07	0.07	0.07	46.68	70.3	76.8	57.35	77.2	81.2	20.35	3435	162	3572	3673
08/08	0.49	0.49	54.17	71.32	75.7	58.5	76.71	81.83	18.63	3438	156.5	3582	3671
08/09	4.02	4.02	62.37	72.77	76.19	62.66	79.07	91.08	16.65	3380	158.3	3450	3620
08/10	0.17	0.17	57.09	72.96	72.89	59.33	73.84	73.36	14.82	3436	151.6	3550	3659

WNAS1X3.WK1

	C3	All	RHrm	Tm	Tr/a	Ts/a	Tm/a	To/a	dT-crx	Eload	GasLd
	(hr)	(hr)	(%)	(F)	(F)	(F)	(F)	(F)	(F)	(W)	(kBtu/h)
06/27	0.00	0.00									
06/28	0.00	0.00									
06/29	0.98	0.98	47.07	79.78	82.42	84.4	83.14	85.57	-1.23	3324	
06/30	0.96	0.96	57.09	79.71	80.73	82.41	80.69	81.42	-1.68	3321	
07/01	2.45	2.46	63.06	78.03	79.65	72.95	79.52	84.05	6.658	3351	94.73
07/02	0.00	0.00									
07/03	0.00	0.00									
07/04	1.99	1.97	55.22	74.79	76.07	76.3	74.48	74.01	-1.79	3287	
07/05	5.24	5.18	55.3	71.83	71.11	68.82	66.95	66.84	-1.87	3319	
07/06	1.11	1.12	53.86	72.58	72.8	71.28	69.31	69.2	-1.96	3300	
07/07	1.19	1.19	45.12	74.89	78.7	79.38	77.15	77.21	-2.19	3256	
07/08	0.00	0.00									
07/09	1.07	1.07	59.32	76.89	79.33	81.32	80.17	83.03	-1.13	3239	
07/10	2.93	2.95	50.27	74.18	77.51	67.42	80.15	91.62	13.01	3411	155.1
07/11	0.17	0.17	57.13	74.14	76.9	62.86	80.93	87.67	18.34	3481	243.2
07/12	0.00	0.00									
07/13	0.62	0.62	61.64	75.88	79.42	81.19	81.71	81.83	0.512	3183	32.84
07/14	2.89	2.90	59.89	74.92	78.63	63.32	82.48	97.92	19.41	3428	243.3
07/15	0.00	0.00									
07/16	0.00	0.00									
07/17	0.00	0.00									
07/18	0.00	0.00									
07/19	0.00	0.00									
07/20	0.94	0.95	58.3	76.55	79.86	81.9	80.98	84.44	-0.9	3243	
07/21	2.45	2.46	59.48	77.28	78.3	75.51	73.5	73.39	-1.99	3254	
07/22	1.70	1.70	46.88	75.02	77.76	77.12	75.07	74.81	-2.03	3265	
07/23	1.81	1.82	54.39	74.99	76.85	78.11	75.01	68.5	-3.06	3274	
07/24	0.00	0.00									
07/25	0.00	0.00									
07/26	1.33	1.33	55.86	75.73	77.55	79.23	77.18	75.54	-2.02	3248	
07/27	1.65	1.66	63.24	75.62	75.83	77.34	75	72.45	-2.3	3248	
07/28	5.74	5.76	50.87	72.29	71.63	69.02	66.89	66.86	-2.13	3274	
07/29	0.81	0.81	54.75	76.35	80.66	83.52	81.4	81.72	-2.07	3166	
07/30	0.00	0.00									
07/31	0.00	0.00									
08/01	0.00	0.00									
08/02	0.00	0.00									
08/03	0.00	0.00									
08/04	0.22	0.22	61	72.14	74.54	59.23	76.79	86.75	17.94	3429	242
08/05	0.00	0.00									
08/06	0.00	0.00									
08/07	0.00	0.00									
08/08	0.00	0.00									
08/09	0.00	0.00									
08/10	0.00	0.00									

WNAS1X4.WK1

	C4 (hr)	All (hr)	RHm (%)	Tm (F)	Ti/a (F)	Ts/a (F)	Tm/a (F)	To/a (F)	dT-cr (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)	EngE (s/hr/d)
06/27	0.00	0.00											
06/28	0.00	0.00											
06/29	0.98	0.98	47.03	80.28	82.96	84.7	83.25	83.8	-1.42	3323		3366	
06/30	9.54	9.54	55.54	83.69	85.87	87.35	85.63	86.11	-1.67	3278		3308	
07/01	1.71	1.71	62.21	79.54	81.04	75.8	81.13	84.04	5.41	3321	132.1	3371	1358
07/02	0.00	0.00											
07/03	0.00	0.00											
07/04	2.66	2.66	55.67	73.62	73.66	71.38	69.52	69.41	-1.86	3303		3351	
07/05	12.50	12.30	51.53	75.45	79.57	80.05	78.13	79.08	-1.88	3224		3314	
07/06	16.92	16.87	59.27	73.9	75.14	74.25	72.24	72.18	-1.99	3270		3318	
07/07	5.54	5.54	43.46	75.82	80.94	81.62	79.44	79.54	-2.14	3232		3270	
07/08	0.00	0.00											
07/09	8.03	8.03	56.84	78.26	82.25	84.67	84.26	90.98	-0.4	3204		3238	
07/10	6.21	6.21	48.75	75.34	78.42	66.77	81.21	93.67	14.76	3390	237.9	3435	2483
07/11	0.00	0.00											
07/12	0.00	0.00											
07/13	0.00	0.00											
07/14	0.20	0.20	57.73	75.6	79.35	62.36	83.3	99.15	21.27	3431	342.8	3518	3649
07/15	0.00	0.00											
07/16	0.00	0.00											
07/17	0.00	0.00											
07/18	0.00	0.00											
07/19	0.00	0.00											
07/20	4.40	4.30	62.03	77.13	79.16	79.18	77.44	77.58	-1.72	3233		3351	
07/21	20.11	19.96	62.57	76.68	79.7	79.99	77.95	78.03	-2	3220		3278	
07/22	5.46	5.46	47.37	75.73	78.89	78.35	76.32	76.12	-2	3261		3303	
07/23	4.69	4.69	54.35	75.08	77.14	78.46	75.32	68.68	-3.1	3276		3319	
07/24	0.00	0.00											
07/25	0.00	0.00											
07/26	4.06	4.06	55.09	75.77	78.28	79.73	77.33	73.53	-2.36	3239		3277	
07/27	20.27	20.23	58.05	76.24	78.28	80.13	78.29	78.05	-1.81	3227		3272	
07/28	11.95	11.74	50.11	74.91	75.9	74.44	72.23	71.73	-2.2	3244		3344	
07/29	1.84	1.84	54.78	77.47	83.21	86.51	84.45	84.69	-2	3136		3182	
07/30	0.00	0.00											
07/31	0.00	0.00											
08/01	0.00	0.00											
08/02	0.00	0.00											
08/03	0.00	0.00											
08/04	0.00	0.00											
08/05	0.00	0.00											
08/06	0.00	0.00											
08/07	0.00	0.00											
08/08	0.00	0.00											
08/09	0.00	0.00											
08/10	0.00	0.00											

