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HVAC EQUIPMENT REPLACEMENT FOR BEST SIZE AND EFFICIENCY

A TECHNOLOGY TRANSFER REPORT

Urban Consortium
Energy Task Force

City of Phoenix

Urban Consortium for Technology Initiatives

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The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. The Urban Consortium is a coalition of 42 major Urban governments, 30 cities and 12 counties, with populations over 400,000. These 42 governments represent over 20% of the nation's population and have combined purchasing power of over $25 billion.

Formed in 1974, the Urban Consortium represents a unified local government market for new technologies. The Consortium is organized to encourage public and private investment to develop new products or systems which will improve delivery of local public services and provide cost-effective solutions to urban problems. The Consortium also serves as a clearinghouse in the coordination and application of existing technology and information.

To achieve its goal, the Urban Consortium identifies the common needs of its members, establishes priorities, stimulates investment from Federal, private and other sources and then provides on-site technical assistance to assure that solutions will be applied. The work of the Consortium is focused through 10 task forces: Community and Economic Development; Criminal Justice; Environmental Services; Energy; Fire Safety and Disaster Preparedness; Health; Human Resources Management; Finance and Personnel; Public Works and Public Utilities; and Transportation.

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Energy Task Force
of the Urban Consortium
for Technology Initiative

CITY OF PHOENIX

Conducted by:

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Energy Conservation Administrator
Public Works Department
Phoenix, Arizona

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 twenty-one Consortium jurisdictions has sponsored over 180 energy management and technology projects in forty-six 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 Ninth Year (1986-89) 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 Ninth Year Unit consisted of six projects:

- **Kansas City, Missouri** -- *Direct Digital Control of an Air Washer System*
- **Memphis, Tennessee** -- *The Use of Transportation Management Associations to Achieve Energy Conservation Benefits in Urban Areas*
- **Montgomery County, Maryland** -- *Requirements for Energy Efficient Building Construction*
- **Phoenix, Arizona** -- *Energy Cost Reduction in Comfort Cooling Through Cogeneration*
- **Phoenix, Arizona** -- *HVAC Equipment Replacement for Best Size and Efficiency (Technology Transfer)*
- **San Jose, California** -- *Energy Master Planning for Local Government Facilities*

UNIT -- COMMUNITY AND ECONOMIC DEVELOPMENT

Of the nation's estimate population of nearly 240 million, approximately 60 percent reside or work in urban areas. The 543 cities an 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 an reducing energy costs for the community as a whole. This Year Nine unit consisted of six projects:

- **Chicago, Illinois** -- *Chicago Energy Demonstration Zone*
- **Houston, Texas** -- *The Feasibility of Incorporating Alternative/Innovative Technologies in Mass Single Family Housing Rehabilitation Strategies*
- **New Orleans, Louisiana** -- *Small Business Assistance Program to Reduce Energy Consumption Through Innovative Financing Methods (Technology Transfer)*

- **New Orleans, Louisiana** -- *Development of an Energy Information an Referral Service*

- **New York, New York** -- *Marketing Energy Efficiency Programs to Commercial an Industrial Firms*

- **San Francisco, California** -- *Energy Planning for Economic Development*

UNIT -- ENERGY AND WASTE MANAGEMENT

Effective use of advanced energy technology an 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 an improve capabilities for the use of alternative energy resources by serving as test beds for the application of new technology. This Year Nine unit consisted of four projects:

- **Albuquerque, New Mexico** -- *Hazardous Waste as an Energy Manager's Issue*

- **Baltimore, Maryland** -- *Ammonia Oxidation by Separable Micro-supported Biomass for Nitrification of Sewage*

- **Denver, Colorado** -- *Regional Workshops on Waste-to-Energy and the Management of Special Wastes*

- **Detroit, Michigan** -- *Feasibility Assessment: Conversion of Resource Recovery Steam to Hot and Chilled Water Systems*

- **Hennepin County, Minneapolis** -- *Special Household Waste Management*

- **Seattle, Washington** -- *Implementation of Hazardous Waste Collection Option*

- **Seattle, Washington** -- *Computerizing Municipal Procurement Choices (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
(202) 626-2400

Acknowledgments

The originator of this project was Darshan Teji, Energy Conservation Administrator for the City of Phoenix and Project Director for this project. The entire implementation work of this 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 composition of project documentation. Paul Hudson assisted in the actual testing of the equipment and writing of procedures. Ken Kennedy was involved with scheduling and supervising the technicians. G.P. White and Rusty McNeil performed the actual equipment testing. 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 Dewayne Huckabay, Chairman of the Energy Task Force of the Urban Consortium. Special thanks for assistance go to Unit Manager Philip Whittenberg with Shelby County and to Richard Zelinski with the Public Technology, Inc.

Contents

Chapter 1 - Overview

ABSTRACT

Heating, ventilating and air conditioning (HVAC) equipment has typically been replaced only when it fails or when the cost of maintaining it exceeds its worth. The concept of replacing such equipment based primarily on the efficiency of its performance or lack of it, is somewhat new.

Three factors can cause the energy requirement of equipment to be excessively high. The first is that normal wear over time can cause equipment to operate less efficiently than is acceptable. The second is due to overdesign of the original equipment or a change in the building usage. This can result in larger-sized equipment than is required with less efficient operation. The third factor is that much of the equipment in current use was manufactured having lower efficiency than is possible with today's technology. Most municipalities have existing equipment that falls into one or more of the categories above.

In 1987, The Urban Consortium Energy Task Force approved funding for a City of Phoenix project, HVAC Equipment Replacement for Best Size and Efficiency. This project was successfully completed with a number of lessons learned. During the year 1987, project research on equipment testing was accomplished and an equipment replacement demonstration was done.

There are jurisdictions where the potential for similar applications exist, but due to lack of guidelines and experience replacement actions may not be pursued. The purpose of this report is

to provide other jurisdictions with ready-to-use guidelines applicable to their own equipment replacement situations. The guidelines will help local governments begin the collection of appropriate information, and aid them in performing both technical and economic evaluations which are necessary for effective decision making for HVAC equipment replacement.

PROJECT PURPOSE

The purpose of this project is to transfer to other local governments the experience and technique of replacing HVAC equipment based solely on savings brought about by improved operating efficiency. This transfer project presents the steps to be taken in successfully selecting the schedule of replacement. Some of the problems and pitfalls are included to enable a jurisdiction to effectively implement a program and to quickly identify the greatest number of potential replacements with the fastest paybacks.

The specific objectives of this report were as follows:

1. To show that equipment replacement justified by energy savings is a viable equipment management tool.
2. To transfer the technology of equipment testing and replacement to other local governments.
3. To provide a ready-to-use quide to assist local governments.

ORGANIZATION OF THE GUIDE

Four main chapters and four appendices comprise this guide. The major sections are organized as follows:

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

Chapter 2 -- a brief non-technical explanation of HVAC equipment and the factors affecting its efficiency.

Chapter 3 -- a guide for evaluating HVAC equipment utilizing equipment audits and actual equipment testing examples for economic analyses of equipment with replacement potential.

Chapter 4 -- lessons learned from testing HVAC equipment and the problems with the demonstration replacement equipment.

Appendices -- a bibliography for additional reading, a list of the test equipment used, an update of high efficiency HVAC equipment, and copies of the test forms used.

Chapter 2 - HVAC Fundamentals

INTRODUCTION

This chapter will present some of the basic fundamentals of HVAC equipment and specifically air conditioning equipment. If more in-depth information is required, additional reading can be found in the bibliography. However this chapter will provide a background on the types of equipment tested and discuss some of the factors that effect the equipment efficiency. A list of definitions is presented below to provide an easy reference for some of the terminology used. A previous report by the City of Phoenix, HVAC Equipment Replacement for Best Size and Efficiency, is the basis for this report and is available as noted 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 distributuion to meet the requirements of the conditioned space.

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

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

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 energy 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.

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 Drive (VFD). An electric motor drive that is capable of changing existing power-line, alternating 60-cycle current, to a variable frequency alternating current.

COMPONENTS OF AN HVAC SYSTEM

The terms involved in a discussion of refrigeration equipment come from the basic components of the system itself. Figure 1 is a simple schematic of the refrigeration cycle showing the compressor, condenser, expansion valve and evaporator. Each of these components will be described in greater detail in the following paragraphs.

