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HVAC EQUIPMENT REPLACEMENT FOR BEST SIZE AND EFFICIENCY

DOE/IR/05106--T117

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Energy Task Force
of the Urban Consortium
for Technology Initiatives

CITY OF PHOENIX

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PREFACE

The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. The Urban Consortium conducts its work program under the guidance of Task Forces structured according to the functions and concerns of local governments. The Energy Task Force, with a membership of municipal managers and technical professionals from eighteen Consortium jurisdictions has sponsored over 140 energy management and technology projects in thirty-five Consortium member jurisdictions since 1978.

To develop in-house energy expertise, individual projects sponsored by the Task Force are managed and conducted by staff of participating city and county governments. Projects with similar subjects are organized into *Units* of four to five projects each, with each Unit managed by a selected Task Force member. A description of the Units and projects included in the Eighth Year (1986-87) Energy Task Force program follows:

UNIT -- LOCAL GOVERNMENT OPERATIONS

Energy used for public facilities and services by the nation's local governments totals about 1.5 quadrillion BTU's per year. By focusing on applied research to improve energy use in municipal operations, the Energy Task Force helps reduce operating costs without increasing tax burdens on residents and commercial establishments. This Eighth Year Unit consisted of seven projects:

- **Baltimore, Maryland** -- *Sewage Sludge Conversion to Fuel by Acid Hydrolysis*
- **Baltimore, Maryland** -- *Full Scale Plant Demonstration: Inhibition of an Activated Sludge Process (Technology Transfer)*
- **Houston, Texas** -- *The Impact of Budget Incentives on Energy Management*
- **New Orleans, Louisiana** -- *Computer-based Training for Energy Management*
- **Phoenix, Arizona** -- *HVAC Equipment Replacement for Best Size and Efficiency*
- **Phoenix, Arizona** -- *Thermal Energy Storage: An Application Guide (Technology Transfer)*
- **Seattle, Washington** -- *Reducing Energy Consumption through Upgraded O&M Purchases (Technology Transfer)*

UNIT -- COMMUNITY ENERGY MANAGEMENT

Of the nation's estimated population of nearly 240 million, approximately 60 percent reside or work in urban areas. The 543 cities and counties that contain populations greater than 100,000 consume 50 quadrillion BTU's annually. Applied research by the Energy Task Force helps improve the economic vitality of this urban community by aiding energy efficiency and reducing energy costs for the community as a whole. This Year Eight unit consisted of seven projects:

- **Hennepin County, Minnesota** -- *Energy Enhancements in New Residential Construction*
- **Hennepin County, Minnesota** -- *Shared Savings in the Residential Market: Lessons Learned (Technology Transfer)*
- **Kansas City, Missouri** -- *An Energy-Based Economic Development Strategy*
- **New York, New York** -- *A City/Utility Partnership to Reduce Business Energy Costs*

- o **Public Technology, Inc.** -- *Energy and Economic Development -- Phase II: Public/Private Financing*

- o **San Francisco, California** -- *An Energy Plan for Mission Bay*

- o **San Francisco, California** -- *Commercial Building Energy Assessment (Technology Transfer)*

UNIT -- ENHANCED ENERGY TECHNOLOGIES

Effective use of advanced energy technology and integrated energy systems in urban areas could save from 4 to 8 quadrillion BTU's during the next two decades. Urban governments can aid the capture of these savings and improve capabilities for the use of alternative energy resources by serving as test beds for the application of new technology. This Year Eight unit consisted of four projects:

- o **Albuquerque, New Mexico** -- *Municipal Underground Storage Tanks: A Local Manager's Guide*

- o **Denver, Colorado** -- *Waste-to-Energy Facilities: An Implementation Guide*

- o **San Jose, California** -- *Energy Efficient Cooling Technologies: Pilot Applications and Conference Proceedings*

- o **Washington, DC** -- *Energy Management for St. Elizabeth's Hospital: An Evaluation Guide*

UNIT -- UTILITY MANAGEMENT

Electric and gas utilities have a formal responsibility to provide stable supplies of energy at reasonable prices to all segments of a community's residential, commercial and industrial populace. By working closely with their utilities, local government staff can help to assure both supply and price stability. This Year Eight Unit consisted of five projects:

- o **Chicago, Illinois** -- *Municipal Utility Franchise Renewal*

- o **Columbus, Ohio** -- *Integrated and Computer-aided Database Management for Utility Network Planning*

- o **Houston, Texas** -- *Electric Utility Franchise Guide (Technology Transfer)*

- o **Memphis, Tennessee** -- *Energy Technology Transfer Strategies: Marketing and Economic Incentives*

- o **Memphis, Tennessee** -- *Memphis Area Rideshare Handbook (Technology Transfer)*

Reports from each of these projects are specifically designed to aid the transfer of proven experience to staff of other local governments. Readers interested in obtaining any of these reports of further information about the Energy Task Force and the Urban Consortium should contact:

Applied Research Center
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
Washington, DC 20004
(202) 626-2400

Acknowledgements

The originator of this project was Darshan Teji, Energy Conservation Manager for the City of Phoenix and project Director for this project. The entire implementation work of his project was performed under his direction. Scott Wilkins was the Project Manager responsible for project management, engineering assistance and overall supervision of the project. John Kirby was the Project Engineer and was responsible for the day-to-day monitoring of the demonstration and for the composition of project documentation. Greg Robbins assisted as Project Coordinator and was responsible for all aspects of the installation and instrumentation of the demonstration project. He also supervised the equipment efficiency testing. Tim Gustafson and Nicholas Golubovich worked as mechanical installers on the project. Electrical work was performed by David Robinson and Steve Geist. Nidhi Chauhan was Engineering Aide for the project and kept the project accounts in order and provided valuable computer assistance. Special thanks go to the U. S. Department of Energy for providing the grant which made this project possible. Thanks for managing the grant go to Herbert Fivehouse, Chairman of the Energy Task Force of the Urban Consortium, and the staff of the City of Baltimore. Special thanks for assistance go to Unit Manager Anthony Laska with the City of New Orleans and to Richard Zelinski with the Public Technology, Inc.

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ABSTRACT

The energy crisis has come and gone; or has it? A crisis may not exist at present, but energy concerns still plague municipalities across the country. Much of the initial no-cost/low-cost energy conservation measures have been accomplished by cities and counties, but in many cases that is where energy management has stopped. It is time to look at other options for saving dollars in city and county budgets. A very practical option that has been overlooked by many municipalities due to its perceived complexity is that of HVAC equipment replacement and the savings that can be accomplished due to increased equipment efficiencies, optimum sizing of equipment, new utility incentives and time-of-use rates.

Increased Equipment Efficiency. HVAC system components (compressors, boilers, pumps, fans, and motors) typically have long lifetimes, some lasting for twenty years or more. Much of this equipment was manufactured in times when energy cost to run the equipment was of secondary importance. Energy costs are now in the minds of most city managers and the means to reduce these costs are always welcomed. Many advancements have been made in the area of HVAC equipment efficiency, increasing it quite substantially from that of equipment available fifteen to twenty years ago. The research accomplished by the Phoenix Energy Office looked at HVAC equipment replacement with respect to efficiency and cost savings, and compared new equipment with the existing equipment.

Optimum Sizing. Another area of energy waste that is missed by many local governments results from changes made in the function of existing buildings without a concurrent evaluation of the new cooling and heating load. Existing equipment is often oversized for a building's new function, and equipment that operates below its design capacity can be very inefficient. In some instances, the original equipment was overdesigned in the first place by overly conservative safety factors. A mismatch in capacity and building load creates an energy problem in HVAC equipment which may justify replacement prior to the end of its useful life.

Utility Incentives. HVAC equipment operates in response to a building's varying load, thus the peak cooling occurs in the middle of a summer day and the peak heating on a cold winter morning. This creates problems for the local utility which is required to supply peak cooling or heating load to all customers at the same time. Recently many utilities have been offering attractive incentives and rates for using electricity during off-peak times, usually at night. By using off-peak electricity, generally thermal energy storage, a municipality has the opportunity to substantially reduce its electricity cost.

The City of Phoenix operates over 250 buildings, all of which have potential savings in one of these three areas. To define this potential more specifically, the research performed during this project consisted of five primary tasks:

* An extensive building survey and equipment analysis;
* Actual equipment testing to determine efficiency for comparison with estimated calculations;
* An actual equipment replacement demonstration at an appropriate site;
* Monitoring of both existing HVAC equipment and new replacement equipment during the demonstration;
* Determining the cost effectiveness of the demonstration project and of the surveyed equipment.

Results from the project indicated that estimated calculations can at times have substantial errors. A more reliable method to evaluate existing HVAC equipment is actual system testing. After completing tests on a sampling of the original 82 buildings surveyed, some surprising results were obtained. It was found, for example, that most of the HVAC equipment tested had substantially higher run times than the study estimates and also operated below the published Energy Efficiency Rating (EER). This observation seems reasonable since the published rating was completed in a laboratory at set conditions. It was interesting to note that the test program also became a useful tool to find maintenance problems such as dirty filters, duct losses, and compressor problems. In many cases the reason for poor efficiency is inadequate maintenance and proper maintenance might be the least expensive option to improved efficiency and energy savings.

The demonstration project indicated that savings could possibly justify certain equipment replacements. The thermal energy storage equipment operated more efficiently than the original equipment, but since it was required to produce ice instead of chilled water it did consume more energy. In spite of the increased energy consumption (15-20%) the demonstration was still able to save money due to the utility time-of-use rates. While this technology seems to be a practical option for certain applications in the City, we strongly recommend that replacing equipment before its useful life is finished should be done on the basis of accurate testing and sound economic estimates.

PROJECT PURPOSE

The purpose of this project was to explore the potential benefits of HVAC equipment replacement for buildings owned by the City of Phoenix. The specific research objectives were as follows:

1. Establish an understanding of the magnitude and sources of saving available through equipment replacement. This understanding should encompass:

   a. The major items of HVAC systems, namely compressors, chillers, boilers, cooling towers, fans, pumps, and motors,
   b. An equipment inventory of City buildings (82 sites),
   c. Background research on new technologies and high-efficiency equipment,
   d. An actual equipment testing program to verify estimated values.

2. Establish an economic model for understanding equipment replacement and deciding when equipment should be replaced.

3. Establish technical methods for calculating savings from replacement of various types of equipment.

4. Demonstrate the replacement of a major item of HVAC equipment and document the savings through actual experimentation and measurement.

5. Provide guidance material for other jurisdictions wishing to investigate equipment replacement.

REPORT ORGANIZATION

Five main chapters and five appendices comprise this report. The major sections are organized as follows:

Chapter 1 -- provides an abstract and overview of the document.

Chapter 2 -- provides the technical background of HVAC equipment to allow the reader to understand the terminology and concepts presented in the text.

Chapter 3 -- outlines the equipment survey accomplished for the City by an energy consultant and explains the equipment testing program completed by the Energy Conservation Office staff.

Chapter 4 -- details the demonstration project to include the system installation, equipment monitoring, and technical and economic findings from the replaced equipment.

Chapter 5 -- summarizes the results from the equipment survey and the actual equipment testing, and summarizes the results of the demonstration project to include the economic feasibility and the lessons learned from installing and operating the replacement equipment.

Appendices-- provide detailed information on the replacement equipment used, a list of the manufacturers of thermal storage, a list of HVAC manufacturers, equipment, and Energy Efficiency Ratings (EER), an outline of Salt River Project's Thermal Energy Storage Incentive Program, and a detailed bibliography for further study.

Chapter 2 - HVAC Technical Background

INTRODUCTION

This chapter is intended to provide enough background information for understanding the basic terminology and theory associated with HVAC systems and equipment. It is not intended to make the reader an expert in air conditioning equipment, and if more information is desired, the Bibliography, Appendix A, contains several good HVAC publications. Included in this chapter is a list of definitions covering most of the terms that may cause confusion. Following that is a short summary of HVAC equipment which will provide a better understanding of its operation and what affects its efficiency. Those readers who would like additional background on thermal energy storage should obtain copies of "Thermal Storage Strategies for Energy Cost Reduction" and "Thermal Energy Storage: An Application Guide for Local Governments" both available from the City of Phoenix, Energy Conservation Office. The address is supplied on the last page of this report.

DEFINITION OF IMPORTANT TERMS

Air Conditioning. The process of treating air to control simultaneously its temperature, humidity, cleanliness and distribution to meet the requirements of the conditioned space.

Coefficient of Performance (COP). A measure of efficiency for refrigerating equipment defined as:

$$\text{Coefficient of Performance} = \frac{\text{Useful Refrigeration}}{\text{Net Work}}$$

Degree Day, Heating. A unit based on temperature and time used in estimating fuel consumption and specifying nominal heating load of a building in winter. For any one day, when the mean temperature is less than 65 degrees F, there exist as many degree days as there are Fahrenheit degrees difference in temperature between the mean temperature for the day and 65 degrees F.

Economizer Cycle. Used in cooling systems capable of bringing in 100 percent outdoor air. Economizer cycles use control sequences which allow the selection of outside or return air for cooling based on lowest dry bulb temperature or enthalpy (total heat content).

Energy Efficiency Ratio (EER). The ratio of net cooling capacity to total rate of electric input at standard operating conditions of 95 degree F dry bulb air temperature on the condenser, 80 degree F dry bulb and 67 degree F wet bulb air temperature on the cooling coil (evaporator), and a 40 degree F evaporating temperature. This ratio is expressed as:

$$\text{Energy Efficiency Ratio (EER)} = \frac{\text{Cooling Rate in Btu per hour}}{\text{Input in Watts}}$$

Heat Pump. A refrigeration machine which is arranged to either heat or cool a building by using heat from the condenser section or by using cooling from the evaporator section.

Peak Load. The maximum electrical or thermal load reached during an arbitrary period of time, measured in kilowatts. Also expressed as demand, power or capacity.

Ratchet. Ratchet demand (kilowatt) is equal to the highest actual demand or a specified percentage of the highest actual demand during the ratchet period, which is usually a full year. Utilities will charge the current month's demand or a percentage of a previous demand, whichever is the greatest.

Time-of-Use Rates. In time-of-use rates the utility company defines a time period during which building peak demand is measured for billing purposes. This is called the on-peak period and all other hours of the day are by definition termed off-peak. On-peak electrical rates are higher than those charged during off-peak time.

Variable Air Volume (VAV). A method used to cool or heat a space or zone by varying the amount of air volume delivered to that space as conditions change compared to holding the air constant and changing the air temperature.

Variable Frequency Motor Drive (VFD). A motor drive that is capable of converting existing power line, alternating 60 cycle current, to a variable frequency alternating current.

OUTLINE OF HVAC EQUIPMENT

Classification of Air Conditioning Systems.

An air conditioning system may be classified as a central station, unitary system or a combination of the two.

Central Station. A central station system is one in which the primary components of the system are grouped together in a central mechanical room and the conditioned air is distributed from there to the spaces to be conditioned. Large systems are usually site-built while smaller systems (250 to 300 tons) use factory assembled units.

Unitary System. Unitary or packaged systems make use of factory assembled, balanced, and tested units. These units may be installed in or adjacent to the space to be conditioned. The primary distinguishing feature is that these systems utilize factory-matched refrigeration, heating and air circulation components.

Combined System. This system combines the features of both the central station and the unitary system. The heating and cooling equipment can be located in a central mechanical room and hot and chilled water can be pumped to terminal fan-coil units located in each space or zone.

Types of Refrigeration Compression

Reciprocating Compressors. Probably the most common method of compression in air conditioning systems is by reciprocating compressors. These compressors are best suited to handling refrigerants of relatively high vapor density and those whose condensing pressures are high. The majority of compressors are driven by electric motors. Figure 1 shows a refrigeration cycle utilizing a reciprocating compressor.

Advantages of Reciprocating Compressors. The following are the advantages of reciprocating compressors:

1. Positive displacement of the refrigerant gas;
2. Relatively low rotative velocities and safe operation;
3. Ability to handle refrigerants of high vapor density. This property allows a large weight of refrigerant to be circulated in small pipes. Refrigerants can be pumped to and from evaporators at a considerable distance away from the compressor.
4. Ability to maintain relatively high pressures on the discharge side. This allows the use of air-cooled condensers, even in hot climates.
5. Simplicity of construction and relative ease of maintenance and repair.
6. Relatively low cost.

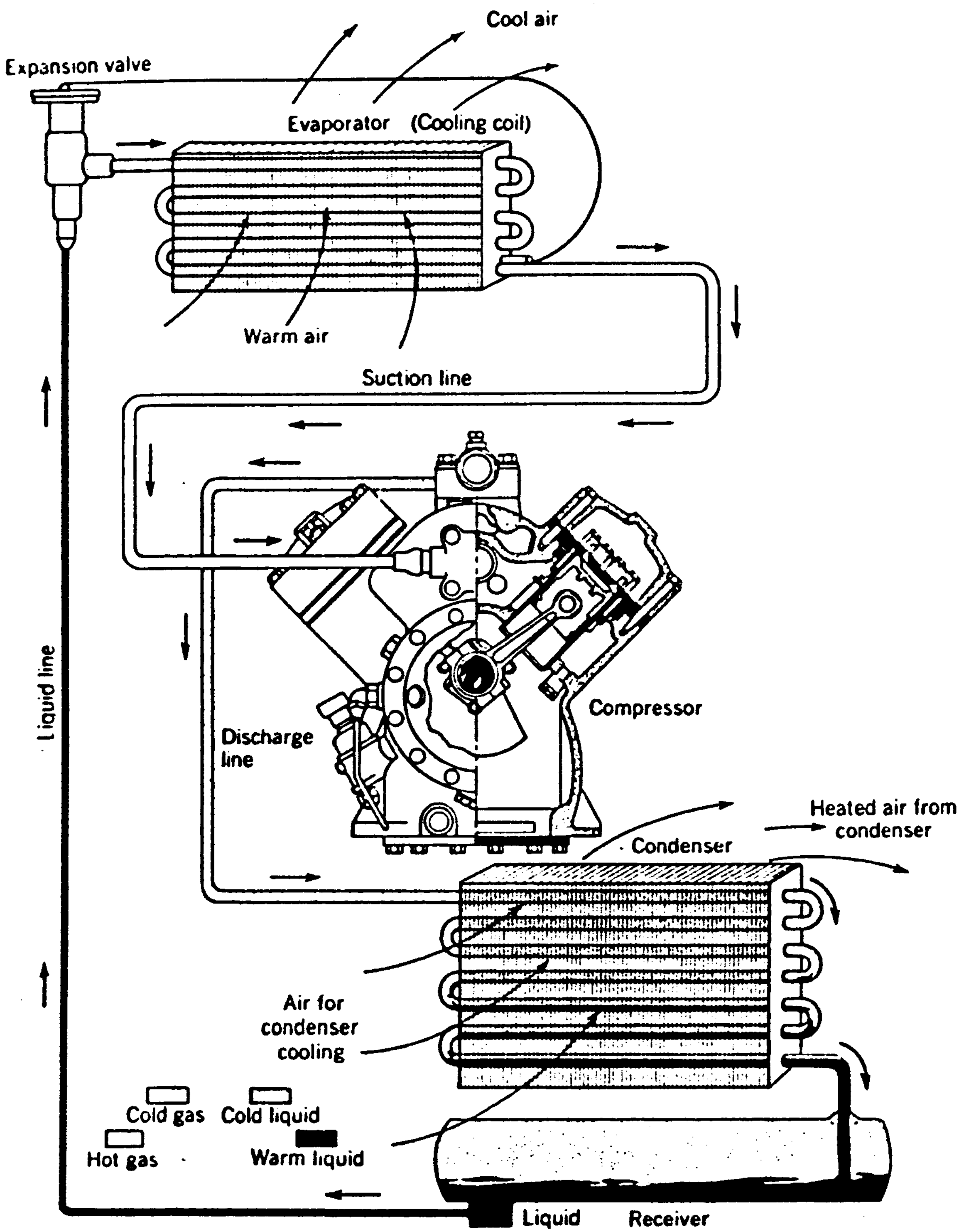

FIGURE 1 - Refrigeration Cycle

Disadvantages of Reciprocating Compressors. The disadvantages of these compressors are:

1. For larger capacity loads (200 tons or more) either cylinder size or number of cylinders becomes excessive.
2. Cooling and lubrication of larger units are compounded.

Centrifugal Compressors. This type of compressor builds up a pressure head by means of centrifugal force. Rapidly turning rotors pick up the low-pressure refrigerant from the evaporator (suction) and use centrifugal force to produce the discharge pressure. These compressors are often used with low pressure refrigerants such as R-11 and R-113. Sometimes both the evaporator and the condenser work at less than atmospheric pressure. Centrifugal compressors are well suited to large capacity systems of 250 to 5000 tons and are suitable for a wide range of operating temperatures, from +50 to -100 degrees F. Since they are not positive-displacement machines, they operate at reasonably good efficiencies even when the demand is less than 40 percent of the design capacity. The principal advantages of centrifugal compressors are related to large capacity and begin to become apparent at about 500 tons. Another plus for the centrifugal is that there are fewer moving parts than large multicylinder reciprocating equipment and the lubrication system is much less complex.

Rotary Screw Compressors. The screw compressor was developed in the 1930's and first became popular for refrigeration service in Europe in the 1950's and 1960's. The refrigerant enters one end of the compressor at the top and the trapped gas is moved circumferentially around the housing, the compressor and the meshing of the lobes decreases volume in the cavity, compressing the gas. While peak efficiencies are quite high, there is a loss of efficiency as the capacity is reduced. These compressors have found a market between the large reciprocating machines and the small centrifugal compressors and in some cases will be utilized as base load cooling due to their high efficiencies at full load.

Evaporators

The transfer of heat from the conditioned space to the cooling material is accomplished in the evaporator. Looking back at Figure 1 will help visualize this equipment in the refrigeration process. Two types of evaporators are commonly in use in air conditioning systems: 1) direct-expansion (DX) coils, and 2) water chillers.

Direct-Expansion (DX) Coils. Direct cooling of the air takes place with the direct-expansion by thin, usually aluminum, sheets referred to as fins. These fins provide greater surface area for increased heat transfer. The warm air is forced across this coil and fin arrangement where it boils or evaporates the refrigerant. If insufficient refrigerant is circulated, the air will not be cooled properly. If too much refrigerant is supplied it will not all be evaporated and may result in compressor problems.

Water Chillers. Chilled water is used in most central-station systems where many zones and long pipe runs require a different working fluid than a refrigerant. The water is cooled in the equipment room to about 45 degrees F and circulated to the various units. A flooded chiller is one in which the water flows into the tubes and the shell is flooded with liquid refrigerant. Flooded-type chillers are more common with large centrifugal compressors using refrigerants of high specific volume. A dry-expansion-type chiller is just the reverse with the refrigerant circulating in the tubes and the water in the shell. Reciprocating compressors are ordinarily used with the dry-expansion-type chiller.

