AIR FORCE
REFRIGERANT MANAGEMENT PROGRAM

REFRIGERANT MANAGEMENT HANDBOOK

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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EXECUTIVE SUMMARY

This Refrigerant Management Handbook (Handbook) includes everything the base civil engineer (BCE) needs to develop a Base Refrigerant Management Program (BRMP). The BRMP will help the BCE manage refrigerants that have a damaging effect on the ozone layer. These are part of a class of substances called ozone-depleting chemicals (ODC). They must be controlled to eliminate their dispersion into the atmosphere.

The policies and regulations that support the reduction of ozone depletion require the BCE to carefully control refrigerants and monitor air conditioning/refrigeration (AC/R) equipment. These policies are:

The Montreal Protocol and subsequent amendments that placed a worldwide ban on the production of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants starting in 1996 and 2031, respectively.

The Environmental Protection Agency (EPA) regulation issued in May 1993 to minimize CFC, HCFC and, starting on 15 November 1995, hydrofluorocarbon (HFC) emissions during operations, maintenance, repair, and disposal of refrigerant-using equipment.

The Secretary and Chief of Staff of the Air Force Action Memorandum, date 7 January 1993, which prohibits the purchase of any CFC refrigerants and AC/R equipment which use these refrigerants starting in June 1993. Exceptions are approved only by an Air Staff waiver.

To effectively manage AC/R equipment and regulated refrigerants, the BRMP, through the base Refrigerant Manager (RM), focuses on conservation measures and the development of a Refrigerant Management Plan (RMP). The conservation measures will help the BCE meet the EPA requirements of minimal releases of refrigerant through improved servicing techniques, training and certifying technicians, and recording equipment maintenance and refrigerant usage. The RMP provides a plan to ensure adequate refrigerant supplies will be available to meet mission needs until the last of the units using CFC refrigerants have achieved their full economic life. The RMP provides a refrigerant inventory timeline that shows refrigerant consumption rates, equipment retirements, and other activities which affect the inventory of refrigerant. An implementation schedule is part of the RMP. Its purpose is to assist in keeping equipment retirement on schedule. A simple comparison of a plan’s projected refrigerant inventory quantity versus what is actually on-hand will tell the BCE whether the base is meeting its goals or is in danger of a negative mission impact.

The Handbook includes all the information the RM needs to initiate and carry out a BRMP. The Handbook's appendices cover the:

- National and Air Force policies on ODC refrigerants,
- technical criteria for mechanical room design to support alternative refrigerants,
- procedures for making a retrofit or replacement decision using life-cycle cost analysis,
- methods to correctly size a replacement chiller or justify a central plant,
- use of the Work Information Management System (WIMS) software for tracking refrigerant usage and equipment maintenance,
- various types of funding available to pay for new conservation equipment and AC/R units, and
- conservation techniques for following EPA requirements.

This Handbook represents the Air Force's resolve to protect the environment while meeting its global mission. As stated in the Secretary and Chief of Staff of the Air Force Action Memorandum:

> "The sooner we learn to live without these substances, the less likely we are to suffer a mission stoppage because they are not available, and the less we will contribute to the depletion of the earth's ozone layer."

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Chapter 1 — Introduction

1.1 Background

1.1.1 Refrigerant Management Required

The Air Force Civil Engineer directed the Air Force Civil Engineer Support Agency (AFCESA) to develop base guidance for managing refrigerant inventories to ensure all air conditioning and refrigeration (AC/R) equipment operates until the end of its economic life. This requirement was in the Action Memorandum, 7 January 1993, from the Secretary and Chief of Staff of the Air Force implementing the Air Force ozone-depleting chemicals (ODC) policy. The memorandum was a direct result of the worldwide movement to reduce ODCS, including production bans starting in January 1996.

1.1.2 CFCS and HCFCs - Class I and Class II Refrigerants

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFC) are ODCs and are categorized as Class I and II refrigerants, respectively. The Environmental Protection Agency (EPA) published regulation 40 C.F.R. Part 82 (1993) to minimize Class I and 11 emissions during operations, maintenance, repair, and disposal of refrigerant-using equipment. The regulation applies to persons who work on this equipment as well as refrigerant reclaimers, equipment owners, and refrigerant recycling and recovery equipment. The EPA may levy stiff fines for noncompliance (See Appendix A, *Update on Refrigerants: Translating the Laws, Regulations, and Policies into Practice).*

1.2 Air Force Goal

The Air Force goal is to manage the inventory of regulated refrigerants and AC/R equipment to ensure uninterrupted mission support while operating this equipment until the end of its economic life. The maintenance procedures used by base civil engineer (BCE) personnel must be compatible with the EPA's environmental compliance regulations. The Refrigerant Management Handbook's (Handbook) objective is to make each base self-sufficient in CFC refrigerants. It assists the BCE in developing a Base Refrigerant Management Program (BRMP) to manage refrigerant resources and operate AC/R equipment to ensure continued mission support and environmental compliance. Using strong conservation procedures and life-cycle costing methods, the BRMP will extend the availability of the existing refrigerant supplies and prioritize equipment retirements. Although the emphasis is on CFCs and HCFCs, the Handbook's procedures to standardize operation and maintenance practices should be applied to all refrigerants. It is also intended the Handbook be used by the base refrigerant manager (RM) in developing the Refrigerant Management Plan (RMP). Following the guidelines provided in the text and appendices, the RM will be able to successfully complete all essential elements of the RMP.

1.3 The Base Refrigerant Management Program

The BRMP implements refrigerant conservation procedures and develops a base RMP that prioritizes AC/R equipment retirements. The RMP includes graphs and tables to predict the rate of refrigerant consumption, schedule equipment retirements, and identify the need for refrigerant to prevent negative mission impacts. The RMP will ensure the availability of adequate refrigerant supplies through the remaining life of existing equipment. It must be updated periodically to accurately reflect the changes in funding and mission.

1.4 Handbook Organization

The Handbook contains four chapters that describe how to establish the BRMP. The appendices supplement the chapters on specific technical topics. Figure 1-1, *Refrigerant Management Handbook Flowchart,* shows the relationship between chapters and appendices. The flowchart, highlighting the applicable chapter and appendices, also appears at the beginning of each chapter.

1.4.1 BRMP Elements

The Handbook separates the BRMP into two elements:

- recommendations to reduce refrigerant consumption and meet EPA requirements, and
- the development and implementation of the base RMP.

1.4.1.1 The first element, discussed in Chapter 2, *Conservation Efforts for the Base Refrigerant Management Program,* contains a set of recommended actions to reduce refrigerant consumption and help the BCE meet EPA requirements such as:

- releasing minimal amounts of CFC and HCFC refrigerants into the atmosphere,
- practicing refrigerant conservation servicing techniques,
- training and certifying technicians to handle refrigerants,
- recording equipment maintenance and refrigerant usage, and
- controlling refrigerant inventory.

Integral to recording and controlling refrigerant is the use of the Work Information Management System (WIMS) and WIMS Refrigerant Management Software.

1.4.1.2 The second element of the BRMP is addressed in Chapter 3, *Refrigerant Management Plan Development,* and Chapter 4, *Refrigerant Management Plan Implementation. The* RMP will help the base manage its regulated refrigerants and the AC/R equipment that uses those refrigerants. The RMP requires engineering and life-cycle cost analyses to determine if a unit should be retrofitted to a non-CFC refrigerant, replaced in kind, or replaced with another type of equipment or process (such as a central plant or absorption unit).

1.4.2 Appendix Summary

Following is a summary of each appendix.

Appendix A – details of applicable requirements of the Clean Air Act Amendments or CAAA, Title VI, and Air Force Policies to implement them;

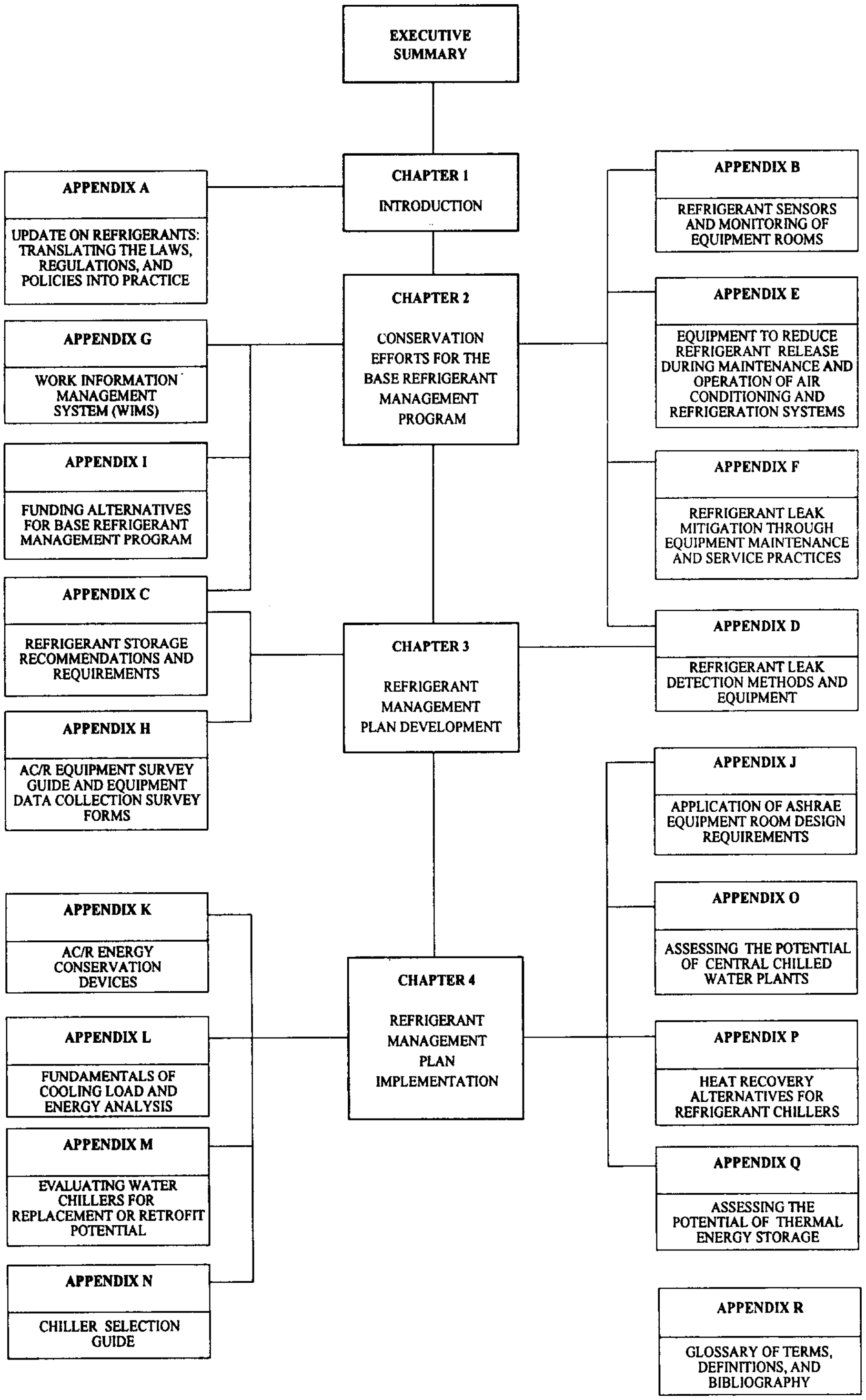

Figure 1-1. Refrigerant Management Handbook Flowchart

Appendix B — descriptions, availability, and applications of refrigerant area monitors for use in mechanical rooms and refrigerant storage areas;