WNAS1E3.WQI

	C1 (hr)	All (hr)	Wrm (ppt)	Trm (F)	Wtr/a (ppt)	Tr/a (F)	Wsa (ppt)	Tsa (F)	Tm/a (F)	Wo/a (ppt)	To/a (F)	dT-crx (F)	GasLd (kBtu/h)	Epuls (W)
03/19	0.07	0.07	11.33	76.2	10.96	79.4	9.6	67.2	79.4	12.1	82.2	12.27	154.3	708.7
08/20	0.00	0.00												
08/21	1.36	1.36	8.574	74.67	8.928	78.38	7.67	63.33	78.66	8.94	82.17	15.54	161.4	667.5
08/22	5.62	5.62	9.399	73.08	9.285	75.75	8.11	57.53	76.44	10.1	81.83	19.38	159.3	654.5
08/23	6.48	6.30	9.369	72.82	9.447	75.74	8.12	58.13	76.96	9.42	83.07	19.27	160	672.9
08/24	6.11	6.03	10.13	72.79	9.88	73.77	8.37	58.49	72.55	11.6	75.7	14.38	156.9	669.7
08/25	7.55	7.56	11.55	73.64	11.41	76.77	9.85	61.51	79.22	15.3	90.35	18.01	155.3	638.9
08/26	6.69	6.72	11.76	73.3	11.77	75.7	9.91	60.56	77.54	16.1	88	17.3	156	631.3
08/27	7.67	7.70	11.38	72.84	11.48	75.85	9.92	60.49	77.67	16.1	88.45	17.51	153.3	632.2
08/28	6.94	6.98	11.53	72.86	11.76	75.5	10	60.65	78.1	17.5	79.5	15.73	151.9	634.9
08/29	5.99	5.99	8.623	72.43	8.442	72.8	7.08	56.24	72.04	8.77	71.84	16.23	155.3	660.4
08/30	4.06	4.07	8.683	73.04	8.831	75.2	7.67	59.55	75.83	10	79.23	16.63	154.2	655.6
08/31	8.71	8.45	9.119	72.68	9.032	74.36	7.73	60	74.37	10.4	76.21	14.65	153.2	684.2
09/01	3.18	3.18	7.077	73.19	7.199	75.77	5.92	60.71	-3002	7.64	-3002	-3124	157.7	651.9
09/02	4.62	4.62	8.117	72.34	8.174	73.02	7.3	58.12	72.02	9.97	72.16	14.23	155.4	648.7
09/03	4.38	4.39	11.02	73.66	10.99	74.65	9.62	62.76	-433	16	-433	-500	152.5	643.8
09/04	6.03	6.04	11.2	73.46	11.04	75.07	9.86	63.27	-2580	15.7	-2579	-2677	158.2	642.2
09/05	9.08	9.11	10.44	73.2	10.29	74.99	9.24	63.57	-169	13.5	-507	-235	156.9	654.7
09/06	2.02	2.02	10.65	72.44	9.898	69.99	9.26	60	65.62	11.9	65.66	5.728	155.6	668
09/07	4.17	4.17	12.06	72.79	11.39	72.53	10.9	67.45	71.6	14.8	68.85	4.166	156.5	666.3
09/08	4.03	4.04	12.26	73.59	11.65	74.08	11.4	69.66	73.72	15.9	72.6	4.066	157.6	645.8
09/09	0.00	0.00												
09/10	0.07	0.07	10.14	71.8	11.16	75.4	9.78	60.78	77.2	17.4	83.5	16.72	150.7	659.8
09/11	5.83	5.83	9.492	72.62	8.767	71.16	7.34	55.36	71.33	9.63	71.7	16.43	159.4	655.1
09/12	1.88	1.88	6.797	72.92	6.521	72.68	4.77	55.98	69.89	6.39	70.06	14.3	163.2	671
09/13	1.86	1.86	7.545	73.07	7.32	73.33	5.85	57.74	70.67	7.97	70.68	13.25	161.3	666.4
09/14	0.12	0.12	7.78	71.9	7.26	66.32	5.68	46.89	53.59	8.63	53.55	7.011	159	707.6

WNAS1E4.WQI

	C2	All	Wm	Tm	Wr/a	Tr/a	Ws/a	Ts/a	Tm/a	Wo/a	To/a	dT-crx	GasL	Epuls
	(hr)	(hr)	(ppt)	(F)	(ppt)	(F)	(ppt)	(F)	(F)	(ppt)	(F)	(F)	(kBtu)	(W)
08/19	0.07	0.07	11	75.5	10.93	78.7	9.72	62.62	78.7	12.2	82.7	16.32	161	3493
08/20	0.00	0.00												
08/21	0.00	0.00												
08/22	0.00	0.00												
08/23	0.00	0.00												
08/24	0.00	0.00												
08/25	0.83	0.83	11.5	73.58	11.77	78.32	11	64.15	80.85	16.2	91.57	16.9	156	3527
08/26	5.31	5.31	11.7	72.91	11.92	77.7	11.2	64.69	80.7	15.9	92.48	16.18	158	3448
08/27	2.98	2.98	11.4	72.51	11.76	77.88	10.9	64.19	80.41	15.9	90.13	16.42	154	3482
08/28	5.21	5.21	11.7	72.58	11.91	76.46	10.9	64.04	77.82	17	83.36	13.95	152	3477
08/29	0.00	0.00												
08/30	0.00	0.00												
08/31	0.00	0.00												
09/01	0.00	0.00												
09/02	0.00	0.00												
09/03	4.37	4.39	11.4	74.08	11.43	76.11	10.8	69.97	76.82	16.3	80.06	6.855	151	3397
09/04	3.78	3.78	11	73.8	11.07	77.16	10.5	70.14	78.49	14.7	83.81	8.364	158	3406
09/05	3.91	3.91	10.1	72.73	10.05	75.21	9.7	68.83	73.87	12.7	70.01	5.06	155	3484
09/06	0.00	0.00												
09/07	0.00	0.00												
09/08	1.66	1.66	12.6	75.1	12.11	76.94	12.2	75.85	78.36	16.5	83.15	2.487	157	3316
09/09	0.00	0.00												
09/10	0.07	0.07	9.79	70.9	10.7	74.8	9.74	61.6	76.4	17.1	82.9	15.05	150	3552
09/11	0.00	0.00												
09/12	0.00	0.00												
09/13	0.00	0.00												
09/14	0.00	0.00												