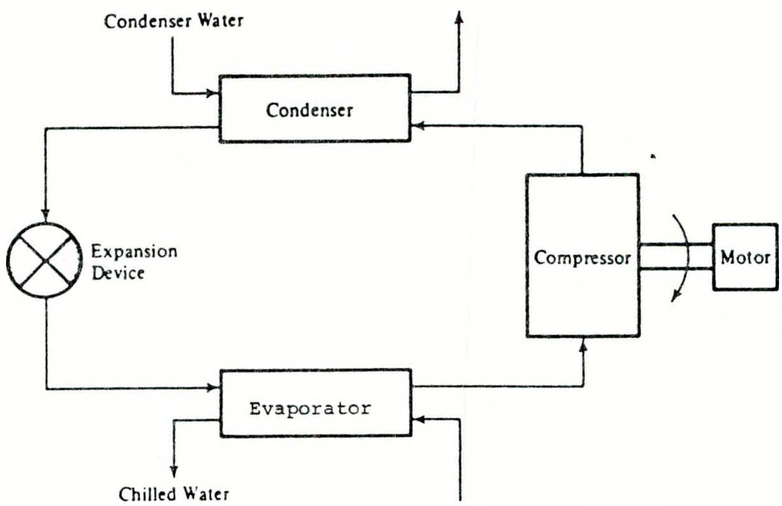

Figure 1 - Vapor Compression Refrigeration Cycle

The Compressor

The compressor receives low pressure refrigerant vapor from the evaporator and delivers it at high pressure to the condenser. Typical compressors used in the cycle are reciprocating, centrifugal and screw.

Reciprocating Compressor. This type of compressor is the most common in air conditioning systems. They are best suited to handling refrigerants of relatively high vapor density and high condensing pressures. The reciprocating compressor is available in sizes ranging from a few tons to a few hundred tons. The output of the compressor is modulated by a combination of speed control and cylinder unloading and can achieve a Coefficient of Performance (COP) of up to four. The reciprocating compressor is simply constructed and thus easier to maintain and repair. This feature adds to the popularity of this compressor by having a lower cost than other types. The disadvantages of these machines are that they tend to be noisier and less efficient than rotating compressors and usually not available in sizes of 200 tons or more.

Screw Compressor. These compressors are capable of a COP of almost five and have found a market between the large reciprocating and smaller centrifugal compressors. They are available in sizes of several tons to almost 1000 tons. While peak efficiency is quite high, there is an efficiency loss as capacity is reduced. These compressors are becoming popular for base-load cooling.

Centrifugal Compressors. The centrifugal compressor is available in a broad range of capacities from a few hundred tons to 5000 tons, and operate at relatively higher efficiencies especially at part loads. These compressors have fewer moving parts than the large multicylinder type with less maintenance and repairs. The most common application is in large central cooling plants above 500 tons.

Multiple and Two-Speed Compressors. To improve the efficiency of cooling equipment in the spring or fall when the cooling load is lower, air conditioning systems are available with multiple or two-speed compressors. Multiple compressors can be cycled on and off to more closely follow the load. Two-speed compressors will also reduce energy input when reduced cooling is required.

Condenser

The condenser is the component of the cycle that rejects the heat collected from the evaporator. Figure 1 shows the condenser downstream from the compressor.

Water-Cooled Condenser. These condensers can be shell-and-tube or shell-and-coil type. It is important to circulate the proper amount of water since lower water flow will increase the power consumption and shorten compressor life.

Air-Cooled Condenser. These condensers are commonly used with small and medium sized air conditioning equipment. The advantages of these condensers are:

* Lower first cost,
* No water hookup required,
* No need for water disposal.

The major disadvantages are higher power costs, reduced compressor life, and lower system efficiency.

Evaporative Condenser. These condensers are a combination of an air-cooled, water-cooled, and a forced-draft type water-cooling tower. The high latent heat of vaporization of water produces significant cooling for a small amount of water. 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. A higher compressor efficiency is usually associated with an evaporative condenser.

The Evaporator

The liquid refrigerant is fed to the evaporator through an expansion valve where the pressure is reduced causing the refrigerant to vaporize. The cooled gas then absorbs heat from the conditioned space, cooling the building in the process. Two types of evaporators are commonly used in air conditioning systems: 1) direct-expansion (DX) coils, and 2) water chillers.

Direct-Expansion (DX) Coils. Air is moved directly across a coil and fin arrangement cooling the air flow. The fins provide a greater surface area for increased heat transfer. If insufficient refrigerant is circulated the air will not be cooled and if too much refrigerant is supplied it will not all be evaporated and may result in compressor problems.

Water Chillers. Long pipe runs associated with central station systems require a different working fluid than a refrigerant. A dry expansion chiller has the refrigerant circulating in the tube surrounded by water in the shell. A flooded chiller has the water flowing through the tubes and the refrigerant in the shell. These chillers are more common with large centrifugal compressors using refrigerants of high specific volume. Reciprocating compressors are ordinarily used with the dry expansion chiller.

TYPES OF AIR CONDITIONING SYSTEMS

Air conditioning systems can be classified as centralized, unitary or a combination of the two.

Centralized System. The centralized system utilizes a mechanical room where the primary components of the refrigeration system are grouped together. Air from the spaces to be conditioned is cooled at the equipment site and distributed to the building.

Unitary System. Also referred to as packaged systems due to the fact that all the components are assembled, balanced, and tested at the factory and shipped out as a pre-packaged system. The total system can be installed in, on, or adjacent to the building. The primary distinguishing feature is that these systems utilize factory matched refrigeration, heating and air circulation equipment.

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

Unitary Air Conditioning Systems

These systems can be classified in four major types: single packaged units, split systems, rooftop or roof-mounted units, and fan-coil units. These systems are explained in more detail below.

Single Packaged Units. This type of system incorporates the refrigeration, air-handling equipment, and controls all in one cabinet. Packaged units may also include gas-fired, electric, steam or hot-water heating source for year-round operation. These systems are available in small sizes, one-third to two tons, such as window units or room coolers. Large systems which are vertical or free-standing units are available in sizes of three to twenty tons and can either be free-blowing or duct type systems.

Split systems. The split system or remote unit refers to the separation of the condensing unit from the air-handling unit. The most common arrangement is an indoor fan-coil unit and an outdoor condensing unit connected by refrigerant tubing and controls. These units are available in small sizes, three to twenty tons, and also in large sizes of several hundred tons.

Rooftop Units. Rooftop systems are made up of three modular sections: 1) air-cooled condensing section, 2) blower-coil section 3) heating section. These systems are available in sizes up to fifty tons. Multiple units can provide zoning, minimum ductwork, and control of individual areas with no loss of valuable floor space within the building. The disadvantages of these systems are that the roof structure must be capable of supporting the added weight of the unit and vibration and noise may cause problems. Adding a mixing plenum and outside return air dampers will allow the use of outside air for free cooling when the temperature and humidity conditions are right. Rooftop systems are popular with supermarkets, schools and city buildings.

Fan-Coil Units. Fan-coil systems provide 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.

Heat Pumps

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 most common heat pump for residential and small commercial applications in mild climates is the air-to-air heat pump. Water-to-air or water-to-water are better suited to severe winter climates and large installations. One problem with the air-to-air heat pump is that when heat is needed most, the air temperature is the lowest. A central water circulation system can be utilized for the water-to-air systems. This system is a reverse cycle, water cooled air conditioner using a chiller condenser connected to a closed piping circuit. Industrial heat pumps are usually water-to-water systems and utilize waste heat from the specific process involved. With an inlet water temperature of 60 to 120 degrees F the heat pump can deliver hot water in the 150 to 220 degree F range. Since water-to-water heat pumps are not used on the cooling cycle they are termed nonreversible.

FACTORS AFFECTING HVAC EFFICIENCY

To begin a discussion on the HVAC system efficiency, the factors that influence the equipment's performance need to be presented. The most popular measure of efficiency in heating and cooling equipment is the Coefficient of Performance (COP) and is shown in equation form as:

$$\text{COP (Cooling)} = \frac{\text{Net Heat Removed (Btu/hr)}}{\text{Total Energy Input (Btu/hr)}}$$

$$\text{COP (Heating)} = \frac{\text{Net Heat Delivered (Btu/hr)}}{\text{Total Energy Input (Btu/hr)}}$$

Another measure of equipment effectiveness that has gained acceptance in the last 10 years is the Energy Efficiency Ratio or EER. The equation for EER is:

$$\text{EER} = \frac{\text{Net Heat Removed (Btu/hr)}}{\text{Total Energy Input (watts)}}$$

This equation can be changed somewhat to give another value that is used when discussing equipment efficiency.

$$\text{Kilowatts per Ton} = \frac{\text{Total Energy Input (kw)}}{\text{Cooling Rate (tons)}}$$

When researching HVAC equipment performance any or all of these values may be presented as a performance guage.

These efficiency figures refer to the effectiveness of the system. Depending on whether the equipment is a packaged system or a chilled water system the system efficiency can include all the components or just the compressor. In a packaged system the efficiency value includes pumps, fans, and compressor while in most cases the published efficiency for a chiller is only for the compressor. The efficiency of the HVAC system is dependent on the performance of each individual component of the system. Generally the components that form the air conditioning and heating systems are pumps, fans, and compressors. Fans and pumps will be discussed in more detail below.