Appendix C — refrigerant storage requirements for facilities and containers and safe handling of refrigerants;

Appendix D — refrigerant leak detection methods and equipment for high- and low-pressure refrigerants when the equipment is operating or idle, advantages and disadvantages of portable units that pinpoint leak locations, common equipment leak locations;

Appendix E — terms and reviews of equipment used for recovery, recycling, and reclamation;

Appendix F — major changes to refrigerant leak mitigation procedures during equipment servicing practices that will meet EPA requirements and recommendations;

Appendix G — how the WIMS Refrigerant Management Software helps the RM monitor AC/R equipment and refrigerant usage;

Appendix H — how to perform an Equipment Survey, providing the tools and personnel requirements and a line-by-line explanation of the equipment survey forms;

Appendix I — different funding avenues that can pay for refrigerant conservation equipment and AC/R equipment retirement projects, including criteria and examples of programming documents;

Appendix J — mechanical equipment room design requirements for refrigeration systems in ASHRAE 15-1992, Refrigerant-Quality Rule 4;

Appendix K — use of energy conservation devices for AC/R equipment;

Appendix L – calculations for a building's cooling load and energy usage analysis (Appendices L, M, N, O, P, and Q have a distinct relationship in the selection process. This relationship is shown graphically on the back of the tab of each appendix);

Appendix M — procedures and guidelines for evaluating replacement and retrofit options for existing water chillers by comparing life-cycle costs taking into consideration age, mechanical condition, operating efficiency, and criticality to the building(s) or system(s) they serve;

Appendix N — guidelines and procedures to select water chillers based on efficiency, availability of fuel sources, load matching, initial cost, and annual operating cost;

Appendix O — guidelines for determining the potential to replace several individual chillers with a central plant that can be a combination of retrofitted and new chillers in a new structure or an expanded, existing mechanical room;

Appendix P — guidelines for determining when heat recovery chillers may be economically feasible by comparing the life-cycle cost of the alternatives;

Appendix Q — guidelines for determining when thermal energy storage systems (TESS) may be an economically feasible alternative for integration into an existing or proposed chilled water system; and

Appendix R — glossary of terms and definitions, and bibliography.

1.5 The Refrigerant Manager

The BRMP will be developed by the BCE-appointed RM. This Handbook provides the RM with the background, tools, and methods needed to manage the base refrigerant and equipment resources. The RM has several responsibilities and must possess certain capabilities in order to accomplish the job.

1.5.1 RM's Responsibilities

The RM must track:

- refrigerant consumption by each piece of equipment,
- base refrigerant inventory levels,
- consumption rates for each type of refrigerant,
- project cost and schedule for equipment retirement,
- equipment service records and maintenance and repair requirements, and
- the status of the AC/R technicians' training and certification.

1.5.2 RM's Capabilities

The RM must:

- be familiar with the WIMS Refrigerant Management Software,
- be able to use various spreadsheet and graphics software,
- have a working knowledge of the EPA requirements governing the use of regulated refrigerants,
- be able to do life-cycle cost and cooling load analysis on AC/R equipment, and
- understand procedures to justify different types of funding.

A team whose members share these capabilities and have access to other talent in the BCE organization can perform the RM's responsibilities. A possible duty location for the RM is in Maintenance Engineering.

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Chapter 2 — Conservation Efforts for the Base Refrigerant Management Program

2.1 Introduction

This chapter provides information and recommendations on refrigerant conservation that will aid the RM in establishing the BRMP. The information and recommendations will help the RM comply with the EPA and Air Force requirements that pertain to both CFC and HCFC refrigerants.

2.2 EPA Requirements

2.2.1 Equipment Servicing and Repairs Detailed requirements and information on accomplishing equipment servicing and repairs are found in Appendix E, *Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air Conditioning and Refrigeration Systems,* and Appendix F, *Refrigerant Leak Mitigation through Equipment Maintenance and Service Practices.*

2.2.1.1 Technicians must be EPA certified by 14 November 1994 to service AC/R equipment using CFC and HCFC refrigerants.

2.2.1.2 Since 1 July 1992, no one could knowingly release CFC or HCFC refrigerants into the atmosphere. This will apply to hydrofluorocarbons (HFC) refrigerants starting 15 November 1995.

2.2.1.3 Anyone who disposes of AC/R equipment must recover the remaining refrigerant and/or verify that the refrigerant has been evacuated from the equipment.

2.2.1.4 Personnel who maintain, repair, or dispose of AC/R equipment must certify their recovery and recycling equipment to EPA.

2.2.1.5 Operators of equipment containing 50 or more pounds of CFC- and HCFC-regulated refrigerants must keep up-to-date service records for the previous three years showing date, type of service, and quantity of refrigerant added-and purchased.

2.2.1.6 Commercial refrigeration equipment with over 50 pounds of refrigerant (that is, cold storage plants) must be repaired of all leaks within 30 days if the equipment is leaking at a rate which will exceed 35 percent of the total charge during a 12-month period.

2.2.1.7 Equipment, other than commercial refrigeration, containing 50 or more pounds of refrigerant (that is, comfort cooling) must be repaired of all leaks within 30 days if the unit leaks at a rate exceeding 15 percent of the total charge during a 12-month period.

2.2.1.8 Equipment does not require repair if, within 30 days after leak identification (as described in 2.2.1.6 and 2.2.1.7), a plan is developed for retirement of that equipment within one year. A copy of the retirement plan must be available at the site of the equipment.

2.2.2 EPA Maximum Leak Rates

The following example shows how to calculate the EPA maximum leak rates. This rate is shown in the WIMS Refrigerant Consumption Rates - by Facility, Equipment, and Service Date report (see Appendix G, *Work Information Management System (W7MS)).*

EXAMPLE

An office building is cooled by a 200-ton centrifugal chiller with an 800-pound CFC-12 refrigerant charge. Fifteen pounds of CFC-12 were added during the last servicing. Because the chiller provides comfort cooling and has more than 50 pounds of charge, use the 15 percent leak rate. (If this were a commercial refrigerant system, the 35 percent leak rate would apply.)

Service Records

Service Dates		**Refrigerant Added**
Calendar Date	Julian Date	
1 October	274	10 lb
4 December	338	15 lb

1. Determine the EPA Maximum Leak Rate (EPAMLR):

   EPAMLR = 800 lb x 15%/yr = 120 lb/yr

   (This is the maximum amount of refrigerant this unit can lose in a 12-month period without violating the EPA regulation.)

2. Determine the actual leak rate (ALR):

   $$ALR = \frac{\text{lb refrigerant added since last servicing}}{\text{(Days between servicing)/(365 days/yr)}}$$

   $$ALR = \frac{\text{15 lb of CFC-12}}{\text{(338-274 days)/(365 days/yr)}}$$

   ALR = 85 lb/yr

3. Is ALR > EPAMLR?

   85 lb/yr is less than 120 lb/yr

   Action is NOT necessary. However, the unit did use 15 pounds of refrigerant. Good conservation practice recommends performing a leak check and repairing the leak.

   If the ALR had been > EPAMLR, then the equipment would have to be repaired in 30 days or a plan developed within 30 days to retire the unit within 12 months.

2.3 Air Force Requirements

2.3.1 Managing Base Refrigerants

Air Force policy governing the use of CFC refrigerants has dictated the following requirements.

2.3.1.1 An Air Force waiver is required to purchase CFC refrigerants.

2.3.1.2 Purchasing new facility air conditioning systems that use CFCs is prohibited.

2.3.1.3 Manage the base's refrigerant inventory so existing equipment can be maintained until the end of its economic life.

2.3.1.4 When AC/R equipment is retired, its refrigerant must be recovered for use in the remaining operational systems.

2.3.1.5 Refrigerant ownership cannot be sold or transferred outside of the Department of Defense (DoD). Transfer of excess refrigerant to other bases is encouraged and should be coordinated through the Major Command (MAJCOM). If refrigerant is to be turned in to the Defense Logistics Agency (DLA) Refrigerant Bank, it should first be coordinated through the MAJCOM.

2.4 Training and Certification

All technicians who work with refrigerant must meet EPA certification requirements. The EPA deadline is 14 November 1994. Training and certification sessions include improved maintenance practices, identification of potential improvements to existing AC/R equipment, and familiarization with new equipment. There are two ways the RM can obtain training and certification opportunities for technicians.

2.4.1 CerTest Module

AFCESA Maintenance Directorate and the Civil Engineering School (School) at Sheppard AFB, Texas developed a 100-page study guide and a Certification Test (CerTest) module for EPA certification. All Air Force technicians will be able to review the guide and take the certification test at their home stations. The School is approved by EPA to certify technicians.

2.4.2 Local Vendors

The RM can contract with local vendors for refrigeration training and EPA certification. The RM must verify EPA has approved the vendor as a certifying agent. Depending on availability, both Operations and Maintenance and Pollution Prevention Program funds can be used for buying training and certification testing.

2.5 BCE Conservation Methods

In considering the base's conservation effort, the RM should take into account leak detection, AC/R equipment modification, and secure storage areas for refrigerant.

2.5.1 Leak Detection

The RM should develop a leak detection program that matches each piece of AC/R equipment with a specific type of leak detection. The RM should also develop an equipment leak check schedule based on the type of equipment and its past leak history. The greater the equipment's history of leaks, the more frequently it should be checked.

2.5.1.1 Leak detection procedures vary from soap bubbles to sophisticated sensors. Some of the leak detection equipment items qualify for Pollution Prevention Funds. For detailed information, review Appendix D, *Refrigerant Leak Detection Methods and Equipment;* Appendix F, *Refrigerant Leak Mitigation through Equipment Maintenance and Service Practices;* and Appendix I, *Funding Alternatives for Base Refrigerant Management Program.*

2.5.2 AC/R Equipment Modifications

Several equipment modifications can be used to prevent excessive amounts of refrigerant from escaping into the atmosphere. For example, the RM should identify all requirements for high-efficiency purge units and pressurization systems for low-pressure equipment. More information is available in Appendix E.

Pollution prevention funds can provide a resource to pay for equipment modifications (see Appendix I).

2.5.3 WIMS Refrigerant Management Software

To develop a successful conservation effort, the RM must control refrigerant when it is not in equipment and identify equipment exceeding the EPA maximum leak rate. To help the RM with refrigerant and equipment control, AFCESA developed the WIMS Refrigerant Management Software. Appendix G covers the subject extensively. The software files contain all the data for the base's AC/R equipment and refrigerant inventory. With regular input of equipment service records and inventory transactions into WIMS software files, the RIM can generate reports showing which pieces of equipment are not in compliance and the amount of refrigerant in storage. Regular data entry will satisfy the EPA recordkeeping requirement.