WNAS1E5.WQI

	C3 (hr)	All (hr)	Wtm (ppt)	Ttm (F)	Wr/a (ppt)	Tr/a (F)	Ws/a (ppt)	Ts/a (F)	Tm/a (F)	Wo/a (ppt)	To/a (F)	dT-crx (F)	GasLd (kBluh (W)	Epuls (W)
08/19	0.13	0.13	10.52	74.68	10.62	77.67	8.966	59.31	78.22	12.45	84.31	19.32	243	3515
08/20	0.00	0.00												
08/21	0.00	0.00												
08/22	0.00	0.00												
08/23	0.00	0.00												
08/24	0.00	0.00												
08/25	0.00	0.00												
08/26	0.00	0.00												
08/27	0.00	0.00												
08/28	0.00	0.00												
08/29	0.00	0.00												
08/30	0.00	0.00												
08/31	0.00	0.00												
09/01	0.00	0.00												
09/02	0.00	0.00												
09/03	1.80	1.80	10.87	73.69	11.17	76.29	10.45	70.4	76.55	16.16	77.93	6.154	202.4	3482
09/04	0.25	0.25	10.69	73.7	10.73	77.4	10.05	70.67	78.77	14.14	83.4	8.096	215.1	3505
09/05	0.00	0.00												
09/06	0.00	0.00												
09/07	0.00	0.00												
09/08	1.34	1.34	12.68	75.82	12.27	78.2	12.26	77.15	79.83	15.72	84.89	2.644	203	3296
09/09	0.00	0.00												
09/10	0.56	0.57	10.04	71.77	10.8	75.51	9.014	61.31	76.99	16.89	82.76	15.96	230.2	3564
09/11	0.00	0.00												
09/12	0.00	0.00												
09/13	0.00	0.00												
09/14	0.00	0.00												

WNAS1E6.WQI

	C4	All	Wrm	Trm	Wt/a	Tr/a	Ws/a	Ts/a	Tm/a	Wo/a	To/a	dT-cr	GasLd	Epuls
	(hr)	(hr)	(ppt)	(F)	(ppt)	(F)	(ppt)	(F)	(F)	(ppt)	(F)	(F)	(kBtu/h)	(W)
08/19	0.19	0.19	10.4	74.6	10.58	77.6	8.15	57.13	78.4	12.42	85.6	21.82	352.9	3553
08/20	0.00	0.00												
08/21	0.00	0.00												
08/22	0.00	0.00												
08/23	0.00	0.00												
08/24	0.00	0.00												
08/25	0.00	0.00												
08/26	0.00	0.00												
08/27	0.00	0.00												
08/28	0.00	0.00												
08/29	0.00	0.00												
08/30	0.00	0.00												
08/31	0.00	0.00												
09/01	0.00	0.00												
09/02	0.00	0.00												
09/03	0.00	0.00												
09/04	0.00	0.00												
09/05	0.00	0.00												
09/06	0.00	0.00												
09/07	0.00	0.00												
09/08	0.85	0.85	12.91	76.37	12.48	79.2	12.47	78.1	80.7	15.57	84.95	2.563	248.5	3241
09/09	0.00	0.00												
09/10	4.92	4.92	11.83	74.74	12.14	77.74	10.48	66.29	78.98	17.62	83.62	12.84	279.1	3459
09/11	0.00	0.00												
09/12	0.00	0.00												
09/13	0.00	0.00												
09/14	0.00	0.00												