Fans

Fans are used in an HVAC system to distribute hot or cold air to the building and to cool refrigerant in air cooled systems. The brake horsepower of a fan is given as:

$$BHP = \frac{\text{Air Flow Rate (CFM)} \times \text{Fan Static Pressure (inches)}}{6356 \times \text{Efficiency}}$$

this equation can be rewritten as:

$$\text{Efficiency} = \frac{CFM \times FSP}{6356 \times BHP}$$

As the fan speed varies, the air flow, (CFM), total pressure, and power will also vary according to the fan laws. These laws are:

* Air volume (CFM) varies directly as the speed.
* Static velocity or total pressure varies as the square of the fan speed.
* Power varies as the cube of the fan speed.

The power relationship can be presented as:

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

As the air flow rate is reduced, the fan energy is lowered by the cube of the fan speed. This relationship is what makes variable air volume (VAV) so cost effective. In cases where a fan will run full speed but has been improperly designed, a change to the correct fan size could be justified by a reasonable payback.

Pumps

Pumps are used in HVAC systems for chilled water and condenser water circulation. Additional pumps may be required in thermal storage applications. The efficiency of pumps is given by the equation:

$$\text{Efficiency} = \frac{\text{Head (feet)} \times \text{GPM}}{3960 \times \text{BHP}}$$

Using the affinity law for pumps for brake horsepower (BHP):

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

As with the fan, a reduction in flow rate will yield substantial energy savings.

One method of reducing the flow rate or GPM is to install a variable frequency drive (VFD). The pump can then follow the load and will be required to pump at full flow only on the hottest time of the day. Another method of reducing the airflow is to install a smaller impeller or to change the size of the motor sheave. Variable speed pumps are also effective when the loads can be matched with corresponding speeds. If the load reduction is down to a steady flow rate (GPM), a second smaller pump may be installed for those hours of use.

Distribution - Ducts and Piping

The distribution system can also influence the total system efficiency. However, it is not as easily retrofitted as fans or pumps. Older plumbing is usually corroded and can cause higher pumping costs. Improperly sized or designed piping will effect the efficiency of the HVAC system. Air distribution ducts can have problems similar to piping with improper sizing, dirty sidewalls, or leaky joints all adding up to the resistance to flow of hot or cold air to the building. Under these conditions it may be justifiable to replace the existing distribution system with a new one for substantial energy savings.

PROCEDURES FOR TESTING HVAC EQUIPMENT

Heating and cooling equipment can be tested and evaluated to determine if their energy use is excessive. System efficiencies can be compared to new high efficiency equipment and under certain circumstances the equipment can be replaced using the energy savings as justification. To compare actual operating efficiency to new equipment efficiency, the existing equipment must be tested. Using the equations for COP, EER and Kw/ton the data for the heat removed from a room or building is needed as well as the energy input to the equipment. The testing procedure is somewhat different for chilled water systems than it is for packaged systems. The test procedure for each type of equipment will be outlined in the following paragraphs.

Chilled Water System

To obtain data on the rate of heat removal from a space, the flow rate and temperature differential must be recorded. The equation for heat removal for water is:

BTU/Hr Removed = 500 x Water Flow (GPM) x (Return Temp - Supply Temp)

The water flow rate is in gallons per minute (GPM) and the temperatures are in degrees F. The steps required to test the chilled water systems are listed below.

Step 1. Record the flow rate of the water, in gallon per minute, using a flow measuring instrument.

Step 2. Using a thermometer, record the supply (inlet to the building) and the return (outlet from the building) water temperatures in degrees F.

Step 3. With a wattmeter, record the input kilowatt (kw) of the equipment simultaneously with the temperatures and flow rate recordings.

Packaged System

The tests required for these systems are quite similar to chilled water systems except for the air flow. The equation for heat (Btu) removal for this type of system is:

Btu/Hr Removed = 1.10 x Air Flow(CFM) x (Return Temp - Supply Temp)

The steps for testing packaged systems are:

Step 1. Using a portable manometer, the flow rate of the air stream can be measured. This measurement is done as close to the system as possible to reduce duct losses. A flow hood can be used by recording all supply duct flow rates, however there will be some errors from duct losses due to leakage.

Step 2. Using a thermometer, record the supply (inlet to the building) and the return (outlet from the building) air temperatures in degrees F.

Step 3. Same as chilled water test.

Pumps and Fans

Individual pumps and fans can be tested using the same test equipment. The actual water flow rate (gpm) can be compared to the design water flow rate (gpm) and the energy savings calculated using the equation presented in the pump section. Using the electrical energy input the pump efficiency can be calculated. Using these values it can be determined if replacement with a more efficient pump is economical.

Similar analysis can be performed for fans using actual air flow rate (CFM) and the design air flow rate (CFM). For the fans operating on variable loads, it will be cost effective to change them to variable air volume (VAV) systems.

The other important variables in determining the cost effectiveness of new equipment replacement are electric energy costs and system run time. Run time meters were installed on most City HVAC equipment to record exact run time. Both electricity costs and run times will be discussed in the next chapter along with the economic analysis of the equipment replacement.

Chapter 3 - HVAC Equipment Evaluation

INTRODUCTION

Testing and monitoring the equipment is only one aspect of the equipment evaluation process. To effectively analyze the possibility of changing one piece of equipment for a more efficient one, other variables must be considered. This chapter outlines the complete evaluation process using actual test data and actual utility rates. After reading the contents of this chapter, other municipalities should be able to follow the City of Phoenix equipment replacement program example.

THE ENERGY AUDIT

In most cases an energy audit of the equipment or building should have already been accomplished. If this audit is outdated, another one is recommended since HVAC equipment is replaced from time to time. The City of Phoenix has audited 82 of its large buildings documenting both the building data (square footage, function, etc) and the equipment data (size, type compressor, model numbers, etc). This audit becomes a useful tool in making decisions concerning more than just HVAC system replacement. This audit may prove useful in analyzing the application of other technologies such as thermal energy storage or cogeneration. The energy audit is a convenient starting point that provides opportunity for energy analysis of the buildings and equipment. Table 1 is an example of the City of Phoenix building energy audit.

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	COM 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

The building energy audit can be broken down into specific areas, such as fans, pumps, packaged systems, and chillers. The City energy audit was divided into equipment categories such as:

* Packaged Systems
* Chillers
* Boilers
* Cooling Towers
* Fans
* Pumps
* Other Heating Units

EQUIPMENT TESTING PROGRAM

The test program for the City of Phoenix was initiated for the Year 8 Energy Task Force report, HVAC Equipment Replacement for Best Size and Efficiency. The test program was found to be a useful technique for finding out if the equipment is in need of replacement or in some cases in need of repair. Since the completion of last year's report much of the City's HVAC equipment has been tested. The testing program can be divided into chilled water systems and packaged systems.

Chilled Water System Testing

All large City buildings have chilled water systems. The procedures used to test these chilled water systems are outlined below. A copy of the form used to record the test data can be found in Appendix D.

Testing for Water Flow Rate (GPM). The basic equation for calculating water flow rate is:

Flow rate (gpm) = 7.5 x Pipe Area (sq ft) x Velocity (ft/min)

Since the test instrument measured the flow velocity in feet per second the formula for the flow rate becomes:

GPM = 450 x Area (sq ft) x Velocity (ft/sec)

A flow meter using the doppler effect was used for testing the water flow rate because it could be easily moved from one test location to another. The flowmeter uses two transducers containing piezo-electric crystals that convert mechanical vibrations or sound waves into electrical energy. The transducers are clamped on the pipe so that they face each other through the pipe, 180 degrees apart as shown in Figure 2.

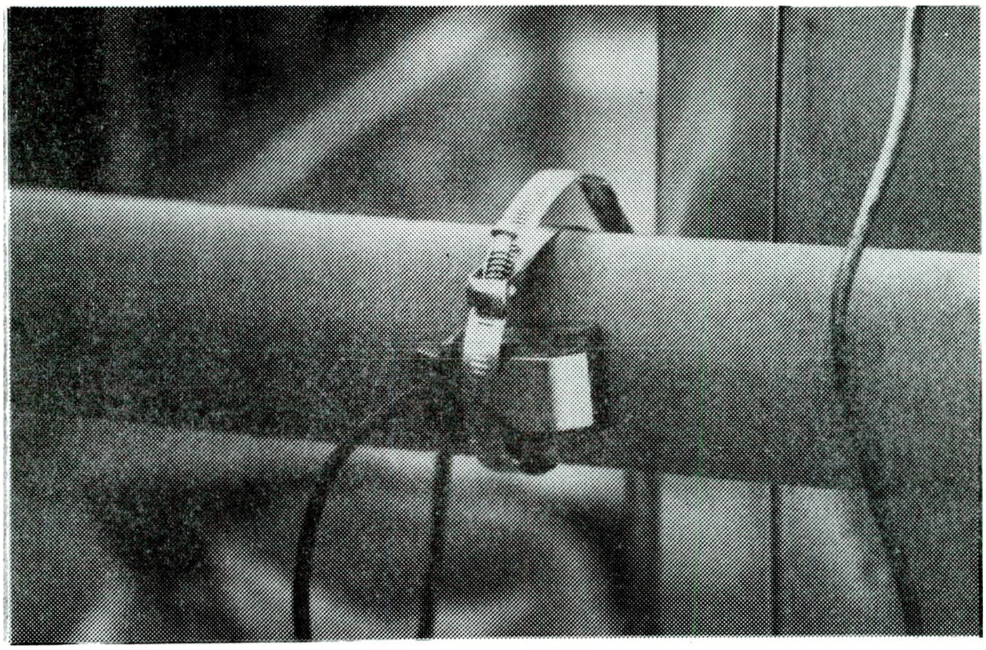

Figure 2 - Flowmeter Transducer Placement

One transducer functions as a sound transmitter directing a beam of energy through the pipe wall into the flowing water. A portion of the transmitted energy is recieved by the second transducer and converted into an electrical signal. The difference in frequency between the transmitted signal and the received signal (the doppler shift) is processed by the electronic circuitry of the instrument and the result displayed in feet per second on the flow rate meter.