Condensers

The heat collected from the conditioned space must be rejected so the refrigeration process can continue. A condenser is the device where this heat transfer occurs. Again, Figure 1 shows the relationship of the condenser in the refrigeration cycle. The different types of condensers are water-cooled, air-cooled and a combination of the two termed evaporative condenser.

Water-Cooled Condensers. These condensers can be of the shell-and-tube type or the shell-and-coil type. Circulating the proper amount of water can be important since the more water that is circulated the lower the condensing pressure which reduces power costs and increases compressor life.

Air-Cooled Condensers. Air-cooled condensers are commonly used in small and medium sized air conditioning systems. The trade off for lower maintenance and lower initial equipment costs are higher power costs, reduced compressor life, and lower system efficiency. The only external connection or an air-cooled condenser is a power source, therefore, the problem of water supply, water disposal and water cooling do not have to be addressed.

Evaporative Condensers. Evaporative condensers are a combination of an air-cooled, water-cooled, and a forced-draft type water-cooling tower. The operation of the evaporative condenser can be summarized as:

1. Hot compressed refrigerant vapor enters the refrigerant coil from the compressor and heat transfer through the tube walls to the water film sprayed on the coil occurs;
2. Some water is evaporated by the heat from the refrigerant, and the high latent heat of vaporation of water (1036 Btu/lb at 100 degrees F) produces significant cooling and condensing effect for a small weight of water evaporated;
3. The unevaporated water is warmed up as it absorbs heat from the refrigerant;
4. The air being drawn through the dripping water results in cooling the water by evaporation, and will be cooled to within a few degrees of the leaving air wet-bulb temperature.

Unitary Air Conditioning Systems

Unitary or packaged equipment can be classified as: 1) Single packages (self-contained) units, 2) Split systems, 3) Rooftop or roof-mounted units, 4) Fan-coil units. These categories will be summarized below.

Single Packaged Units. A single packaged unit has the refrigeration, air-handling equipment, and controls all in one cabinet. The system may also include gas-fired, electric, steam, or hot-water heat for year-round operation. These units can be free-blowing or duct type systems and are available in smaller sizes (window units or room cooler from one-third to two tons), and larger systems (vertical or free-standing units in sizes of three to twenty tons).

Split System. Split-system or remote unit refers to the separation of the condensing unit from the air-handling unit. This is usually an indoor fan-coil unit and an outdoor condensing unit connected by refrigerant tubing and controls. These units are available in smaller sizes ranging from three to twenty tons as well as larger sizes of several hundred tons.

Rooftop Units. Rooftop units are popular with supermarkets, schools and city buildings and air distribution can be by a duct system or a combination supply and return attached directly to the unit. Most units are made up of three modular sections: an air-cooled condensing unit, a blower-coil section, and a heating section. This equipment is available in capacities up to fifty tons with multiple units providing zoning, minimum ductwork, and control of individual areas with no loss of valuable floor space within the building. The roof structure must be capable of bearing the weight of these systems and vibration and noise suppression must be considered. The addition of a mixing plenum and outside return air dampers allows the use of outside air for cooling when the temperature and humidity conditions are right and is called an economizer cycle.

Fan-Coil Units. These units provide complete air conditioning using chilled water for cooling and hot water for heating. Water systems occupy relatively little space and are often the lowest first-cost systems. The systems usually lack humidity control and ventilation can be a problem.

Multiple Compressors and Two-Speed Compressors.

To reduce the power requirement of larger systems especially during spring and fall seasons when reduced cooling is required, manufacturers supply systems with multiple compressors or two-speed compressors. One or more of the compressors can by cycled on and off to meet the load requirement which is generally done by evaporator pressure. Another way to reduce capacity is the use of a two-speed compressor.

Heat Pumps

The packaged heat pump cools in summer and heats in winter by mechanical refrigeration and is primarily a heat mover rather than a heat producer. Heat pumps are classified according to the heat sources and heat sink such as air-to-air, water-to-air, or water-to-water. The air-to-air heat pump is the most common for residential and small commercial applications in mild climates. Water-to-air or water-to-water are better suited to severe winter climates and larger installations. Switchover from winter to summer operation is accomplished by rerouting refrigerant flow rather than by reversing air flow in air-to-air applications. The major disadvantage of air-to-air systems is that when heat is needed most, the least is available from the cold outside air. Water-to-air heat pumps can be used in conjunction with a central water circulation system. The basic unit is a reverse cycle, water cooled air conditioner using a chiller condenser connected to a closed piping circuit. Industrial heat pumps are most commonly water-to-water heat pumps and utilize waste heat from the specific process involved. The inlet water temperature is usually 60 to 120 degrees F with the heat pump providing hot water in the 150 to 220 degree F range. Water-to-water heat pumps are not ordinarily used on the cooling cycle thus are termed nonreversible.

Chapter 3 - HVAC Inventory and Test Procedures

INTRODUCTION

The most significant aspect of this chapter is the work performed for the City by the energy engineering consultant. The objectives of this study were to:

* Provide equipment data for all larger HVAC equipment, including chillers, boilers, unitary air conditioning units and heat pumps, fans, pumps and cooling towers, in 82 City of Phoenix buildings. This includes any air conditioning unit with a cooling capacity of two tons or greater and any pump or fan with a two-horsepower motor or greater.
* Provide a capacity optimization analysis, comparing existing equipment with actual capacity required, for pumping systems, air handling systems, chillers and boilers.
* Provide an efficiency analysis, comparing state-of-the-art high efficiency HVAC equipment available on the market today with existing HVAC efficiency, for chillers, boilers, and unitary air conditioning units and heat pumps.
* Provide an economic analysis for all equipment considered as candidates for replacement because they are nearing the end of their useful life. The economic analysis includes the cost to purchase and install the highest efficiency, optimally sized replacement unit, as well as the estimated annual savings that can be achieved with the replacement, and the resulting payback period. Any unitary air conditioning unit that is five years old or older, and any

chiller or boiler that is ten years old or older, shall be considered as a candidate for replacement.

HVAC EQUIPMENT STUDY

Table of Contents

The table of contents of the consultant's equipment study is:

The energy consultant's study is summarized below:

Summary of City Buildings

An overview of each of the 82 buildings including information such as building square footage, estimated occupied hours per year, air conditioning tons and type (air cooled or water cooled), types of HVAC equipment within the building, type of energy management system, if any, and type of controls. Table 1 is an example of the building summary.

Chillers and Boilers

The survey of existing chillers is presented in Table 2 with chillers ten years and older as candidates for replacement. The study concluded that the best payback would be accomplished by

TABLE 1 - Summary of City Buildings

BUILDING NAME	BLDG SQ FT	EST OCCUP HR	# TON	TONS AIR COOLED	TONS WATER COOL	CNTRL CHILL	CNTRL DIR EX	PKG CHILL	PKG HEAT PUMP	REMOTE "A" COIL	AIR HANDLERS	INV	TWR	COND PUMP	CHILLED WTR PUMP	HOT WTR. PUMP	BOILERS	GAS FURN	ELEC FURN	DUCT STRIP HEATER	WINDOW UNITS	DOM HW CIRC PUMP	TYPE OF CONTROLS	ENERGY MANG. SYSTEM
MUNICIPAL BUILDING	144,721	2,860	802.0	2.0	800.0	2				1	12	3	2	2	2	2	2				1	6	Pneumatic, R. Shaw	Honeywell Delta 1000
PLAZA MUNICIPAL BUILDING	117,940	2,860	672.0	22.0	650.0	3			2	3	7	7	2	2	3	1	1				5	1	Pneumatic	Honeywell Delta 1000
OLD CITY HALL (CITY SIDE)	18,726	3,000	80.0		80.0		2				2		2	2			1							
POLICE-PUBLIC SAFETY BLDG	147,705	8,760	566.0	6.0	560.0	3			2		11		8	8	4					Yes		1	Pneumatic, R. Shaw	Honeywell Delta 1000
		3,600																						
FACILITIES MAINTENANCE	32,160	2,343	66.0	66.0					7														Electric	Paragon EC 700
NORTHWEST SERVICE CENTER	7,128	4,015	22.0	22.0					5	1								3			1		Electric	EC-74 on shwer trlr
SOUTHWEST SERVICE CENTER	12,302	4,015	52.0	52.0					11									7	10		1			Robertshaw 2616
SOUTHEAST SERVICE CENTER	12,294	4,015	13.5	13.5					3	1	1							2		Yes			Electric	
NORTH SERVICE CENTER	8,700	4,015	16.5	16.5					5												1	1	Electric	Honeywell W-7000
CENTRAL EQUIP. MAINT.	88,032	5,824	24.5	24.5					3	4	4							14	10		2	1	Electric	Honeywell W-7000
ADMINISTRATIVE SUPPORT	7,720	5,824	33.0	33.0					3														Electric	
POLICE ACADEMY	35,000	4,000	140.0	20.0	120.0	1			2		7		1	1	1					Yes				Honeywell W-7000
CACTUS PARK BR. STATION	12,056	8,760	27.5		27.5				11				2	4									Electric	
AIR SUPPORT BLDG.	5,000	8,760	30.0	30.0					4	1	1								5			1	Electric	
SKY HARBOR BR. STATION	15,000	8,760	58.0	58.0					11													1	Electric	
UNION HILLS BR. STATION	11,381	8,760	60.0	60.0				2			8				2					Yes		1	Electric	
SOUTH MOUNTAIN BR. STATION	10,430	8,760	60.0		60.0	2					2	2	1	1	2	1	1					1	Pneumatic	
SQUAW PEAK BR. STATION	9,329	8,760	37.5	37.5					7											Yes		1	Electric	
MARYVALE BR. STATION	11,500	8,760	42.5	42.5					4														Electric	Honeywell W-7000
FIRE STATION 1	20,000	8,760	50.0	50.0					3									2			1	1	Electric	
FIRE STATION 3	2,201	8,760	5.0	5.0						1								1			1		Electric	
FIRE STATION 4	2,040	8,760	15.0	15.0					3														Electric	
FIRE STATION 5	1,110	8,760	5.0	5.0						1								1					Electric	
FIRE STATION 6	2,300	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 7	2,110	8,760	7.0	7.0						2								2					Electric	
OLD FIRE STATION 8	1,606	8,760	8.0	8.0						2	1							1					Electric	
FIRE STATION 9	1,950	8,760	23.5	23.5					4									1				1	Electric	
FIRE STATION 10	2,366	8,760	7.0	7.0						2	1							1					Electric	
FIRE STATION 11	3,082	8,760	10.0	10.0					2											Yes			Electric	
FIRE STATION 12	1,780	8,760	5.0	5.0						1								1					Electric	
FIRE STATION 13	1,780	8,760	5.0	5.0						1								1					Electric	
FIRE STATION 14	1,800	8,760	5.0	5.0						1								1					Electric	
FIRE COMPUTER AIDED DISP.	1,950	8,760	5.0	5.0						1									1				Electric	
FIRE STATION 16	2,464	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 17	2,330	8,760	7.5	7.5						2								2					Electric	
FIRE STATION 18	1,850	8,760	6.0	6.0						2								2					Electric	
FIRE STATION 19	4,500	8,760	15.0	15.0						3								2		Yes			Electric	
FIRE STATION 20	2,112	8,760	11.0	11.0					1	3	1							2					Electric	
FIRE STATION 21	2,300	8,760	8.5	8.5						2								2					Electric	
FIRE STATION 22	3,082	8,760	10.0	10.0					2												1		Electric	
FIRE STATION 23	2,500	8,760	10.0	10.0					2														Electric	
FIRE STATION 24	3,082	8,760	10.0	10.0					2											Yes			Electric	
FIRE STATION 25	2,300	8,760	7.0	7.0						2								2					Electric	
FIRE STATION 26	2,300	8,760	8.5	8.5						2								2					Electric	
FIRE STATION 27	2,305	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 28	2,305	8,760	6.5	6.5						2								2					Electric	

TABLE 1 -(continued)

BUILDING NAME	BLDG SQ FT	EST OCCUP HR	#TONS	TONS AIR COOLED	TONS WATER COOL	CNTRL CHILL	CNTRL DIR EX	PKG CHILL	PKG HEAT PUMP	REMOTE "A" COIL	AIR HANDLERS	INV	TWR	COND PUMP	CHILLED WTR PUMP	HOT WTR PUMP	BOILERS	GAS FURN	ELEC FURN	DUCT STRIP HEATER	WINDOW UNITS	DOM HW CIRC PUMP	TYPE OF CONTROLS	ENERGY MANG. SYSTEM
FIRE STATION 29	2,330	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 30	2,150	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 31	2,384	8,760	5.0	5.0						1									1				Electric	
FIRE STATION 33	2,830	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 34	2,264	8,760	6.5	6.5						2								2					Electric	
FIRE STATION 35	2,348	8,760	15.0	15.0					3														Electric	
FIRE STATION 36	2,400	8,760	4.0	4.0					2														Electric	
FIRE STATION 37	3,000	8,760	10.0	10.0					2														Electric	
FIRE STATION 38	2,100	8,760	4.0	4.0						1										Yes			Electric	
FIRE STATION 39	2,345	8,760	4.0	4.0						1										Yes			Electric	
FIRE STATION 40	3,100	8,760	10.0	10.0					2														Electric	
FIRE STATION 42	2,156	8,760	5.0	5.0						1									1				Electric	
FIRE TRAINING ACADEMY	7,900	3,000	42.5	42.5					4	3	1	1				1	1		1				Electric	Pacific Tech BASIC 4
EMERGENCY MEDICAL SERVICE	2,040	5,840	8.5	8.5						2	1							1					Electric	
FIRE RESOURCE MANAGEMENT	9,300	3,000	15.0	15.0					1	3	1									Yes			Electric	
SOUTH PHX ADULT CTR	13,500	4,200	50.0	50.0				1			5				1					Yes			Electronic	Paragon EC 128
PERFORMING ARTS BLDG	14,010	2,080	72.5	72.5						9													Electric	Honeywell W7000
ARTS & CRAFTS BLDG	11,404	2,080	40.0	40.0					4	2												1	Electric	Honeywell W7000
WASHINGTON ADULT CENTER	9,880	4,160	64.0	64.0					2	4	2									Yes			Electronic	Honeywell W-7000
PUEBLO GRANDE MUSEUM	9,598	3,000	55.0	55.0					6											Yes			Electric	Cyborex Microprocessor
CENTRAL LIBRARY	141,500	3,432	430.0	20.0	410.0	2	4				4	2	6	6	2	4	2			No			Pneumatic	Honeywell Delta 1000
ACACIA LIBRARY	6,336	3,100	35.0	35.0					3											Yes			Electric	Honeywell W-7000
HARMON LIBRARY	7,480	3,432	33.0	33.0					5	1	1												Electric	EC403, P.T. BASIC 4
MESQUITE LIBRARY	13,200	3,100	32.5	32.5					4											Yes			Electric	Honeywell W-7000
OCOTILLO LIBRARY	6,600	3,100	32.5	32.5					3											Yes			Electric	Honeywell W-7000
PALO VERDE LIBRARY	9,900	3,100	40.0	40.0			2				4						1					1	Pneumatic	Honeywell W-7000
SAGUARO LIBRARY	10,000	3,100	40.0	40.0						3	4					1	1					1	Pneumatic, R. Shaw	Honeywell W-7000
YUCCA LIBRARY	9,725	3,100	40.0	40.0					1		1									Yes			Electric	Honeywell W-7000
CENTURY LIBRARY	7,224	3,100	40.0	40.0		1					1	1			1					Yes			Pneumatic	Honeywell W-7000
CHOLLA LIBRARY	11,243	3,100	40.0		40.0	1					1	1	1	1	1					Yes		1	Pneumatic	Honeywell W-7000
SPECIAL SERVICES BLDG	770	2,600	4.0	4.0					3												3		Electric	
HUMAN RESOURCE CENTER #1	17,500	2,860	50.0	50.0					5														Electric	W7000, EC700, EC403
HUMAN RESOURCE CENTER #2	12,292	2,860	40.0	40.0			2		2		1					1	1						Pneumatic	
HUMAN RESOURCE CENTER #3	21,170	2,860	80.0	80.0	0.0				10															Paragon EC 700
FIELD ENGINEERING	8,200	2,120	61.0	61.0					5			1								Yes			Pneumatic	Paragon EC 700

TABLE 2 - Summary of City Chillers

				1	2	3	4	5	6	7	8	9	10	11
BUILDING NAME	MAKE	MODEL #	EQUIP STARTUP	TONS	CHILLER TYPE	REFRIGER	COMPR 1 MFG	VOLTS/PH	AMPS	COMPR 2 MFG	# FANS	HP EACH	VOLTS/PH	AMPS EACH
MUNICIPAL BUILDING	Trane	K-KD2-KQ2	MAY 63	400.0	Centrifugal	R-11	Trane	480/3	435.0	Lewis Allis Co				
MUNICIPAL BUILDING	Trane	K-KD2-KQ2	MAY 63	400.0	Centrifugal	R-11	Trane	480/3	435.0	Lewis Allis Co				
MUNICIPAL BUILDING	York			200.0	Centrifugal									
PLAZA MUNICIPAL BLDG	Carrier	19DH5127AF	JAN 81	175.0	Centrifugal	R-11	Carrier	208/3	407.0	Carrier				
PLAZA MUNICIPAL BLDG	Carrier	19DH5127AF	JAN 81	175.0	Centrifugal	R-11	Carrier	208/3	407.0	Carrier				
PLAZA MUNICIPAL BLDG	Worthington	55-C6	JAN 51	300.0	Centrifugal	R-11	Worthington	208/3	770.0	GE				
OLD CITY HALL	Carrier	5H80-149-20	JAN 54	60.0	DX Compressor		Carrier	220/3	142.0					
OLD CITY HALL	Carrier	5F60-149-20	JAN 54	20.0	DX Compressor		Carrier	220/3	51.0					
POLICE & PUBLIC SAFTY	Westinghouse	PF170	JAN 73	170.0	Centrifugal			460/3						
POLICE & PUBLIC SAFTY	Westinghouse	PF170	JAN 73	170.0	Centrifugal			460/3						
POLICE & PUBLIC SAFTY	Westinghouse	PF170	JAN 73	170.0	Centrifugal			460/3						
POLICE ACADEMY @ RANGE	Air temp	HWW11530420BCA	JAN 81	120.0	Reciprocating	R-22	Copeland	460/3	21.0	Copeland				
UNION HILLS POLICE BLDG	Carrier	30GA020620	JAN 77	30.0	Reciprocating	R-22	Carrier	460/3	35.7		3	1.0	460/3	
UNION HILLS POLICE BLDG	Carrier	30GA020620	JAN 77	30.0	Reciprocating	R-22	Carrier	460/3	35.7		3	1.0	460/3	
SOUTH MOUNTAIN BRIE ST.	Trane	CCWBC604MANG660	JAN 83	60.0	Reciprocating	R-22	Trane	460/3	26.0					
SOUTH MOUNTAIN BRIE ST.	Trane	?	JAN 68	60.0	Reciprocating	R-22	Trane	460/3						
SOUTH PHOENIX ADULT CTR	Climatrol	LRS050001	JAN 76	50.0	Reciprocating	R-22		480/3	84.0		6		480/1	2.3
CENTRAL LIBRARY	Trane	CWGA-7504-EA	JAN 75	75.0	Reciprocating	R-22	Trane	460/3	101.0					
CENTRAL LIBRARY	Trane	CWGA-7504-EA	JAN 75	75.0	Reciprocating	R-22	Trane	460/3	101.0					
CENTRAL LIBRARY	Carrier	H40A289	JAN 52	75.0	DX Compressor	R-22	Carrier	208/3	180.0	Carrier				
CENTRAL LIBRARY	Carrier	H40A289	JAN 52	75.0	DX Compressor	R-22	Carrier	208/3	180.0	Carrier				
CENTRAL LIBRARY	Carrier	H80A-229	JAN 52	60.0	DX Compressor	R-22	Carrier	208/3	146.0					
CENTRAL LIBRARY	Carrier	H80A-229	JAN 52	50.0	DX Compressor	R-22	Carrier	208/3	124.0					
CENTURY LIBRARY	McQuay	AHR-038CD	JAN 73	40.0	Reciprocating	R-22	Copeland	208/3	76.0	Dayton	2	3.0	230/3	9.9
CHOLLA LIBRARY	Chrysler	HWW 40-1	JAN 76	40.0	Reciprocating	R-22	Chrysler	230/3	119.0					

reusing the shell of one of the existing 400-ton Trane chillers at the Municipal Building, and replacing the compressor and motor with a 200-ton compressor and motor. The total cost was estimated at $85,000 with estimated annual savings of $21,000 for a payback of about four years. Also according to the study, reciprocating chillers would not be cost effective to replace because the efficiency of reciprocating chillers has not changed significantly. When a reciprocating chiller is due for replacement, then it would prove beneficial to look for the highest efficiency model available.

There are few boilers in the City buildings due to the low number of annual heating degree days (1765 DD). The Municipal Building showed a payback of 6.3 years by replacing one boiler with five 150,000 BTUH gas-fired pulse combustion boilers. Table 3 summarizes the boiler survey. The estimated annual usage in thousand Btu per year is shown in column 5 and was derived in one of the two methods.

Method 1 - In buildings where a Technical Assistance energy audit report had been completed, a breakdown of gas usage was accomplished in the report.

Method 2 - In buildings where a Technical Assistance report had not been completed, summer and winter gas bills were analyzed to estimate the gas used for space heating.

Column 6 is the recommended Btuh output capacity for all boilers installed before 1978 (more than ten years old). This capacity optimization was either taken from load calculations accomplished for the Technical Assistance audit or where no loads were available, new load calculations were performed using Trakload computer simulations. The estimated installation cost in column 9 includes equipment and labor costs from 1987 Mean Cost Data and modified to account for the normal lower cost to install pulse combustion boilers compared to standard boiler installation.