WNAS2A3.WK1

	C1 (hr)	All (hr)	Wmm (ppt)	Tmm (F)	Wtr/a (ppt)	Tr/a (F)	Ws/a (ppt)	Ts/a (F)	Wo/a (ppt)	To/a (F)	Eload (W)	GasLd (kBTuh)	Epuls (W)
06/25	0.00	0.00											
06/26	0.00	0.00											
06/27	0.00	0.00											
06/28	0.00	0.00											
06/29	0.00	0.00											
06/30	0.00	0.00											
07/01	0.35	0.36	13.69	81.11	12.24	79.4	12.07	69.21	11.25	94.91	674.4	171.4	680.8
07/02	6.76	6.77	8.22	75.25	7.558	70.96	6.278	52.5	4.479	77.81	646.7	177.3	686.1
07/03	4.96	4.96	8.84	74.86	7.585	66.35	6.264	52.94	7.513	69.99	652.6	174.2	675.6
07/04	7.90	7.91	10.92	75.01	9.976	72.08	7.995	57.02	10.09	80.46	634.7	173.4	652.8
07/05	3.05	3.06	10.86	76.1	9.756	73.58	8.062	58.39	5.596	91.53	639.2	170.7	658.4
07/06	8.61	8.62	10.44	75.09	9.76	71.82	7.316	54.67	8.042	75.83	439.9	176.1	652
07/07	4.31	4.32	9.269	75.42	8.473	72.02	7.007	54.54	5.833	77.88	434.9	177.1	662.2
07/08	3.26	3.28	9.208	75.46	8.601	72.65	7.242	55.26	6.225	84.2	656.1	173.9	671
07/09	1.38	1.39	11.27	76.96	10.75	74.17	8.68	59.37	13.54	79.71	650.3	170.8	663.4
07/10	1.09	1.10	10.85	77.61	10.35	73.75	8.176	58.26	9.592	78.84	650.1	171.3	667
07/11	1.09	1.09	12.15	77.43	11.5	74.63	9.087	60.71	10.72	81.67	650.5	166.8	660.9
07/12	6.16	6.17	10.67	75.03	9.787	71.83	7.754	55.88	10.71	78.29	516.5	174.3	657.5
07/13	7.13	7.15	11.91	74.52	11.51	73.27	9.32	60.2	9.014	92	281.1	168.9	639.3
07/14	2.24	2.26	12.25	76.05	11.2	73.34	9.008	59.64	13.56	80.32	643.6	170.9	654.8
07/15	0.85	0.85	14.34	79.1	12.65	76.1	10.49	64.36	13.07	81.68	630	170.1	648.8
07/16	5.11	5.13	11.05	75.26	10.17	72.16	8.174	57.15	10.18	77.72	637.7	174.2	653.3
07/17	6.31	6.33	11.38	75.21	10.61	72.31	8.22	57.16	12.26	72.2	640.3	175.8	654.2
07/18	2.59	2.60	12.08	76.02	11.55	74.18	9.142	59.93	12.41	79.08	641.5	173.1	655.1
07/19	5.40	5.41	11.37	75.2	10.37	73.02	8.488	57.94	9.412	84.1	637.3	172.2	653.3
07/20	9.14	9.14	11.83	75.06	10.79	74.86	9.275	60.21	7.435	92.63	440.5	171.8	641.2
07/21	1.60	1.61	12.75	76.77	11.14	72.82	9.037	59.81	10.24	77.68	-280	172.2	644.3
07/22	6.57	6.58	9.083	75.04	8.089	68.73	6.675	52.44	6.55	73.38	633.8	178.8	652.9
07/23	5.63	5.64	10.52	75.27	9.703	71.13	7.486	54.62	11.78	65.44	642.5	177.2	659.8
07/24	3.51	3.51	10.89	74.77	8.907	65.22	7.329	53.69	9.185	64.73	638.9	176.8	664.9
07/25	4.73	4.74	10.95	75.9	9.668	71.07	7.799	55.85	8.577	75.93	393.2	176.9	655.3
07/26	4.71	4.72	11.24	75.47	10.15	71.9	8.105	56.57	10.41	75.84	631.2	173.2	648.6
7/27	1.45	1.46	12.79	77.13	11.62	73.83	9.258	60.1	13.92	75.46	642.7	171.3	654.3
07/28	4.99	5.00	9.727	75.38	8.912	72.67	7.448	55.34	6.417	75.85	634.7	173.2	653.3
07/29	3.51	3.52	10.57	75.54	9.791	72.71	8.04	56.77	7.786	82.81	627.8	171.1	647.1
07/30	5.01	5.03	10.6	75.3	9.739	73.3	8.114	56.71	8.861	78.9	391.2	174.4	649.2
07/31	3.80	3.82	11.67	75.65	11.04	73.51	8.934	58.92	14.58	74.13	517.5	172.6	647.2
08/01	6.16	6.18	9.274	75.37	8.256	71.63	7.078	55.33	5.05	76.22	642.8	174.1	663
08/02	4.41	4.42	10.36	75.4	9.334	72.95	7.992	57.57	5.428	85.93	33.55	172.4	657.3
08/03	8.64	8.64	11.65	74.6	10.61	73.38	8.976	58.9	9.124	86.95	626.7	170.2	647.8
08/04	8.02	8.03	12.03	76.3	10.86	74.48	9.024	59.57	9.774	82.96	619.3	170.4	637.7
08/05	5.25	5.25	9.871	76.02	9.033	74.36	7.803	59.19	5.519	79.81	633.7	175.1	657
08/06	7.13	7.14	9.353	76.04	8.907	75.9	7.549	57.94	4.428	81.03	630.3	178.8	649.4
08/07	5.65	5.67	9.145	76.55	8.339	74.43	7.055	58.48	4.504	81.2	642.2	176.6	656.4
08/08	5.50	5.52	10.46	76.42	9.517	74.2	8.148	58.02	7.294	85.61	470.1	172.8	651.1
08/09	6.37	6.39	11.83	76.65	10.93	75.18	9.56	61.33	11.32	85.98	625.5	170	642.6
08/10	3.87	3.87	11.77	76	10.71	75.09	9.251	64.38	8.173	87.25	622.5	170.7	652.8
08/11	4.96	4.97	13.14	77.28	11.8	76.01	10.32	63.37	12	90.57	352.1	167.3	631
08/12	9.21	9.21	10.1	76.2	9.312	73.83	7.857	57	6.593	78.13	622	175	642
08/13	6.68	6.68	10.73	76.37	9.839	73.05	8.086	57.94	8.461	79.76	622.2	173.5	642.1