Most problems experienced during the use of doppler effect flowmeters are the result of poor transducer mounting on the pipe.

Some tips for the use of this type of equipment are:

* Choose a location which will be easily accessible for transducer placement,
* Avoid mounting transducers on severely vibrating pipe,
* Do not mount on pipes that have temperatures exceeding 400 degrees F,
* Select a vertical pipe with upflow or a long horizontal section of the pipe,
* If a horizontal section of pipe is selected, mount the transducers in the three o'clock and nine o'clock positions.

Figure 3 shows a City technician measuring the water flow rate of a chilled water line.

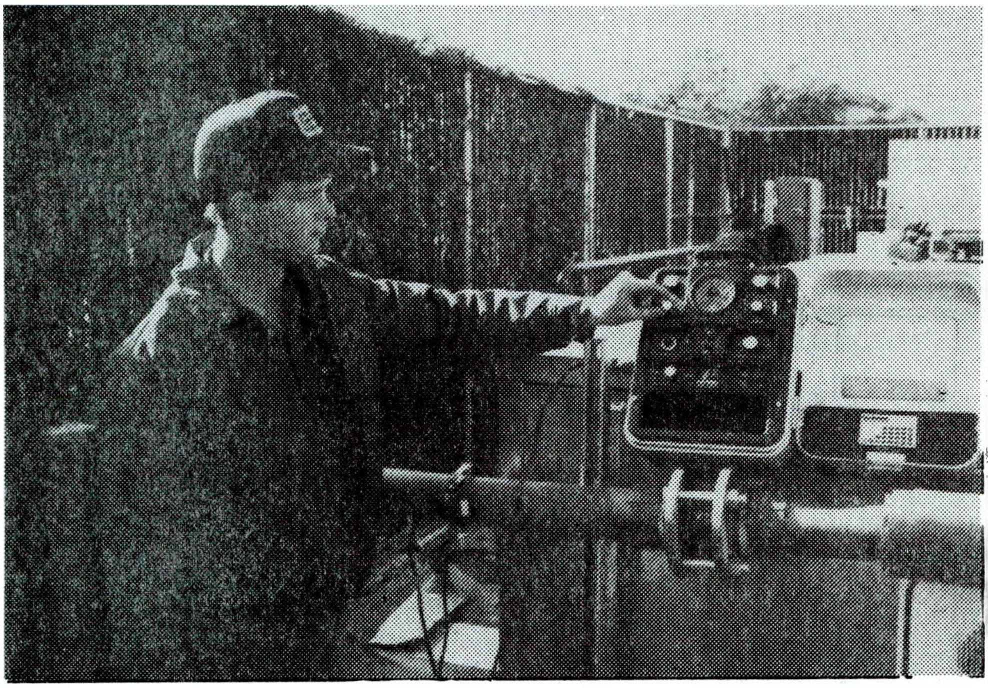

Figure 3 - Testing the Chilled Water Flow Rate

<u>Temperature Differential</u>. The temperatures of the supply water to the building and the return water from the building, were measured

using a digital electronic temperature measuring instrument. The sensors were placed under the pipe insulation to record a more accurate temperature. Figure 4 shows a temperature reading being made on a chilled water supply line with the pipe insulation removed for the photograph.

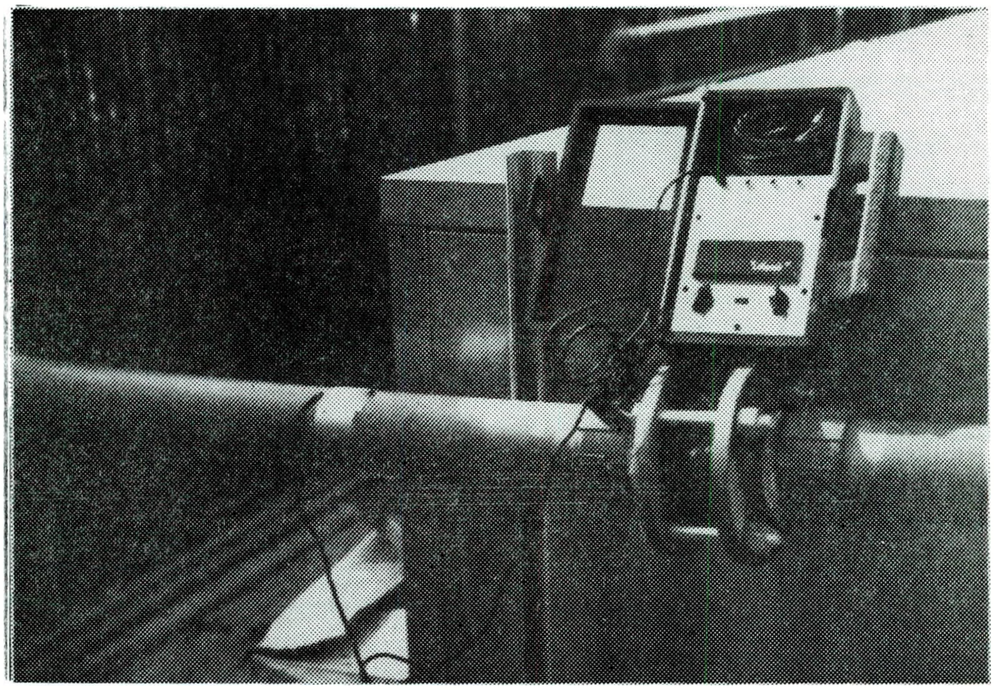

Figure 4 - Measuring Temperature of Chilled Water System

Kilowatt Usage. The energy input to the equipment is measured in watts. The instrument used was a hand-held clamp-on digital wattmeter which measures true watts. Figure 5 shows the wattmeter connected to the input electrical lines to the air conditioning equipment.

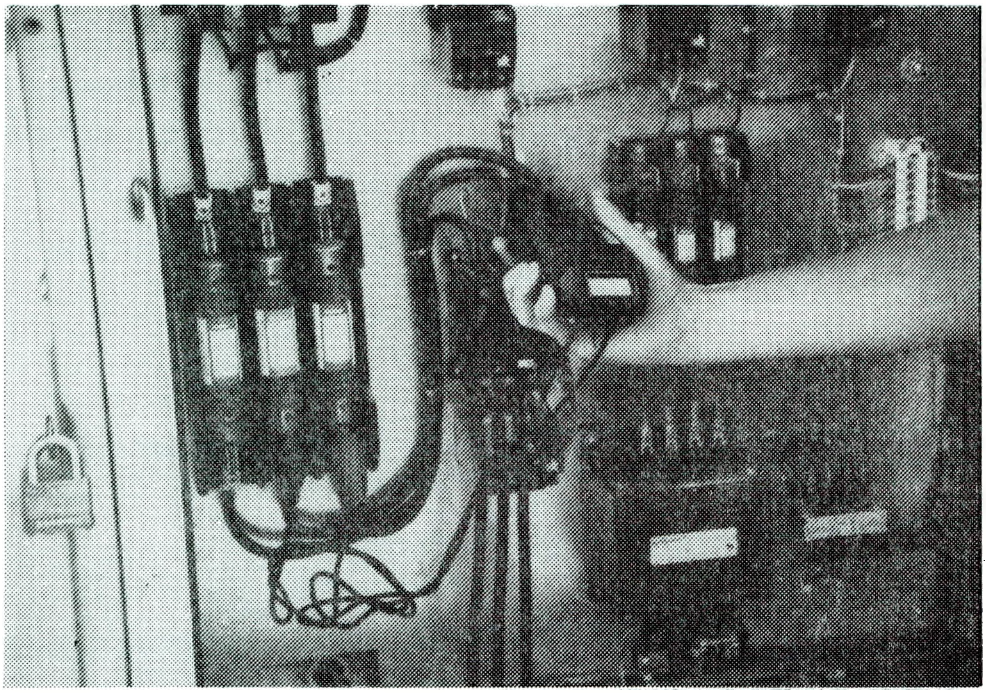

Figure 5 - Wattmeter Electrical Connections

Figure 6 shows the city technician recording the kilowatt reading of one of the City's refrigerating compressors.