2.5.4 Secure Storage Areas

Because refrigerant is a valuable and diminishing resource, the base should have one or more secure storage areas. Mechanical rooms do not qualify. The RM should establish storage location(s) based on ease of accessibility for technicians and positive control of the resource. This could mean designating one or more people to be responsible for the distribution and accounting of the refrigerant. For information on storage room construction standards see Appendix C, *Refrigerant Storage Recommendations and Requirements.*

Chapter 3 — Refrigerant Management Plan Development

3.1 Introduction

This chapter describes how to develop an RMP for all AC/R equipment which use regulated refrigerants. A plan should first be developed for managing equipment which use CFC refrigerants because CFC production will cease in January 1996. Eventually, an RMP needs to be developed for all equipment containing regulated refrigerants. Appendix H, *AC/R Equipment Survey Guide and Equipment Data Collection Survey Forms, is* integral to the development of the RMP.

3.2 RMP Development Procedures

The RMP development begins with a thorough physical survey and assessment of the condition of all equipment. From the survey and assessment, a prioritized Equipment Retirement Schedule (Schedule) is developed. This Schedule is combined with refrigerant consumption rates into a timeline forecasting the base's refrigerant inventory and possible mission impacts as the retirement schedule is implemented. Next, a funding chart is developed showing all the retirement projects' costs by fiscal year. After completion of a funds distribution analysis, an implementation schedule is created to show all required RMP actions.

3.3 RMP Products

The seven main products in the RMP are the:

- Equipment List,
- Equipment Assessment Table,
- Equipment Retirement Schedule,
- Refrigerant Inventory Timeline,
- Project List,
- Funding Chart, and
- Implementation Schedule.

Together these products give the total picture of how refrigerants are managed at the base by showing all equipment retirements, what they cost, when more refrigerant will be needed, and increases of refrigerant inventory by recovery, purchases, or interbase transfers. They highlight the effects of conservation efforts on the refrigerant consumption rates.

3.4 Metrics

The RM can use the RMP to brief the BCE and staff on the status of the BRMP. The RMP details whether retirement schedules are on track and whether refrigerant inventories are adequate. The RMP shows the big picture and aids the BCE in deciding proper use of base resources. The information in the RMP can be the basis for funds justifications for equipment retirement projects and waivers for CFC purchases.

3.5 Step 1: Equipment Survey

The RM can begin the initial survey by identifying on a base map the locations of all CFC equipment containing more than 50 pounds of refrigerant. Using this map, the RM establishes an inspection sequence. The map should also show where central plants may replace existing individual units. A method to identify possible central plant locations is in Appendix H, section H. 3.4. The personnel accomplishing the survey should have a working knowledge of the major components of AC/R and leak detection equipment, understand the purpose of the BRMP, and how to use the survey forms. It will take approximately an hour to survey each piece of equipment. Most leak detection can be done at the time of the survey. Normally, the only equipment the surveyor will need is a portable leak detector. Information on these devices is in Appendix D, *Refrigerant Leak Detection Methods and Equipment.* Included in Appendix H is a utility rate information form. This form should be filled out initially and used to perform life-cycle cost analyses (LCC).

3.5.1 Survey Results

The survey results can be used to:

- complete the RMP;
- request a retrofit analysis from original equipment manufacturer (OEM);
- estimate the cost of an equipment retirement project;
- identify potential locations for a central chilled water plant;
- estimate the cost for complying with ASHRAE 15-1994;
- identify refrigerant leaks and equipment conservation modifications:
- provide a data base for the WIMS refrigerant management soft ware; and
- compute the LCC analysis for equipment replacements.

3.6 Step 2: Equipment List

The RM uses the data from the equipment survey to develop an Equipment List by refrigerant. Figure 3-1, *Sample Completed Equipment List,* demonstrates how data gathered in the Equipment Survey are used to develop the Equipment List. The best way to develop this list and other charts and graphs in the RMP is with a computer software program with spreadsheet and graphics capabilities. Software programs used to develop the examples in this book were Lotus® 1-2-3 and Lotus® Freelance Graphics.

3.6.1 Equipment List Completion

Information for columns A, B, C, D, E, and F (Figure 3-1) comes from the equipment survey forms (ESF) and data from WIMS Refrigerant Management Software. To designate the manufacturer in column C, it may be necessary to assign a “letter.” For example, “Y” is for York, “T” is for TRANE, and “C” is for Carrier. The equipment capacity and operating charge, columns E and F respectively, are obtained from the equipment nameplate or the manufacturer, if a model or serial number is known. Columns G and H are the EPA maximum leak rate for one year in both percentage and pounds of refrigerant. For column G, if the equipment is used for commercial refrigeration, use 35 percent, and for all others (for example, comfort cooling) use 15 percent. The pounds per

R–xx EQUIPMENT LIST
XYZ AIR FORCE BASE
Survey Date October 6, 1993

A	B	C	D	E	F	G	H	I	J	K	L
Building Number	Unit Number	Mfr	Equipment Description	Equipment Cap (Tons)	Equipment Operating Charge (Lb)	EPA Maximum Allowable Leak Rate (%)	EPA Maximum Allowable Leak Rate (Lb/yr)	Chiller Energy Efficiency: Full Load Amps	Chiller Energy Efficiency: Volts	Chiller Energy Efficiency: kW/ton	Equipment Age (Years)
115	1	Y	Chiller: Semi–Herm Centrif	259	640	15%	96	280	460	0.77	7
115	2	Y	Chiller: Semi–Herm Centrif	259	640	15%	96	280	460	0.77	7
146		T	Chiller: Semi–Herm Centrif	140	340	15%	51	134	460	0.69	2
147	1	Y	Chiller: Semi–Herm Centrif	120	340	15%	51	150	460	0.90	2
147	2	Y	Chiller: Semi–Herm Centrif	125	600	15%	90	116	460	0.66	2
156		C	Chiller: Semi–Herm Centrif	150	500	15%	75	170	460	0.81	21
1385		T	Chiller: Open–End Centrif	280	545	15%	82	322	460	0.82	8
5570		T	Chiller: Hermetic Centrif	280	545	15%	82	358	460	0.92	8
5616		Y	Chiller: Open–End Centrif	300	400	15%	60	322	460	0.77	2
5725		T	Chiller: Semi–Herm Centrif	290	575	15%	86	312	460	0.77	2
6275		T	Chiller: Semi–Herm Centrif	250	545	15%	82	358	460	1.03	10
6418		T	Chiller: Semi–Herm Centrif	200	340	15%	51	116	460	0.42	3
6576		T	Chiller: Semi–Herm Centrif	200	340	15%	51	116	460	0.42	2
7065		T	Chiller: Hermetic Centrif	250	525	15%	79	237	460	0.68	8
7246		T	Chiller: Semi–Herm Centrif	150	375	15%	56	116	460	0.55	2
7359		T	Chiller: Hermetic Centrif	525	600	15%	90	620	480	0.88	21
9016		Y	Chiller: Semi–Herm Centrif	260	600	15%	90	222	460	0.61	12
9050	1	T	Chiller: Semi–Herm Centrif	300	635	15%	95	335	460	0.80	26
9110		T	Chiller: Semi–Herm Centrif	250	545	15%	82	238	460	0.68	10
9210		T	Chiller: Semi–Herm Centrif	280	440	15%	66	197	460	0.50	10
9225		T	Chiller: Semi–Herm Centrif	320	635	15%	95	Unknown	Unknown	0.00	10
9310		Y	Chiller: Semi–Herm Centrif	280	440	15%	66	197	460	0.50	10
9410		T	Chiller: Semi–Herm Centrif	320	545	15%	82	Unknown	Unknown	0.00	10
10056	1	Y	Chiller: Semi–Herm Centrif	1000	1200	15%	180	218	460	0.16	1
10416		T	Chiller: Semi–Herm Centrif	250	545	15%	82	Unknown	Unknown	0.00	8
Hospital	1	T	Chiller: Semi–Herm Centrif	1000	1600	15%	240	Unknown	Unknown	0.00	30
			REFRIGERANT TOTALS	8038	15035		2255				

Key:

A = Building Number
B = Unit number (Used when building has more than one unit.)
C = Original equipment manufacturer (name abbreviated)
D = Equipment type
E = Equipment capacity, in tons
F = Equipment charge, in pounds
G = EPA maximum leak rate percentage, 15% or 35%
H = F lb x G % / 100 (EPA Maximum Leak Rate, lb/year)
I = Equipment full load amps
J = Equipment voltage
K = Equipment efficiency (If not available use (1.73 x I amps x J volts x 0.90 power factor)/(E tons x 1000 volt–amp per kW)
L = Equipment age

Figure 3-1. Sample Completed Equipment List

year in column H are determined by multiplying the total charge in a particular unit, column F, by the percentage in column G. Columns I, J, and K determine energy efficiency. Full load amps (FLA) and volts are shown on the equipment. The efficiency, if not listed on the equipment, can be obtained from the equipment manufacturer, the original submittal data, or by calculation (see key at the bottom of Figure 3-l). The power factor can vary from 0.80 to 0.95, depending on motor size, type, and manufacturer or National Electric Manufacturers Association (NEMA) standards. Column L, Equipment Age, is obtained from base records showing installation date or from the "manufactured date" found on the equipment.

3.7 Step 3: Equipment Assessment Table

The Equipment Assessment Table is used to determine the priorities for equipment retirements. Columns A, B, C, and D are repeated from the Equipment List. Columns M, N, O, P, Q, and R are determined by selecting the value which corresponds to the range found in "Assessment Ranges and Values" at the bottom of Figure 3-2, *Sample Completed Equipment Assessment Table.* Column S is the sum of the values in all the columns for each piece of equipment. Column T values are the priorities of equipment replacements **after factoring in subjective considerations.**

3.7.1 Value Determinations

To determine values for columns M, N, O, and P of the Equipment Assessment Table use data found in the Equipment List, the ESFs, or the WIMS Refrigerant Management Software Reports. Column P values are either "0" for minor leaks or "5" for major leaks. A leak is considered minor if it requires a small amount of time and funds to repair (such as tightening loose connections or installing a pressure relief valve (PRV) and high-efficiency purge). Even if the machine had a significant refrigerant loss, it is considered a minor leak because the repair is inexpensive. A leak is considered major if it requires a large expenditure of funds and labor to repair (such as a casing leak or tube bundle replacement). The actual amount of refrigerant lost may not necessarily be large, but the repair is expensive. This information should be on the ESFs and can be verified by technicians familiar with the equipment. Column R of the Equipment Assessment Table is either "O" for no overhaul required or "5" for overhaul required in less than three years. Column S of the table is the total of all the other columns and indicates retirement priorities based on objective reasons. The higher the number, the sooner the unit should be replaced. The rating increases as the equipment becomes older, less efficient, and larger. This reinforces the strategies of not retiring the equipment until the end of its life expectancy and eliminating the least energy-efficient equipment first.