TABLE 3 - Summary of City Boilers

			1	2	3	4	5	6	7	8	9	10	11	12
BUILDING NAME	MAKE	MODEL	EQUIP START DATE	FUEL	BTUH INPUT	EST ANN EFF	EST MBTUH USAGE/YEAR	REC BTUH OUTPUT CAP	REPLACEMENT MAKE/MODEL	REPLACE ANN EFF	INSTALL COST	MBTUH/YR SAVINGS	$/YEAR SAVINGS	PAYBACK YEARS
MUNICIPAL BUILDING	York-Shipley	SPWC-60-N	01-May-63	Ngas	2,008,500	0.65	1,783,080	750,000	(5)Hydrotherm	0.91	$14,500	463,601	$2,318	6.3
MUNICIPAL BUILDING	York-Shipley	SPWC-60-N	01-May-63	G/O	2,008,500	0.65								
MUNICIPAL BUILDING	Teledyne-Larrs	HK250 HNO1B	07-Jan-84	Ngas	250,000	0.65	143,340							
PLAZA MUNICIPAL BLDG	Rite-Boiler	275	01-Jan-75	Ngas	2,750,000	0.65	1,068,000	750,000	(5)Hydrotherm	0.91	$14,500	277,680	$1,388	10.4
OLD CITY HALL	National	7-300	01-Jan-54	Ngas	1,020,000	0.65	546,500							
S. MTN POLICE BRIEF ST	Lochnivar	CBN-0760	12-Jan-83	Ngas	760,000	0.65	350,000							
FIRE TRAINING ACADEMY	Laars	CR 154	01-Jan-78	Ngas	154,000	0.65	422,800							
CENTRAL LIBRARY	Laars	HB-1330	01-Jan-75	Ngas	1,330,000	0.65	50,000							
CENTRAL LIBRARY	Mueller	?	01-Jan-52	Ngas	1,000,000	0.65	200,000							
PALO VERDE LIBRARY	Ajax	WG-400	01-Jan-74	Ngas	450,000	0.65	223,200	300,000	(2)Hydrotherm	0.91	$5,800	58,032	$290	20.0
SAGUARO LIBRARY	Ajax	WG-400	01-Jan-64	Ngas	400,000	0.65	289,100	300,000	(2)Hydrotherm	0.91	$5,800	75,166	$376	15.4
HUMAN RESOURCE CNTR #2	Ajax	WG-300	01-Jan-70	Ngas	300,000	0.65	324,400	300,000	(2)Hydrotherm	0.91	$5,800	84,344	$422	13.8

Pumps

All HVAC pumps with motors two horsepower or greater were analyzed. HVAC pumps include chilled water, hot water, condenser water pumps, and combination chilled water/hot water or chilled/condenser water pumps. A sample of the pump information is given in Table 4. Columns 4 and 5 show the design flow in gallons per minute and design head in feet. Column 6 is the estimated pump run time obtained from City personnel and column 7 was the actual flow rate as measured by a portable ultrasonic flow meter. In column 8, the measured head was determined by observing the pressure guages on the suction and the discharge sides of the pump, and multiplying the difference by 2.31. Column 9 shows the actual amp draw by the motor as measured by a hand-held amprobe. The measured brake horsepower of the pump motor in column 10 was calculated using the equation:

$$BHP = \frac{1.73 \times E \times I \times PF \times Em}{746} \qquad \text{for three phase motor}$$

where BHP = brake horsepower

E = line voltage

I = measured current draw

PF = power factor

Em = efficiency of the motor

For pumps with variable frequency drives, a power factor of 0.95 was assumed and for all other pumps 0.80 was used. Motor efficiencies were estimated using the ASHRAE Fundamentals Handbook. Estimated pump efficiencies are found in column 11 and calculated using the equation:

$$E = \frac{Q \times H}{3960 \times BHP} \times 100$$

Where E = pump efficiency (in percent)

Q = measured flow rate (in gallons per minute)

H = measured total head (in feet)

BHP = brake horsepower calculated in column 12

TABLE 4 - Summary of City Pumps

BUILDING NAME	PUMP MAKE/MODEL	1 EQUIP START	2 HP	3 IMPELLER SIZE *	4 DGN GPM	5 DGN HEAD	6 EST RU HRS/YR	7 MSRD GPM	8 MSRD HEAD	9 MSRD AMPS	10 MSRD BHP	11 EST EFFIC	12 BHP SAV INVERTER DSGN FLOW	13 BHP SAV CHANGING/ VALV POS	14 KWH/YEAR SAVINGS	15 $/YEAR SAVINGS	16 DESIGN FLA	17 VOLTS	18 RPM	19 MOTOR MAKE	20 MOTOR MODEL	21 COMMENTS
MUNICIPAL BLDG	Aurora OJ	MAY 63	50.0		1300	100	8,760	1800	73	53.0	49.9	66.5	31.1		203174	$14,222	63.4	480/3	1760	Dayton	3n306	Inverter installed
MUNICIPAL BLDG	Aurora OJ	MAY 63	50.0		1300	100	8,760										62	480/3	1800	US Electrical	Type H, Design B	Inverter installed
MUNICIPAL BLDG	Aurora OJ	MAY 63	30.0		1200	75	8,760	1600	66	34.0	32.0	83.3	18.5		120894	$8,463	34.5	480/3	1800	US Electrical	Type H, Design B	Motor Ser.#3300184, Code F
MUNICIPAL BLDG	Aurora OJ	MAY 63	30.0		1200	75	8,760										34.5	480/3	1750	US Electrical	Type H, Design B	Motor Ser.#3300202, Code F
MUNICIPAL BLDG	Aurora GGU 626388-2 2Bx2.5	MAY 63	7.5		214	60	1,000	170	?	7.7	5.8						9.5	480/3	1800	US Electrical	Type H, Design B	Motor Ser.#3308131, Code 3
MUNICIPAL BLDG	Aurora GGU 626388-2 2Bx2.5	MAY 63	7.5		214	60	1,000										9.5	480/3	1800	US Electrical	Type H, Design B	Motor Ser #3305502, Code G
PLAZA MUNI BLDG	Pacific 11 30121-746C61	JAN 85	15.0	10.75	408	90	3,285	436	62	38.5	16.8	46.6	7.4		18230	$1,276	41	230/3	1755	Baldor		Inverter installed
PLAZA MUNI BLDG	Pacific 11 30121-746C61	JAN 85	15.0	10.75	408	90	3,285										41	230/3	1755	Baldor		
PLAZA MUNI BLDG	Pacific ?	JAN 81	25.0				0										72	230/3	1765			Insulation covers info tag
PLAZA MUNI BLDG	Paco 11-50121-046C61	JAN 81	25.0	10.75	1020	75	3,285										66	230/3	1750	Baldor		Inverter installed
PLAZA MUNI BLDG	Paco 29501257400111872	JAN 81	25.0		900	75	3,285	967	83	64.0	28.5	71.0					72	230/3	2765			Inverter installed
PLAZA MUNI BLDG	Paco 11259517332111742	JAN 81	7.5		220	60	400										23	230/3	1725	Baldor		
P&P SAFETY BLDG	Aurora 73-6645-2	JAN 73	40.0		510	180	5,840										47	460/3	3500	US Electric	RV	
P&P SAFETY BLDG	Aurora 73-6645-2	JAN 73	40.0		510	180	5,840										47	460/3	3500	US Electric	RV	
P&P SAFETY BLDG	Aurora 73-6645-2	JAN 73	40.0		510	180	4,100	505	157	42.0	31.9	62.8					47	460/3	3500	US Electric	RV	
P&P SAFETY BLDG	Aurora 73-6646-2	JAN 73	3.0		356	15	5,840							0.3	1307	$91	10.3	460/3	1730	Imperial Electric	G	Type 32-BF Size 4x7B
P&P SAFETY BLDG	Aurora 73-6646-2	JAN 73	3.0		356	15	5,840							0.3	1307	$91	10.3	460/3	1730	Imperial Electric	G	Type 32-BF Size 4x7B
P&P SAFETY BLDG	Aurora 73-6646-2	JAN 73	3.0		356	15	4,100	514	14	4.4	3.0	59.7		0.3	918	$64	10.3	460/3	1730	Imperial Electric	G	Type 32-BF Size 4x7B
P&P SAFETY BLDG	Aurora 73 91132-2	JAN 73	7.5		500	37	8,760										10.3	460/3	1550	Imperial Electric		Manual speed control for pump
P&P SAFETY BLDG	Aurora 73 91132-2	JAN 73	7.5		500	37	8,760	764	21	10.4	7.5	54.3	5.4		35064	$2,454	10.3	460/3	1550	Imperial Electric		Manual speed control for pump
POLICE ACADEMY	Aurora 341A-BF 3x4x9B	JAN 81	10.0		290	65	6,570	302	?	11.0	8.3							480/3	1750			
POLICE ACADEMY	Aurora 341A-BC 2.5x3x12	JAN 81	20.0		290	125	6,570	477	114	20.0	15.5	88.9	12.0		58878	$5,299		480/3	1750			Inverter to be re-installed
CACTUS BRIEF STA	Paco 11-20705-732201A10-1	JAN 83	2.0	6.75	102	42	8,760	120	?	7.2	2.2			0.1	653	$59	7.9	208/3	1750			
CACTUS BRIEF STA	Paco 11-20705-732201A10-1	JAN 83	2.0	6.75	102	42	8,760										7.9	208/3	1750			
S. MTN BRIEF STA	B & G 1510-107T 2 CW	JAN 79	3.0		180		6,570	280	?	4.5	3.1			0.4	1960	$176	4.5	460/3	1745			
S. MTN BRIEF STA	B & G 1510-107T 2 CW	JAN 79	3.0		150		6,570	161	42	4.0	2.8	61.8					4.5	460/3	1745			
SPAC	Paco 1015501100061-1561	JAN 87	2.0	4.38	115	90	6,570										6.0	230/3	3450			To be replaced w/ B&G 5 hp pump
CENTRAL LIBRARY	Paco 10-2050111061-1681	JAN 75	5.0	4.4	200	50	3,840	230	30	3.2	2.3	74.6					7.1	480/3	1750	GE	5K182JX27	Replaces 7.5 HP B&G pump
CENTRAL LIBRARY	B & G 1510 BB7 7/8BF	JAN 75	7.5		346	50	3,840	287	30	9.5	7.1	30.6					11.0	480/3	1750	Baldor	37 B01-428	
CENTRAL LIBRARY	B & G 1510 4AB 7 BF	JAN 75	7.5		450	40	3,840	180	28	9.5	7.1	17.3					11.0	480/3	1750	Baldor	37 B01-428	
CENTRAL LIBRARY	B & G 1510 4AB 7 BF	JAN 75	7.5		450	40	3,840										11.0	480/3	1750	Baldor	37 B01-428	
CENTURY LIBRARY	B & G 80-6-3/4BF	JAN 73	2.0		58	45	8,760	40	?	7.0	1.2						7.0	208/1	1750	B & G		In-line pump #668741
CHOLLA LIBRARY	Teel 3P606	JAN 76	3.0		75	50	4,550	58	?	7.5	2.6						9.4	230/3	3525	Dayton	3N085	
CHOLLA LIBRARY	Armstrong2D 4280 BF	JAN 76	3.0		114	45	4,550	147	?	9.0	3.1			0.4	1358	122	10.8	230/3	1750	US Electric	6604980-808	

The brake horsepower savings that can be achieved by those pumps with high flow rates and already connected to a variable frequency drive are shown in column 12. The equation used to calculate savings was:

$$BHP2 = \left(\frac{\text{GPM Design}}{\text{GPM Actual}}\right)^3 \times BHP1$$

In column 13, pump horsepower savings were calculated for pumps not connected to variable frequency drives and with measured flow rates significantly higher than design gallons per minute. For those pumps with motors less than 7.5 horsepower, brake horsepower savings that could be achieved by closing a valve, as necessary to reduce flow to rated design, were estimated. These savings were estimated by referring to the pump curve, and following the appropriate curve to the rated design gallons per minute. The calculated kilowatt-hour per year and dollar savings per year are presented in column 14 and 15 and columns 16 through 20 are self-explanatory.

The pump analysis revealed that many of the chilled water, condenser water, and hot water pumps are actually providing excessive flow (gallons per minute). An estimated $32,000 per year could be saved if the pumps were slowed down to design flow.

Fans

All fans with motors two horsepower or greater were analyzed in a similar fashion as the pumps. The information presented in Table 5 shows the fan survey. Column 3 is the design flow rate in cubic feet per minute with column 4 being the design external static pressure and column 5 showing total static pressure. Most of the air handling units are already using variable air volume systems with inverters, inlet guide vanes or variable pitch axial fans, so did not require an optimization analysis. The fan horsepower savings shown in column 7 were calculated based on the fan laws and the equation:

TABLE 5 - Summary of City Fans

BUILDING NAME	MAKE	MODEL	1 EQUIP STARTUP DATE	2 HP	3 DESIGN CFM	4 DESIGN E.S.P.	5 DESIGN T.S.P.	6 EST RUN HRS/YR	7 EST. HP SAVINGS	8 EST KWH/YR SAVINGS	9 EST $/YR SAVINGS	10 VOLTS	11 AMPS	12 COMMENTS
MUNICIPAL BUILDING	Trane	42	MAY 63	60.00	N/A			8,760				480/3	67.5	Inverter installed
MUNICIPAL BUILDING	Trane	42	MAY 63	60.00	N/A			0				480/3	74.0	Out of service
MUNICIPAL BUILDING	Trane		MAY 63	60.00	N/A			8,760				480/3	67.5	Inverter installed
MUNICIPAL BUILDING	Trane	42	MAY 63	60.00	N/A			0				480/3	67.5	Out of service
MUNICIPAL BUILDING	Trane	41	MAY 63	50.00	N/A			0				480/3	56.3	Out of service
MUNICIPAL BUILDING	Trane		MAY 63	50.00	N/A			0				480/3	56.3	Out of service
MUNICIPAL BUILDING	Drayer Hanson	#2 V23	MAY 63	5.00	14,800			3,000	2.9	6469	$453	480/3	6.5	
MUNICIPAL BUILDING	Drayer-Hanson	FZ 219	MAY 63	5.00	9,320			3,000				480/3		
MUNICIPAL BUILDING	McQuay	XIML-III-V	MAY 63	3.00	5,600	0.70	1.25	8,760						also 3-20x10x2
MUNICIPAL BUILDING	McQuay	XIML-III-V	MAY 63	3.00	5,750	0.70	1.30	8,760						
MUNICIPAL BUILDING	Re-Cold	MU-280	MAY 63	7.50	17,000	0.63	1.50	1,500	4.4	4975	$348	220/3	23.2	
PLAZA MUNICIPAL BLDG	Sturtevent	100	JAN 81	20.00	34,045		1.75	8,760				208/3	52.0	Inverter installed
PLAZA MUNICIPAL BLDG	Sturtevent	90-P24896	JAN 81	15.00	22,804		1.75	8,760				208/3	41.0	Inverter installed
PLAZA MUNICIPAL BLDG	Sturtevent	95	JAN 81	15.00	30,370		1.75	8,760				208/3	41.0	Inverter installed
PLAZA MUNICIPAL BLDG	Sturtevent	100	JAN 81	20.00	27,680		1.75	8,760				208/3	52.0	Inverter installed
PLAZA MUNICIPAL BLDG	Sturtevent	100	JAN 81	15.00	22,300		1.75	8,760				208/3	40.8	Inverter installed
POLICE & PUBLIC SAFETY	Joy	42 1/4-26 1/2-1750	JAN 73	50.00	40,000		6.00	8,760				460/3	62.0	Var pitch axial fan
POLICE & PUBLIC SAFETY	Joy	42 1/4-26 1/2-1750	JAN 73	50.00	40,000		6.00	8,760				460/3	62.0	Var pitch axial fan
POLICE & PUBLIC SAFETY	Joy	42 1/4-26 1/2-1750	JAN 73	50.00	40,000		6.00	8,760				460/3	62.0	Var pitch axial fan
POLICE & PUBLIC SAFETY	Joy	42 1/4-26 1/2-1750	JAN 73	50.00	40,000		6.00	8,760				460/3	62.0	Var pitch axial fan
POLICE & PUBLIC SAFETY	Joy	42 1/4-26 1/2-1750	JAN 73	50.00	40,000		6.00	8,760				460/3	62.0	Var pitch axial fan
POLICE ACADEMY	Governaire	RSA 02	JAN 81	10.00	9,900	2.10	3.20	4,250				460/3	13.0	Var vol-Inlet
POLICE ACADEMY	Governaire	RSA 02	JAN 81	3.00	8,650		0.75	4,250				460/3	4.2	Var vol-Inlet
POLICE ACADEMY	Governaire		JAN 81	7.50	8,315	0.80	2.00	4,250				460/3		Var vol-Inlet
POLICE ACADEMY	Governaire		JAN 81	3.00	7,315		0.75	4,250				460/3		Var vol-Inlet
POLICE ACADEMY	Governaire		JAN 81	7.50	8,075	0.80	2.00	4,250				460/3		Var vol-Inlet
POLICE ACADEMY	Governaire		JAN 81	2.00	6,700		0.75	4,250				460/3		Var vol-Inlet
S. MTN BRIEF STATION	Dunham/Bush	MZ-18C	JAN 68	20.00	?			8,760				460/3		Inverter installed
S. MTN BRIEF STATION	Dunham/Bush	?	JAN 68	5.00	?			8,760				230/3	14.4	Inverter installed
FIRE TRAINING ACADEMY	Acme	PACW-25MZ	JAN 67	5.00	8,523		1.75	8,760				230/3	14.4	Inverter installed
S. PHX ADULT CENTER	Climatrol	YFL08B0A10E GBA	JAN 76	3.00	3,880	0.50	2.25					208/3		Out of service
S. PHX ADULT CENTER	Climatrol	YBJ126001	JAN 76	3.00	4,820	0.60	2.25					208/3	8.4	Out of service
CENTRAL LIBRARY	Trane	73	JAN 75	40.00	34,000	2.80	4.00	4,800				460/3	45.0	Inverter installed
CENTRAL LIBRARY	Trane	41	JAN 75	15.00	20,000	1.80	3.00	4,800				460/3		Inverter installed
CENTRAL LIBRARY	Trane	41	JAN 75	10.00	20,000		1.50	4,800				460/3		Inverter installed
CENTURY LIBRARY	McQuay	LML 217 BI	JAN 73	7.50	9,350	0.75		3,370				200/3		Inverter installed
CHOLLA LIBRARY	Temtrol	BZ-21SMB	JAN 76	15.00	10,970	1.30	2.30	4,732				208/3	46.8	Inverter installed

$$HP2 = \left(\frac{\text{Optimal CFM}}{\text{Design CFM}}\right)^3 \times HP1$$

The kilowatt-hour savings per year in column 8 were calculated using this equation:

KWH/yr = HP saved x Fan Run hrs/yr(column 8) x .746 KW/HP/motor eff.

The estimated dollar savings in column 9 were calculated by:

$/yr = KWH/yr (column 11) x $/KWH (cost of electricity)

The costs per kilowatt-hour used were; $.07/KWH for large downtown buildings; $.09/KWH for medium sized buildings; and $.11/Kwh for small buildings. Additional information about the air handling units is provided in columns 10 through 12.

The findings of the survey showed that almost all of the HVAC supply and return air fans have been optimized with variable air volume fans which automatically vary the air flow based on actual building load. Two fans that could be slowed down in the Municipal Building showed an estimated savings of approximately $1000 per year.

Other Heating Units

A list of furnaces, electric resistance heat and radiant heaters were surveyed and examples are presented in Table 6. It was recommended that natural gas furnaces be replaced with new gas-fired pulse combustion furnaces at the end of their useful life.

Cooling Towers

Table 7 shows a survey of cooling towers, however they were not analyzed in this study. Some of the towers utilize large motors but should not be changed unless the compressor is being replaced with a smaller size.

TABLE 6 - Summary of Other Heating Units

BUILDING NAME	EQUIPMENT DESCRIPTION	MAKE	MODEL	EQUIP START DATE	FUEL	BTUH	KW
NORTHWEST SERVICE CNTR	E. cooler/furnace	Goettl	GF 50-56	JAN 69	Ngas	100000	
NORTHWEST SERVICE CNTR	Middle cooler/frnce	Goettl	GF 50-56	JAN 69	Ngas	100000	
NORTHWEST SERVICE CNTR	West cooler/frnce	Goettl	GF-75	JAN 69	Ngas	75000	
NORTHWEST SERVICE CNTR	Gas furnace	Carrier	58 BV 150-1	JAN 69	Ngas	150000	
NORTHWEST SERVICE CNTR	Gas furnace	Lennox	G12 D2E-56-6	JAN 81	Ngas	43000	
NORTHWEST SERVICE CNTR	Unitary heater	Reznor	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine		JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
NORTHWEST SERVICE CNTR	I.R. gas heater	Modine	?	JAN 70	Ngas		
SOUTHWEST SERVICE CNTR	Gas unit heater	Reznor	?	JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Electric unit heater	Federal-Pacific	USA 2813	JAN 80	Elec		3
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?	?	JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?		JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?		JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?		JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?		JAN 75	Ngas		
SOUTHWEST SERVICE CNTR	Infra-red gas unit	?		JAN 75	Ngas		
SOUTHEAST SERVICE CNTR	Gas furnace	Day & Night	394 GAW000150A	JAN 83	Ngas	150000	
SOUTHEAST SERVICE CNTR	Gas furnace	Bryant	80-394U	JAN 77	Ngas	80000	
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	XA-150-SER-1	JAN 74	Ngas	150000	
CENTRAL EQUIP MAINT	Air washer pre-heat	Hastings	LB-20 A	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Gas furnace	Lux-aire	TOOO-LD14N120B	JAN 86	Ngas	120000	
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10

TABLE 6 -(continued)

BUILDING NAME	EQUIPMENT DESCRIPTION	MAKE	MODEL	EQUIP START DATE	FUEL	BTUH	KW
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	XA-150-SER-1	JAN 74	Ngas	150000	
CENTRAL EQUIP MAINT	Gas unit heater #6	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Gas unit heater #7	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Electric unit heater #8	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater #10	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Electric unit heater	Reznor	EUH10348A	JAN 74	Elec		10
CENTRAL EQUIP MAINT	Gas I.R. heater	Reznor	IR-30	JAN 74	Ngas	30000	
CENTRAL EQUIP MAINT	Gas I.R. heater	Reznor	IR-30	JAN 74	Ngas	30000	
CENTRAL EQUIP MAINT	Gas I.R. heater	Reznor	IR-30	JAN 74	Ngas	30000	
CENTRAL EQUIP MAINT	Gas I.R. heater	Reznor	IR-30	JAN 74	Ngas	30000	
CENTRAL EQUIP MAINT	Gas unit heater	Reznor	UA-35	JAN 74	Ngas		
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	125000	
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	500000	
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	500000	
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	500000	
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	500000	
CENTRAL EQUIP MAINT	Hung from ceiling	Reznor	DFAH-500	JAN 74	Ngas	500000	
DEER VAL. AIR SUPPORT	Unit heater #1	Reznor	?	JAN 80	Elec		
DEER VAL. AIR SUPPORT	Unit heater #2	Reznor	?	JAN 80	Elec		
DEER VAL. AIR SUPPORT	Unit heater #3	Reznor	?	JAN 80	Elec		
DEER VAL. AIR SUPPORT	Unit heater #3	Reznor	?	JAN 80	Elec		
DEER VAL. AIR SUPPORT	Unit heater #4	Reznor	?	JAN 80	Elec		
FIRE STATION 1	Unitary heater	Chromalux	?	JAN 77	Elec		
FIRE STATION 1	Unitary heater	Chromalux	?	JAN 77	Elec		
FIRE STATION 3	Main gas furnace	Carrier	58GS 125-4	FEB 84	Ngas	125000	
FIRE STATION 5	Gas furnace	Payne	394 GAW 060125	JAN 79	Ngas	125000	
FIRE STATION 6	#2 gas furnace	Payne	394 GAW 036075	JAN 83	Ngas	75000	
FIRE STATION 6	#1 gas furnace	Payne	394 GAW 048100	JAN 83	Ngas	100000	
FIRE STATION 7	#2 gas furnace	Payne	394 GAW 036075	DEC 83	Ngas	75000	
FIRE STATION 7	#1 gas furnace	Payne	394 GAW 048100	DEC 83	Ngas	100000	
OLD FIRE STATION 8	Gas furnace	Carrier	58 GS 125-4	JAN 82	Ngas	125000	
FIRE STATION 10	#1 gas furnace	Payne	394 GAW 048100	FEB 83	Ngas	100000	
FIRE STATION 12	Main gas furnace	Carrier	58GS 125-4	MAY 84	Ngas	125000	
FIRE STATION 13	Gas furnace	Carrier	58GS 125-4	JAN 83	Ngas	125000	
FIRE STATION 14	Main gas furnace	Bryant	394GAW 060125	OCT 83	Ngas	125000	
FIRE STATION 16	#1 gas furnace	American-Stnd.	UGF 105 AC 3E4	JAN 66	Ngas	105000	
FIRE STATION 16	#2 gas furnace	Payne	394 GAW 048100	APR 83	Ngas	100000	
FIRE STATION 17	#1 furnace	Gaffers/Sattler	ACD12-U100-4-1	JAN 78	NGAS	1000000	