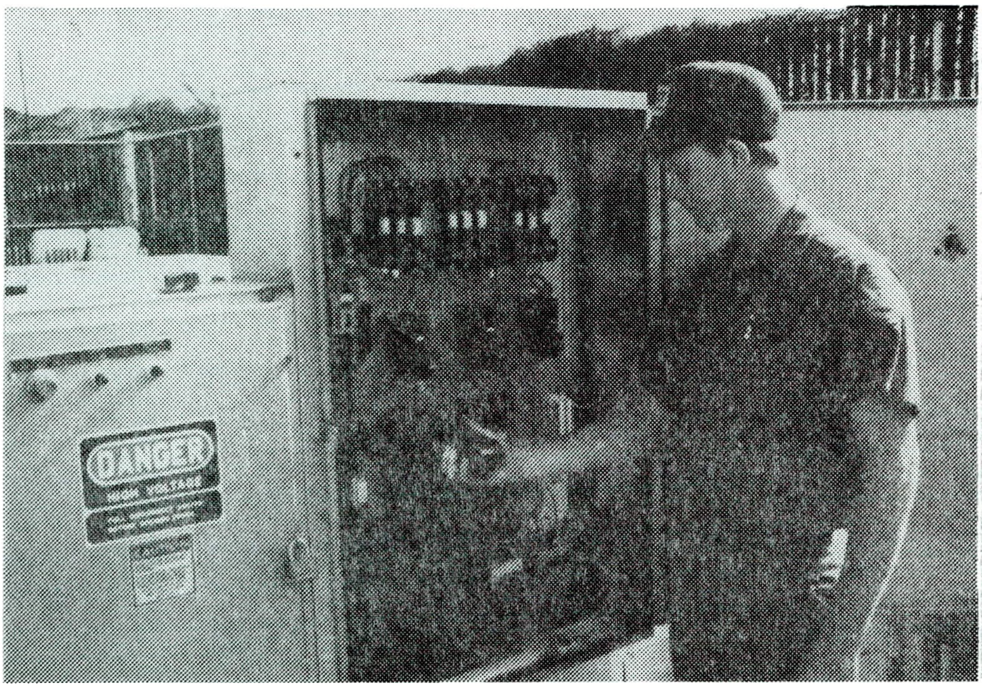

Figure 6 - Measuring Kilowatt Input to a Refrigerating Compressor

Chilled Water System Efficiency

The energy use of the equipment was calculated using the equation;

$$\text{Energy (Btu/hr)} = 500 \times \text{Flow Rate (gpm)} \times \text{Temp Differential (Deg F)}$$

Using the recorded watt-hour reading, the efficiency can be calculated and compared to published ratings or to other similar equipment. The efficiency of the equipment can be presented as Energy Efficiecy Rating (EER), Coefficient of Performance (COP), or Kilowatts per Ton (kw/ton).

$$\text{EER} = \frac{\text{Cooling Rate (Btu/hr)}}{\text{Energy Input (watts)}}$$

$$\text{COP} = \frac{\text{Heat Removed (Btu/hr)}}{\text{Energy Input (Btu/hr)}}$$

$$\text{KW/Ton} = \frac{\text{Energy Input (kw)}}{\text{Cooling Rate (tons)}}$$

By inserting the actual test readings into the above equations the desired efficiency can be calculated. Table 2 lists the efficiencies for the major chillers tested in this project.

Packaged System Testing

The greatest number of air conditioning systems in the City are packaged systems, therefore the efficiency test for these systems was quite important. The test procedure for these systems was similar to that used for the chilled water system test except that the flow rate of air instead of water was required. A copy of the form used to record the test data for packaged systems is presented in Appendix D.

Testing for Air Flow Rate (CFM). The City had used a flow hood in last year's project, however it was decided that the readings

TABLE 2 - CHILLER EFFICIENCY TEST RESULTS

	LOCATION	MODEL	TEST DATE	KW/TON
TEST 1	MB	CENTRAVAC #1	Ø5/18/88	Ø.67
TEST 2	MB	CENTRAVAC #1	Ø5/18/88	Ø.62
TEST 3	MB	CENTRAVAC #1	Ø5/19/88	Ø.67
TEST 4	MB	CENTRAVAC #1	Ø5/19/88	Ø.71
TEST 5	MB	CENTRAVAC #1	Ø5/19/88	Ø.63
TEST 6	MB	CENTRAVAC #1	Ø5/19/88	Ø.65
			TEST AVERAGE	Ø.66
TEST 1	MB	CENTRAVAC #2	Ø5/24/88	Ø.66
TEST 2	MB	CENTRAVAC #2	Ø5/24/88	Ø.66
TEST 3	MB	CENTRAVAC #2	Ø5/24/88	Ø.66
TEST 4	MB	CENTRAVAC #2	Ø5/24/88	Ø.63
TEST 5	MB	CENTRAVAC #2	Ø5/24/88	Ø.66
TEST 6	MB	CENTRAVAC #2	Ø5/24/88	Ø.67
			TEST AVERAGE	Ø.66
TEST 1	MB	YORK TURBO	Ø5/26/88	Ø.66
TEST 2	MB	YORK TURBO	Ø5/26/88	Ø.65
TEST 3	MB	YORK TURBO	Ø5/26/88	Ø.62
TEST 4	MB	YORK TURBO	Ø5/26/88	Ø.63
TEST 5	MB	YORK TURBO	Ø5/26/88	Ø.66
			TEST AVERAGE	Ø.64
TEST 1	PLAZA MB	CARRIER #1	Ø6/23/88	Ø.45

obtained were more prone to error such as duct loss or the possibility of missing air input ducts that were not known to the technician. Therefore a portable manometer was used that would test the air flow directly. This insures that the air flow rate for the total air from the air conditioning equipment is being recorded more accurately.

The air pressures in the ducts of most air conditioning and ventilating systems is generally in the very low range. Ordinary pressure gages, such as the Bourdon-tube type, cannot be used to measure such small pressures with any degree of accuracy. Electronic test instruments are now available that will measure air pressure to an accuracy of 0.001 inches of water. Pressure in ducts is usually designated in units of inches of water. The test instrument used can instantaneously convert the measurement to pounds per square inch (psi) or inches of mercury (in Hg).

Total pressure is the sum of static pressure (Ps) and velocity pressure (Pv).

$$\text{Total Pressure} = \text{Velocity Pressure} + \text{Static Pressure}$$

Total and static pressures can be measured directly and velocity pressure can be obtained by subtraction. The relationship between velocity pressure and velocity is:

$$V = 1096 \times \sqrt{Pv \times Va}$$

where V = velocity, feet per minute
Pv = velocity pressure, inches of water
Va = specific volume of air, cubic feet per pound

Using standard air with a specific volume of 13.34 cubic feet per pound the equation becomes:

$$V = 4003 \times \sqrt{Pv}$$

In actual tests, the manometer can be set up to indicate directly the velocity pressure in the duct by connecting one sensing tube to the duct to record static pressure, and inserting the other tube of the instrument into the duct pointing directly against the airflow stream to read the total pressure in the duct. Connected in this way, the test instrument operates like a pitot tube sensing the difference between total and static pressure. Sixteen measurements were taken in each duct and the average reading was multiplied by the cross sectional area of the duct to obtain the air flow rate (CFM). Figure 7 shows the equipment in use while measuring the air flow of one of the City's packaged units.