3.7.2 Subjective Considerations

The RM must consider subjective, as well as objective, criteria to determine the order in which to retire equipment. Some subjective considerations include:

- equipment already scheduled for retirement because it is under contract or in design,

R–xx EQUIPMENT ASSESSMENT TABLE
XYZ AIR FORCE BASE
Survey Date October 6, 1993

A	B	C	D	M	N	O	P	Q	R	S	T
				Assessment Rating Values						Objective	Subjective
Building Number	Unit Number	Mfr	Equipment Description	Age	Cap	Eff	Leak Rate	Maint Req'mt	Over Haul	Rating Total	Rating Total
115	1	Y	Chiller: Semi–Herm Centrif	0	1	2	0	0	0	3	8
115	2	Y	Chiller: Semi–Herm Centrif	0	1	2	0	0	0	3	8
146		T	Chiller: Semi–Herm Centrif	0	1	1	0	0	0	2	3
147	1	Y	Chiller: Semi–Herm Centrif	0	1	2	0	0	0	3	3
147	2	Y	Chiller: Semi–Herm Centrif	0	1	1	0	0	0	2	9
156		C	Chiller: Semi–Herm Centrif	2	1	2	0	0	0	5	9
1385		T	Chiller: Open–End Centrif	0	1	2	5	0	0	8	11
5570		T	Chiller: Hermetic Centrif	0	1	3	5	0	0	9	13
5616		Y	Chiller: Open–End Centrif	0	2	2	0	0	0	4	2
5725		T	Chiller: Semi–Herm Centrif	0	1	2	0	0	0	3	2
6275		T	Chiller: Semi–Herm Centrif	1	1	3	0	0	0	5	5
6418		T	Chiller: Semi–Herm Centrif	0	1		0	0	0	1	7
6576		T	Chiller: Semi–Herm Centrif	0	1		0	0	0	1	1
7065		T	Chiller: Hermetic Centrif	0	1	1	0	0	0	2	4
7246		T	Chiller: Semi–Herm Centrif	0	1	0	0	0	0	1	1
7359		T	Chiller: Hermetic Centrif	2	2	2	5	2	5	13	15
9016		Y	Chiller: Semi–Herm Centrif	1	1	0	5	0	5	7	11
9050	1	T	Chiller: Semi–Herm Centrif	3	2	2	5	2	5	14	12
9110		T	Chiller: Semi–Herm Centrif	1	1	1	5	0	5	8	6
9210		T	Chiller: Semi–Herm Centrif	1	1	0	5	0	5	7	6
9225		T	Chiller: Semi–Herm Centrif	1	2		0	0	5	3	5
9310		Y	Chiller: Semi–Herm Centrif	1	1	0	5	0	5	7	6
9410		T	Chiller: Semi–Herm Centrif	1	2		0	0	5	3	6
10056	1	Y	Chiller: Semi–Herm Centrif	0	3		5	0	0	8	14
10416		T	Chiller: Semi–Herm Centrif	0	1		5	0	0	6	10
Hospital	1	T	Chiller: Semi–Herm Centrif	3	3	2	5	2	5	15	16

ASSESSMENT RANGES AND VALUES

COLUMN	RANGE DESCRIPTION	VALUE	COLUMN	RANGE DESCRIPTION	VALUE
M: Age	< 8 years	0	P: Leak Rate	Minor	0
	8–15 years	1		Major	5
	16–25 years	2			
	> 25 years	3			
N: Capacity	< 100 tons	0	Q: Maintenance Requirements	Low	0
	100–300 tons	1		Medium	1
	301–700 tons	2		High	2
	> 700 tons	3			
O: Efficiency	< 0.65 kW/ton	0	R: Overhaul Status	Not Needed	0
	0.65–0.75 kW/ton	1		Needed in < 3 years	5
	0.76–0.90 kW/ton	2			
	> 0.90 kW/ton	3			

Figure 3-2. Sample Completed Equipment Assessment Table

- number of units scheduled for replacement at the same time by a central plant,
- equipment, neither old nor large, with a major leak, and
- other local factors.

Column T of the Equipment Assessment Table. incorporates the values in column S, revised by the subjective considerations.

3.7.3 Method of Replacement

At this stage in the RMP, a preliminary decision should be made on how to retire the equipment: by retrofitting the existing unit with different refrigerant, by replacing the unit, or with a central plant? This programming decision will be refined during the RMP implementation process described in Chapter 4, *Refrigerant Management Plan Implementation.* Information from the WIMS database can help make this decision along with the following general guidelines:

- replace a unit over 15 years old,
- retrofit a unit which is less than 15 years old during overhaul or major repair,
- retrofit a unit that has excess capacity,
- replace a unit that is undersized,
- replace a unit with a very poor efficiency, and
- replace a unit with a history of frequent maintenance.

3.8 Step 4: Equipment Retirement Schedule and Refrigerant Inventory Timeline

Developing the Schedule and Refrigerant Inventory Timeline (Timeline) for each refrigerant gives the RM a complete picture of the BRMP. The Schedule (Figure 3-3, *Sample Completed Equipment Retirement Schedule)* shows all the activities that cause the refrigerant inventory to fluctuate with time. The Timeline (Figure 3-4, *Sample Completed Refrigerant Inventory Timeline)* shows the anticipated inventory as a result of the retirement schedule.

3.8.1 Definition of Terms

To complete the schedule, several terms must first be defined.

3.8.1.1 The total installed charge (TIC) is the operating charge, in pounds, for all equipment having the same refrigerant. The initial TIC is the total in column F of the Equipment List. As each piece of equipment is retired, the TIC is recalculated by deducting the retired unit's refrigerant charge from the previous TIC,

3.8.1.2 The total EPA maximum leak rate (total EPAMLR) is the total of column H of the Equipment List. The total EPAMLR is the summation of all the individual equipment's EPA maximum leak rates, measured in pounds per year. As equipment is retired, the total EPAMLR is reduced by the retired equipment's individual EPAMLR. The individual EPAMLR is found in column H of the Equipment List.

3.8.1.3 The critical refrigerant reserve (CRR) is the number of pounds of refrigerant in the piece of equipment with the largest refrigerant charge for each type of refrigerant. When the piece of equipment

R–xx EQUIPMENT RETIREMENT SCHEDULE
XYZ AIR FORCE BASE

Survey Date October 6, 1993

A	B	C	D	E	F	G	H	I	J	K
Activity	Fiscal Year	Equipment Operating Charge (Lb)	Total Installed Charge (Lb)	Consumption Rate (Lb/yr)	Inventory Transaction (Lb)	Benchstock Refrigerant Inventory (Lb)	Critical Refrigerant Reserve (Lb)	Time Until CRR (Years)	Marginal Refrigerant Reserve (Lb)	Time Until MRR (Years)
Present Refrigerant Inventory	1994		15035	9136		6400	1600	0.53	3855	0.28
3 Mos. Repair Leaks	1994.25		15035	4702	0	4116	1600	0.54	3855	0.06
Purge Unit Installations	1994.5		15035	2284	0	2940	1600	0.59	3855	−0.40
Hospital Equip. Refrigerant Recycle: 1600#	1994.5	1600	13435	2015	1600	4540	1200	1.66	3215	0.66
Operational Refrigerant Consumption	1995		13435	2015	0	3533	1200	1.16	3215	0.16
7359 Replacement already Funded	1995	600	12835	1925	600	4133	1200	1.52	3125	0.52
Operational Refrigerant Consumption	1995.5		12835	1925	0	3170	1200	1.02	3125	0.02
10056 Convertible Change–out	1995.5	1200	11635	1745	1200	4370	640	2.14	2385	1.14
Operational Refrigerant Consumption	1996		11635	1745	0	3498	640	1.64	2385	0.64
5570 Retrofit/Replace Opportunity	1996	545	11090	1664	545	4043	640	2.05	2304	1.05
Operational Refrigerant Consumption	1997		11090	1664	0	2379	640	1.05	2304	0.05
9050 Presently in COE Design Phase	1997	635	10455	1568	635	3014	640	1.51	2208	0.51
Operational Refrigerant Consumption	1997.5		10455	1568	0	2230	640	1.01	2208	0.01
1385 Retrofit/Replace Opportunity	1997.5	545	9910	1487	545	2775	640	1.44	2127	0.44
9016 Retrofit/Replace Opportunity	1997.5	600	9310	1397	600	3375	640	1.96	2037	0.96
Operational Refrigerant Consumption	1998		9310	1397	0	2677	640	1.46	2037	0.46
10416 Retrofit/Replace Opportunity	1998	545	8765	1315	545	3222	640	1.96	1955	0.96
Operational Refrigerant Consumption	1998.5		8765	1315	0	2564	640	1.46	1955	0.46
156 Replacement Opportunity	1998.5	500	8265	1240	500	3064	640	1.96	1880	0.96
147–2 Retrofit Opportunity	1998.5	600	7665	1150	600	3664	640	2.63	1790	1.63
Operational Refrigerant Consumption	1999.5		7665	1150	0	2515	640	1.63	1790	0.63
115/115 Retrofit Opportunities	1999.5	1280	6385	958	1280	3795	635	3.30	1593	2.30
Operational Refrigerant Consumption	2000		6385	958	0	3316	635	2.80	1593	1.80
6418 Retrofit Opportunity	2000	340	6045	907	340	3656	635	3.33	1542	2.33
Operational Refrigerant Consumption	2002		6045	907	0	1842	635	1.33	1542	0.33
9110/20/30/40 Central Plant Opportunity	2002	1970	4075	611	1970	3812	635	5.20	1246	4.20
Operational Refrigerant Consumption	2005		4075	611	0	1978	635	2.20	1246	1.20
6275/9225 Replace Opportunity	2005	1180	2895	434	1180	3158	600	5.89	1034	4.89
Operational Refrigerant Consumption	2007		2895	434	0	2290	600	3.89	1034	2.89
7065 Replace Opportunity	2007	525	2370	356	525	2815	600	6.23	956	5.23
Operational Refrigerant Consumption	2012		2370	356	0	1037	600	1.23	956	0.23
146/147–1 (Convertible) Retrofit/Replace	2012	680	1690	254	680	1717	575	4.51	829	3.51
Operational Refrigerant Consumption	2013		1690	254	0	1464	575	3.51	829	2.51
5616/5725 (Convertible) Retrofit/Replace	2013	975	715	107	975	2439	375	19.24	482	18.24
Operational Refrigerant Consumption	2014		715	107	0	2332	375	18.24	482	17.24
6576/7246 (Convertible) Retrofit/Replace	2014	715	0	0	715	3047	0		0	

Keys:

A = Manually input retirement or consumption activities
B = Fiscal year
C = Individual equipment operating charge in pounds of refrigerant
D = Total installed refrigerant charge for all machines on base using the same refrigerant
= Previous D – C (Initial value is total of Column F in the Equipment List)
E = Previous E – EPAMLR for unit retired (True only after EPAMLR is achieved)

F = Refrigerant recovered, purchased, or transferred
G = Previous G + F – [Previous E x (B – Previous B)]
H = Charge of machine with the largest charge of all R–XX equipment
I = (G – H) / E
J = H + Total EPAMLR
K = (G – J) / E