TABLE 6 -(continued)

BUILDING NAME	EQUIPMENT DESCRIPTION	MAKE	MODEL	EQUIP START DATE	FUEL	BTUH	KW
FIRE STATION 17	#2 gas furnace	Tappan	UG80D16E-1	JAN 78	Ngas	80000	
FIRE STATION 18	#2 gas furnace	Payne	394 GAW036125	SEP 84	Ngas	125000	
FIRE STATION 19	gas furnace #1	Lennox	C465-00-2		Ngas	137000	
FIRE STATION 19	gás furnace #2	Lennox	C465-00-2		Ngas	137000	
FIRE STATION 19	Heat strips for A/C#1				Elec		
FIRE STATION 20	gas furnace #2	Borg-Warner	UG120020N-18	JAN 79	ngas	120000	
FIRE STATION 20	gas furnace #1	Borg-Warner	UG120020N-18	JAN 79	ngas	120000	
FIRE STATION 21	#1 gas furnace	American Furnac	SV-140-BB-3	JAN 75	Ngas	140000	
FIRE STATION 21	#2 gas furnace	American Furnac	SV—BB-3	JAN 75	Ngas	100000	
FIRE STATION 25	#1 gas furnace	Payne	394GAW 060125	NOV 83	Ngas	125000	
FIRE STATION 25	#2 gas furnace	Tappan	UG 80 D 16E-1	JAN 78	Ngas	80000	
FIRE STATION 26	#1 gas furnace	American Furnac	SV 140 BB-3	JAN 68	Ngas	140000	
FIRE STATION 26	#2 gas furnace	American Furnac	SV 100 BB-3	JAN 68	Ngas	100000	
FIRE STATION 27	#1 gas furnace	Payne	394 GAW 048100	APR 83	Ngas	100000	
FIRE STATION 27	#2 gas furnace	Payne	394 GAW 048100	APR 83	Ngas	100000	
FIRE STATION 28	#1 furnace	Borg-Warner	UG120-B5N	JAN 70	Ngas	120000	
FIRE STATION 28	#2 furnace	Borg-Warner	UG0-80-B3N	JAN 70	Ngas	80000	
FIRE STATION 29	#1 gas furnace	Payne	394 GAW 048125	APR 83	Ngas	125000	
FIRE STATION 29	#2 gas furnace	Payne	394 GAW 036075	DEC 82	Ngas	75000	
FIRE STATION 30	#2 gas furnace	Payne	394 GAW 036075	APR 84	Ngas	75000	
FIRE STATION 30	#2 gas furnace	Payne	394 GAW 048100	APR 84	Ngas	100000	
FIRE STATION 31	Electric furnace	Lennox	B10-65-1P	JAN 77	Elec		8
FIRE STATION 33	#2 gas furnace	Payne	394 GAW 036075	APR 83	Ngas	75000	
FIRE STATION 33	#1 gas furnace	Payne	394 GAW 060125	APR 83	Ngas	125000	
FIRE STATION 34	#1 gas furnace	Borg-Warner	UG 120-5BN	JAN 69	Ngas	120000	
FIRE STATION 34	#2 Gas furnace	Borg-Warner	UG080-B3N	JAN 69	Ngas	80000	
FIRE STATION 38	Elec heat strips				Elec		15
FIRE STATION 39	Elec heat strips				Elec		15
FIRE STATION 42	Electric furnace	Carrier	40FS220300	JAN 79	Elec		6
FIRE TRAINING ACADEMY	Electric furnace	BDP	505C060CUHFC	JAN 78	Elec	33000	
EMERGENCY MED SERVICE	Gas furnce to W. unit	Day & Night	394GAW060150	JAN 82	Ngas	150000	
FIRE RESOURCE MGMT	Solar space heater			JAN 77			
S. PHX ADULT CENTER	Electric heat strips			JAN 76	Elec		110
CHOLLA LIBRARY	Electric heat strips			JAN 76	Elec		68

TABLE 7 · Summary of City Cooling Towers

BUILDING NAME	MAKE	MODEL	DATE STARTUP	CAPACITY TONS	# CELLS	# FANS	AXIAL	DRIVE	FAN MOTOR MAKE	FAN MOTOR MODEL	FAN HP	VOLTS	AMPERES	RPM	COMMENTS
MUNICIPAL BUILDING	BAC	4238-2	APR 85	800	2	2	Yes	gb			20.0	480/3	27.0	1760	Built on the old base,minor basin leaks
MUNICIPAL BUILDING	BAC	FXT 116 RC	AUG 84	116	1	1	Yes	B			5.0	480/3	7.0	1725	
MUNICIPAL ANNEX	BAC	FXT-15-RC	JAN 83	15	1	1	Yes	D			0.5	230/1	4.1	1140	
MUNICIPAL ANNEX	BAC	FXT-60	MAR 84	60	1	1	Yes	B			3.0	230/1	8.8	1725	
PLAZA MUNICIPAL BUILDING	BAC	GFT 2420RC	MAR 84	350	1	1	Yes	B	Baldor		15.0	208/3	55.0	1750	
PLAZA MUNICIPAL BUILDING	Marley	SC-2864D-FMA	JAN 75	350	1	1	Yes	B	Century Elec.	SC28640	20.0	208/3	54.0	1730	Motor model#cont' FMA EMI9-313800-01
OLD CITY HALL	BAC	VXC-65		65	1										To be replaced in renovation
OLD CITY HALL	BAC	VXC-25		25	1										To be replaced in renovation
POLICE-PUBLIC SAFETY BLDG	BAC	FXT-27-C	JAN 83	27	1	1	Yes	B	Baldor	M3116T	3.0	460/3	1.7	1725	
POLICE-PUBLIC SAFETY BLDG	BAC	FXT-27-C	JAN 83	27	1	1	Yes	B	Baldor	M3116T	3.0	460/3	1.7	1725	
POLICE-PUBLIC SAFETY BLDG	BAC	FXT-27-C	JAN 81	27	1	1	Yes	B	Baldor	M3116T	3.0	460/3	1.8	1725	
POLICE-PUBLIC SAFETY BLDG	BAC	FXT-27-C		27	1	1	Yes	B	Baldor	M3116T	3.0	230/3	4.0	1725	
POLICE-PUBLIC SAFETY BLDG	BAC	J 15-B28	JAN 73	151	1	0									No fans, Ejector type
POLICE-PUBLIC SAFETY BLDG	BAC	J 15-B28	JAN 73	151	1	0									No fans, Ejector type
POLICE-PUBLIC SAFETY BLDG	BAC	J 15-B28	JAN 73	151	1	0									No fans, Ejector type
POLICE-PUBLIC SAFETY BLDG	Marley	4625		25	1	1	Yes	B	Lincoln	2508	1.0	230/3	3.8	1740	
POLICE ACADEMY	BAC		JAN 87	150	1	1									NEW 150 TON TOWER TO BE INSTALLED
CACTUS PARK BRIEFING STN	Evapco	LSW-18B	JAN 83	18			No	B			5.0	240/3	14.0	1725	Cools condensor loop for H/P's
CACTUS PARK BRIEFING STN	Evapco	LSW-18B	JAN 83	18			No	B			5.0	240/3	14.0	1725	Cools condensor loop for H/P's
SOUTH MOUNTAIN PRECINCT	BAC	VXT-65-C	JAN 79	65	1	1	No	B	No ID tag	No ID tag	5.0	?		1750	
CENTRAL LIBRARY	BAC	VI-50-3	JAN 75	50		1			US Electric		20.0				
CENTRAL LIBRARY	BAC	VI-50-3	JAN 75	50		1			US Electric		20.0				
CHOLLA LIBRARY	BAC	VNT-40 B	JAN 76	40	1	1	No	B	US Electric	F-9635-01-566	3.0	230/3		1740	

DX Air Conditioning Units and Heat Pumps

Lastly, Table 8 is a summary of some of the package and remote direct expansion (DX) air conditioning units installed throughout the City. Since these are the predominant types of air conditioning equipment used throughout the city, a thorough evaluation was done on units of two tons or larger and recommendations for replacement were accomplished on all units five years and older. The following is a summary of the methodology used to derive the table.

The first several columns identify the building and the equipment and should be self explanatory. Numbered columns 1 - 3 show the age of the equipment, size in tons, and the efficiency expressed as EER. Column 4 shows the estimated compressor equivalent full load run hours in the cooling mode and were obtained in one of two methods.

Method 1- This method utilized the Technical Assistance report previously completed by the City. The cooling kilowatt-hour was defined as the electricity used by the compressors and condenser fans and the equivalent full load hours were calculated by:

$$\text{Building Cooling KWH/yr} \times \frac{\text{Unit EER or SEER}}{\text{Total Bldg. Tons} \times 12} = \text{Unit Equiv. F L Hrs.}$$

Method 2- Where no Technical Assistance report was available a computer simulation program, TRAKLOAD, was used to estimate equivalent full load run hours.

Upon evaluation of this report it was observed that the run hours per year were lower than expected, which prompted the actual run time testing which will be explained later in this chapter. The recommended or optimal unit nominal cooling capacity is presented in column 5 and utilized either the Technical Assistance report or

TABLE 8 - Summary of City Remote / Packaged Units

BUILDING NAME	UNIT MAKE/MODEL #		1 START DATE	2 TONS	3 EER	4 RUN HRS/YR	5 REC TONS	6 REPLACEMENT MAKE/MODEL #	7 REPL EER	8 EST INST COST	9 KWH/YEAR SAVINGS	10 $/YEAR SAVINGS	11 PAYBACK YEARS
PLAZA MUNICIPAL BLDG	York	CHP 048-25B	Jan-84	4.0	7.9								
PLAZA MUNICIPAL BLDG	Carrier	50EP006500AA	Jan-81	5.0	7.6								
PLAZA MUNICIPAL BLDG	Carrier	50EP006500AA	Jan-81	5.0	7.6								
FACILITIES MAINT	BDP	542EB060	Jan-85	5.0	8.3								
FACILITIES MAINT	BDP	599C120027PACDH	Nov-79	10.0	8.2	630	5.0	Carrier 50-CV/CZ006 5/6	9.5	$3,004	1261	$114	26.5
FACILITIES MAINT	BDP	599C120027PACDH	Nov-79	10.0	8.2	586	7.5	Carrier 50-CV/CZ008	9.3	$4,404	1014	$91	48.3
FACILITIES MAINT	BDP	599C120027PACDH	Nov-79	10.0	8.2	630	5.0	Carrier 50-CV/CZ006 5/6	9.5	$3,004	1261	$114	26.5
FACILITIES MAINT	BDP	599C090027PACDH	Nov-79	7.5	8.7	622	5.0	Carrier 50-CV/CZ006 5/6	9.5	$3,004	541	$49	61.6
FACILITIES MAINT	BDP	559D048PAC	Nov-79	4.0	6.9	493	4.0	Trane BTC048D	8.6	$1,710	678	$61	28.0
FACILITIES MAINT	Carrier	50YH036500	Oct-85	3.0	8.2								
NORTHWEST SERVICE CNTR	York	D2EC036N06006A	Jan-85	3.0	8.0								
NORTHWEST SERVICE CNTR	Trane	BYC036D312H0	Jan-85	3.0	8.4								
NORTHWEST SERVICE CNTR	Westinghouse	HB 036 KDW	Jan-83	3.0	6.7								
NORTHWEST SERVICE CNTR	Westinghouse	HB 036 KDW	Jan-83	3.0	6.7								
NORTHWEST SERVICE CNTR	Westinghouse	48BL006530	Jan-84	5.0	8.5								
NORTHWEST SERVICE CNTR	Chrysler	1206-02R	Jan-69	5.0	6.2	713	5.0	Lennox HS14-653V	9.5	$3,107	2373	$214	14.5
SOUTHWEST SERVICE CNTR	Lennox	CHA8-953-7Y	Jan-80	7.5	7.6	517	4.0	Trane BTC048D	8.6	$1,710	712	$64	26.7
SOUTHWEST SERVICE CNTR	Lennox	CHA10-653-1Y	Jan-80	5.0	6.9	1367	5.0	Carrier 50CV/CZ006 5/6	9.5	$4,404	3252	$293	15.0
SOUTHWEST SERVICE CNTR	Lennox	CHA10-653-1Y	Jan-80	5.0	6.9								
SOUTHWEST SERVICE CNTR	Lennox	CHA10-653-1Y	Jan-80	5.0	6.9	1410	5.0	Carrier 50CV/CZ006 5/6	9.5	$4,404	3355	$302	14.6
SOUTHWEST SERVICE CNTR	Lennox	CHA9-261-2P	Jan-80	2.0	6.9	1494	2.5	Carrier 48-KLA130	9.5	$1,309	1422	$128	10.2
SOUTHWEST SERVICE CNTR	Lennox	CHA9-261-2P	Jan-80	2.0	6.9	1105	2.0	Carrier 50EE024	9.5	$1,270	1052	$95	13.4
SOUTHWEST SERVICE CNTR	Lennox	CHA10-413-1Y	Jan-80	3.0	7.3	991	2.0	Carrier 50EE024	9.5	$1,270	1132	$102	12.5
SOUTHWEST SERVICE CNTR	Lennox	CHA10-413-1Y	Jan-80	3.0	7.3	1208	3.0	York D2PF036	9.1	$1,145	1178	$106	10.8
SOUTHWEST SERVICE CNTR	Lennox	CHA9-513-3Y	Jan-80	4.0	6.7	1119	4.0	Trane BTC048D	8.6	$1,710	1771	$159	10.7
SOUTHWEST SERVICE CNTR	Payne	30/80YAC-106T-C	Jan-80	2.5	6.3	1100	2.5	Carrier 48-KLA130	9.5	$1,309	1764	$159	8.2
SOUTHWEST SERVICE CNTR	Payne	48/110 YAC-104C	Jan-80	5.0	6.7	1100	5.0	Carrier 48-HV/HZ006	9.7	$3,420	3047	$274	12.5
SOUTHWEST SERVICE CNTR	Bard	36WA1	Jan-83	3.0	9.0								
SOUTHEAST SERVICE CNTR	Bard	36WH	Jan-83	3.0	9.0								
SOUTHEAST SERVICE CNTR	Bard	24 WA 4	Jan-85	2.0	8.0								
SOUTHEAST SERVICE CNTR	Goettl	ACU-40	Jan-77	3.5	7.2	1017	3.5	Lennox HS19-461V	12.0	$1,889	2374	$214	8.8
SOUTHEAST SERVICE CNTR	York	PF60-6E	Jan-79	5.0	6.3	727	5.0	Carrier 50CV/CZ006 5/6	9.5	$4,404	2333	$210	21.0
NORTH SERVICE CENTER	Lennox	CHP9-653-2G	Jan-78	5.0	5.6	669	5.0	Carrier 50QV/QZ006	9.0	$3,118	2709	$244	12.8
NORTH SERVICE CENTER	Lennox	CHP9-463-1G	Jan-78	3.5	7.0	1203	3.5	Carrier 50QQ042	8.5	$1,888	1273	$115	16.5
NORTH SERVICE CENTER	Goettl	GAHP 253	Jan-80	2.0	7.7	1100	2.0	Carrier 50QQ024	9.0	$1,420	495	$45	31.9
NORTH SERVICE CENTER	Carrier	50YH030500	Jan-85	2.5	7.8								

TABLE 8 -(continued)

BUILDING NAME	UNIT MAKE/MODEL #		1 START DATE	2 TONS	3 EER	4 RUN HRS/YR	5 REC TONS	6 REPLACEMENT MAKE/MODEL #	7 REPLACE SEER/E	8 EST INST COST	9 KWH/YEAR SAVINGS	10 $/YEAR SAVINGS	11 PAYBACK YEARS
NORTH SERVICE CENTER	Carrier	50YH042400	Jan-85	3.5	7.8								
CENTRAL EQUIP. MAINT.	Rheem	ADP-38B3SA	Jan-82	3.0	8.0	1100	3.0	Carrier 38QH036	8.7	$1,654	398	$36	46.1
CENTRAL EQUIP. MAINT.	Trane	SFHA-404-HB	Jan-79	4.0	7.4	1100	4.0	Carrier 48-KLA048	8.5	$1,941	923	$83	23.4
CENTRAL EQUIP. MAINT.	Fraser Johnson	EBC036TAA	Jan-75	6.9	6.9	1100	3.0	Lennox HS14-413V	10.4	$2,293	4442	$400	5.7
CENTRAL EQUIP. MAINT.	Lennox	CHA9-311-1P	Jan-74	2.5	7.0	1100	2.5	Carrier 50EE030	9.5	$1,488	1241	$112	13.3
CENTRAL EQUIP. MAINT.	Carrier	48KL03600E	Jan-82	3.0	8.2	1100	3.0	Carrier 48-KLA036	8.5	$1,462	170	$15	95.3
CENTRAL EQUIP. MAINT.	Fraser Johnson	EBC036TAA	Jan-77	3.0	6.9	1100	3.0	Lennox HS14-413V	10.4	$2,293	1931	$174	13.2
CENTRAL EQUIP. MAINT.	Fraser Johnson	EBC036TAA	Jan-79	3.0	6.9	1100	3.0	Lennox HS14-413V	10.4	$2,293	1931	$174	13.2
ADMINISTRATIVE SUPPORT	Trane	SACA-1254A	Jan-75	12.5	7.5	889	11.0	Trane BTC130G	8.4	$5,608	1905	$171	32.7
ADMINISTRATIVE SUPPORT	Trane	SACA-1004A	Jan-75	10.0	6.5	770	7.5	Carrier 50CV/CZ008	9.3	$4,404	4282	$385	11.4
ADMINISTRATIVE SUPPORT	Trane	SAHA-504C	Jan-75	5.0	6.5	770	7.5	Carrier 50CV/CZ008	9.30	$4,404	2141	$193	22.9
ADMINISTRATIVE SUPPORT	Bohn	DVS0132BU11	Oct-85	15.5	8.2								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
CACTUS PARK BRIEF STN	Command-Air	SPNph 283	Jan-83	2.5	8.9								
AIR SUPPORT UNIT	Lennox	CHP8-953-7Y	Jan-79	7.5	7.1	2014	7.5	Trane BWC090E/C	8.90	$4,708	5164	$465	10.1
AIR SUPPORT UNIT	Lennox	CHP8-953-7Y	Jan-79	7.5	7.1	1437	5.0	Carrier 50QV/QZ006	9.00	$3,118	3846	$346	9.0
AIR SUPPORT UNIT	York	BISP090A25B	Jan-80	7.5	8.1	1558	7.5	Trane BWC090E/C	8.90	$4,708	1556	$140	33.6
AIR SUPPORT UNIT	York	BISP090A25B	Jan-80	7.5	8.1	1558	7.5	Trane BWC090E/C	8.90	$4,708	1556	$140	33.6
SKY HARBOR BRIEF ST.	Lennox	CHA8-953-7	Jan-79	7.5	7.6	1419	7.5	Carrier 50CV/CZ008	9.30	$4,404	3071	$276	15.9
SKY HARBOR BRIEF ST.	Lennox	CHA8-953-7	Jan-79	7.5	7.6	1419	7.5	Carrier 50CV/CZ008	9.30	$4,404	3071	$276	15.9
SKY HARBOR BRIEF ST.	Lennox	CHA-10-653-1Y	Jan-79	5.0	6.9	1288	3.0	York D2PF036	9.10	$1,145	2708	$244	4.7
SKY HARBOR BRIEF ST.	Tappan	RTA-60	Jan-73	5.0	6.3	1176	3.0	Carrier 48-KLA036	8.50	$1,462	2899	$261	5.6
SKY HARBOR BRIEF ST.	Tappan	RTA-60	Jan-73	5.0	6.3	1176	5.0	Carrier 48-HV/HZ006	9.20	$3,420	3531	$318	10.8
SKY HARBOR BRIEF ST.	Tappan	RTA-60	Jan-73	5.0	6.3	1176	4.0	Carrier 48-KLA048	8.50	$1,941	2899	$261	7.4
SKY HARBOR BRIEF ST.	Tappan	RTA36-100-32T	Jan-73	3.0	6.4	1195	5.0	Carrier 48-HV/HZ006	9.20	$3,420	2045	$184	18.6
SKY HARBOR BRIEF ST.	Tappan	RTA36-100-32T	Jan-73	3.0	6.4	1195	3.0	Carrier 48-KLA036	8.50	$1,462			
SKY HARBOR BRIEF ST.	Carrier	50DP008400DA	Jan-79	7.5	7.8	1456	5.0	Carrier 50CV/CZ006 5/6	9.50	$4,404	3006	$271	16.3
SKY HARBOR BRIEF ST.	Carrier	50DP008400DA	Jan-79	7.5	7.8	1456	7.5	Carrier 50CV/CZ008	9.30	$4,404	2710	$244	18.1
SKY HARBOR BRIEF ST.	Carrier	50MH024340CA	Jan-79	2.0	6.9	0							
SKY HARBOR BRIEF ST.	Lennox	CCS3-653-120/15	Jan-74	5.0	7.1	1542	5.0	Carrier 48-HV/HZ006	9.20	$3,420	2975	$268	12.8
SKY HARBOR BRIEF ST.	Lennox	CCS3-513-120/15	Jan-74	4.0	6.6	1434	3.0	Carrier 48-KLA036	8.50	$1,462	2330	$210	7.0