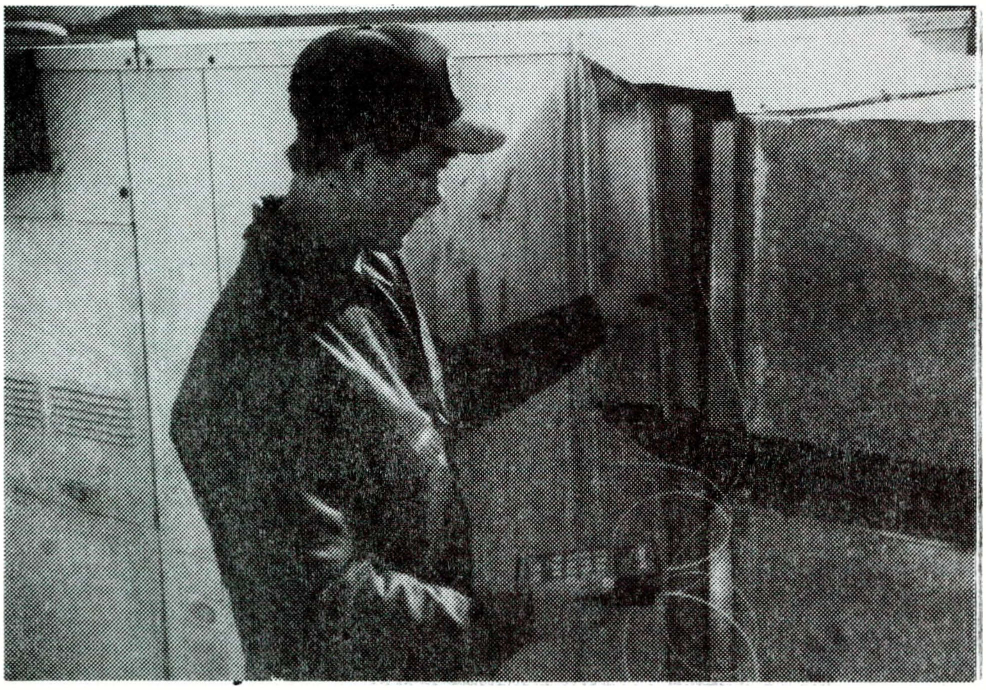

Figure 7 - Measuring the Air Flow Rate

Temperature Differential. The supply and return air temperatures were measured. This was accomplished with the digital electronic temperature instrument used in the chilled water testing. Figure 8 shows the temperature differential being measured on a packaged system.

Figure 8 - Measuring Temperature of Packaged System

Energy Input. The input electrical energy to the equipment (watts) was measured using the same hand held wattmeter used in the chilled water equipment testing. Figure 9 shows a City technician testing the watt usage of a packaged system.

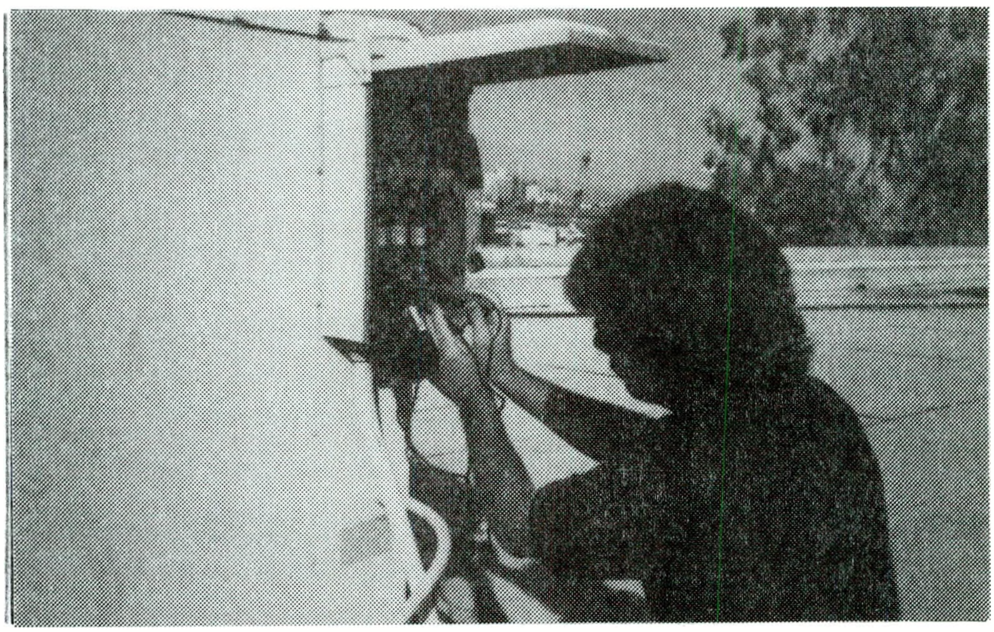

Figure 9 - Measuring Electrical Energy Input (watts) to a Packaged System

The electrical energy recorded for packaged systems included condenser fans and matches the total system efficiency compared to that of the compressor tested in the chilled water systems. The published efficiency for packaged systems includes all energy consuming equipment in the package, therefore this test is equivalent to the manufacturer's test.

Packaged System Efficiency

The useful work done by the packaged systems can be calculated using the test data and the formula below:

Total Heat Gain = Sensible Heat Gain + Latent Heat Gain

Sensible Heat Gain. The following formula was used to calculate the sensible heat content of the air flow in the duct:

Btu/hr = 1.10 x Flow Rate (cfm) x Dry Bulb Temp Differential (deg F)

Latent Heat Gain. The latent heat of water vapor at room temperature is approximately 1075.5 Btu per pound. Multiplying this figure by the number of pounds of moisture in the air gives the latent heat content of the air. This can be expressed by the formula below:

Latent Heat = 4840 x CFM x Humidity Ratio Diff. (lb water /lb dry air)

Inserting the calculated useful work done, total heat gain, and the electrical energy consumed during the test into the equations previously presented for EER, COP, and KW/ton; the packaged system efficiency can be obtained. This efficiency can now be compared to published efficiency of equipment similar in tonnage. The major difference from the actual test and the manufacturers' test are the climatic conditions. Where the manufacturer can control the dry bulb and wet bulb temperatures, the tests performed by the City technican were taken at the actual climatic conditions on the day of testing.

ECONOMIC ANALYSIS

The efficiency of the equipment was only one factor in the overall analysis of equipment replacement. Another very important input was the cost of electricity which was a complex variable. An electric utility may have a number of rates that can be very confusing to the beginner. A simple method to obtain the electrical cost is to use the monthly average of the total electric bill divided by the total electrical consumption. This will usually give a fairly accurate average electrical cost in cents per kilowatt-hour (kwh). This technique however does not take into account the demand charge and the change in demand brought about by more efficient equipment. Many utilities have computer programs and can insert consumption and demand into the program and get a more accurate electrical cost. The City's analysis used the simple average electrical costs which was considered to be accurate enough for the equipment comparison.

Another very important factor when calculating energy savings is the equipment operating time. In many cases this is estimated from local climatic data taken from ASHRAE Handbook. During last year's project it was found that the estimated equipment operating time was grossly underestimated. This prompted the air conditioning equipment to be equiped with elapsed time meters to record the actual operating hours of the equipment in a cooling season. Table 3 shows the considerable difference between estimated run times and actual run times. The importance of this finding can be appreciated when the electrical savings are calculated.

Table 3 - Comparison of Package System Test Results

BLDG	TONS	CONSULTANT STUDY PUB EER	REPLC EER	RUN TIME	KWH/YR SAVE	PYBK YRS	ACTUAL TEST ACT EER	RUN TIME	KWH/YR SAVE	PYBK YR
FAC MAINT	10.0	8.2	9.5	630	1261	34.0	7.5	2187	7367	8.5
FAC MAINT	10.0	8.2	9.0	630	1261	26.5	4.7	2136	25482	2.6
FAC MAINT	10.0	8.2	9.5	586	1174	36.6	7.2	586	2365	18.2
FAC MAINT	7.5	8.7	9.3	622	541	61.6	7.0	622	1866	17.8
FAC MAINT	4.0	6.9	8.6	493	678	36.0	6.6	493	833	22.8
NSC	5.0	5.6	9.0	669	2709	12.8	4.8	2307	13458	2.6
SWCC	2.5	6.3	9.5	1100	1764	8.2	3.9	1100	4988	2.9
SQ PK BRIEF	7.5	7.6	9.2	1651	3400	16.4	4.0	2516	31997	1.7
FIRE ST #1	2.0	7.5	8.5	1950	7341	13.2	6.7	1950	14792	6.5
FIRE ST #4	5.0	6.9	8.3	1190	2232	15.5	5.0	1190	5678	6.1
FIRE ST #5	5.0	6.9	8.3	1190	2232	15.5	5.0	1190	5678	6.1
FIRE ST #6	2.5	7.7	11.9	1437	1961	7.3	7.8	2498	3284	4.4
FIRE ST #10	2.5	7.2	9.5	1714	1758	7.6	5.5	1714	3936	4.2
FIRE ST #11	5.0	6.3	8.6	1629	4148	3.7	6.3	1629	4148	3.7
FIRE ST #16	4.0	7.0	13.2	2044	6584	3.6	5.6	2044	10087	2.3
FIRE ST #22	5.0	6.3	8.6	1872	5024	3.1	4.5	1972	12535	1.2
FIRE ST #22	5.0	6.3	8.6	1972	5024	3.1	8.0	1972	6642	2.3