Figure 3-3. Sample Completed Equipment Retirement Schedule

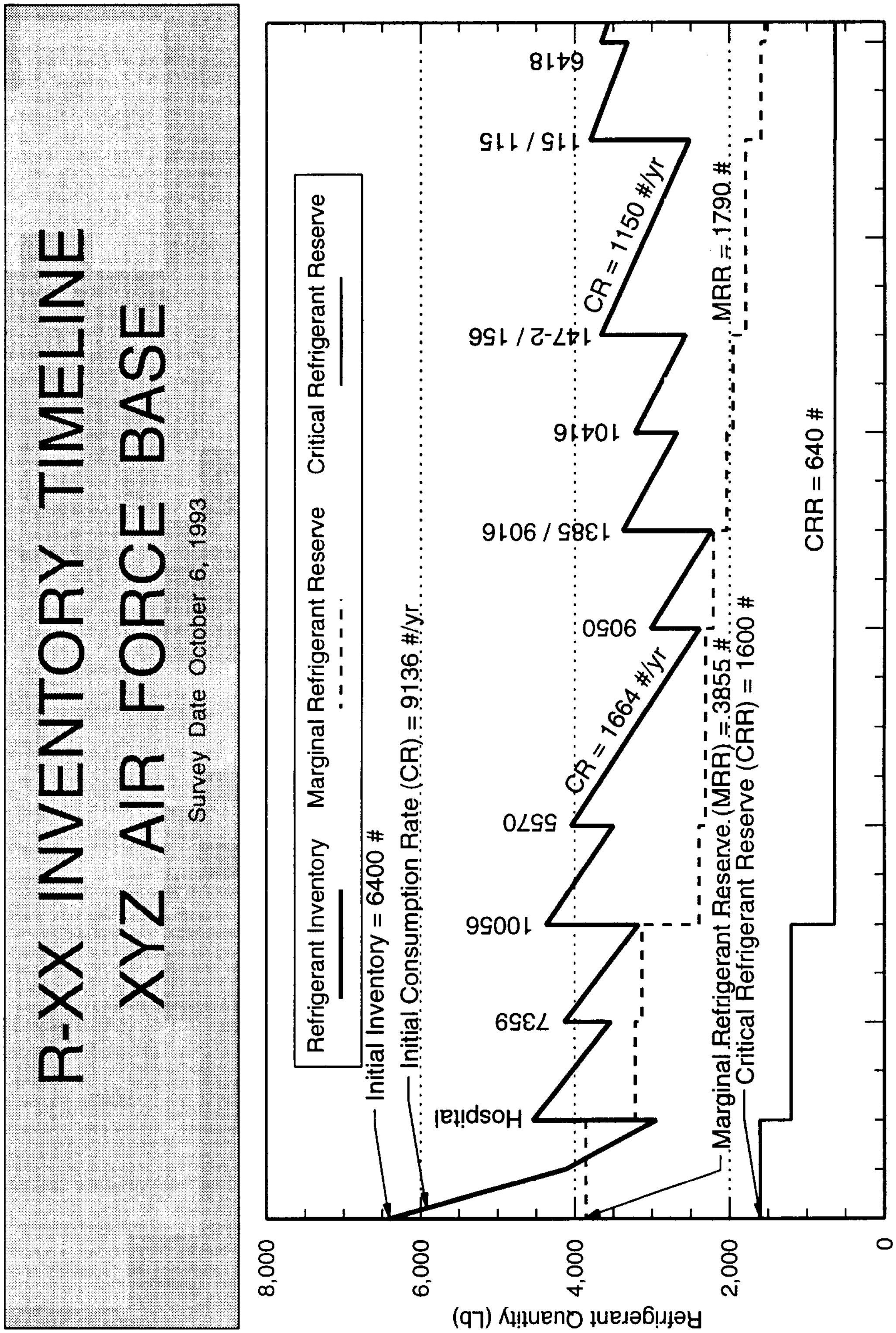

Figure 3-4. Sample Completed Refrigerant Inventory Timeline

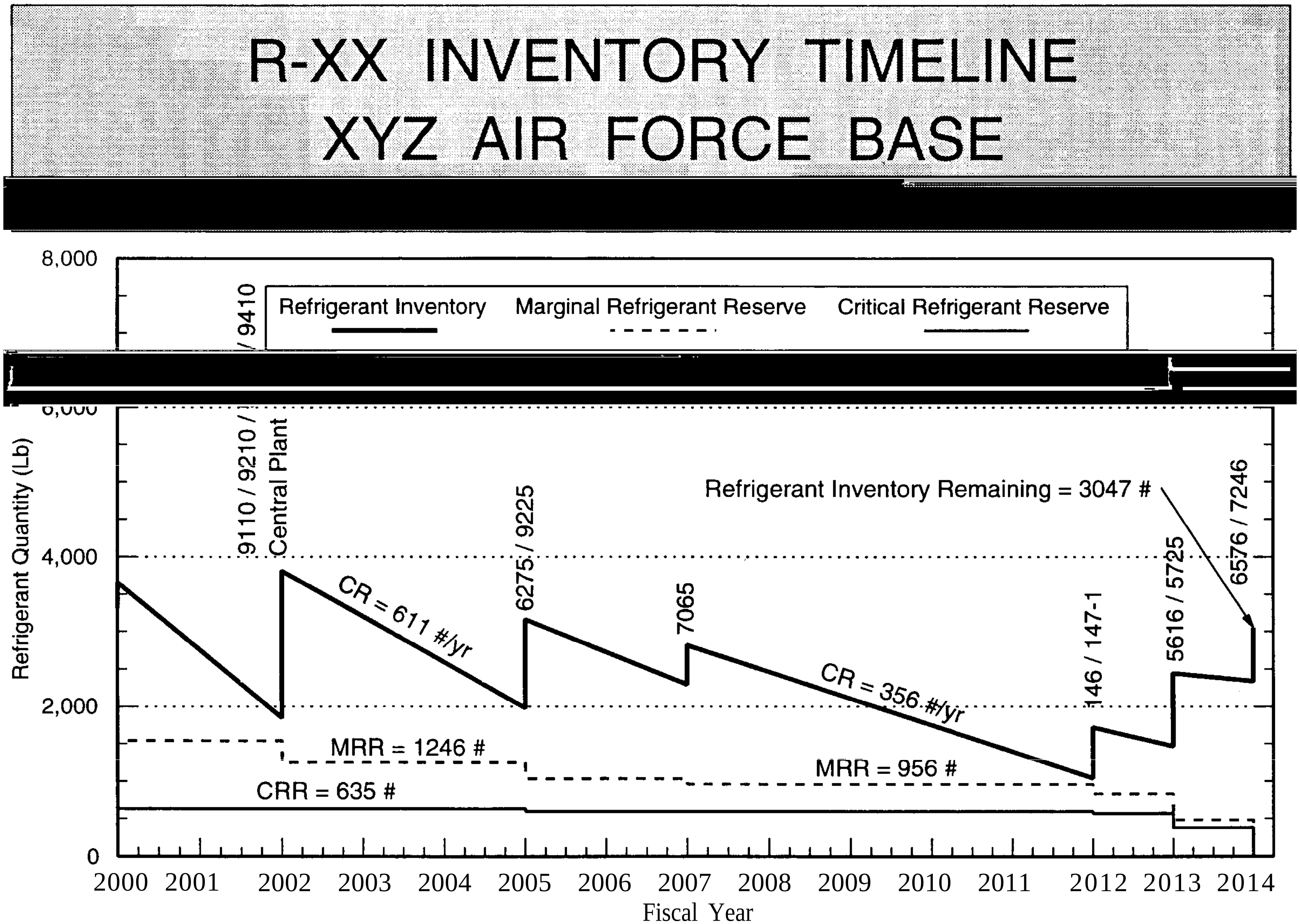

Figure 3-4. Sample Completed Refrigerant Inventory Timeline (continued)

with the largest operating charge is retired, the CRR decreases to the quantity of refrigerant in the remaining unit with the largest operating charge. If the base does not have more refrigerant than the CRR in its inventory, the base cannot handle a catastrophic refrigerant loss in this piece of equipment.

3.8.1.4 The marginal refrigerant reserve (MRR) is the summation of the charge in the piece of equipment with the largest operating charge (the CRR) and the total EPAMLR for that particular refrigerant. If the refrigerant's inventory quantity goes below the MRR, the base must take action, within a year, to prevent the inventory from going below the CRR. The MRR is stated in pounds of refrigerant and equals the amount of refrigerant the base needs to handle a catastrophic refrigerant leak in the equipment with the largest operating charge plus operate all the units at the maximum EPA leak rate for one year. The initial MRR equals the initial CRR plus the initial total EPAMLR. Each time a unit is retired the MRR must be recalculated:

1) Determine if the retired unit has the largest operating charge. If so, recalculate the CRR.
2) Reduce the total EPAMLR by the individual EPAMLR charge of the retired unit.
3) CRR + total EPAMLR = MRR

3.8.1.5 Consumption rate (CR) is the average amount of a specific refrigerant, in pounds per year, the base is using to maintain its equipment for one year. The CR is found by using the Consumption Report in the WIMS Refrigerant Management Software or by calculations using historical refrigerant purchases. The Material Acquisition Element can provide the amount of refrigerant purchased over a specific period of time. If 500 pounds of CFC-12 were purchased in FY93 and there are 100 pounds in shop inventory, then it could be assumed that 400 pounds of CFC-12 were used in FY93 for a 400 pounds/year CR. If 300 poundsofCFC-11 were purchased in the first three months of FY94 and 100 pounds are in inventory, it could be assumed that 200 pounds were used in three months, for an 800 pounds/year CR.

3.8.2 Developing the Equipment Retirement Schedule

The Equipment Retirement Schedule, Figure 3-3, is developed using the same spreadsheet software used for the Equipment List and Equipment Assessment Table. Abbreviated definitions of the values in each column are listed at the bottom of Figure 3-3.

3.8.2.1 Column A (Activities) lists the activities that cause increases and decreases of inventory for a specific refrigerant; column B (Fiscal Year) lists the elapsed time for each. Column B is the total elapsed time, in fiscal years, from the start of the Equipment Retirement Schedule to the completion of a specific activity. It is the ***cumulative*** time, ***not*** *the* time ***between*** each activity. Each increase and decrease to the refrigerant inventory must be shown as an activity. The increases can include conservation efforts reducing the CR, interbase refrigerant transfers, refrigerant purchases, and equipment retirements. The decreases can be "operational refrigerant consumption" occurring between implementation of other activities and inventory transfers to another base.

3.8.2.1.1 Activities are listed in chronological order. The frost activity, the initial refrigerant inventory, is used only at the beginning of the schedule. Its elapsed time is always listed as the quarter and fiscal year nearest the date the inventory is determined. The next activity in the example is repairing the leaks found during the equipment survey. This activity may also include the completion of technician training and EPA certification and establishment of equipment monitoring through the WIMS Refrigerant Management Software. For this activity example, elapsed time is estimated at three months (0.25 years). In Figure 3-3, the next reduction in refrigerant consumption occurs as a result of large repairs or modifications to equipment; estimated to take six months (0.5 years). (Repairs and modifications must be accomplished as quickly as possible to reduce CR and support the base mission without the need for an outside source of refrigerant. Each base must strive for self-sufficiency.) The example entry, "Hospital Equipment Refrigerant Recycle 1600#," represents the addition of refrigerant to the inventory due to a retirement of equipment. Other activities could include purchasing additional refrigerant or receiving a transfer from another base. These activities are base-specific and determined by the RM. All the equipment retirement activities in the example can be found in column T of Figure 3-2.