TABLE 8 -(continued)

BUILDING NAME	UNIT MAKE/MODEL #		1 START DATE	2 TONS	3 EER	4 RUN HRS/YR	5 REC TONS	6 REPLACEMENT MAKE/MODEL #	7 REPL EER	8 EST INST COST	9 KWH/YEAR SAVINGS	10 $/YEAR SAVINGS	11 PAYBACK YEARS
SQUAW PEAK BRIEF ST.	Lennox	CCS3-513-120/15	Jan-74	4.0	6.6	1434	3.0	Carrier 48-KLA036	8.50	$1,462	2330	$210	7.0
SQUAW PEAK BRIEF ST.	Lennox	CCS3-953-120/12	Jan-74	7.5	7.6	1651	7.5	Carrier 48-LV/LZ008	9.20	$5,008	3400	$306	16.4
SQUAW PEAK BRIEF ST.	Carrier	50DP008400MA	Jan-79	7.5	7.8	1694	7.5	Carrier 50CV/CZ008	9.30	$4,404	3153	$284	15.5
SQUAW PEAK BRIEF ST.	Carrier	50DP008400MA	Jan-79	7.5	7.8	1694	7.5	Carrier 50CV/CZ008	9.30	$4,404	3153	$284	15.5
SQUAW PEAK BRIEF ST.	Carrier	50MH024340C	Jan-75	2.0	6.9	0							
MARYVALE BRIEFING ST.	BDP	585EP090146	May-85	7.5	8.2								
MARYVALE BRIEFING ST.	BDP	579DP120231	May-85	10.0	8.3								
MARYVALE BRIEFING ST.	BDP	579DP18027	May-85	15.0	8.2								
MARYVALE BRIEFING ST.	Lennox	CHP8-1353-6Y	Jan-74	10.0	6.9	1686	10.0	York B1SP120	8.30	$5,831	4947	$445	13.1
FIRE STATION 1	Carrier	48DD012A	Jan-76	10.0	7.0	1820	10.0	Trane BYC130G	8.40	$7,150	5200	$468	15.3
FIRE STATION 1	Carrier	48DA024B	Jan-76	20.0	7.5	1950	15.0	Trane BYC170G	8.50	$8,710	7341	$661	13.2
FIRE STATION 1	Carrier	48DA024B	Jan-76	20.0	7.5	1950	15.0	Trane BYC170G	8.50	$8,710	7341	$661	13.2
FIRE STATION 3	Goettl	AGW-63-3	Sep-83	5.0	6.7								
FIRE STATION 4	Lennox	CHP10-653-1Y	Sep-80	5.0	6.9	1100	5.0	Carrier 50QV/QZ006	9.00	$3,118	2232	$201	15.5
FIRE STATION 4	Lennox	CHP10-653-1Y	Sep-80	5.0	6.9	1190	4.0	Lennox CHP15-513	8.30	$2,158	1745	$157	13.7
FIRE STATION 4	Lennox	CHP10-653-1Y	Sep-80	5.0	6.9	1190	4.0	Lennox CHP15-513	8.30	$2,158	1745	$157	13.7
FIRE STATION 5	Day & Night	60 DRN-308C	Jan-72	5.0	7.2	1908							
FIRE STATION 6	York	CA48-10AY	Jan-67	4.00	7.7	2468	4.0	Lennox HS14-511V	13.20	$2,604	6410	$705	3.7
FIRE STATION 6	York	CA31-10-A	Jan-67	2.50	7.7	1437	2.5	Lennox HS19-311V	11.85	$1,573	1961	$216	7.3
FIRE STATION 7	Goettl	ACU-31	Jan-83	2.50	5.4								
FIRE STATION 7	Goettl	AGW-52	Jan-83	4.50	6.9								
FIRE STATION 9	Carrier	50PQ008510	Jan-84	7.50	7.6								
FIRE STATION 9	Carrier	50PQ012510	Jan-84	10.00	8.2								
FIRE STATION 9	Carrier	50YQ048400	Jan-84	4.00	7.5								
FIRE STATION 9	Carrier	50YQ024300	Jan-84	2.00	7.9								
FIRE STATION 10	Westinghouse	BGWA 824R1A	Jan-75	2.50	7.2	1714	2.5	Carrier 38QH030	9.55	$1,472	1758	$193	7.6
FIRE STATION 10	Goettl	AGW52-3	Jan-83	4.50	7.1								
FIRE STATION 11	York	PF60-25E	Jan-77	5.00	6.3	1629	4.0	Trane BTC048D	8.60	$1,710	4148	$456	3.7
FIRE STATION 11	York	PF60-25E	Jan-77	5.00	6.3	1629	4.0	Trane BTC048D	8.60	$1,710	4148	$456	3.7
FIRE STATION 12	Payne	60RAC-1S8C	Jan-70	5.00	7.0	2122	5.0	Lennox HS14-651V	13.00	$3,107	8395	$923	3.4
FIRE STATION 13	Goettl	AGW-63	Jan-83	5.00	6.2								
FIRE STATION 14	Goettl	AGW-63	Jan-83	5.00	6.2								
FIRE STATION 15	Lennox	HP8-653-V5Y	Jan-77	5.00	6.6	1320	5.0	York E1CS060	8.50	$2,588	2682	$295	8.8
FIRE STATION 16	Payne	48 RAC-1S6	Jan-67	4.00	7.0	2044	4.0	Lennox HS14-511V	13.20	$2,604	6584	$724	3.6
FIRE STATION 16	Goettl	RECU 301 A	Jan-84	2.50	7.7								
FIRE STATION 17	Goettl	RECU 601B	Apr-85	5.00	7.5								

TABLE 8 -(continued)

BUILDING NAME	UNIT MAKE/MODEL #		1 START DATE	2 TONS	3 EER	4 RUN HRS/YR	5 REC TONS	6 REPLACEMENT MAKE/MODEL #	7 REPL EER	8 EST COST	9 KWH/YEAR SAVINGS	10 $/YEAR SAVINGS	11 PAYBACK YEARS
FIRE STATION 17	Goettl	RBCU 301 A	Apr-85	2.50	7.7								
FIRE STATION 18	Goettl	RBCU-361A3	Jan-84	3.00	8.4								
FIRE STATION 18	Goettl	RBCU-361A3	Jan-84	3.00	8.4								
FIRE STATION 19	Payne	60RAC 358C	Jan-83	5.00	7.5								
FIRE STATION 19	Lennox	HS8 653V5F	Jan-75	5.00	7.2	1785	4.0	Lennox HS14-513V	9.95	$2,604	4111	$452	5.8
FIRE STATION 19	Lennox	HS8 653V5F	Jan-75	5.00	7.2	1785	4.0	Lennox HS14-513V	9.95	$2,604	4111	$452	5.8
FIRE STATION 20	Goettl	GW3-3A	Jan-78	4.00	6.7	1015	4.0	Lennox HS14-513V	9.95	$2,604	2374	$261	10.0
FIRE STATION 20	York	MC42-25A	Jan-78	3.50	7.0	1060	3.5	Lennox HS19-461V	11.00	$1,889	2313	$254	7.4
FIRE STATION 20	Trane	BWC030C100A0	Sep-84	2.50	8.6								
FIRE STATION 21	Goettl	GW 5-1D	Jan-75	5.00	6.9	1548	5.0	Lennox HS14-651V	13.00	$3,107	6314	$695	4.5
FIRE STATION 21	Goettl	ACU-40	Jan-84	3.50	6.4								
FIRE STATION 22	York	PF60-25E	Jan-77	5.00	6.3	1972	4.0	Trane BTC048D	8.60	$1,710	5024	$553	3.1
FIRE STATION 22	York	PF60-25E	Jan-77	5.00	6.3	1972	4.0	Trane BTC048D	8.60	$1,710	5024	$553	3.1
FIRE STATION 23	Carrier	48LD006500 DA	Jun-84	5.00	7.3								
FIRE STATION 23	Carrier	48LD006500 DA	Jun-84	5.00	7.3								
FIRE STATION 24	York	PF60-25D	Jan-77	5.00	6.3	1508	4.0	Trane BTC048D	8.60	$1,710	3841	$423	4.0
FIRE STATION 24	York	PF60-25D	Jan-77	5.00	6.3	1508	4.0	Trane BTC048D	8.60	$1,710	3841	$423	4.0
FIRE STATION 25	Goettl	AGW-63	Jan-83	5.00	6.2								
FIRE STATION 25	Goettl	GW-25-1	Jan-83	2.00	6.5								
FIRE STATION 26	Goettl	AGW-63	Jan-83	5.00	6.2								
FIRE STATION 26	Goettl	ACU-40	Jan-83	3.50	6.4								
FIRE STATION 27	Payne	48RAC-1S6	Jan-67	4.00	7.0	1636	4.0	Lennox HS14-511V	13.20	$2,604	5268	$579	4.5
FIRE STATION 27	Payne	30 RAC-1S6A	Jan-67	2.50	6.9	1612	2.5	Lennox HS19-311V	11.85	$1,573	2929	$322	4.9
FIRE STATION 28	York	CM48-6A	Jan-70	4.00	7.7	1823	4.0	Lennox HS14-511V	13.20	$2,604	4734	$521	5.0
FIRE STATION 28	York	CM30-6A	Jan-70	2.50	7.7	1823	2.5	LENNOX HS19-311V	11.85	$1,573	2487	274	5.8
FIRE STATION 29	Goettl	RBCU-481A	Jan-84	4.00	8.0								
FIRE STATION 29	York	CA31-10-A	Jan-67	2.50	7.7	1967	2.5	LENNOX HS19-311V	11.85	$1,573	2484	295	5.3
FIRE STATION 30	York	CA48-10AY	Jan-67	4.00	7.7	1632	4.0	LENNOX HS14-511V	13.20	$2,604	4240	466	5.6
FIRE STATION 30	York	CA31-10-A	Jan-67	2.50	7.7	1632	2.5	Lennox HS19-311V	11.85	$1,573	2227	$245	6.4
FIRE STATION 31	Lennox	HP8-653V-1L	Jan-77	5.00	6.6	1947	5.0	York E1CS060	8.50	$2,588	3956	$435	5.9
FIRE STATION 33	Payne	30 RAC-1S6	Jan-67	2.50	6.9	2012	2.5	Lennox HS19-311V	11.85	$1,573	3654	$402	3.9
FIRE STATION 33	Payne	48 RAC-1S6	Jan-67	4.00	7.0	2041	4.0	Lennox HS14-511V	13.20	$2,604	6575	$723	3.6
FIRE STATION 34	York	CM 30-6A	Jan-67	2.50	7.7	2049	2.5	Lennox HS19-311V	11.85	$1,573	2796	$308	5.1
FIRE STATION 34	York	CM 48-6A	Jan-67	4.00	7.7	2049	4.0	Lennox HS14-511V	13.20	$2,604	5322	$585	4.4
FIRE STATION 35	BDP	542ED60HP	Sep-80	5.00	7.5	1100	5.0	Carrier 50QV/QZ006	9.00	$3,118	1467	$132	23.6
FIRE STATION 35	BDP	542ED60HP	Sep-80	5.00	7.5	1190	4.0	Lennox CHP15-513	8.30	$2,158	917	$83	26.1
FIRE STATION 35	BDP	542ED60HP	Sep-80	5.00	7.5	1190	4.0	Lennox CHP15-513	8.30	$2,158	917	$83	26.1
FIRE STATION 36	Westinghouse	HR022KCW	Jan-76	2.00	7.0	2006	2.0	Lennox HS16-211V	11.30	$1,367	2617	$288	4.7
FIRE STATION 36	Westinghouse	HR022KCW	Jan-76	2.00	7.0	2006	2.0	Lennox HS16-211V	11.30	$1,367	2617	$288	4.7
FIRE STATION 37	Carrier	48LD006500 DA	JUN-84	5.00	7.3								

TABLE 8 -(continued)

BUILDING NAME	UNIT MAKE/MODEL #		1 START DATE	2 TONS	3 EER	4 RUN HRS/YR	5 REC TONS	6 REPLACEMENT MAKE/MODEL #	7 REPL EER	8 EST INST COST	9 KWH/YEAR SAVINGS	10 $/YEAR SAVINGS	11 PAYBACK YEARS
FIRE STATION 37	Carrier	48LD006530 DA	Jun-84	5.00	7.3								
FIRE STATION 38	Intertherm	ACC048EAVAA	Jan-78	4.00	8.5								
FIRE STATION 39	Intertherm	ACC048EAVAA	Jan-78	4.00	8.5								
FIRE STATION 40	BDP	542 EP 060	Jan-82	5.00	7.6	1819	4.0	Trane BTC048D	8.60	$1,710	1670	$184	9.3
FIRE STATION 40	BDP	542 EP 060	Jan-82	5.00	7.6	1819	4.0	Trane BTC048D	8.60	$1,710	1670	$184	9.3
FIRE STATION 42	Carrier	38EQ006410	Jun-80	5.00	7.8	2310	5.0	York E1CS060	8.50	$2,588	1464	$161	16.1
FIRE TRAINING ACADEMY	BDP	566CP135	Jun-85	10.00	8.2								
FIRE TRAINING ACADEMY	BDP	566CP135	Jun-85	10.00	8.2								
FIRE TRAINING ACADEMY	BDP	585GJ030040	Jun-85	2.50	8.2								
FIRE TRAINING ACADEMY	BDP	599C0600L1PACDH	Jan-78	5.00	7.0	1098	5.0	Carrier 50-CV/CZ006 5/6	9.50	$3,004	2477	$223	13.5
FIRE TRAINING ACADEMY	BDP	599C0600L1PACDH	Jan-78	5.00	7.0	1098	5.0	Carrier 50-CV/CZ006 5/6	9.50	$3,004	2477	$223	13.5
FIRE TRAINING ACADEMY	BDP	559B048PAC	Jan-78	4.00	6.7	1051	4.0	Trane BTC048D	8.60	$1,710	1663	$150	11.4
FIRE TRAINING ACADEMY	BDP	568B060RCUHL	Jan-78	5.00	7.0	1098	3.0	Lennox HS14-413	10.40	$2,293	3077	$277	8.3
EMERGENCY MED SERVICE	Day & Night	569CP060	Jan-82	5.00	7.7	1657	5.0	Lennox HS14-653V	9.45	$3,107	2391	$215	14.4
EMERGENCY MED SERVICE	Day & Night	510C042	Jan-82	3.50	7.5	1614	3.5	Lennox HS19-461V	12.00	$1,889	3390	$305	6.2
FIRE RESOURCE MGMT	Carrier	38EA009430	Jan-77	8.50	7.9	1233	8.5	Carrier 38EA008	9.50	$4,398	2681	$241	18.2
FIRE RESOURCE MGMT	York	PF 60-25H	Jan-77	5.00	6.3	983	5.0	Lennox HS14-653V	9.45	$3,107	3121	$281	11.1
PERFORMING ARTS BLDG	GE	BGWA090C2D	Jan-76	7.50	7.8	447	7.5						
PERFORMING ARTS BLDG	GE	BGWA090C2D	Jan-76	7.50	7.8	485	7.5						
PERFORMING ARTS BLDG	GE	BGWA120C2D	Jan-76	10.00	8.0	348	7.5						
PERFORMING ARTS BLDG	GE	BGWA860R3B	Jan-76	5.00	7.2	435	5.0						
PERFORMING ARTS BLDG	GE	BGWA860R3B	Jan-76	5.00	7.2	435	5.0						
PERFORMING ARTS BLDG	GE	BGWA090C2D	Jan-76	7.50	7.8	276	5.0						
PERFORMING ARTS BLDG	GE	BGWA120C2D	Jan-76	10.00	8.0	443	10.0						
PERFORMING ARTS BLDG	GE	BGWA120C2D	Jan-76	10.00	8.0	440	7.5						
PERFORMING ARTS BLDG	GE	BGWA120C2D	Jan-76	10.00	8.0	439	7.5						
ARTS & CRAFTS BLDG	GE	BGWA860R3A	Jan-73	5.00	7.2	369	4.0	Carrier 38QH048	8.15	$3,172	358	$32	98.4
ARTS & CRAFTS BLDG	GE	BGWC060B3E	Jan-73	5.00	6.8	578	5.0	Carrier 50QV/QZ006	9.00	$3,118	1246	$112	27.8
ARTS & CRAFTS BLDG	GE	BGWC120A2C	Jan-73	10.00	8.0	356	7.5	Trane BWC090E/C	8.90	$4,708	539	$49	97.0
ARTS & CRAFTS BLDG	GE	BGWC120A2C	Jan-73	10.00	8.0	356	7.5	Trane BWC090E/C	8.90	$4,708	539	$49	97.0
ARTS & CRAFTS BLDG	GE	BGWC060B3E	Jan-73	5.00	6.8	555	5.0	Carrier 50QV/QZ006	9.00	$3,118	1197	$128	28.9
ARTS & CRAFTS BLDG	GE	BGWA360R3A	Jan-73	5.00	7.2	398	4.0	Carrier 38QH048	8.15	$3,172	387	$35	91.1
WASH ADULT CENTER	Lennox	?	Jan-69	12.00	6.6	710	11.0	Trane BTC130G	8.40	$5,608	3320	$299	18.8
WASH ADULT CENTER	Lennox	?	Jan-69	12.00	6.6	710	11.0	Trane BTC130G	8.40	$5,608	3320	$299	18.8
WASH ADULT CENTER	Lennox	HP6-1353V-3EW	Jan-69	10.00	6.6	710	10.0	Carrier 38AQ012	9.00	$5,986	3443	$310	19.3

TRAKLOAD computer simulations described above. The recommended replacement manufacturer and model number in column 6 was determined from researching the latest HVAC equipment from Trane, Carrier, Lennox and York. A printout of all units researched for each manufacturer is included in Appendix B. In looking at the efficiencies in the Appendix it becomes apparent that some unit types, such as electropacks, have not improved appreciably in performance. This scenario will be evaluated later in the text.

The replacement Energy Efficiency Rating (EER) is shown in column 7. The estimated installed cost to replace the existing system appears in column 8 and includes labor costs from the 1987 Mean Cost Data and 20 per cent for profit and overhead. The kilowatt-hour savings per year realized by replacing the existing equipment is presented in column 9 and was derived entirely from the increased efficiency of the new equipment. The equation used to calculate the savings was:

$$\text{KWH/yr Savings} = \frac{\text{Unit Run Hrs/yr}}{\text{Exist Unit EER}} \times \text{Existing Unit Nominal Tons} \times 12 - \frac{\text{Unit Run Hrs/yr}}{\text{Repl. Unit EER}} \times \text{Existing Unit Nominal Tons} \times 12$$

The dollar savings per year in column 10 were calculated by multiplying the savings in column 9 by \$.07 per KWH for large downtown buildings, \$.09 per KWH for medium size buildings and \$.11 per KWH for the smaller buildings. It becomes obvious here that if a lower run time is used, the yearly savings will be lower which then affects the payback in column 11. Thus an erroneous estimate of system run time can cause a poor payback analysis which could eliminate potentially acceptable projects.

ACTUAL EQUIPMENT TESTING

As was mentioned earlier, some results from the survey seemed to vary from the expected, so an actual testing program was initiated. This testing program was designed to produce actual documented data in place of the estimated audit information and then to evaluate the economics of equipment replacement with these results. A comparison of the consultants survey results and of the actual test data will be presented here. The information in question was the estimated run time on much of the air conditioning equipment, the Energy Efficiency Ratings on existing equipment, and the low Energy Efficiency Rating on the replacement equipment. Each of these areas will be expanded upon below.

Actual Run Time Testing

When the original report was evaluated the engineers at the Energy Conservation Office felt that the estimated run times of the chillers and the package units were somewhat low. Since this number becomes quite important in the final calculations it was determined that a sampling of the equipment would be tested for actual run time. Elapsed run time meters were installed on eighteen air conditioners throughout the city and read on a monthly basis. Recalling the equation used to calculate kilowatt-hour savings:

$$\text{Kwh/yr Savings} = \frac{\text{Unit Run Hrs/yr}}{\text{Exist Unit EER}} \times \text{Existing Unit Nominal Tons} \times 12$$

$$- \frac{\text{Unit Run Hrs/yr}}{\text{Repl. Unit EER}} \times \text{Existing Unit Nominal Tons} \times 12$$

From this equation it can easily be seen that run time is critical to the savings calculation. The actual run time is compared to the estimated run time in Table 9.

Testing for Actual Energy Efficiency Rating

Another aspect of the survey that caused some questions was the fact that published Energy Efficiency Ratings were used in the above equation. One

TABLE 9 - Test Result Comparison

BLDG	TONS	PUB EER	REPLC EER	RUN TIME	KWH/YR SAV	PYBK YRS	ACT EER	RUN TIME	KWH/YR SAV	PYBK YR
	CONSULTANT STUDY						ACTUAL TEST			
FAC MAINT	10.0	8.2	9.0	630	1261	26.5	4.75	2136	25,482	2.6
FAC MAINT	7.5	8.7	9.3	622	541	61.6	7.00 a	2187	6,954	7.0
NSC	5.0	5.6	9.0	669	2709	12.8	4.80	2307	13,458	2.6
SQ PK BRIEF	7.5	7.6	9.2	1651	3400	16.4	3.95	2516	32,714	1.5
FIRE #6	4.0	7.7	13.2	2468	6410	3.7	6.90 b	3074	10,206	2.3
FIRE #6	2.5	7.7	11.9	1437	1961	7.3	7.80 b	2498	3,284	4.4
FIRE #27	4.0	7.0	13.2	1636	5268	4.5	6.00 a	2598	11,337	2.1
FIRE #27	2.5	6.9	11.9	1612	2928	4.9	5.90 a	2446	6,245	2.3
FIRE #16	4.0	7.0	13.2	2044	6584	3.6	5.60	2044	10,087	2.3
FIRE #22	5.0	6.3	8.6	1972	5024	3.1	4.50	1972	12,535	1.2
FIRE #22	5.0	6.3	8.6	1972	5024	3.1	5.80	1972	6,642	2.3
FIRE #24	5.0	6.3	8.6	1508	3841	4.0	5.40	2000	8,269	1.9
FIRE #24	5.0	6.3	8.6	1508	3841	4.0	4.40	2000	13,319	1.2
FIRE #30	4.0	7.7	13.2	1632	4240	5.6	7.00 a	2076	6,686	3.5
FIRE #30	2.5	7.7	11.9	1632	2227	6.4	7.00 a	2770	4,859	2.9
WASH AC	10.0	6.6	9.0	710	3443	19.3	5.60 a	1939	15,697	4.2

NOTE:

a - Estimates using actual test results from other buildings.
b - New equipment installed after consultant's study published.

objective of this study was to determine the extent of degradation of HVAC equipment over the years, since published ratings would not reflect the lower efficiencies expected from equipment as it gets older. By using a higher Energy Efficiency Rating in the above equation it is obvious that the savings will be reduced and that paybacks will be increased. To determine if HVAC equipment does in fact run less efficiently over time, a sampling of buildings were tested for efficiency.