WNAS2A3.WK1

	C1 (hr)	All (hr)	Wrm (ppt)	Trm (F)	Wtr/a (ppt)	Tr/a (F)	Wsa/a (ppt)	Ts/a (F)	Woa/a (ppt)	To/a (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)
08/14	3.58	3.58	11.62	76.1	9.757	68.56	8.117	56.96	9.266	70.79	632	174.8	655.7
08/15	0.95	0.95	11.82	75.78	9.423	65.15	7.624	54.76	10.13	61.67	635.9	174.7	662.6
08/16	0.82	0.82	12.88	76.01	10.42	66.96	8.826	57.73	11.43	65.09	628	173.8	654.7
08/17	0.08	0.08	14.28	75.9	12.57	71.4	10.15	64.96	14.39	71.2	655.4	171.6	682.2
08/18	5.55	5.56	13.85	77.14	12.49	74.97	10.06	61.98	11.02	82.23	620.4	173.1	641.6
08/19	5.55	5.57	12.72	77.01	11.44	74.88	9.316	60.48	8.316	82.58	370.4	171.6	645.6
08/20	4.65	4.65	9.364	75.68	8.833	73.77	7.34	59.61	5.566	77.02	632.6	175.6	660.1
08/21	5.37	5.39	9.343	76.45	8.787	74.92	7.287	57.67	5.019	78.41	320.4	177.8	653.6
08/22	5.67	5.69	10.4	76.44	9.5	74.31	7.912	58.16	6.032	81.3	637.2	176.5	653.3
08/23	4.20	4.22	10.28	76.38	9.272	75.08	7.791	59.71	5.3	84.25	641.9	177	660.1
08/24	2.96	2.96	11.52	76.04	10.54	74.78	8.743	64.03	7.259	85.75	633	172.7	666.1
08/25	4.31	4.31	13.12	77.16	11.75	75.53	10	62.97	10.21	88.58	623.7	170.5	642.4
08/26	5.52	5.54	13.48	77.19	12.29	75.8	10.36	62.98	12.18	84.11	326.8	171.4	641.4
08/27	4.32	4.34	13.11	76.82	11.94	75.05	10.08	62.14	12.05	84.9	623.6	170.5	640.5
08/28	4.79	4.80	13.4	77.14	12.47	75.51	10.13	62.04	13.84	83.34	620.5	167.6	639
08/29	6.33	6.33	9.513	75.65	8.235	70.48	6.672	56.37	5.594	73.88	628.7	171.5	652.3
08/30	4.57	4.57	9.604	76.06	9.136	74.82	7.511	58.63	5.762	80.28	628.7	171.4	650.9
08/31	5.99	5.99	10.02	75.75	9.447	74.07	7.664	59.83	5.132	80.79	632	170.4	656.9
09/01	5.57	5.57	8.025	76.01	7.7	74.87	6.2	57.52	3.686	79.01	631	174.8	651.6
09/02	6.17	6.17	8.95	75.61	8.414	70.55	6.907	55.57	6.429	78.77	622.9	174	643
09/03	7.63	7.65	12.03	76.49	11.05	74.03	8.945	59.88	12.64	79.32	627	169.3	643.4
09/04	7.48	7.50	12.63	77.06	11.68	75.42	9.553	61.31	11.51	81.23	622.8	172.6	638.7
09/05	8.55	8.55	11.86	76.33	10.89	73.63	8.498	58.55	11.15	72.82	628.7	173.1	648.3
09/06	2.42	2.42	11.76	75.67	9.754	67.5	7.942	56.94	10.03	67.41	635	173.4	660.7
09/07	1.26	1.26	13.97	75.92	12.3	71.01	9.942	63.05	13.41	72.82	638.4	170.8	668.3
09/08	5.45	5.46	13.9	77.57	12.48	75.05	10.09	62.46	12.27	82.44	619.1	170.6	635.5
09/09	5.71	5.72	14.17	78.43	12.79	76.05	10.14	62.36	11.88	81.34	627.9	169.7	647.4
09/10	2.03	2.04	14.87	78.37	13.14	75.02	10.8	63.8	14.9	78.2	632.4	167.8	642.7
09/11	6.49	6.49	10.36	76.05	8.77	70.8	7.208	57.15	6.732	73.63	623.5	174.5	646
09/12	4.41	4.41	7.533	75.76	6.419	68.42	4.892	53.43	3.763	69.87	634.4	180.2	661
09/13	4.17	4.17	8.375	75.81	7.478	70.14	6.025	55.17	4.902	74.43	638.4	177.6	661.2
09/14	1.33	1.33	9.1	76.3	8.432	73.42	6.765	62.02	5.366	75.85	646.3	176.4	674.7
09/15	5.60	5.61	10.16	76.12	9.548	75.56	7.851	58.81	7.101	79.94	630.9	175.7	653.4
09/16	4.90	4.91	11.61	77.11	10.61	75.44	8.899	61.1	9.038	84.74	231.9	172.4	643.9
09/17	4.81	4.82	12.11	77.02	10.85	74.22	9.027	60.33	9.299	82.59	621.7	170.6	643.1
09/18	4.61	4.62	12.17	77.05	10.96	73.86	9.045	60.07	9.572	82.06	620.4	169	640.4
09/19	8.64	8.64	10.16	76.07	8.66	69.04	6.866	54.23	7.053	71.41	619.7	172.6	640.3
09/20	3.98	3.98	7.499	75.86	6.795	69.89	5.276	55.12	3.945	73.36	632.7	176.7	661.1
09/21	4.10	4.10	10.36	76.03	9.719	73.55	7.785	58.57	8.566	78.44	633.1	170	657.6
09/22	3.43	3.44	12.73	77.38	11.55	73.82	9.229	60.2	14.44	75.54	244.8	168.1	643.3
09/23	0.86	0.86	6.59	75.76	5.892	66.91	4.256	54.59	3.489	63.86	639.7	179.2	676.6
09/24	0.00	0.00											
09/25	0.00	0.00											
09/26	0.47	0.47	11.3	75.76	9.119	65.22	6.999	55.12	9.715	63.39	649.3	171.2	680.8
09/27	4.82	4.82	12.74	76.94	11.51	73.33	8.968	59.73	13.65	73.1	622.3	169.4	645
09/28	0.00	0.00											
09/29	0.07	0.07	8.62	71	6.566	59.09	4.551	47.72	5.259	54.28	667.4	172.3	702.4
09/30	0.07	0.07	4.65	71.6	4.341	60.29	2.968	45.99	2.635	52.77	668.1	172.8	705.3