3.8.2.1.2 The “operational refrigerant consumption” activity represents the amount of refrigerant consumed by equipment operations and maintenance. The amount of consumed refrigerant is based on the CR. It is very important to understand that the completion of a specific activity is when the refrigerant is added to or subtracted from the inventory and not necessarily when the activity starts.

3.8.2.2 The values in column C (Equipment Operating Charge) are input manually and found in the Equipment List. The Total Installed Charge, column D, is lowered each time an equipment retirement occurs. The CR represents the annualized refrigerant consumption. Initially, the CR, column E (Consumption Rate), is based on historical data. All other entries are projections determined by the RM. The example shows 9136 pounds per year as the first entry in column E. This amount was determined by reviewing the amounts of refrigerant purchased by the BCE for the previous year. The next amount, 4702 pounds per year, represents the result of a decrease in consumption over a three-month period as the units are leak tested and identified repairs completed. It is a projection by the RM based upon achieving an annual consumption rate equal to the total EPAMLR. The next number, 2284 pounds per year, is the new consumption rate projection after all purge units are installed. Both activities represent a base’s initial conservation effort.

3.8.2.2.1 It is assumed the continuing conservation efforts achieve a consumption rate equal to the total EPAMLR. **The Air Force goal is to achieve a near-zero consumption rate.** Because the purpose of the RMP is to forecast future refrigerant requirements in support of the Air Force mission, a conservative approach is taken by using the total EPAMLR. Reductions in the CR in relation to the total EPAMLR will result in increased refrigerant reserves. The Handbook example shows the CR decreasing to 2015 pounds per year which is the total EPAMLR for all equipment using this type of refrigerant.

3.8.2.3 Column F (Inventory Transaction) shows how the base's refrigerant inventory is affected by an activity.

3.8.2.4 Column G (Benchstock Refrigerant Inventory) shows the projected changes in the refrigerant benchstock inventory as the RMP is implemented. The values are dependent on the time since the last activity (column B), the CR, and the recovered refrigerant amounts listed in column F. The first entry is the amount of refrigerant stored on base at the start of the RMP. This is all the refrigerant under the BCE's control and in Base Supply that the BCE could purchase. It should not include the refrigerant in the operating equipment, TIC, or any refrigerant represented by Air Force-approved waiver authority but not yet purchased. All entries after the first one are determined by the equation shown on the bottom of Figure 3-3.

3.8.2.5 Column H (Critical Refrigerant Reserve) and column J (Marginal Refrigerant Reserve) are the CRR and MRR. Column I (Time Until CRR) and column K (Time Until MRR) show the time remaining in years before the refrigerant inventory reaches either the MRR or the CRR. CRR, the amount of refrigerant needed in inventory to prevent mission impact, changes when the unit with the largest charge is retired. If the inventory quantity goes below the MRR, it is a warning to the RM that, with the estimated CR, refrigerant supplies will be below the CRR if replenishment activities do not occur within one year. It decreases as the CRR and the total EPAMLR decrease. Column I and column K are determined by subtracting either the CRR or the MRR from the Refrigerant Inventory and dividing by the CR. A negative value shows that the inventory quantity is below the MRR or CRR.

3.8.3 Refrigerant Inventory Timeline

The Timeline is a graph that forecasts refrigerant as a function of time. It takes into account consumption rates and other activities which effect the amount of refrigerant in benchstock and projects future levels. The Timeline graphically represents refrigerant conservation efforts and levels of refrigerant to meet mission requirements. By using a graph, it is easier to see if adequate refrigerant supplies will be maintained over the remaining life of existing equipment. Because much of the base conservation actions will be taken early in the RMP, the first six years of the Timeline should be broken into quarters to depict more detail, as shown in Figure 3-4.

3.8.3.1 The Timeline is plotted from information found on the Equipment Retirement Schedule. The Elapsed Time (column B) is the x-axis and the Refrigerant Inventory (column G), the y-axis. The Timeline depicts the refrigerant inventory decreasing and increasing as the activities in the Equipment Retirement Schedule are completed. The initial value for the refrigerant inventory level is the refrigerant in storage when the RMP is developed. This is the first value in column G of the Equipment Retirement Schedule.

3.8.3.2 In Figure 3-4 refrigerant consumption starts high (steep slope), but is reduced through leak repairs and equipment modifications. Because the Timeline is being used to forecast refrigerant inventory levels, a conservative approach assumes the consumption rate will be reduced to at least the total EPAMLR for all equipment (column H total in the Equipment List for each particular refrigerant). **The length of time refrigerant inventories will last will be increased by striving to achieve the Air Force goal of reducing refrigerant consumption to as near zero as possible.** As equipment is retired, the CR should continue to decrease because there is less TIC. The CRR line stair-steps down each time the unit using the largest charge is replaced, and the MRR line goes down every time an equipment retirement occurs.

3.8.3.3 If the Timeline goes below the CRR, the base cannot replenish the refrigerant of the piece of equipment with the largest charge if the machine has a catastrophic refrigerant loss. The example in Figure 3-4 took several iterations to complete. The activities in the Equipment Retirement Schedule must be organized so the Timeline never goes below the CRR. To prevent this from happening, change the Equipment Retirement Schedule by using the following actions, in priority sequence:

- increase conservation efforts to reduce the CR by taking less time to complete an activity or scheduling more activities in an earlier time frame,
- obtain additional refrigerant inventory through purchase or interbase transfer, and
- change the Equipment Retirement Schedule (least desirable because equipment should not be retired before the end of its economic life).

3.8.3.4 When the Timeline goes below the MRR, it is a visual warning the base must implement its plan to put more refrigerant back into its inventory or reduce its CR before the CRR is reached. The Equipment Retirement Schedule does not require revision if activities are scheduled to keep refrigerant inventory above the CRR. If those activities are not scheduled, the Equipment Retirement Schedule must be changed. Use the same actions recommended in the previous paragraph.

3.8.3.5 The Timeline can be used to clearly depict actual conservation efforts. Plot a point, on the Timeline, showing current time and actual consumption rates. Compare this point to the projected point. If the actual point on the Timeline is on or above the projected point on the Timeline, the BRMP is not behind schedule. If the actual point is below the projected point, management must take steps to adjust.

3.9 Step 5: Project List and Funding Bar Chart

The Project List shows the equipment to be retired (from the Equipment Retirement Schedule); the Funding Bar Chart shows how much the retirements will cost, by fiscal year.

3.9.1 Project List

Develop the Project List (Figure 3-5, *Sample Completed Project List) for each* refrigerant. The Project List includes the building and unit number, capacity, charge, current age, design and construction costs, and date of retirement. The equipment retired as the result of installing a chilled water plant should be highlighted so they can be kept together. The programming cost estimates are based on replacing equipment with new equipment identical in type and capacity. Allowing for the highest-cost option provides a conservative estimate. Equipment costs can be obtained from an equipment manufacturer or by employing a commercial cost estimating manual or software program. To arrive at a construction cost, increase the equipment estimate by 75 percent for removal and the installation costs. Based on the information in the equipment survey forms, this percentage can be adjusted. Add $5,000 to $10,000 for upgrading equipment rooms to ASHRAE 15-1994. This range can be narrowed with information from the equipment survey forms. Ten percent of the construction cost should be used for the design cost estimate to include a site study and facility cooling load analysis. For all above computations, use local figures based on local experience if available.

3.9.2 Funding Bar Chart

The Funding Bar Chart depicts all CFC refrigerants, as shown in Figure 3-6, *Sample Completed Funding Bar Chart.*

3.9.3 Funding Bar Chart Analysis

The general goal is to flatten spending over the full length of the RMP. The years with a high funding requirement should be decreased and the years with a low funding requirement should be increased. This can be accomplished by going back to the individual Equipment Retirement Schedules and altering equipment retirement dates. The most obvious place to start is the CFC with the highest funding requirement in a particular year. The same subjective approach used to create a Timeline can also be used to develop a funding level.

3.10 Step 6: The Implementation Schedule

The Implementation Schedule, shown in Figure 3-7, *Sample Completed Implementation Schedule, is* developed by combining the information on all the Project Lists for all CFCs and adding other specific tasks. The Implementation Schedule shows the milestones needed to ensure projects are completed by their scheduled dates. Milestones include: cooling load analyses, OEM analyses, design start, bidding period, contract award time, construction start, and construction completion.

3.10.1 Time Lengths

When creating the Implementation Schedule, show the fiscal years (across the top) with the first six years divided into quarters to match the Refrigerant Inventory Timeline. Figure 3-7 shows the placement for the equipment designation, event, and costs. The data points should be placed on the chart in reverse order, starting with the

R- xx PROJECT LIST
XYZ AIR FORCE BASE

Survey Date October 6, 1993

Building - Unit Designation	Equipment Capacity (Tons)	Refrigerant Charge (Lb)	Current Age (Years)	Project Costs: Design & Analysis ($)	Project Costs: Construction ($)	Scheduled Retirement (End of Qtr & FY)
Hospital	1000	1600	3 0	0	0	2nd Qtr 1994
7359	525	600	21	0	0	4th Qtr 1994
10056	1000	1200	1	5,000	45,000	2nd Qtr 1995
5570	280	545	8	18,000	175,000	4th Qtr 1995
9050	300	635	26	0	0	4th Qtr 1996
1385	280	545	8	21,500	175,000	2nd Qtr 1997
9016	260	600	12	21,500	175,000	2nd Qtr 1997
10416	250	545	8	20,000	145,000	4th Qtr 1997
156	150	500	21	13,000	87,500	2nd Qtr 1998
147 -2	125	600	2	13,000	87,500	2nd Qtr 1998
115 - 1	259	640	7	7,500	125,000	2nd Qtr 1999
115 - 2	259	640	7	7,500	125,000	2nd Qtr 1999
6418	200	340	3	10,000	150,000	4th Qtr 1999
9110	250	545	10	26,500	225,000	* 4th Qtr 2001 *
9210	280	440	10	26,500	225,000	* 4th Qtr 2001 *
9310	280	440	10	26,500	225,00	* 4th Qtr 2001 *
9410	320	545	10	26,500	225,000	* 4th Qtr 2001 *
6275	250	545	10	20,000	136,000	4th Qtr 2004
9225	320	635	10	23,000	157,000	4th Qtr 2004
7065	250	525	8	20,000	136,000	4th Qtr 2006
146	140	340	2	14,000	98,000	4th Qtr 2011
147 -1	120	340	2	13,000	85,000	4th Qtr 2011
5616	300	400	2	22,000	152,000	4th Qtr 2012
5725	290	575	2	22,000	148,000	4th Qtr 2012
6576	200	340	2	16,000	106,000	4th Qtr 2013
7246	150	375	2	15,000	103,000	4th Qtr 2013
REFRIGERANT COST TOTALS				$408,000	$3,311,000	