HVAC efficiency was discussed earlier in the text, and the equation for Energy Efficiency Rating was given as:

$$\text{Energy Efficiency Rating} = \frac{\text{Net Cooling Capacity (Btu/hr)}}{\text{Electric Input (watts)}}$$

Published values are calculated at designated operating conditions, 95 degrees F dry bulb air on the condenser, 80 degrees F dry bulb and 67 degrees F wet bulb on the cooling coil (evaporator), and 40 degrees F evaporating temperature.

Also the equation for determining the net cooling capacity is:

Net Cooling Capacity = Fluid Flow Rate x Temperature Differential x Conversion Factor

or further stated:

Q (Btu/hr) = Air or Water (cfm or gpm) x Inlet Temp - Outlet Temp.(deg. F) x Conversion Factor

These variables and the test required to obtain them are outlined below. To provide a useful comparison, similar weather conditions to the 95 degree F standard were approximated, which allowed only about two weeks of testing prior to the end of the cooling season.

Air Flow Rates. Air flow rates were obtained by the use of a duct flowhood. This instrument is capable of relatively easy measuring with acceptable accuracy. Both supply and exhaust air was measured for comparison but only the supply readings were used in the calculations. The flow rate equipment used for this test is listed in Appendix C.

Water Flow Rates. An ultrasonic flow measuring instrument was used to record the water flow rate in chilled water systems. This instrument is also found in Appendix C.

Temperature Differential. Supply and return temperatures were taken with an electronic temperature analyzer. Temperatures were recorded just before entering the air conditioning unit and just after exiting the unit to reduce temperature losses.

Actual Kilowatt Usage. The kilowatt usage was recorded using a hand held kilowatt meter concurrent with recording temperatures and flow rates.

Using the data obtained by the above techniques the equations for efficiency and Energy Efficiency Rating could be calculated and compared to the presented ratings that the units had when new. Several pieces of equipment had been replaced since the audits were done and the new equipment was tested and compared to its published rating. Another aspect of the report worth bringing up was the fact that most units were replaced with the same types of equipment presently installed. It is interesting to note that the new packaged units have not improved efficiencies to any great degree and that if these units are replaced with higher efficiency heat pumps the savings will also increase, thus giving a still better payback.

MAGNITUDE OF EQUIPMENT REPLACEMENT OPPORTUNITIES

As was originally presented by the consultant's report, the opportunities for replacing equipment were not widespread. After some of the equipment was actually tested it became apparent that equipment replacement could make a bigger impact than was originally presented. Table 9 shows a comparison of the consultant's study and of the results from testing. Since the sampling was small, a more extensive testing program is being recommended to update the survey data with actual test data on all 82 city buildings. Since the test conditions such as temperature and humidity will affect these test results, several tests are recommended with the results averaged for a more representative efficiency than the single test result.

Chapter 4 - Thermal Storage Demonstration Project

INTRODUCTION

The City of Phoenix began energy conservation efforts in August of 1978 with the creation of the Energy Conservation Office. This office was placed in the Public Works Department and coordinated by the Energy Conservation Manager. The first two years of projects dealt with low-cost/no-cost, fast-payback projects which where in abundance in city facilities. These projects included: the reduction of excessive lighting levels in non-task and unoccupied areas, turning off heating and cooling equipment in unoccupied areas, and enforcing temperature set-backs on water heaters and heating and cooling thermostats.

In July of 1980 the Energy Conservation Office turned to projects of a larger scope. Energy audits of the City's major facilities were completed and cost effective conservation measures were implemented. These innovative retrofits included variable capacity air and water flows in HVAC systems and efficiency improvements in water treatment plants. A portion of the savings these projects earned was put back into the Energy Conservation Office to continue conservation measures. In 1984 the Energy Office began to pursue thermal energy storage and in the following years installed three ice storage systems. The Energy Conservation Office continues to perform lighting retrofits and to install energy management systems. From the initial work completed on the HVAC systems, pumps and motors, it became obvious that substantial savings could be obtained by putting more efficient equipment into operation. This background led to the proposal to the Energy Task Force to investigate HVAC equipment with respect to its efficiency and to demonstrate results from an equipment retrofit. The research in this area has brought out some interesting observations concerning the operation of existing HVAC equipment and the actual efficiencies of this equipment.

DEMONSTRATION PROJECT

Site Selection

Selecting the location to do a demonstration project can be time consuming and nerve-racking. One aspect that helped the Energy Conservation Office in this process was the Technical Assistance energy audit discussed previously. With this type of audit completed and an equipment list compiled, the results can be used in any number of evaluations. The audit information was evaluated to narrow down the options for the equipment replacement demonstration site. As this project evolved it became apparent that it would be useful to look at thermal energy storage as an energy efficient and cost effective retrofit. With this in mind, the locations for the demonstration were reduced due to constraints such as space for storage, the utility servicing these sites, and buildings with existing chillers. The requirements for site selection for thermal storage were outlined in two previous reports, "Thermal Storage Strategies for Energy Cost Reduction" and "Thermal Energy Storage: An Application Guide for Local Governments", so will not be repeated here.

The South Phoenix Adult Center became the final site selection for the equipment replacement demonstration for these reasons:

* Adequate space existed for ice storage;
* The existing equipment was not working effectively and was scheduled for replacement;
* The utility that services the area has an advantageous time-of-use rate structure.

Background on the South Phoenix Adult Center

The South Phoenix Adult Center was constructed in 1976 and the building has not been extensively modified. The building is used for activities for the elderly during the day, seven days a week, and is open for community club, exercise classes and craft meetings in the evenings five nights a week. Noon meals are prepared and served in the building to the elderly five days a week. The HVAC equipment and other appliances will be outlined below. Figure 2 shows the front entrance of the South Phoenix Adult Center.

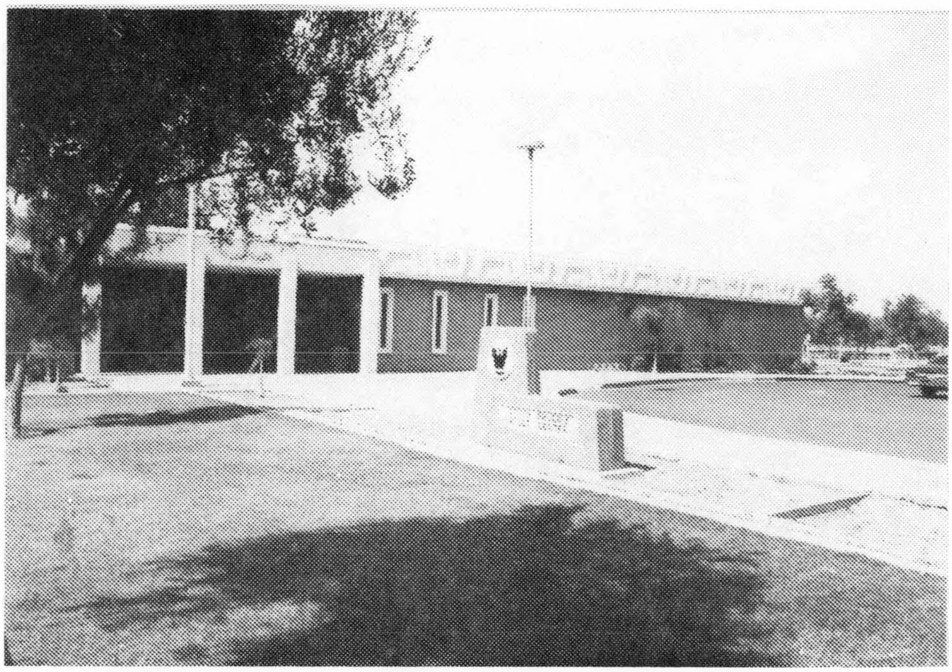

Figure 2 - South Phoenix Adult Center

Ventilation. The building has five exhaust fans that ventilate the restrooms and a single kitchen hood exhaust fan. Exhaust venting was estimated at 2200 cubic feet per minute. Outside air make-up is made directly into the air handlers through ducts and the total intake was estimated at 3350 cubic feet per minute. Three relief hoods are located on the building to allow for the exhaust of excess inlet air.

Heating System. The building has heat strips located in the ducts of each of the five air handler units with a total available heating of 375,340 BTUH. Four of the air handler units are single zone type while the fifth is a multi-zone unit. In the single zone units, heat strips are activated by two control modes. Outdoor temperature is monitored and the outdoor thermostat limits activation of the thermostats to the time when the outdoor temperature is below the outdoor thermostat set point. An indoor thermostat then regulates the two-stage heat strips to maintain indoor temperatures at the indoor set point. Temperature controls for the multi-zone air handler regulates mixing dampers on the hot and cold ducts out of the unit. On a call for heat from a zone thermostat, mixing dampers will close off the chilled air duct and open the heating duct to that zone. Once dampers are fully closed and zone temperature continues to decline, the thermostat will start activating heat strips in the heating duct. The heat strips are in a common duct that connects to the eight zone ducts. If one zone is calling for cooling and another zone requests heating, the potential for mixing heated and cooled air exists if a damper is in a partially closed position. Heating and cooling are controlled by a single thermostat without setback. During winter months no heating is usually required above a 62 degree F outdoor temperature when the building is in use and the lights are on.

Domestic hot water is provided by a single 480 volt, three phase electric water heater where a single nine kilowatt element provides heat for the unit.

Cooling System. The building had a single air cooled 50 ton chiller which circulated chilled water to each of the five air handlers. The four single-zone units utilize a three-way regulating valve to control the amount of water bypass around the cooling air handler coil. For the multi-zone air handler a constant volume of chilled water passes through the coil and zone temperature control is regulated by the air dampers that adjust the amount of cold air going to that zone. Chiller controls unload and shut down the compressor as chilled water temperature decreases. The cooling load at the Adult Center accounts for approximately 48 percent of the building electrical use.

Lighting Systems. The entire building utilizes fluorescent lighting. Light switches are provided to each room allowing lights to be shut off when the room is not in use. The average daytime light load was estimated at 21 kilowatt-hours or 1.49 watts/square foot and the night load was estimated at 8 kilowatt-hours. Total lighting accounts for about 21 percent of the building power usage and produces 59,000 BTUH of heat that must be removed by the building cooling system.

Air and Water Distribution. Chilled water was circulated to the air handlers by a five horsepower chilled water pump. The pump operation was designed to be regulated by outside air temperature and if the outside temperature drops below the outdoor-temperature thermostat set point, the chilled water pump shuts down. The chiller was interlocked with the chilled water pump such that shut down of the chilled water pump automatically shut down the chiller. Air distribution through the building is provided by the five air handlers. The west wing, kitchen and auditorium are cooled by the single zone units and have return air ducts. The east wing utilizes a multi-zone air handler and the return air plenum is the space above the dropped ceiling.

Miscellaneous Equipment. The building is equipped with a kitchen for use in preparing noon meals for senior citizens. The equipment includes a freezer, refrigerator, dishwasher, coffee maker, range and stove. Other appliances include two water coolers, a soft drink machine and copy machine. It was estimated that this equipment uses about 3 kilowatts per hour of power and adds approximately 10,000 Btu/hr to the cooling load of the building.

Monitoring Existing Equipment

The testing procedure for air conditioning equipment has been explained in some detail in the previous chapter and will not be elaborated here. The previous equipment at the Adult Center was a 50 ton air cooled chiller, a reciprocating compressor and using R-22 refrigerant. This unit had been scheduled for replacement by the Air Conditioning Shop due to repeated maintenance requirements and poor cooling performance, so was chosen as the equipment to be replaced for this demonstration.

To calculate the operating efficiency of the existing equipment the following information was required:

* Kilowatt-hour and kilowatt demand;
* Supply and return chilled water temperatures and;
* Flow rate of the chilled water loop.

The initial instrumentation selected to record continuous supply and return chilled water temperatures was a personal computer. This computer was outfitted with a hardware and software package which allowed temperature sensors to be attached to the supply and return plumbing and change the signal for the computer to read and record the data. These temperatures, plus ambient temperature, were logged at fifteen minute intervals. Each disk was capable of holding readings for approximately one month.

An ultrasonic flowmeter was used to record flow rate of the chilled water loop. This information was logged and since the flow rate remained constant until system replacement, the instrument was removed for use in other building testing.

To obtain an electrical power usage of the air conditioning equipment a kilowatt-hour and kilowatt chart recorder was installed. This instrument was capable of recording energy consumed and demand of the compressor, chilled water circulation pump, and the condensing fans on a continuous 24 hour basis.

Appendix C lists the equipment used in the demonstration.

Replacement Equipment Selection

In early evaluation for this project, it was determined that a thermal energy storage system would prove to be the most cost effective due to utility incentives and the time-of-use rate. Appendix D is a compilation of thermal energy storage systems currently on the market. Since the project was to replace inefficient equipment, an ice builder that utilized the existing chiller was not an option, therefore, an ice harvestor was selected. The equipment specifications of the ice harvester can be found in Appendix C. According to the manufacturer's data the compressor efficiency is 1 kilowatt per ton when making ice, which was much more efficient than the original equipment efficiency of 2.2 kilowatts per ton.

Equipment Installation

Installation of the replacement equipment proceeded in the following sequence of steps:

* Site Preparation - Since the installation would take place at the beginning of summer, the old chiller had to stay in place until the new equipment was installed. The ice harvester was manufactured with all the required equipment; pumps, condensing tower, storage tank, compressor, and control wiring, mounted as a package. A concrete pad was required to accommodate the packaged unit, so a six-inch reinforced concrete slab was laid around the existing equipment pad. The site location was at the back of the building. Figure 3 shows the site preparation with the existing chiller still in place.

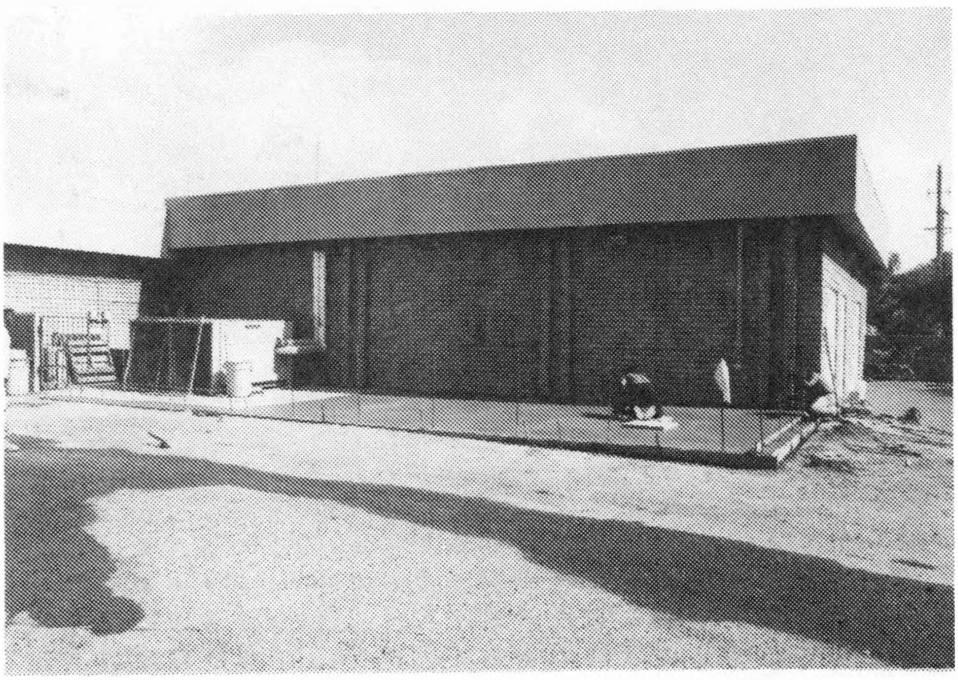

Figure 3 - Thermal Storage Location

* Placement of the Equipment Package - The installation was planned on a Saturday to reduce traffic congestion and because the building is only partially used on weekends when the cooling disruption would have a minimum impact. The ice harvester was

delivered on Saturday morning, June 6, 1987. A large crane was required to lift the old chiller out and the new thermal storage system into place. With the packaged arrangement, this phase of the installation took only four hours. Figure 4 shows the thermal storage package arriving at the Adult Center.

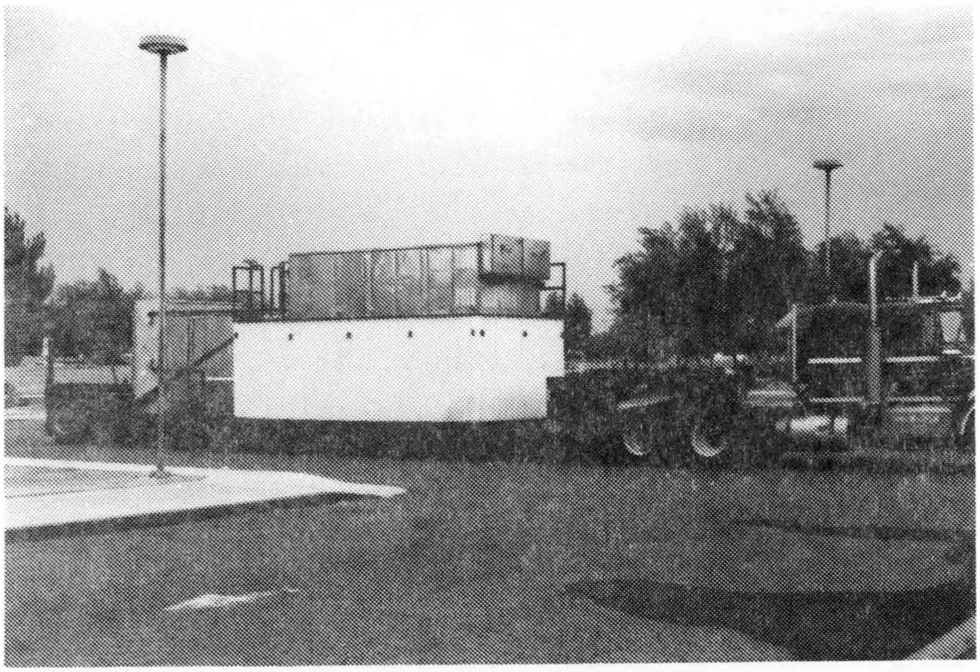

Figure 4 - Equipment Arrival

* Electrical and Plumbing Connections - After the system was placed on the slab, electricity and piping connections were required. The 460-volt electrical power was taken from the old equipment junction box and routed to the control boxes on the equipment. This operation took approximately three hours and was done concurrently with the plumbing. The chilled water supply and return lines were cut from the old chiller and a short pipe run was required to reconnect the new system. This also took only about four hours and by the end of the work day on Saturday the new equipment was ready for testing. The large storage tank was filled with the use of a fire hose and a nearby Fire hydrant, and only required a few hours of time. Figure 5 shows the system in place and ready for testing.

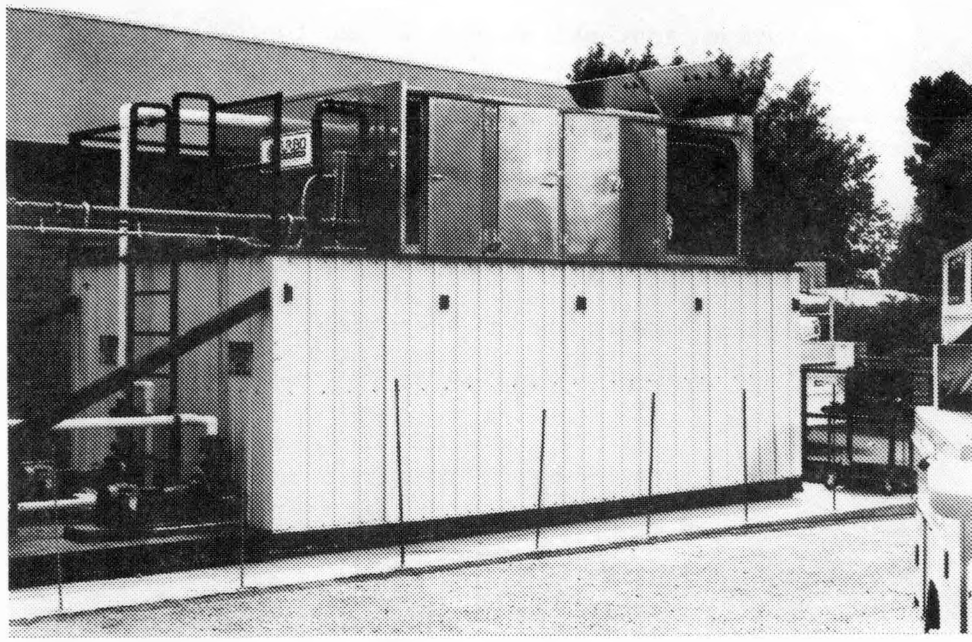

Figure 5 - System In Place

* System Test - On the following day, the equipment was tested to insure correct operation. By that evening the ice harvester was making ice and by the following morning a full tank of ice was ready for suppling chilled water to the building. Figure 6 shows the ice plates and the tank with a full load of ice.

Figure 6 - System Ice Harvesting

* Improving Aesthetics - A seven foot slump block wall matching the building exterior was later built around the equipment. This accomplished several objectives; a) To improve the architectural appearance of the installation, b) To provide security to the equipment and controls and reduce unauthorized tampering with the system, c) To reduce the noise level of the equipment when it is operating. Figure 7 shows the thermal storage system in operation with the block wall installed.

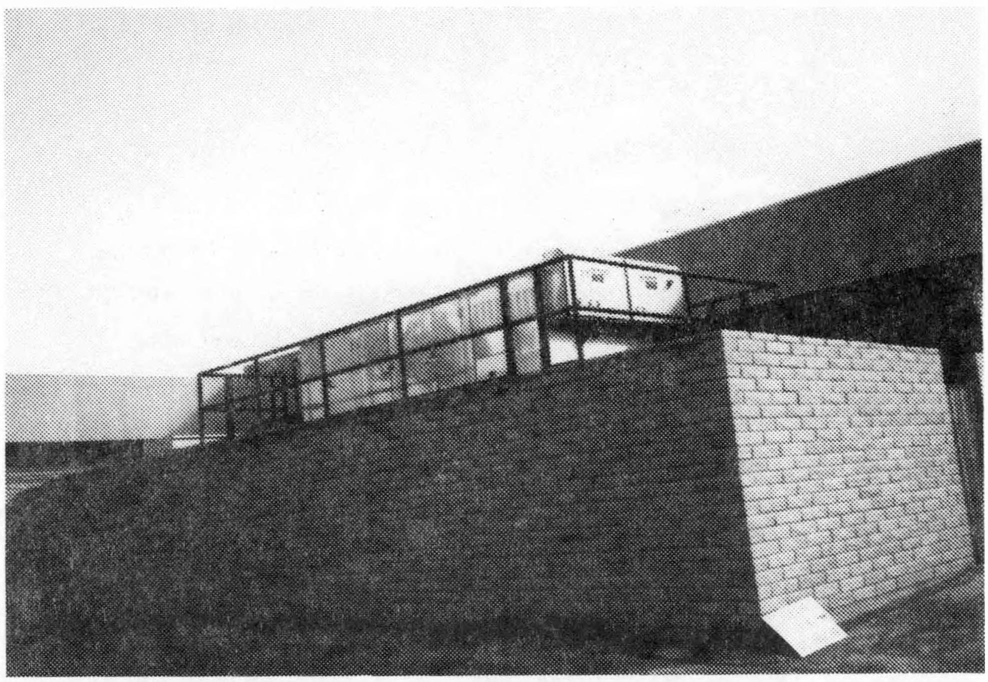

Figure 7 - Completed Installation

Considering the magnitude of the installation and the time it would have taken to install each piece of equipment separately, the packaged arrangement saved considerable time and insured that the equipment would receive a useful test through the hottest part of the summer.