WNAS2A4.WK1

	C2 (hr)	All (hr)	Wm (ppt)	Trm (F)	Wr/a (ppt)	Tr/a (F)	Ws/a (ppt)	Ts/a (F)	Wo/a (ppt)	To/a (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)
07/01	0.92	0.92	13.56	80.96	12.31	79.1	11.42	68.02	11.25	95.71	3324	169.9	3398
07/02	2.60	2.61	8.536	75.05	8.081	75.34	7.453	59.76	4.275	84.25	3465	165.6	3510
07/03	0.00	0.00											
07/04	0.18	0.18	10.65	74.93	10.18	73.36	8.941	59.25	7.697	86.66	3484	161.5	3604
07/05	4.03	4.04	10.39	76.17	9.597	76.52	8.654	60.21	5.539	89.7	3472	160.5	3523
07/06	2.66	2.66	9.648	75.52	9.138	76.03	8.393	59.45	5.451	85.76	3465	163.3	3528
07/07	3.27	3.28	9.278	75.99	8.729	76.49	8.062	59.87	4.692	84.14	3439	164.2	3496
07/08	4.56	4.57	9.636	75.29	9.135	75.8	8.381	59.8	4.055	91.64	3465	163.1	3529
07/09	2.36	2.37	12.44	76.72	11.45	74.55	10.29	63.13	13.23	88.53	3412	157.3	3472
07/10	2.52	2.52	11.01	76.22	10.17	74.21	9.229	60.74	7.636	89.63	3457	159.7	3510
07/11	3.63	3.64	11.81	75.84	11.06	74.39	9.895	62.11	9.024	88.93	3442	156.3	3489
07/12	5.11	5.11	11.43	75.26	10.34	73.43	9.553	61.13	11.32	86.89	3461	160.2	3519
07/13	4.33	4.33	12.23	75.14	11.35	72.71	10.07	62.12	10.17	91.09	3410	156.6	3468
07/14	2.92	2.92	12.55	75.88	11.29	73.83	10.28	62.76	12.71	90.26	3430	158.1	3499
07/15	2.63	2.64	12.58	76.43	11.5	75.12	10.49	63.43	12.21	87.72	3418	156.4	3466
07/16	5.92	5.92	11.48	75.37	10.64	75.05	9.539	61.08	10.03	84.81	3476	162.1	3529
07/17	4.65	4.65	11.87	75.2	10.96	73.74	9.74	61.17	13.12	78.5	3483	164.3	3549
07/18	2.77	2.77	12.31	76.18	11.34	74.71	10.16	62.33	10.86	84.72	3462	160.9	3521
07/19	3.87	3.88	11.78	75.98	10.73	75.76	10.05	62.7	8.181	93.54	3470	160.1	3531
07/20	0.34	0.34	11.86	75.58	11.05	76.79	10.2	62.83	5.473	95.3	3482	159.9	3584
07/21	2.67	2.67	12.83	76.42	11.75	75.4	10.42	62.98	9.441	85.26	3462	160.1	3518
07/22	4.12	4.13	9.925	75.47	9.32	76.14	8.52	58.9	6.067	82.09	3544	167.8	3604
07/23	5.50	5.50	11.09	75.11	10.16	73.02	8.931	58.65	12.85	68.88	3501	166	3559
07/24	0.00	0.00											
07/25	1.95	1.95	10.75	75.54	9.91	74.43	8.774	58.9	8.053	79.59	3514	168.4	3596
07/26	4.02	4.03	11.62	76.03	10.65	74.47	9.426	60.3	11.31	79.8	3467	160.9	3519
07/27	3.68	3.69	12.49	76.12	11.36	74.11	10.25	61.92	12.75	80.01	3436	158.6	3490
07/28	4.75	4.75	9.842	75.29	9.216	75.77	8.539	58.84	6.251	78.66	3457	162.6	3516
07/29	1.66	1.66	12.03	77.08	11	77.22	10.18	62.96	7.87	90.46	3448	158.1	3512
07/30	4.66	4.67	11.27	75.84	10.19	75.99	9.673	61.33	8.234	84.11	3477	164.4	3537
07/31	4.52	4.53	12.21	75.8	11.19	74.27	10.3	62.27	14.68	82.04	3448	160.5	3518
08/01	2.67	2.67	9.222	75.3	8.694	74.53	8.046	58.9	4.146	82.11	3431	162.8	3521
08/02	4.92	4.92	10.48	75.41	9.588	75.88	8.956	60.77	4.483	88.27	3479	161.4	3542
08/03	0.00	0.00											
08/04	0.42	0.42	11.64	74.84	10.45	73.31	9.497	60.26	8.778	90.58	3463	160.8	3552
08/05	0.00	0.00											
08/06	0.25	0.25	9.323	76	9.087	77.2	8.13	59.23	3.888	81.87	3443	169.7	3586
08/07	2.56	2.56	8.648	76.06	8.394	76.39	7.41	60.01	3.55	82.3	3454	167	3548
08/08	2.14	2.14	10.38	75.95	9.508	75.55	9.007	60.18	7.481	86.44	3509	162	3600
08/09	2.64	2.64	12.28	76.71	11.16	76.24	10.55	63.66	8.053	91.91	3430	156.9	3517
08/10	0.00	0.00											
08/11	1.21	1.21	13.9	78.18	12.52	77.59	11.81	66.22	12.24	92.45	3377	154.5	3465
08/12	0.00	0.00											
08/13	0.00	0.00											
08/14	0.00	0.00											
08/15	0.00	0.00											
08/16	0.00	0.00											
08/17	0.00	0.00											
08/18	0.22	0.22	13.23	77.01	12.7	76.74	10.82	63.5	10.73	84.52	3432	162.8	3561
08/19	3.37	3.37	12.19	76.87	11.3	77.1	10.08	62.75	8.004	84.49	3461	159.7	3540

WNAS2A4.WK1

	C2 (hr)	All (hr)	Wrm (ppt)	Trm (F)	Wt/a (ppt)	Tr/a (F)	Ws/a (ppt)	Ts/a (F)	Wo/a (ppt)	To/a (F)	Eload (W)	GasLd (kBtu/h)	Epuls (W)
08/20	0.00	0.00											
08/21	1.55	1.55	9.484	76.07	9.278	76.79	8.191	59.98	4.945	81.87	3436	166.8	3535
08/22	2.19	2.19	10.46	76.24	9.699	76.28	8.78	60.52	5.705	83.04	3515	165	3610
08/23	3.64	3.64	9.777	76.16	9.426	76.68	8.198	61.24	3.854	85.83	3441	165.9	3523
08/24	0.00	0.00											
08/25	2.89	2.90	13.43	77.84	12.21	78.27	11.51	66.88	10.29	95.78	3450	156.5	3514
08/26	3.53	3.54	13.74	77.65	12.59	77.7	11.72	66.47	11.54	89.88	3442	158.8	3513
08/27	4.66	4.67	13.29	77.33	12.31	77.9	11.22	65.67	10.72	92.25	3434	157.6	3494
08/28	3.13	3.14	13.97	77.98	12.88	76.98	11.34	65.46	12.86	87.4	3426	156.9	3494
08/29	0.00	0.00											
08/30	0.00	0.00											
08/31	0.00	0.00											
09/01	0.00	0.00											
09/02	0.00	0.00											
09/03	1.88	1.88	12.26	76.45	11.31	74.66	9.918	61.87	12.06	82.38	3464	158.6	3566
09/04	1.31	1.31	12.37	77.15	11.54	76.72	10.29	63.31	10.14	85.29	3467	162	3566
09/05	0.00	0.00											
09/06	0.00	0.00											
09/07	0.00	0.00											
09/08	2.33	2.33	13.98	78.22	12.81	77.23	11.17	65.25	11.26	87.01	3439	158.5	3517
09/09	2.38	2.38	14.26	78.97	13.31	79.2	11.53	66.55	11.03	89.32	3432	159.5	3507
09/10	5.33	5.35	13.96	77.62	12.77	75.64	11.25	64.85	14.05	81.66	3455	158.4	3517
09/11	0.00	0.00											
09/12	0.00	0.00											
09/13	0.00	0.00											
09/14	0.00	0.00											
09/15	0.15	0.15	10.12	75.92	9.661	76.53	8.52	59.72	7.432	80.08	3543	166.8	3694
09/16	2.40	2.40	11.91	77.23	10.95	77.24	9.978	63.64	9.778	86.52	3485	159.9	3558
09/17	2.92	2.93	11.76	77.4	10.76	77.13	9.782	63.99	5.806	91.78	3436	156.9	3499
09/18	2.48	2.49	12.74	77.93	11.63	77.41	10.42	64.39	9.174	89.1	3430	157.1	3493
09/19	0.15	0.15	13.33	76.8	12.39	74.1	10.28	62.11	11.56	74.4	3438	157.7	3516
09/20	0.00	0.00											
09/21	0.00	0.00											
09/22	2.10	2.10	13.49	77.65	12.16	75.57	10.73	64.11	13.23	84.09	3436	156.3	3502
09/23	0.00	0.00											
09/24	0.00	0.00											
09/25	0.00	0.00											
09/26	0.00	0.00											
09/27	0.00	0.00											
09/28	0.00	0.00											
09/29	0.00	0.00											
09/30	0.00	0.00											