NOTES:
* = Indicates potential Central Chilled Water Plant

Figure 3-5. Sample Completed Project List

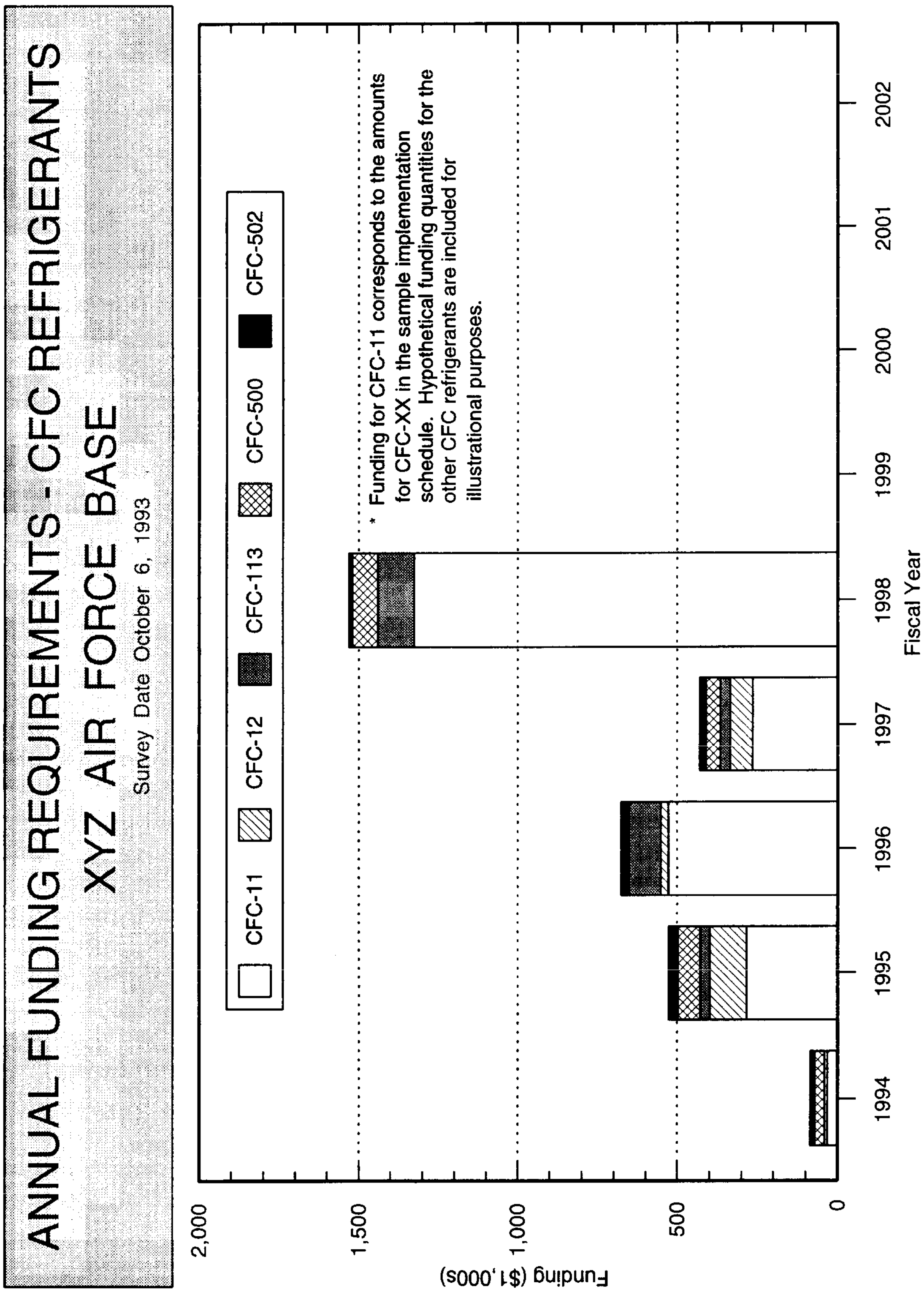

Figure 3-6. Sample Completed Funding Bar Chart

IMPLEMENTATION SCHEDULE – ALL CFC REFRIGERANTS
XYZ AIR FORCE BASE

Survey Date October 6, 1993

FISCAL YEAR		1994				1995				1996				1997				1998				1999	2000	2001	2002
Unit No / Quarter		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4				
Hospital	EVENTS		F																						
CFC–XX	COSTS		0																						
7359	EVENTS		E		F																				
CFC–XX	COSTS		0		0																				
10056	EVENTS		C		D	E	F																		
CFC–XX	COSTS		5			45																			
5570	EVENTS		C		D	E			F																
CFC–XX	COSTS		18			175																			
9050	EVENTS		C					D	E				F												
CFC–XX	COSTS		0						0																
1385/9016	EVENTS		A	B		C			D	E					F										
CFC–XX	COSTS			8		35				350															
10416	EVENTS				A	B		C			D	E					F								
CFC–XX	COSTS					5		15				145													
156 / 147	EVENTS						A	B		C			D	E					F						
CFC–XX	COSTS							8		18				175											
115 / 115	EVENTS																A	C		D	E	F			
CFC–XX	COSTS																	15			250				
6418	EVENTS																A	C		D	E	F			
CFC–XX	COSTS																	10			150				
9110/20/30/40	EVENTS											B				C				D	E			F	
CFC–XX	COSTS											15				90					900				
COST TOTALS		0	23	8	0	260	0	23	0	368	0	160	0	175	0	90	0	25	0	0	1300	0	0	0	0

EVENTS:

A = Cooling Load Analysis: 3 months for single unit
A1 = Cooling Load Analysis: 6–9 months for multi–unit
B = OEM Analysis: 1–2 months
C = Design Start: 6 months for single unit installation
C1 = Design Start: 12 months for multi–unit installation
D = Bid Process: 3 months
E = Award Contract: 3 months
F = Construction Complete: 12 months for single unit
F1 = Construction Complete: 18–24 months for multi–unit

Figure 3-7. Sample Completed Implementation Schedule date of retirement obtained from the Project List. This is the date when refrigerant is available for placing into inventory. The duration of the required tasks projected for each installation must be carefully considered. Depending on the required analyses and funding source, several years may be needed to accomplish all the tasks necessary to retire a machine. OEM analyses take four to eight weeks. Expect single installation cooling load analyses to require three months and central chiller plant analyses, six to nine months. These times are dependent on quantity, type, and size of served facilities. Design time estimates are six months for single installations and 12 months for central plants. Allow six months for bidding and contract award with a construction time of 12 months for a single installation and 18 to 24 months for a chiller plant. These numbers are only estimates and local estimates should be used if available.

3.11 Step 7: The RMP

With the completion of the Implementation Schedule, the RMP development is complete. Figure 3-8, *Sample Tale of Con**tents,*** provides the RM with an outline to use in organizing the RMP.

Title Page

Includes title of plan, base name, date, and preparer's name, office symbol, and phone number.

Executive Summary

One page detailing the highlights of the RMP. This could include how much money over how many years the RMP will take and whether any significant problems are left unresolved requiring senior-level action.

Base Refrigerant Management Program Review

Gives a verbal picture of the RMP. Describes in more detail some of the items discussed in the Executive Summary. Should include the base's ability to execute the plan, funding requirements, number of projects required, and other pertinent information. Gives an overview of the plan's organization, describing what each section addresses. Use descriptions from the Handbook to show the compatibility between the base's conservation efforts and the RMP. The RMP cannot be accomplished without a solid refrigerant conservation effort and vice versa.

Funding Bar Chart for all CFCs

Implementation Schedule

RMP for R-xx

1. Explanation of RMP Products for R-xx
2. R-xx Project List
3. R-xx Refrigerant Inventory Timeline
4. R-xx Equipment Retirement Schedule
5. R-xx Equipment Assessment Table
6. R-xx Equipment List
7. Equipment Survey Forms should be in same sequence as Equipment List. Include:
   a) base map showing existing unit and potential plant locations
   b) Utility Rates Data sheet

RMP for R-xxx

(Repeat same outline as R-xx for remaining refrigerants.)

Figure 3-8. Sample Table of Contents

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Chapter 4 — Refrigerant Management Plan Implementation

4.1 The Philosophy

The CFC RMP is not complete until the last piece of CFC equipment is retired and its refrigerant is in a storage cylinder. RMP implementation needs the right systems and money to pay for them.

4.2 Overview of System Selection

System selection is accomplished by:

- examining the cooling load profile,
- determining whether the existing system should be retrofitted or replaced,
- choosing the best replacement or retrofit option,
- assessing the potential to combine two or more systems into one plant, and
- evaluating the cost-effectiveness of employing heat recovery or thermal storage technologies.

These analyses are described in the Appendices:

K, AC/R Energy Conservation Devices;
L, Fundamentals of Cooling Load and Energy Analysis;
M, Evaluating Water Chillers for Replacement or Retrofit Potential;
N, Chiller Selection Guide;
O, Assessing the Potential of Central Chilled Water Plants;
P, Heat Recovery Alternatives for Refrigerant Chillers; and
Q, Assessing the Potential of Thermal Energy Storage.

4.3 System Selection

The system selection process provides a scope of work, preliminary equipment selection, and a design and construction cost estimate. There are five main steps to finding the right system.

4.3.1 Step 1: Cooling Load Analysis

The frost step is the cooling load analysis, which verifies the facility's current cooling load requirement and determines the cooling load profile. The cooling load results can be used to optimize the retrofit alternative or to correctly size the replacement unit. The load profile is used to optimize equipment selection and to provide the estimate for annual energy consumption (used in determining LCC for each alternative). Review Appendix L for load analysis procedures.

4.3.2 Step 2: Retrofit vs Replacement

The second step is to decide between retrofit or replacement. Some of the decision factors are age, capacity versus cooling load, mechanical condition, operating efficiency, and criticality to the facility the unit serves. These alternatives are compared over a 20-year study period. The alternative with the least LCC is chosen for further development. The procedures are in Appendix M.

4.3.3 Step 3: Replacement Unit Selection

If the decision is a replacement unit, the third step is to decide on a specific replacement unit. Appendix N uses unit efficiency, fuel source, load matching, initial cost, and annual operating cost to determine the correct system.

4.3.4 Step 4: Installing a Central Plant
After steps two and three are complete for all equipment, step four determines if various sets of individual units can be replaced with a central plant. Potential locations for these central plants were identified during the equipment survey. The central plant load profile is generated by combining the profiles of the previously calculated loads for the separate systems. A design concept and cost estimate is prepared for the central plant with performance characteristics and costs obtained from the manufacturer. A 20-year LCC analysis is performed comparing the central plant against the combination of all the separate system alternatives as determined in steps two and three. The advantage of a central plant is reduced LCCs due to lower initial installation and daily operating costs compared to the sum of the individual units. If the central plant is the favored option, the Equipment Retirement Schedule should be reviewed for possible changes to the Refrigerant Timeline, Project List, Funding Chart, and Implementation Schedule. The project will probably require Military Construction Program (MILCON) funds that take longer to program, authorize, and appropriate. Appendix O details these procedures.