Monitoring the New Equipment

After the old unit was removed, data collection began on the replacement system. The supply and return water temperatures and the ambient temperature continued to be recorded by the computer. A new flow rate was measured with the ultrasonic flowrate instrument and the chart recorder continued to record kilowatt-hours and kilowatts.

The chart recorder became quite useful for trouble shooting system problems that occurred in the following months. These problems will be discussed in the next chapter. An energy management system was in use to control air handlers in response to the building occupancy. This system had the capability to expand in the areas we required so was not replaced. In the first week of August a 1200 baud modem was added to the energy management system which allowed remote communication from the Adult Center and permitted the Energy Conservation Office to remove the computer from the building mechanical room. A pulse meter was later added to the energy management system which freed up the chart recorder and permitted remote kilowatt-hour and kilowatt data collection. Figure 8 shows the computer in the Energy Conservation Office being used for data collection from the Adult Center.

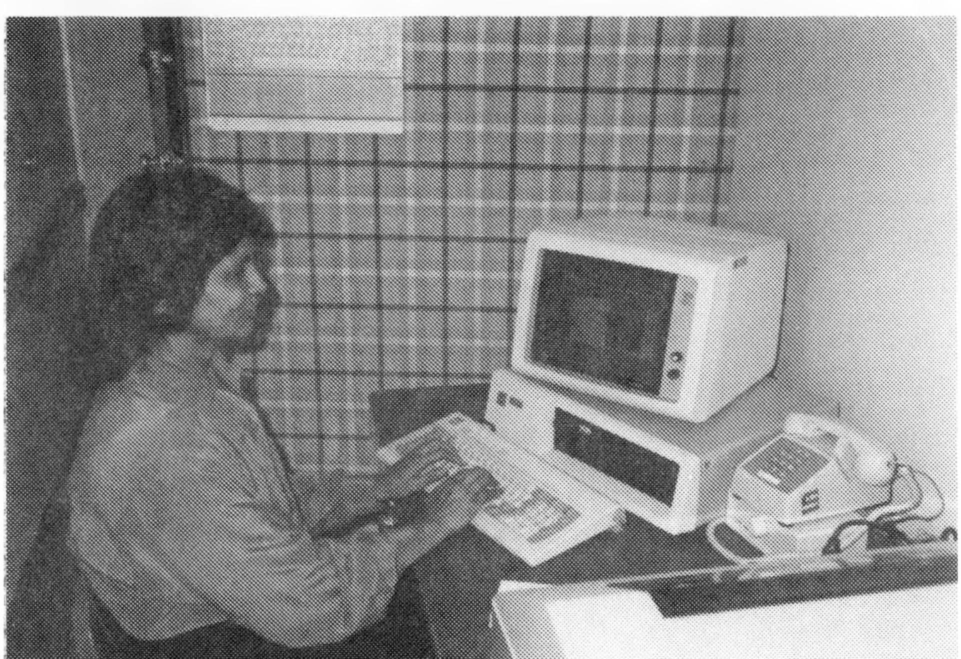

Figure 8 - Remote Data Recovery

The equipment kilowatts (demand) and kilowatt-hours (energy use) along with the chilled water supply and return temperatures were recorded for approximately six months starting in April 1987. Using the energy data from the chart recorder, a load graph for the previous equipment is shown in Figure 9 for Friday, June 5, 1987. It can be seen from this figure that the equipment is operating at full load or close to full load during the occupancy times. This profile does not look like the average load curve which would resemble a bell curve more closely and again brings out the fact that the original equipment was not cooling the building adequately. The equipment change was accomplished on June 6, 1987 and an example of the load profile of the new thermal storage equipment for Tuesday, June 9, 1987 is shown in Figure 10. The thermal storage equipment load was quite consistent throughout the test and averaged approximately 700 to 800 kilowatt-hours per day.

Demonstration Economics. The economics of the demonstration project can be presented in two ways. The first method uses the total cost of the replacement equipment while the second method deducts the cost of replacing the present equipment with a conventional chiller. The City of Phoenix had budgeted $45,000 for equipment to replace the existing chiller compared with a total cost for the thermal storage system, materials and labor, of $99,144. Using the total replacement cost and subtracting the utility incentive of $15,875, a somewhat lower cost of $83,269 is obtained. The Salt River Project, Thermal Energy Storage Incentive Program is outlined in Appendix E along with a copy of the City of Phoenix's incentive application for the South Phoenix Adult Center.

The existing system run time was found to be approximately 1900 hours for the cooling season. From the test data obtained by the methods previously described, the existing equipment had an average Energy Efficiency Rating (EER) of 5.45 and a demand of 2.2 kilowatts per ton. The efficiency of the thermal storage system was given as an Energy Efficiency Rating (EER) of 12 and a demand of 1 kilowatts per ton, rated at 38 tons when making ice.

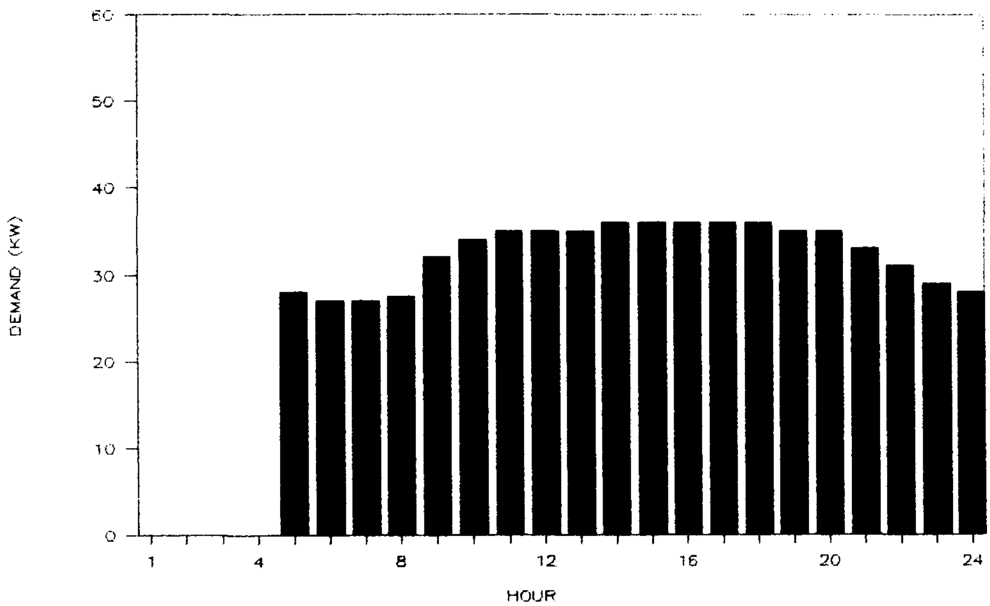

Figure 9 - Original Chiller Load Profile

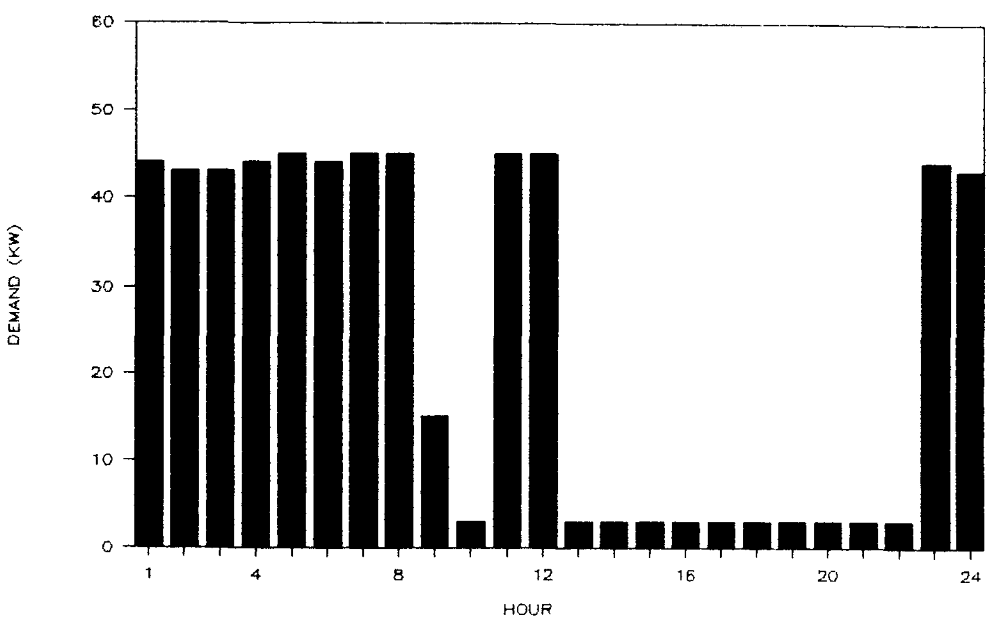

Figure 10 - Thermal Storage Load Profile

Using the equation for energy savings outlined in chapter 3 and applying the results from the Adult Center yields:

$$\text{KWH/yr Savings} = \frac{1900\ \text{hrs/yr}}{5.6\ \text{EER}} \times 50\ \text{tons} \times 12 - \frac{1900\ \text{hrs/yr}}{12\ \text{EER}} \times 38\ \text{tons} \times 12$$

$$= 131{,}371\ \text{kwh/yr}$$

Using the cost of electricity of $0.09 per kilowatt-hour as presented in chapter 3 for medium sized buildings the savings can be calculated as:

$$\text{Yearly Savings} = 131{,}371\ \text{kwh/yr} \times \$0.09\text{/kwh} = \$11{,}823$$

A simple payback will give an approximate measure of the overall economics of this equipment replacement and is accepted and understood by most managers evaluating the economics. First using the total replacement cost, minus the incentive, of $83,269 and the annual thermal storage savings of $11,823, the simple payback can be calculated as:

$$\text{Simple Payback} = \frac{\$83{,}269}{\$11{,}823} = 7\ \text{years}$$

Since this system was already scheduled for replacement, the difference of the cost for higher efficiency can be used in the economics. In the demonstration project, the cost difference for the thermal storage over a conventional chiller was $54,144 and deducting the incentive gives a total added cost of $38,269. Working the simple payback with this cost yields:

$$\text{Simple Payback} = \frac{\$38{,}269}{\$11{,}823} = 3.2\ \text{years}$$

The economics of higher efficiency equipment replacement for systems that are obsolete is quite good for thermal storage where an utility incentive improves the payback considerably. The replacement of low efficiency, but operable equipment, is still within most jurisdictions allowable limits.

Chapter 5 - Summary and Recommendations

HVAC EQUIPMENT SURVEY

Although the study done by the contractor for the City of Phoenix was extensive, it did have some short-comings. It can be seen that this type of survey and equipment list would prove valuable to any municipality and is highly recommended. With access to an outline of this nature, the opportunities for efficient equipment operation and dollar savings is substantial. It is readily apparent that the City building survey is a useful tool, and it is also apparent that unless the data is accurate and complete the information will not prove helpful. The consultant's work was extensive and the list of equipment thorough, however, several miscalculations gave lower than expected savings and higher than acceptable paybacks.

Summary of Report Findings

Following is a summary of the consultant's findings in each of the various categories.

Chillers. The most promising energy conservation opportunity for centrifugal chillers was at the Municipal Building. Three options showed paybacks of five years or less with the best payback accomplished by reusing the shell of one of the existing 400 ton Trane chillers and replacing the compressor and motor with a 200 ton. The cost was estimated at $85,000 with an estimated savings of $21,000 per year for a payback of about four years. The conclusion for reciprocating chillers was that it is not cost effective to replace them because their efficiency has not improved significantly in recent years. When reciprocating chillers are due for replacement it will be beneficial to find the highest efficiency model available.

Boilers. Boiler retrofit or replacement is limited because the City has few boilers and the number of annual heating degree days is low. A payback of 6.3 years is possible by replacing the existing Municipal Building boilers with five 150,000 BTUH gas-fired pulse combustion boilers, which will save about $2,300 per year.

Pumps. Many of the condenser water, chilled water, and hot water pumps are suppling excessive flow. Those pumps with variable frequency drive already installed but operating above design flow rates can save $32,000 per year by slowing the pump motors down to design flow. Significantly more savings can be achieved by using the variable frequency drive for automatic variable speed pumping based on building load conditions. For pumps below 7.5 horsepower a saving can be achieved by valve adjustment to reduce the flow to design.

Fans. Most fans have already been optimized by using variable air volume (VAV) fans which automatically vary the air flow based on actual building load. The cafeteria air handling unit and the Council Chambers multizone air handling unit at the Municipal Building can be slowed down with potential savings of about $1,000 per year.

DX Air Conditioning Units and Heat Pumps. There are a significant number of existing direct expansion air conditioning units and heat pumps that can be replaced with new optimally sized high efficiency units. Nineteen units can be replaced with an approximate five year payback and an annual total savings of $10,000. Another thirty seven units and be replaced for a savings of $11,600 per year and paybacks between five and ten years.

Summary of Actual Testing

The limited test results showed that energy savings are substantially increased when accurate run times and actual Energy Efficiency Ratings are used. It is the intention of the Energy Conservation Office to expand the testing program to include testing all 82 of the buildings and a possible retest program to verify the initial test results.

One aspect of the testing program that bears elaboration is the fact that this type of program can prove valuable for maintenance purposes. One test resulted in a low air flow rate requiring a filter change which brought the measured flow rate up to the design flow rate. When these two readings were used to calculate Energy Efficiency Rating, the low flow rate yielded a value of four while the higher flow rate with clean filters gave a rating of five. Also in testing the air flow it was found that one supply duct had no flow rate and upon closer investigation it was observed that the flexible duct was pinched closed. This type of testing program can actually find many maintenance problems that when corrected will improve the efficiency considerably and will prove more cost effective than equipment replacement. Looking back at Table 9, the deviation between the consultant's study and the test results can be seen.

THE DEMONSTRATION PROJECT

The comparison of the existing 50 ton chiller and the ice storage system was a little more complex than originally contemplated. First, the existing unit was not cooling the building adequately so in fact showed a lower kilowatt-hour usage than was expected. Secondly, the thermal storage system's published efficiency was used since actual testing of the system was more complex than the Energy Conservation Office could undertake. The results of the demonstration project did show that thermal storage could be cost effective utilizing the utility's time-of-use rate. Although it has been difficult to show energy savings on this type of equipment replacement, a dollar savings was recorded.

Lessons Learned

Some useful lessons were learned concerning the actual installation and operation of the demonstration project. The City had already installed two ice-building thermal storage systems , but this was the first ice harvesting system. The relative ease of installation was something the packaged arrangement allowed and which was essential in this project due to time constraints. A major problem that was encountered several times with this equipment was a system shutdown due to the thermal overloads on the motor starters and ultimately resulted in every motor overload protection being replaced with higher rated overload protection. This problem seemed to be the result of high circuit box temperatures which lowered the ratings of these devices. In most other climates the protection shipped with the unit might have been adequate, however in Arizona they should all be increased to the next larger size. Another problem that was encountered concerned the system's high ice sensor and the nature of the ice buildup and burn-off. Because the ice mounds in the center of the tank and can become quite hard after settling, the sensor will not allow the unit to begin ice making until much of the ice is melted. During the critical periods of the cooling season this would lose an hour or more of ice harvesting and could cause a shortage of chilled water before the on-peak time period was over. This situation will be rectified with the replacement of a new high ice sensor.

FURTHER RESEARCH

The following areas bear further investigation by local governments considering equipment evaluation and replacement:

* More actual equipment testing to verify whether operational problems are caused by improper maintenance or equipment inefficiency.
* Continued installation and evaluation of thermal storage for both new and retrofit applications, to include phase change and chilled water storage to determine the most cost effective opportunities.
* Find the most cost effective and reliable test equipment for performing the actual system testing.
* Continued investigation of utility incentives to maximize load management and cost savings.

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Appendix B - New HVAC Equipment Energy Efficiency Rating

ROOFTOP GASPACKS

NOMINAL TON CAPACITY		LENNOX		YORK	
2.5	MODEL #	GCS10-311		D3EC030	
	PHASE	1		1	
	SEER/EER	7.9		8.5	
3	MODEL #	GCS10-411	GCS10-413	DEC036DEC036	
	PHASE	1	3	1	3
	SEER/EER	9.00	8.25	8.5	8.5
4	MODEL #	GCS10-511	GCS10-513	D3EC04D3EC048	
	PHASE	1	3	1	3
	SEER/EER	8.6	8.0	8.0	8.5
5	MODEL #	GCS10-651	GCS10-653	D3EC06D3EC060	
	PHASE	1	3	1	3
	SEER/EER	8.7	8.0	8.5	8.5
7.5	MODEL #		GCS11-953		D1SS090
	PHASE				3
	SEER/EER		8.25		8.2
10	MODEL #		GCS11-1353		D1SS120
	PHASE				3
	SEER/EER		8.2		7.6
15	MODEL #		GCS11-1853		D1SS180
	PHASE				3
	SEER/EER		8.2		8.2
20	MODEL #		GCS11-2753		D1SS240
	PHASE				3
	SEER/EER		8.3		8.0

Note: SEER's are given for single phase units.
EER's are given for three phase units.

ROOFTOP GASPACKS (CON'T)

NOMINAL TON CAPACITY		CARRIER		TRANE
2.5	MODEL #	48-KLA130		
	PHASE	1		
	SEER/EER	9.5		
3	MODEL #	48-KLA136	48-KLA036	
	PHASE	1	3	
	SEER/EER	9.5	8.5	
4	MODEL #	48-KLA148	48-KLA048	
	PHASE	1	3	
	SEER/EER	9.5	8.5	
5	MODEL #	48-HV/HZ006	48-HV/HZ006	BYC060F
	PHASE	1	3	3
	SEER/EER	9.7	9.2	7.8
7.5	MODEL #		48-LV/HV/LZ/HZ008	BYC100G (8.5 Tons)
	PHASE		3	3
	SEER/EER		9.2	8.3
10	MODEL #		48-DP/DR012	BYC130G (11 Tons)
	PHASE		3	3
	SEER/EER		8.3	8.4
15	MODEL #		48-DP/DR016	BYC170G (14 Tons)
	PHASE		3	3
	SEER/EER		8.3	8.5
20	MODEL #		48-DP020 (18 Tons)	SFHC20
	PHASE		3	3
	SEER/EER		8.0	9.0

ELECTRAPACKS

NOMINAL TON CAPACITY		CARRIER		TRANE	
2	MODEL #	50EE024		BTC024C	
	PHASE	1		1	
	SEER/EER	9.5		9.5	
3	MODEL #	50EE036	50EE036	BTC036100B	BTC036300B
	PHASE	1	3	1	3
	SEER/EER	9.5	8.4	9.75	8.35
4	MODEL #	50EE048 3	50EE048 3	BTC048D	BTC048D
	PHASE	1	3	1	3
	SEER/EER	9.5	8.2	9.2	8.6
5	MODEL #	50CV/CZ006 3	50CV/CZ006 5/6	BTC06061	BTC06063/4
	PHASE	1	3	1	3
	SEER/EER	10.0	9.5	9.0	8.25
7.5	MODEL #		50CV/CZ008		BTC090F
	PHASE		3		3
	SEER/EER		9.3		8.75
10	MODEL #		50DP012		BTC120F
	PHASE		3		3
	SEER/EER		8.3		8.65
12.5	MODEL #		50DP014		BTC130G (11 Tons)
	PHASE		3		3
	SEER/EER		8.0		8.4
15	MODEL #		50DP016		BTC170 (14 Tons)
	PHASE		3		3
	SEER/EER		8.3		8.6
20	MODEL #		50DP020		SEHB200
	PHASE		3		3
	SEER/EER		8.0		8.42

ELECTRAPACKS (CON'T)

NOMINAL TON CAPACITY		LENNOX		YORK	
2	MODEL #	CHA15-261		D2PF024	
	PHASE	1		1	
	SEER/EER	9.4		9.05	
3	MODEL #	CHA15-411	CHA15-413	D2PF036	D2PF036
	PHASE	1	3	1	3
	SEER/EER	9.2	8.5	8.85	9.1
4	MODEL #	CHA15-511	CHA15-513	D2PF048	D2PF048A
	PHASE	1	3	1	3
	SEER/EER	9.3	8.4	8.55	8.5
5	MODEL #	CHA15-651	CHA15-653	D4PF060	D4PF060A
	PHASE	1	3	1	3
	SEER/EER	9.45	8.8	8.4	8.3
7.5	MODEL #		CHA11-953		D1CS090
	PHASE		3		3
	SEER/EER		8.25		8.2
10	MODEL #		CHA11-1353		D1CS120
	PHASE		3		3
	SEER/EER		8.2		8.2
12.5	MODEL #				
	PHASE				
	SEER/EER				
15	MODEL #		CHA11-1853		D1SS180
	PHASE		3		3
	SEER/EER		8.2		8.2
20	MODEL #		CHA11-2753		D1SS240
	PHASE		3		3
	SEER/EER		8.3		8.0

Note: SEER's are given for single phase units.
EER's are given for three phase units.