WNAS2A5.WK1

	C3 (hr)	All (hr)	Wrm (ppt)	Trm (F)	Wr/a (ppt)	Tr/a (F)	Ws/a (ppt)	Ts/a (F)	Wo/a (ppt)	To/a (F)	Eload (W)	GasLd (kBtu/h)
07/01	0.79	0.79	13.24	80.4	12.4	79.38	10.73	65.94	10.8	96.88	3433	237
07/02	0.10	0.10	8.38	75.4	7.91	75.7	6.834	54.95	4.1	81.4	3582	235.3
07/03	0.00	0.00										
07/04	0.00	0.00										
07/05	1.05	1.05	10.31	75.84	9.569	76.41	8.149	58.39	6.066	88.84	3549	228.7
07/06	0.00	0.00										
07/07	2.51	2.51	8.955	75.56	8.594	77.36	7.386	56.68	4.503	83.62	3511	236.4
07/08	3.33	3.33	9.344	74.99	9.2	77.4	7.779	58	4.224	88.4	3525	226.4
07/09	1.81	1.82	13.17	77.78	12.11	75.81	10.14	63.56	12.37	93.38	3459	228.9
07/10	3.93	3.96	10.36	75.78	9.519	74.15	8.497	59.27	6.012	94.06	3510	233.4
07/11	6.21	6.22	11	75.33	10.2	73.95	8.67	59.17	5.938	91.7	3511	236
07/12	0.00	0.00										
07/13	0.00	0.00										
07/14	1.71	1.72	13.97	77.41	12.53	76.91	10.75	65.2	9.571	98.51	3458	231.9
07/15	2.84	2.84	12.32	76.26	11.22	75.66	9.882	62.68	10.07	95	3475	230.2
07/16	0.28	0.28	11.52	75.45	10.63	75.38	8.998	60.12	10.61	82.54	3556	224.6
07/17	0.00	0.00										
07/18	5.35	5.36	11.19	75.95	10.48	75.4	9.098	60.5	10.13	88.67	3571	227.3
07/19	1.88	1.88	11.46	75.63	10.58	76.93	9.266	61.63	5.255	94.33	3533	232.8
07/20	0.00	0.00										
07/21	1.51	1.52	13.18	77.47	12.07	78.18	10.06	63.07	9.606	87.87	3524	235.4
07/22	0.38	0.38	10.05	75.37	9.484	76.96	8.011	57.92	6.573	81.65	3629	226.8
07/23	0.00	0.00										
07/24	0.00	0.00										
07/25	0.00	0.00										
07/26	1.44	1.44	11.42	75.6	10.63	74.71	8.896	59.25	12.52	77.24	3552	218.6
07/27	3.80	3.81	11.99	76.09	11.09	75.76	9.563	61.32	11.14	88.14	3511	231
07/28	0.00	0.00										
07/29	2.22	2.23	11.61	77.23	10.77	78.81	9.475	62.75	6.52	92.95	3485	227.8
07/30	1.59	1.59	11.16	75.7	10.21	77.09	8.98	60.25	8.42	84.95	3544	237.4
07/31	3.05	3.05	12.51	76.15	11.62	75.72	10.15	62.97	12.8	88.47	3506	227.1
08/01	0.00	0.00										
08/02	0.00	0.00										
08/03	0.00	0.00										
08/04	0.29	0.29	11.55	74.73	10.48	73.27	9.004	59.26	9.031	89.45	3540	247.9
08/05	0.00	0.00										
08/06	0.00	0.00										
08/07	0.00	0.00										
08/08	0.00	0.00										
08/09	0.00	0.00										
08/10	0.00	0.00										
08/11	0.00	0.00										
08/12	0.00	0.00										
08/13	0.00	0.00										
08/14	0.00	0.00										
08/15	0.00	0.00										
08/16	0.00	0.00										
08/17	0.00	0.00										
08/18	0.00	0.00										
08/19	0.00	0.00										

Appendix D

Glossary of Terms and Abbreviations

Appendix D

Glossary of Terms and Abbreviations

AAFES	Army/Air Force Exchange Service—A DoD agency that owns and operates grocery, dry goods/retail, service station, mini-mart, and related facilities on U.S. military bases
AGA	American Gas Association
AGACC	American Gas Association Cooling Center
AGAL	American Gas Association Laboratory
AP	airport weather station
balance point	mean daily temperature above which a daily cooling load is observed; the x intercept of the best linear fit to the daily cooling load versus mean daily temperature plot
BLCC	the FEMP/DOC/NIST computer program for calculating Building Life-Cycle Costs of alternative investments that affect energy use; the program uses the energy escalation and cost of money rates specified in federal regulations
Btu	British thermal unit
Btuh	Btu per hour
Btu/scf	heat content of a cubic foot of gaseous fuel at standard conditions
BX	base exchange—a dry goods retail store, operated by AAFES, serving military personnel and dependents; aka post exchange (PX) on Army bases