Table 3 - Continued

BLDG	TONS	CONSULTANT STUDY PUB EER	REPLC EER	RUN TIME	KWH/YR SAVE	PYBK YRS	ACTUAL TEST ACT EER	RUN TIME	KWH/YR SAVE	PYBK YR
FIRE ST #24	5.0	6.3	8.6	1508	3841	4.0	5.4	2000	8269	1.9
FIRE ST #24	5.0	6.3	8.6	1508	3841	4.0	4.4	2000	13319	1.2
FIRE ST #27	4.0	7.0	13.2	1636	5268	4.5	6.0	2598	11337	2.1
FIRE ST #27	2.5	6.9	11.9	1612	2928	4.9	5.9	2446	6245	2.3
FIRE ST #30	4.0	7.7	13.2	1632	4240	5.6	7.0	2076	6686	3.5
FIRE ST #30	2.5	7.7	11.9	1632	2227	6.4	7.0	2770	4859	2.9
FIELD ENG	7.5	7.5	8.9	752	1929	27.1	7.0	752	2065	25.3
FIELD ENG	7.5	7.5	8.9	1108	2842	18.4	7.1	1108	2841	18.4
FIELD ENG	5.0	7.4	8.5	520	435	48.7	6.9	520	851	24.7
FIELD ENG	5.0	7.4	9.0	591	726	47.7	7.0	591	1126	31.0
PUEBLO GRAND	15.0	7.5	8.6	695	2218	24.0	4.2	1511	33132	2.9
PUEBLO GRAND	15.0	7.5	8.6	695	2218	24.0	4.3	1397	29240	3.2
PUEBLO GRAND	7.5	8.2	8.6	760	388	49.0	4.3	2146	22458	2.2
PUEBLO GRAND	5.0	6.9	9.1	640	640	9.6	4.0	1078	9062	4.2
WASH AC	10.0	6.6	9.0	710	3443	19.3	5.6	1939	15697	4.2

Calculated Savings

Projected yearly savings can be calculated using the equation below:

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

It can easily be seen from the equation that the equipment operating time can have a substantial effect on the savings. Table 2 shows the dramatic difference in results using the actual equipment operating times instead of the estimated times. Using the calculated kilowatt-hour per year savings multiplied by the utility rate, the dollar savings can be derived. The electrical utility rates used in the table were, \$.07 per kilowatt-hour for large buildings, \$.09 per kilowatt-hour for medium size buildings and \$.11 per kilowatt-hour for the smaller buildings. To calculate a system payback the cost of new equipment installed was required. This is obtained by contacting local air conditioning vendors and estimating the installation cost utilizing the "Means Estimating Guide". Table 4 shows the results of testing the packaged systems utilizing actual run times and revised estimates from buildings with similar functions. The table also presents the annual electrical energy and dollars savings that can be obtained by replacing the equipment with newer, and more efficient equipment. With the estimated replacement equipment installed cost, a simple payback was calculated by dividing the cost of equipment by the annual dollar savings.

EQUIPMENT REPLACEMENT CANDIDATES

After tabulating the equipment test results and their calculated paybacks, similar to Table 4, an acceptable maximum payback must be determined. The Energy Conservation Office uses three to five years payback depending upon the life of the project to be considered. The

Table 4 - Package System Test Results

BLDG	SIZE TONS	TEST EER	EST RNTM	RPLC EER	KWH/HR SAVE	$/YR SAVE	RPLC INST COST	PAY BACK
ADMIN SPT	12.5	6.6	1000	8.3	4655	419	6500	15.5
ADMIN SPT	10.0	6.1	1000	8.5	5554	500	5800	11.6
ADMIN SPT	5.0	5.9	1000	9.0	3502	315	3200	10.0
EASTLAKE PARK	4.0	4.1	1000	9.0	6374	574	1700	3.0
EASTLAKE PARK	7.5	5.1	1000	8.7	7302	657	4400	6.7
FAC MAINT BLDG	10.0	7.5	1500	8.5	2824	254	5800	22.8
FAC MAINT BLDG	10.0	7.2	1500	8.5	3824	344	5800	16.8
FAC MAINT BLDG	7.5	7.1	1500	8.7	3497	314	4400	14.0
FAC MAINT BLDG	4.0	6.6	1500	9.0	2909	262	1700	6.5
FAC MAINT BLDG	3.0	6.3	1500	9.0	2571	231	1500	6.5
FIELD ENG BLDG	7.5	7.7	1100	8.7	1478	133	4400	33.0
FIELD ENG BLDG	7.5	7.9	1100	8.7	1152	104	4400	42.0
FIELD ENG BLDG	5.0	8.0	1100	9.0	917	83	3200	38.0
FIELD ENG BLDG	5.0	8.1	1100	9.0	815	73	3200	44.0
FIRE STATION #1	20.0	6.7	2500	8.3	17263	1556	10400	6.7
FIRE STATION #3	5.0	8.0	2500	9.0	2083	187	3200	17.0
FIRE STATION #4	5.0	4.4	2500	9.0	17424	1568	3200	2.0
FIRE STATION #4	5.0	4.6	2500	9.0	15942	1435	3200	2.2
FIRE STATION #4	5.0	4.7	2500	9.0	15248	1372	3200	2.3

Table 4 - Continued

BLDG	SIZE TONS	TEST EER	EST RNTM	RPLC EER	KWH/HR SAVE	$/YR SAVE	RPLC INST COST	PAY BACK
FIRE STATION #5	5.0	7.3	2500	9.0	3881	349	3200	9.2
FIRE STATION #6	4.0	8.0	2500	9.0	1667	150	1700	11.3
FIRE STATION #6	2.5	7.5	2500	9.5	2105	189	1300	6.9
FIRE STATION #7	4.3	7.6	2500	9.0	2641	238	1700	7.1
FIRE STATION #7	2.5	7.1	2500	9.5	2668	240	1300	5.4
FIRE STATION #9	7.0	8.4	2500	8.7	862	78	4400	56.0
FIRE STATION #9	10.0	8.2	2500	8.5	1291	116	5800	50.0
FIRE STATION #9	4.0	7.0	2500	9.0	3810	343	1700	5.0
FIRE STATION #9	2.0	6.5	2500	9.5	2915	262	1300	5.0
FIRE STATION #1Ø	2.0	5.5	2500	9.5	4593	413	1300	3.1
FIRE STATION #1Ø	4.5	7.7	2500	9.0	2532	228	1300	5.7
FIRE STATION #11	5.0	6.3	2500	9.0	7142	643	3200	5.0
FIRE STATION #11	5.0	6.6	2500	9.0	6060	545	3200	5.9
LOS OLIVOS A.C.	11.0	5.7	2000	8.4	14887	1340	5800	4.3
LOS OLIVOS A.C.	11.0	5.5	2000	8.4	16571	1491	5800	3.9
LOS OLIVOS A.C.	11.0	4.9	2000	8.4	22449	2020	5800	2.9
LOS OLIVOS A.C.	11.0	5.0	2000	8.4	21371	1923	5800	3.0
OCT LBR	15.0	5.3	2413	8.2	28983	26Ø8	7000	2.7
OCT LBR	12.5	5.5	260	8.3	2503	225	6500	28.9
OCT LBR	5.5	5.1	528	9.0	2692	242	3200	13.2

Table 4 - Continued

BLDG	SIZE TONS	TEST EER	EST RNTM	RPLC EER	KWH/HR SAVE	$/YR SAVE	RPLC INST COST	PAY BACK
PUEBLO GNDE MUS	15.5	4.2	1398	8.2	29226	2630	7000	2.7
PUEBLO GNDE MUS	15.0	4.3	1512	8.2	30103	2709	7000	2.6
PUEBLO GNDE MUS	15.0	4.1	693	8.2	15212	1369	7000	5.1
PUEBLO GNDE MUS	7.5	4.3	2146	8.7	22776	2044	4400	2.2
PUEBLO GNDE MUS	5.0	4.0	1079	9.0	8992	809	3200	3.9
SURPLUS PROPERTY	5.0	7.0	800	9.0	1524	137	3200	23.0

table shows over twenty projects that fall within those limits. These systems can be economically replaced using the energy savings obtained by installing high efficiency equipment.

IMPLEMENTING AN EQUIPMENT REPLACEMENT PROGRAM

The process to implement this type of program will be outlined in a step-by-step format so that local governments will not have any trouble understanding and following the City of Phoenix Energy Conservation program. The Energy Office was fortunate in that it was able to dedicate a technician to perform the testing so that the test program could be accomplished in a timely manner.

Step 1) ENERGY AUDIT OF THE HVAC EQUIPMENT. Performing an energy audit of the equipment is time consuming, however it will prove worthwhile in the long run. This audit can be used to serve many purposes besides evaluating the equipment for testing. In some jurisdictions this audit might have already been accomplished by some office or department. There are a number of manuals available to assist in performing the energy audit and are recommended for further study.

Step 2) PURCHASE THE TEST INSTRUMENTATION. Research the test instruments available in the markets and purchase the ones that are easy to use. If the test instruments are easy to use, the technicians will be prone to testing more equipment and make the program more successful. If the accuracy of the instruments is questionable then the efficiency, savings and payback will be equally questionable. The test instruments can be found to be useful for other maintenance testing which could help justify the purchase. A listing of the test instruments used in the City of Phoenix testing program are in Appendix C.