SPLIT SYSTEM HEAT PUMPS

NOMINAL TON CAPACITY		CARRIER		TRANE	
2.5	MODEL #	38QH030	38QH030		
	PHASE	1	3		
	SEER/EER	9.0-9.55	8.0-8.75		
3.5	MODEL #	38QH042	38QH042		
	PHASE	1	3		
	SEER/EER	9.35-9.5	8.15-8.5		
5	MODEL #	38QH060	38QN060		
	PHASE	1	3		
	SEER/EER	9.55-10.3	7.0-7.3		
7.5	MODEL #		38BQ008		BWA090C
	PHASE		3		3
	SEER/EER		9.1		8.8
10	MODEL #		38AQ012		BWA120C
	PHASE		3		3
	SEER/EER		9.0		8.25
20	MODEL #		38AQ024		BWA240C
	PHASE		3		3
	SEER/EER		8.2		8.2

		LENNOX		YORK	
2.5	MODEL #	HP16-311V		E1CS030	
	PHASE	1		1	
	SEER/EER	9.1-9.25		9.0	
3.5	MODEL #	HP16-461V		E1CS042	
	PHASE	1		1	
	SEER/EER	8.55-9.0		9.0-9.5	
5	MODEL #	HP14-651V	HP14-653V	E1CS060	E1CS060
	PHASE	1	3	1	3
	SEER/EER	9.95-11.0	7.95-8.45	9.0	8.5
7.5	MODEL #		HP17-953V		E1CH090
	PHASE		3		3
	SEER/EER		8.5		8.5
10	MODEL #		HP17-1353V		E1CH120
	PHASE		3		3
	SEER/EER		8.2		8.2
20	MODEL #		HP17-1353V		
	PHASE		3		
	SEER/EER		8.2		

PACKAGE HEAT PUMPS

NOMINAL TON CAPACITY		CARRIER		TRANE	
2.5	MODEL #	50QQ030	50QQ030	BWC030C	
	PHASE	1	3	1	
	SEER/EER	9.0	8.9	9.5	
3.5	MODEL #	50QQ042	50QQ042	BWC042D	BWC042D
	PHASE	1	3	1	3
	SEER/EER	9.0	8.5	8.6	8.2
4	MODEL #	50QQ048	50QQ048	BWC048D	BWC048D
	PHASE	1	3	1	3
	SEER/EER	9.0	8.2	8.75	8.05
5	MODEL #	50QV/QZ006	50QV/QZ006	BWC060G	BWC060G
	PHASE	1	3	1	3
	SEER/EER	9.6	9.0	9.05	8.1
7.5	MODEL #		50QD/QH008		BWC090F/C
	PHASE		3		3
	SEER/EER		8.3		8.9
10	MODEL #		50PQ012		BWC120F/C
	PHASE		3		3
	SEER/EER		8.2		8.2

		LENNOX		YORK	
2.5	MODEL #	CHP15-311	CHP15-313	B2SP030	
	PHASE	1	3	1	
	SEER/EER	9.05	8.0	8.3	
3.5	MODEL #	CHP15-461	CHP15-463	B1SP042	
	PHASE	1	3	1	
	SEER/EER	9.0	8.0	7.7	
4	MODEL #	CHP15-511	CHP15-513	B1SP048	B1SP048
	PHASE	1	3	1	3
	SEER/EER	9.55	8.3	8.0	7.75
5	MODEL #	CHP15-651	CHP15-653	B2SP060	B2SP060
	PHASE	1	3	1	3
	SEER/EER	9.0	8.1	8.1	8.15
7.5	MODEL #		CHP11-953		B1SP090
	PHASE		3		3
	SEER/EER		8.2		8.5
10	MODEL #		CHP11-1353		B1SP120
	PHASE		3		3
	SEER/EER		8.2		8.3

SPLIT SYSTEM A/C UNITS

NOMINAL TON CAPACITY		CARRIER		TRANE
2.5	MODEL #	38ED030	38EN030	
	PHASE	1	3	
	SEER/EER	9.7-10.3	7.5-7.75	
3	MODEL #	38ED036	38EH036	
	PHASE	1	3	
	SEER/EER	10.95-11.25	8.1-8.9	
3.5	MODEL #	38ED042	38EH042	
	PHASE	1	3	
	SEER/EER	9.5-10.8	8.0-8.3	
4	MODEL #	38ED048	38EH048	
	PHASE	1	3	
	SEER/EER	9.5-10.0	8.05-8.65	
5	MODEL #	38ED060	38EH060	
	PHASE	1	3	
	SEER/EER	9.0-9.25	8.0-8.2	
7.5	MODEL #		38BA008	BTA090C-M
	PHASE		3	3
	SEER/EER		8.7-9.5	8.75
10	MODEL #		38AE012	BTA120D
	PHASE		3	3
	SEER/EER		8.1-9.3	8.8
15	MODEL #		38JB016	BTA180C-L
	PHASE		3	3
	SEER/EER		8.0	8.25
20	MODEL #		38AD024	RAUB-C20
	PHASE		3	3
	SEER/EER		8.0	8.2
25	MODEL #		38AD034	RAUB-C25
	PHASE		3	3
	SEER/EER		8.0	8.5
40	MODEL #		38AD044	RAUB-C40
	PHASE		3	3
	SEER/EER		7.5	8.4

Note: SEER's are given for single phase units.
EER's are given for three phase units.

SEER's and EER's vary with selection of indoor coil.

SPLIT SYSTEM A/C UNITS

NOMINAL TON CAPACITY		LENNOX		YORK	
2.5	MODEL #	HS19-311V		H1CF030	
	PHASE	1		1	
	SEER/EER	10.15-11.85		10.0	
3	MODEL #	HS14-411V	HS14-413V	H1CF036	H1CB036
	PHASE	1	3	1	3
	SEER/EER	11.8-13.3	9.2-10.4	10.0	8.4
3.5	MODEL #	HS19-461V		H1CF042	
	PHASE	1		1	
	SEER/EER	10.65-12.0		10.0	
4	MODEL #	HS14-511V	HS14-513V	H1CF048	H1CB048
	PHASE	1	3	1	3
	SEER/EER	11.3-13.2	9.1-9.95	9.7-10.0	8.5
5	MODEL #	HS14-651V	HS14-653V	H1CF060	H1CB060
	PHASE	1	3	1	3
	SEER/EER	10.85-13.00	8.4-9.45	10.0	8.2
7.5	MODEL #		HS17-953V		H1CT090
	PHASE		3		3
	SEER/EER		8.4-8.75		7.05
10	MODEL #		HS17-1353V		H1CT120
	PHASE		3		3
	SEER/EER		8.2-8.5		7.15
15	MODEL #		HS17-1853		H1CT180
	PHASE		3		3
	SEER/EER		8.75		7.2
20	MODEL #		HS17-2753		H1CA240
	PHASE		3		3
	SEER/EER		8.55		8.3
25	MODEL #				H1CA300
	PHASE				3
	SEER/EER				8.4
40	MODEL #				H1CA480
	PHASE				3
	SEER/EER				7.9

Note: SEER's are given for single phase units.
EER's are given for three phase units.

SEER's and EER's vary with selection of indoor coil.

Appendix C - Equipment Used

DEMONSTRATION

Original Chiller:	Climatrol, Model No. LRS05001, Nominal Rating - 50 tons Air-Cooled Reciprocating Compressor, Power Supply - 460/3, 84 amps, Six Fans 460/1, 2.3 amps.
Thermal Storage:	Turbo Refrigerating Co., Model No. HP-400B SCE, Compressor - Royce Model No. CG60NTA, Reciprocating, Refrigerant R-22, Compressor Motor - Lincoln, 60 hp, 406/3, 77 amps, Evaporative Condenser - Vilter Model No. VGF 50, Fan Motor - Lincoln, 1 hp, 460 v, 2.15 amps Pump Motor - Century/Scot, 1/2 hp, 460 v, 1 amp, Recirculating Water Pumps (2) - Siemems-Allis, Centrifugal, 3 hp, 460 v, 4.2 amps.
Instrumentation Computer:	IBM-PC Personal Computer, 256k Ram, Two Floppy Disk Drives, Monochrome Monitor.
Scanning System:	Omega Engineering Analog Scanning System, Model No. WB-AIO-B8, Eight Channel, Analog-to-digital Conversion Board and Datalogging System for the IBM-PC.
Temperature Sensors:	Four, Type E Thermocouples, Omega Part No.CXSS-18G-12, Extension Wire, Omega Part No. EXTT-E-20-TCB-100, Temperature Measurement Handbook, Omega Part No. OP-1.

KWH Meter: Esterline Angus, Miniservo III, Power Supply Demand Recorder, Model No. MS 413B.

Flowrate (water): Polysonics Ultrasonic Flowmeters, Model No. UFM 84P.

TEST INSTRUMENTATION

Flowrate (air): Shortridge Instruments Flowhood, Model No. CFM-80.

Temperature: Imperial Eastman Model A-8 Electronic Temperature Analyzer.

Elapsed Run Time: Cramer Type 635K.

KWH Meter: TIF Instruments, 2000 Wattprobe, Clamp-on, Digital Wattmeter.

Appendix D - Manufacturers of Thermal Storage Equipment

1. CALMAC Manufacturing Corporation
   Manufacturers of brine-type ice banks, featuring spiral-wound mats of plastic tubing in cylindrical tanks. Available in 60, 90 and 100 ton-hour sizes.
   150 South Van Brunt Street, P.O. Box 710, Englewood NJ 07631
   (201) 569-0420 (212) 586-5178

2. Turbo Ice Systems Company
   Manufactures high-efficiency, dynamic, ice-harvesting equipment. Packaged systems include ice-maker, storage tank and controls.
   P.O. Box 396 Denton TX 76202 (817) 387-4301

3. Transphase Systems Incorporated
   Manufactures containers of eutectic salts which provide latent cool storage of 44 btu's per pound at 47 degrees F. System design and installation services are offered.
   16552 Burke Lane, Huntington Beach, CA 92647 (714) 893-3920

4. National Integrated Systems
   Manufactures direct-expansion ice builders, featuring durable copper expansion coils, fiberglass-lined tanks and integral subcooling. System design and installation services are offered.
   1700 West Katella Avenue, Suite 360, Orange CA 631-4831

5. Baltimore Aircoil Company Incorporated
Manufactures classic direct-expansion ice builders, featuring steel pipe coils, galvanized steel tank and air-agitation to improve the uniformity of ice building. Twenty-one standard sizes from 120 to 950 latent ton-hours.
P.O. Box 7322, Baltimore Maryland, 21227

6. Chester-Jensen Company Incorporated
Manufactures direct-expansion ice builders, featuring unlined steel tanks, 1 1/4 inch schedule 40 steel pipe coils, and air-agitation. Forty three standard sizes from 1,000 to 100,000 pounds of ice capacity.
Main Office and Factory, Fifth and Tilghman Streets, Chester PA 19013
(215) 876-6276

7. Perma-Pipe
Manufactures direct-expansion ice banks. Unique tank design consists of a 40 foot long cylinder of spiral-welded, 1/4 inch steel, pressure rated at 125 psig for closed systems. The tanks are designed to lie horizontally and may be stacked three deep. Casing is suitable for direct burial. Coils are 1 1/4 inch black steel pipe.
7720 Lehigh Avenue, Niles Illinois 60648, (312) 966-2150

8. Sullair Thermal Systems, Incorporated
Manufactures direct-expansion ice builders, with matching rotary-screw compressors, liquid refrigerant recirculation packages and custom microprocessor control systems. Design assistance and installation guidance provided. Will lease, operate and maintain total systems.
3700 East Michigan Blvd. Michigan City IN 46360, (219) 874-1500

9. Thermal Storage Technology Inc.
Manufactures a phase change system with a latent heat of fusion of 92 btu per pound at 46 degrees F and a high efficiency heat exchanger.
909 South Santa Anita Ave., Suite G, Arcadia CA 91006
(818) 447-0897 (818) 447-0898

10. Ditt Sigma Inc
Distributor for "Cryogel" ice ball storage system. A four inch plastic ball with dimples for expansion/contraction and filled with water.
1255 23 Rd Street NW Suite 450, Washington D.C. 20037,
(202) 659-4333

11. Reaction Thermal Systems Inc.

Manufacturers of a storage system using polyethylene containers filled with deionized water, a storage module, and a high efficiency shell and tube heat exchanger.
Lafayette, Ca. 94549, (415) 284-3828

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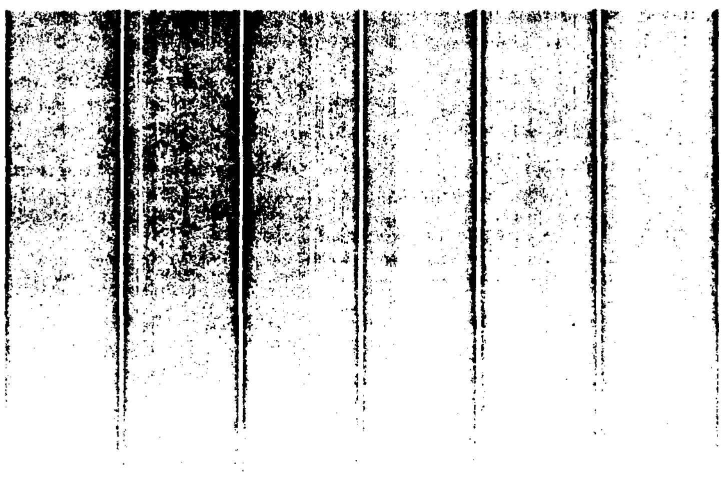
Appendix E - Salt River Project Thermal Storage Incentive Program



THERMAL ENERGY STORAGE

A PROVEN TECHNOLOGY

It's a simple concept — air conditioning equipment operates during off-peak hours to chill water, make ice or freeze salts and store the cooling in large tanks. During on-peak hours, such as on a hot summer afternoon, only fans and pumps are needed to provide cooling to the building, saving money in the process.

Using less energy during times it costs most to produce and using it when it is cheap to produce saves both the user and the utility money. It also helps utilities like Salt River Project delay the need to build expensive new generating stations.

HISTORY

Thermal Energy Storage is no new kid on the block — it was first used at the turn of the century to cool churches and auditoriums, buildings that needed lots of cooling for short periods. Ice was used in those days — ice delivered from ice plants to churches kept people cool, comfortable and happy during the service.

Thermal storage again appeared in the 1970s. Large commercial customers were very interested in the technology and the savings it provided for air conditioning. Today, thermal energy storage systems operate in large and small commercial and industrial buildings in this country as well as Canada and Japan.

BENEFITS

- Cost effective for either new construction or retrofit applications.
- Lower energy costs, either by decreasing demand costs or using optional time-of-day electricity rates.
- Increased building value from increased revenues.
- System maintenance can be done during daytime hours, avoiding overtime, when the units are off.
- Provides increased leasing advantage to building owners.
- Can add cooling capacity without adding expensive refrigeration equipment.
- Easier and less expensive weekend air conditioning.
- Colder air can be used to reduce the size of the ducts, fans and coils — the items that distribute the air in a building. Architects are sure to make use of the extra space.
- Can easily be controlled with present-day energy management systems, time clocks and DDC controls.
- Night cooling more efficient due to cooler outdoor temperatures.
- Fire protection for building can be increased by pumping the stored water into the sprinkler system.

SRP's TES INCENTIVE PROGRAM

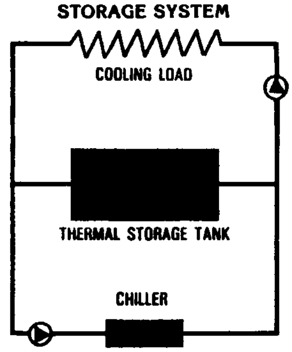
To encourage commercial and industrial customers to install thermal storage systems for load shifting, Salt River Project offers financial incentives to help with the first costs.

AMOUNT: $250 per kW shifted for the first 300 kW; $115 per kW shifted from 300 kW to the program limit of 500 kW.

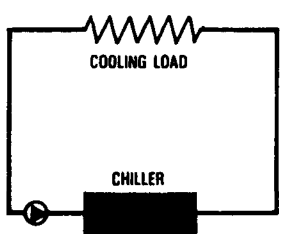
PAYMENT SCHEDULE: Customers receive full payment upon completion of the project.

APPLICATION PROCEDURE: Customers must meet all program requirements and send the documented information to SRP's Energy Services Department with a signed and stamped letter from an Arizona Registered Professional Engineer (PE).

STORAGE SYSTEM



CONVENTIONAL SYSTEM



THERMAL STORAGE MEDIA

The three common storage media are:

1. **CHILLED WATER**—Often used for extremely large cool storage situations. Care must be taken to ensure that cold stored water does not mix with warmer return water. Cooler nighttime temperatures add to higher chiller efficiencies with this media. Existing chillers make ideal applications for retrofit storage applications. The chilled water tanks can be located in a basement, under a parking lot, or under a landscaped courtyard.

2. **ICE STORAGE**—Takes advantage of the greater cooling capacity of ice as compared to water. Therefore, ice storage systems are significantly smaller than chilled water systems. Several types of ice systems exist; some drop ice into storage tanks, others build ice on copper refrigerant tubes, and others use glycol to freeze ice in tanks.

Refrigeration systems that make ice usually are less efficient than ones that chill water because of the colder evaporator temperatures required. Coils, fans, pumps and ducts can be downsized when colder water is used. Existing equipment, however, may not be able to reach the lower evaporator temperatures needed to make ice, so, in these cases, users must buy new equipment.

3. **EUTECTICS** — Use materials which can freeze at temperatures higher than 32 degrees F. For this reason, eutectic solutions can be frozen using less energy than needed to freeze water.

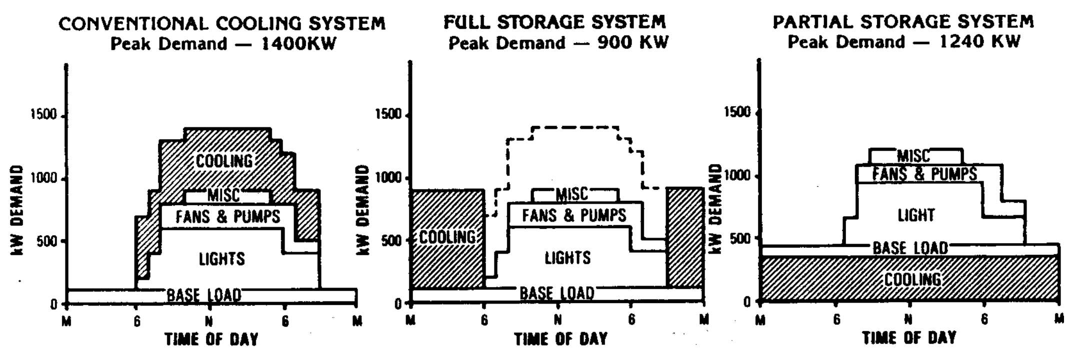
Available technology can use eutectics in storage tanks that can be 30 percent or more smaller than chilled water tanks. Eutectic systems are ideal for retrofit applications because they can use existing chiller equipment.

TES STRATEGIES

Two common strategies exist which help reduce a building's cooling costs.

FULL STORAGE SYSTEMS — Achieve maximum demand reductions. Storage is sized to store enough thermal energy to meet the next day's cooling load. Chillers operate at night, during off-peak hours, and are "locked out" during the next day's on-peak hours. This reduces the building's peak electric demand dramatically. The result is reduced demand charges and cheaper electricity rates for those customers on a Time-of-Day rate.

PARTIAL STORAGE SYSTEMS — Sometimes can be more practical economically in new construction and expansion. A chiller is sized to give a part of the building's peak load. The unit runs continuously and charges the cool storage at night and cools the building during the day. The additional cooling need comes from the cool storage. The benefit is that energy costs are minimized by keeping the kW demand low for the building.



PROGRAM REQUIREMENTS

SRP's TES incentive program requires the peak electric demand (kW) of a reasonably designed conventional cooling system be compared with the system designed with thermal energy storage.

Comparisons will consider not only the refrigeration loads, but also pumps, heat rejection equipment and air handling equipment. Each part of the avoided peak load must be calculated and documented on engineering worksheets. Documentation should include a system schematic and specifications on each major piece of equipment.

Calculations must be signed by a professional engineer registered in Arizona. Calculations must bear the stamp of the engineer and a statement certifying that the calculations comply with the program requirements.

Calculations should follow these guidelines:

They must be based on a 24-hour chiller load profile, calculated using an hourly simulation model. The same calculation method or computer program must be used to calculate the peak kW for both the conventional and the thermal energy storage system.

For new buildings, SRP assumes an average chiller efficiency of at least 0.7 kW/ton for the conventional system.

For retrofits, SRP assumes the following average chiller efficiencies for existing equipment:

Centrifugal	*.85 kW/ton*
Screw	*.90 kW/ton*
Reciprocating	*1.25 kW/ton*

The same operating conditions (interior temperatures and humidity requirements, hours of equipment operation, etc.) are assumed for load calculations in both conventional and base case conditions.

Peak electric load of chilled water pumps, condenser water pumps, fan motors, etc. will be based on the nameplate horsepower or full load amperes.

Both basecase and thermal energy storage systems should be sized based on ASHRAE design conditions.

For full storage systems, an automatic time clock must lock out operation of the refrigeration equipment for the full 10-hour peak period (noon to 10 p.m.) in the summer.

SALT RIVER PROJECT

AN EQUAL OPPORTUNITY EMPLOYER

3089/3-87/2500

Energy Conservation Office
Public Works Department
2631 South 22nd Avenue
Phoenix, Arizona 85009

June 9, 1987

CITY OF PHOENIX

Roger Kirkman
Salt River Project
P. O. Box 52025
Phoenix, Arizona 85072

Dear Roger,

The City of Phoenix is installing a Thermal Energy Storage System at the South Phoenix Adult Center. This letter and the attached information is in response to SRP's Thermal Energy Storage Incentive Requirements. The folllowing information is included with this correspondence:

1. Specifications of the Turbo Refrigerating Company, HP 400B Equipment.

2. Calculated KW demand shift.

3. Load simulation using Turbo 1.02 for the building load and for the ice storage load shifting.

4. System schematic.

A 63.5 KW demand shift was calculated using the Incentive Program guidelines. At $250.00 per KW shifted the incentive for this project has been calculated at $15,875.00.

If you should have any qestions about the information provided, do not hesitate to give us a call. Thank you for your cooperation.

Sincerely,

DARSHAN S. TEJI
Energy Conservation Manager

DST:st

Attachment

Figure 11 - Darshan Teji, Energy Conservation Manager, accepts the thermal storage incentive check from Roger Kirkman, Salt River Project representative.

REPORT AND INFORMATION SOURCES

Additional copies of this report, "HVAC Equipment Replacement for Best Size and Efficiency," are available from:

Publications and Distribution
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
Washington, DC 20004

For additional information on the procedures and results from this project, or for more information on the overall energy management program in the City of Phoenix, please contact:

Darshan Teji
Energy Conservation Manager
2631 South 22nd Avenue
Phoenix, AZ 85009

Two previous projects conducted as a part of the Urban Consortium Energy Task Force program by the City of Phoenix were used as bases for much of the work described in this report.

- "Thermal Storage Strategies for Energy Cost Reduction"
  -- Pub. No. DG/85-307

- "Thermal Energy Storage: An Application Guide for Local Governments"
  -- Pub. No. DG/87-302

Copies of these two additional reports are available on request from either PTI or the City of Phoenix.

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