CBECS	Commercial Building Energy Consumption Survey—a survey conducted by DOE's Energy Information Agency and the title under which the survey results are reported
CDD	cooling degree days—the sum of all positive values of $(T - T_{base})$ in the month, year, or other period of interest, where T is the mean daily temperature and T_{base} is the cooling degree-day base
cfm	cubic foot per minute
CDD base	The degree-day base used in a cooling energy calculation
condenser	a heat exchanger in which a refrigerant is condensed by rejecting heat to another fluid, such as ambient air or cooling tower water, which has a lower temperature than the saturation temperature of the refrigerant
COP	coefficient of performance—the ratio of cooling effect to input energy required to deliver the effect
CRADA	Cooperative Research and Development Agreement
C1,C2,C3,C4	Cooling stage designations where C1 refers to the lowest cooling rate and C4 to the highest cooling rate (nominal capacity) of the machine
DAS	data acquisition system
degree-day	a measure of the temperature distribution of a climate obtained by taking the time integral of the difference between temperature and base temperature whenever that difference is positive (CDD) or negative (HDD)
degree-day base base	The reference temperature (most commonly 65°F) used in a degree day calculation
demand charge	a charge based on the utility customer's peak 15-minute electric load during the billing month
DoD	Department of Defense
DOC	Department of Commerce

DX	direct expansion—a common method of space cooling in which the refrigerant expands inside the tubes of a heat exchanger, the outside surfaces of which are directly exposed to the air stream
evaporator	a heat exchanger in which a refrigerant is boiled, thus extracting heat from another fluid, such as air, water or brine
FEMP	Federal Energy Management Program—the umbrella program under which the Test Bed Demonstration Program operates
HCFC	hydrogenated chlorofluorocarbon—a refrigerant that has low impact (compared to the non-hydrogenated CFC compounds) on the earth's atmospheric ozone, but which will eventually be replaced by refrigerants with even lower impact
HDD	heating degree days—the sum of all positive values of $(T_{base} - T)$ in the month, year, or other period of interest, where T is the mean daily temperature and T_{base} is the heating degree-day base.
HHV	higher heating value—includes the latent heat of water vapor produced in the combustion of a fuel
hp	horsepower—a measure of shaft (output) power and, in the case of motors, of electrical (input) power
HVAC	heating, ventilating and air conditioning
H1,H2	heating stage designations where H1 refers to the lowest heating rate and H2 refers to the highest heating rate (corresponding to the nominal capacity) of a heating or heating unit
IAP	international airport weather station
IC engine	internal combustion engine
IPLV	Integrated Part-Load Value—a seasonal average COP or efficiency or total energy use obtained by convolution (integral of the product) of an HVAC unit's part-load COP, efficiency, or input power function with the load distribution function
JSOW	Joint Statement Of Work

kcf	thousand cubic feet
kWh	kilowatt-hour
LCC	life-cycle cost—the total cost to own and operate a building (or other tangible property)—including cost of money, periodic and aperiodic maintenance and equipment replacement costs, energy escalation rates and salvage value—expressed (usually) as a present value or annualized value
lbf	pound force—a measure of force, in the English system, equal to the force required to accelerate one pound mass at 32.2 ft/s²
lbm	pound mass—a measure of mass (not weight) in the English system.
MBtu	million British thermal units
multi-zone RTU	a rooftop HVAC unit that provides variable supply air flow rates to a distribution system that has dampers or other means of controlling flow independently to two or more zones
NAS	Naval Air Station
NASWG	Naval Air Station at Willow Grove, Pennsylvania
NAVFAC	Naval Facilities Engineering Command
NIST	National Institute for Science and Technology—a DOC laboratory and developer of the FEMP life-cycle cost methodology and computer program
PECO	Philadelphia Electric Company
PNL	Pacific Northwest Laboratory—lead laboratory for the FEMP Test Bed Demonstration Program
ratchet charge	a monthly charge based on the utility customer's highest monthly demand in the preceding 12 months
RTU	rooftop unit—a HVAC unit located outside the building envelope that provides conditioned air to the distribution system via a roof penetration

source energy	the amount of energy input to a power plant (electricity) or energy input to a regional gas transmission system (natural gas) required to provide a given amount of energy at the customer's meter
subcool	to cool a liquid (e.g., refrigerant) below its saturation temperature
superheat	to heat a gas (e.g., refrigerant) above its saturation temperature
TBDP	Test Bed Demonstration Program
TK	Thermo-King Corporation—developer and manufacturer of the gas IC engine driven air conditioning units demonstrated in this project
ton	measure of refrigeration capacity equal to 12,000 Btuh

Distribution

**No. of
Copies**

**No. of
Copies**

- 12 DOE/Office of Scientific and
Technical Information

J. Brogan
Gas Research Institute
8600 West Bryn Mawr Avenue
Chicago, IL 60631

OFFSITE

- 18 Federal Energy Management Program
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585
ATTN: K. Dean DeVine (CE-44)(15)
M. Ginsberg (CE-44)
J. Brodrick (CE-422)
V. Petrolatti (IHEM)

W. Kaplan
U.S. Department of Energy
1421 Cherry St., 10th Floor
Philadelphia, PA 19102

- 2 Pennsylvania Energy Office
116 Pine St.
Harrisburg, PA 17101-1227
ATTN: J. Sada
D. Crawford

- 3 Philadelphia Electric Company
2301 Market St.
Philadelphia, PA 19101-8699
ATTN: Robert McNulty
J. Flanigan
J. Verna

W. Brookover
Independence National
Historic Park
Philadelphia, PA 19102

- 2 Thermo King Corp.
314 West 90th Street
Minneapolis, MN 55420
ATTN: R. Ellis
C. Karr

ONSITE

DOE Richland Operations Office

D. R. Segna (A5-90)

R. Sweetser
American Gas Cooling Center
1515 Wilson Blvd.
Arlington, VA 22209

- 55 **Pacific Northwest Laboratory**

- 3 Public Works Dept. Bldg. 78
U.S. Naval Air Station
Willow Grove, PA 19090-5010
ATTN: J. Edmond
Commander M. Strand
T. Falvey, NAVFAC

P. R. Armstrong (K5-08) (5)
M. R. Brambley (K5-02)
D. M. Carroll (K5-08)
D. R. Conover (BWO) (26)
J. W. Currie (K7-82)
D. R. Dixon (K6-62)
M. Friedrich (K5-16)
F. V. Di Massa (K6-61)

**No. of
Copies**

J. A. Dirks (K6-61)
J. D. Miller (K5-08)
G. B. Parker (K7-82)
S. A. Parker (K5-08)
W. F. Sandusky (K5-06)
L. A. Schienbein (K5-20)
D. L. Shankle (K6-54)

**No. of
Copies**

S. A. Shankle (K6-57)
J. L. Stoops (K5-08)
L. E. Wrench (K5-08)
Project Files (2)
Publishing Coordination
Technical Report Files (5)

END

**DATE
FILMED**

9 / 7 / 93