Step 3) ASSIGN A TECHNICIAN TO PERFORM THE TESTING. If possible assign one or two individuals who will be responsible for the actual testing. It will be easier for these individuals to become familiar with the test intruments and to streamline the test procedure. The technician will be required to test during the heating or cooling season, depending on the type of HVAC equipment to be tested. This is usually also the time for highest demand time for the maintenance of this equipment. If possible a maintenance and testing program might be combined so that the equipment can be tested immediately following any repairs.

Step 4) TEST ALL SELECTED EQUIPMENT. Test all the equipment identified by the energy audit. Record the data from all tests and if possible utilize a computer to document the information. If a computer is available, log the data in files that are compatible with other programs that can compute the efficiency equations, for electrical energy savings, and simple payback.

Step 5) RESEARCH HIGH EFFICIENCY EQUIPMENT. Obtain manufacturer's documentation on efficiencies and costs of HVAC equipment. Also research installed costs for both contractor and in-house installations. If a computer is avaiable record these values to be used later in the evaluation process.

Step 6) COMPARE RESULTS. Process the data obtained in the above steps. Calculate the efficiencies of the old equipment and compare with that of the new high efficiency equipment. Using the equations presented in this chapter, the kilowatt-hour savings can be calculated. With the estimated installed cost of the replacement equipment and the estimated utility cost, a simple payback can be calculated. Depending on the computer programs used a concise printout showing all the desired information can be obtained. This becomes the working tool to evaluate HVAC equipment for replacement candidates. From a table of this type, the worst systems can be replaced until the budget runs out.

Chapter 4 - Lessons Learned

INTRODUCTION

After two years of testing HVAC equipment, The Energy Conservation Office has developed a test program that seems to operate smoothly and with acceptable accuracy. During this two year period the method and test instrumentation has been changed to simplify the testing at a reasonable cost. Another consideration was to make the test procedure simple enough so that the technician would be willing to complete the tests in a timely manner.

TEST INSTRUMENTATION

The original testing of air flow rates in packaged systems was accomplished by a flow hood. Although the instrument itself had fairly good accuracy, it proved to be cumbersome and disrupted the building occupants. Also the readings obtained did not allow for duct leaks. To improve the air flow measurements a portable manometer was used. This equipment allowed the technician to take air flow measurements at the point where it leaves the equipment thus minimizing the duct losses. This instrument is used on the roof with the rest of the test equipment, therefore there is no disruption of the working occupants. The total time to test equipment was thus reduced which resulted in testing more equipment.

The first kilowatt-hour meter used was a hand-held meter that did not account for power factor. This resulted in erroneous kilowatt-hour readings which affected the efficiency calculations. After this was realized a recording kilowatt-hour meter was used, however due to its size it was difficult to move from building to building and even more difficult to use. A hand-held wattmeter was obtained that gave true watts and the test procedure moved more rapidly. A listing of the kilowatt-hour instruments used is presented in Appendix C.

PROBLEMS WITH EQUIPMENT REPLACEMENT

The equipment replacement project from last years program was outlined in detail in the Year 8 Report HVAC Equipment Replacement for Best Size and Efficiency. The original equipment was a 50-ton chiller that was operating inefficiently and was replaced with an efficient thermal storage system with ice harvester. This system was to save money in two ways. First, the equipment was more efficient so would utilize less electricity and secondly, the thermal storage system was to operate at night when the lower time-of-day rates went into effect. Ater two cooling seasons, problems encountered with the ice harvesting equipment caused considerable concern and negated any savings expected.

The ice harvesting equipment had several major design defects and required continual maintenance. Because of these defects the equipment was not capable of charging the ice tanks for the next day's cooling load and the unit was required to operate around the clock. This caused the electric billing to be higher than normal due to the fact that the ice equipment was operating during the high demand on-peak rates. The equipment manufacturer was informed of the problems and has undertaken a program to repair the design defects. The manufacturer has assured the City that the thermal storage equipment will operate properly for the next cooling season.

A possible suggestion for other jurisdictions investigating high efficiency equipment and thermal storage is to insure that the replacement equipment is reliable and time-tested. This is not always possible in the case of thermal storage equipment and new and innovative HVAC equipment. Researching the new replacement equipment thoroughly may identify potential problem areas. Contacting other building users in the area that have installed similar equipment is also an effective method of researching the actual operating equipment and is always a good purchasing practice regardless of the type of equipment. The only way a replacement program can possibly work is if the new HVAC equipment performs as advertised.

TEST RESULTS

Packaged Systems. The results of the efficiency tests for the packaged systems were generally as expected. The older air conditioners proved to be less efficient. The newer models had higher efficiencies, however these models were still one or two EER below the published rating. This becomes important when performing an economic analysis for an equipment replacement and the published EER shows a higher savings than will actually be achieved.

Chilled Water Systems. Test results on chillers showed no correlation between the age of the chiller and its efficiency. Twenty-year old chillers operated with an efficiency equal to chillers with half that age. A preliminary conclusion from this test program could be that chilled water systems can operate very efficiently for many years if properly maintained by the equipment operators.

PROGRAM UPDATE

Much of the City of Phoenix building inventory of equipment has been tested to date. Testing will continue on the remainder of the equipment and entered into the data file. After completion of these tests, a program will be initiated to test new equipment installed due to normal equipment change out and the new equipment installed from this program. Actual test results of new high efficiency equipment is needed to utilize in the formula in place of the manufacturers published efficiencies. Actual operating efficiencies can be recorded on the newer equipment thus giving a more accurate energy and dollars savings for analysis purposes.

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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		9.8
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 - Test Instrumentation and Equipment

TEST INSTRUMENTATION

Wattmeters:	Esterline Angus, Miniservo III, Power Supply Demand Recorder, Model No. UFM 84P.
	TIF Instruments, 2000 Wattprobe, Clamp-on, Digital Wattmeter, Measures Apparent Watts.
	TIF Instruments, 2000A Wattprobe, Clamp-on, Digital Wattmeter, Measures True Watts.
Temperature:	Imperial Eastman Model A-8 Electronic Temperature Analyzer.
Elapsed Run Time:	Cramer Type 635K.
Flowrate (Air):	Shortridge Instruments Flowhood, Model No. CFM-80.
	Omega PCL-200 Series, Portable Manometer/Calibrator.
Flowrate (Water):	Ploysonics Ultrasonic Flowmeters, Model No. UFM 84P.

1987 DEMONSTRATION PROJECT

Original Chiller:	Climatrol, Model No. LRSØ5ØØ1, Nominal Rating - 5Ø tons, Air-Cooled Reciprocating Compressor, Power Supply - 46Ø/3, 84 amps, Six Fans 46Ø/1, 2.3 amps.
Thermal Storage:	Turbo Refrigerating Co., Model No. HP-4ØØB SCE, Compressor - Royce Model No. CG6ØNTA, Recipricating, Refrigerant R-22, Compressor Motor - Lincoln, 1 hp, 46Ø v, 2.15 amps, Pump Motor - Century/Scot, 1/2 hp, 46Ø v, 1 amp, Recirculating Water Pumps (2) - Siemens-Allis, Centrifugal, 3 hp, 46Ø v, 4.2 amps.

Appendix D - Sample Test Forms

CHILLER EFFICIENCY TEST

1. Location ______________________________ Date __________
2. Manufacturer ______________________________
3. Model No.______________________________
4. Serial No.______________________________
5. Other Nameplate Info.______________________________
6. Nominal Pipe Inside Diameter (ID) = __________ in.
7. Supply Water Temp. = __________ deg. F
8. Return Water Temp. = __________ deg. F
9. Supply/Return Temp. Differential (ΔT) = __________ deg. F
11. Electrical Input (KWH) =__________
10. Flow Velocity (V) = __________ ft./sec.
12. GPM = 2.45 X (ID X ID) X V = __________ GPM
13. BTUH = 500 X __________GPM X __________ ΔT = ______________ BTUH
14. EER = __________ BTUH / 1000 KWH = __________

AIR CONDITONER EFFICIENCY TEST

1. Location ______________________________ Date __________

2. Manufacturer ______________________________

3. Model No.______________________________

4. Serial No.______________________________

5. Other Nameplate Info.______________________________

6. Supply Duct:________ in. wide________ in. deep = ___________ sq. ft.

DUCT VELOCITY PRESSURE (Pv)

		1/8 width	3/8 width	5/8 width	7/8 width
7.	1/8 depth				
8.	3/8 depth				
9.	5/8 depth				
10.	7/8 depth				

11. Air Velocity = 4003 $\sqrt{Pv}$ = ____________ feet per minute.

12.CFM = Air Velocity _________ X Duct Area __________ = _____________ CFM

TEMPERATURES

		DB	WB	W
13.	SUPPLY			
14.	RETURN			
15.	Δ T=		Δ W =	

16. Qs = 1.10 CFM X T = ______________

17. Qs = 4840 CFM X W = ______________

18. Q total = ______________ BTUH

19. Electrical Input (KW) = ______________

20. EER = BTUH / 1000 KW = ______________

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