4.3.5 Step 5: Heat Recovery and Thermal Storage Technologies
In step five, the effectiveness of using heat recovery and thermal storage technologies on the final equipment replacement choices is evaluated. Appendices P and Q detail these procedures. If local conditions are favorable to one or both options, then LCC analysis should be used to select the best approach.

4.4 System Selection Resources

4.4.1 Personnel
The personnel required to accomplish the system selections must be engineers with an understanding of design and operations of chilled water systems, energy analysis of building mechanical systems, and economic evaluations.

4.4.2 Time
The effort required to perform these tasks varies considerably, based upon system and installation. The following time estimates illustrate how complicated some of these analyses are:

- cooling load analysis of one building - 80 hours;
- retrofit versus replacement analysis - 40 hours (does not include up to six weeks to receive information from OEM);
- central plant analysis to replace single units -160 hours (includes cooling load analysis; may require more hours if previous individual facility load profiles do not already exist);
- heat recovery analysis -80 hours (if cooling load analysis is complete); and
- thermal storage analysis -120 hours (if cooling load analysis is complete)

4.4.3 Technical References

Technical literature needed to complete system selection includes all the references cited in this Handbook, local documents, and, if desired, computer software.

4.5 Importance of Funding

The availability of funds is very important to the completion of the RMP. The RMP products should be used as the basis for funding justifications. There are five sources of funds for projects identified in the RMP: Operations and Maintenance (O&M), Military Construction Program (MILCON), Energy Conservation Investment Program (ECIP), Federal Energy Management Program (FEMP), and Pollution Prevention Program (PPP) funds. ECIP, FEMP, and PPP funds have special criteria that are not as widely known as O&M and MILCON. Appendix I is a detailed description of these three funds including definitions, criteria, and examples of project justifications.

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Appendix A — Update on Refrigerants: Translating the Laws, Regulations, and Policies into Practice

ABSTRACT: This appendix details the policies which effect the use of ozone-depleting chemicals (ODCs) and, in particular, refrigerants. It covers the Montreal Protocol, federal taxes, the Clean Air Act Amendments (CAAA), Environmental Protection Agency's (EPA) rules and regulations, and Air Force policy directives.

A.1 The Montreal Protocol

Since 1974, atmospheric scientists worldwide have substantiated and refined the hypothesis confirming the long-term, negative consequences of chlorofluorocarbon (CFC) use. In response to the scientists' concerns, representatives of 35 nations met in 1987 at the United Nations Environment Programme (UNEP) in Montreal and established an international protocol for restricting CFC and halon production. Representatives from 93 nations met in London in 1990 to revise the Protocol in light of new information on ozone destruction. This meeting resulted in an accelerated CFC phase-out schedule. Copenhagen was the site of UNEP's November 1992 meeting with the outcome taking the form of accelerated phase-out schedules.

A.1.l Phase-Out Schedules

The 1992 UNEP meeting accelerated the CFC phase-out schedule from the Montreal Protocol and included a phase-out schedule for hydrochlorofluorocarbons (HCFCS). CFC production must cease by January 1996 and HCFC production must be down to 0.5 percent of 1989 levels by 2020, with total production stoppage by 2030. Specifically, the HCFC-22 phase-out date for use in new equipment is 2010 and 2020 for full production ban. HCFC-123 will stay in production until 2030. The reason for the special consideration for HCFC-123 is because of its low ozone-depletion potential (ODP) and short atmospheric lifetime (less than two years).

A.1.2 Applicable CFCs

The CFC refrigerants used by the Air Force for air conditioning and refrigeration (AC/R) and affected by the Protocol are CFC-11, CFC-12, CFC-113, CFC-500, CFC-501, CFC-502, and CFC-503.

A.1.3 Applicable HCFCs

The HCFC refrigerants affected by the Protocol are HCFC-22 and HCFC-123.

A.2 Taxes

A.2.1 Federal Excise Tax

The Omnibus Budget Reconciliation Act of 1989 imposed an excise tax on certain ODCs and imports of products made with or containing such chemicals. The tax, which was increased in late 1992, was designed to penalize consumers of ODCs and bring the prices of these chemicals closer to those of the new alternatives. The tax, applied only to new refrigerant, is determined by multiplying each chemical's ODP by the base tax rate. The base tax per pound started at $1.37 in 1991 and increases to $7.15 by 1999. The Air Force started in June 1993 to significantly restrict the purchase of refrigerant. This excise tax will have negligible effects on Air Force AC/R operations.

A.2.2 Floor Stocks Tax

ODCs are subject to a floor stocks tax that are held for sale or use in further manufacture on the date the tax is imposed. This tax is not applicable to Air Force operations. An ODC that is held by a government for its own use is not held for sale even if the ODC will be transferred between agencies or other subdivisions that have or are required to have different employer identification numbers.

A.3 Clean Air Act Amendments (CAAA)

The CAAA was passed in November 1990. CAAA, Title VI, Section 608 of that law established national goals for the reduction and elimination of stratospheric ozone-depleting substances. It banned production of CFCs by the year 2000, established a production cessation date of 2030 for HCFCs, and required EPA to establish dates and requirements prohibiting venting of CFCs during servicing. In February 1992, 11 months before the Copenhagen meeting of the Protocol, the President of the United States issued an Order to ban production of CFC refrigerants after December 1995. The Order called for reevaluation and possibly moving up the production ban for HCFCs. This Order set the stage for the final results of the Copenhagen meeting that took place later that year.

A.4 EPA Regulations

Following is an overview of the refrigerant recycling requirements of CAAA, Section 608. It includes final regulations published in the 14 May 1993 *Federal Register* 40 C.F.R. Part 82 (1993) and the prohibition on venting that became effective on 1 July 1992. These requirements have a direct impact on the day-to-day activities of the base civil engineer (BCE). For additional information call the United States Environmental Protection Agency's Stratospheric Ozone Information Hotline, 800-296-1996, from 10:00 am to 4:00 pm, eastern time, Monday through Friday. The regulations include the following procedures.

- Require service practices that maximize recycling of ODCs during the servicing and disposal of AC/R equipment.
- Set certification requirements for recycling and recovery equipment, technicians, and reclaimers.
- Restrict the sale of refrigerant to certified technicians.
- Require persons servicing or disposing of AC/R equipment to certify to EPA that they have acquired recycling or recovery equipment and are complying with the requirements of the rule.
- Require the repair of substantial leaks in AC/R equipment with a charge greater than 50 pounds.
- Establish safe disposal requirements to ensure removal of refrigerants from goods that enter the waste stream with the charge intact (for example, home

refrigerators and room air conditioners).

A.4.1 Prohibition on Venting

Effective 1 July 1992, the CAAA prohibits individuals from knowingly venting ODCs used as refrigerants into the atmosphere while maintaining, servicing, repairing, or disposing of AC/R equipment. Only four types of releases are permitted under the prohibition.

A.4.1.1 "De minimis" quantities of refrigerant released in the course of making good faith attempts to recapture and recycle or safely dispose of refrigerant.

A.4.1.2 Refrigerants emitted in the course of normal operation of AC/R equipment (as opposed to the maintenance, servicing, repair, or disposal of this equipment) such as from mechanical purging and leaks. However, EPA is requiring the repair of substantial leaks.

A.4.1.3 Mixtures of nitrogen and R-22 are used as holding charges or as leak test gases, because in these cases the ODC is not used as a refrigerant. However, a technician may not avoid recovering refrigerant by adding nitrogen to a charged system. Before nitrogen is added, the system must be evacuated to the appropriate level (see Table A-1, *Required Levels of Evacuation for Appliances except for Small Appliances, MVACs, and MVAC-Like Appliances). Otherwise, the* CFC or HCFC vented along with the nitrogen will be considered a refrigerant. Similarly, pure CFCs or HCFCs released from appliances will be presumed to be refrigerants. Their release will be considered a violation of the prohibition on venting.

A.4.1.4 Small releases of refrigerant resulting from purging hoses or connecting or disconnecting hoses to charge or service appliances will not be considered violations of the prohibition on venting. However, recovery and recycling equipment, manufactured after 15 November 1993, must be equipped with low-loss fittings.

A.4.2 Service Practice Requirements

EPA has also established requirements which must be met in servicing AC/R equipment.

A.4.2.1 Beginning 13 July 1993, technicians are required to evacuate AC/R equipment to established vacuum levels. If the technician's recovery or recycling equipment is manufactured any time before 15 November 1993, the AC/R equipment must be evacuated to the levels described in the first column of Table A-1. The recovery or recycling equipment must have been certified by an EPA-approved equipment testing organization (see 40 C.F.R. Part 82 (1993), Subpart F, . 158). Technicians repairing small appliances, such as household refrigerators, household freezers, and water coolers, are required to recover 80 to 90 percent of the refrigerant in the system, depending on the status of the system's compressor.

A.4.2.2 EPA has established limited exceptions to its evacuation requirements for repairs to leaky equipment and repairs not major and not followed by an evacuation of the equipment to the environment.

Table A-1. Required Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances[1]

Type of Appliance	Inches of Mercury Vacuum* Using Equipment Manufactured: Before 15 Nov 1993	Inches of Mercury Vacuum* Using Equipment Manufactured: On or After 15 Nov 1993
HCFC-22 appliance** normally containing less than 200 pounds of refrigerant	0	0
HCFC-22 appliance** normally containing 200 pounds or more of refrigerant	4	10
Other high-pressure appliance** normally containing less than 200 pounds of refrigerant (CFC-12, -500,-502, -144)	4	10
Other high-pressure appliance** normally containing 200 pounds or more of refrigerant (CFC-12, -500,-502, -144)	4	15
Very high-pressure appliance (CFC-13, -503)	o	0
Low-pressure appliance (CFC-11, HCFC-123)	25	29

* Relative to standard atmospheric pressure of 29.9* Hg
** Or isolated component of such an appliance
1 Federal Register, Vol. 58, No. 52, Friday, May, 1993, pg. 28

If, due to leaks, evacuation to the levels in Table A-1 is not attainable, or would substantially contaminate the refrigerant being recovered, persons opening the appliance must

- isolate leaking from non-leaking components wherever possible,
- evacuate non-leaking components to the levels shown in Table A-1, and
- evacuate leaking components to the levels that can be attained without substantially contaminating the refrigerant ($\leq$ O pounds per square inch (psig)).

A.4.2.2.1 If evacuation of the equipment to the environment is not to be performed when repairs are complete, and if the repair is not major, then the appliance must

- be evacuated to at least O psig before it is opened if it is a high- or very high--pressure appliance; or
- be pressurized to O psig before it is opened if it is a low-pressure appliance.

Methods that require subsequent purging (for example, nitrogen) cannot be used.

A.4.2.2.2 Repairs considered major are those involving removal of the compressor, condenser, evaporator, or auxiliary heat exchanger coil.

A.4.2.3 EPA has established refrigerant recovered and/or recycled can be returned to the same system or other systems owned by the same person without restriction. If refrigerant changes ownership, however, that refrigerant must be reclaimed (that is, cleaned to the ARI 700-98 standard of purity and chemically analyzed to verify that it meets this standard). This provision will expire in May 1995, when it may be replaced by an off-site recycling standard. (The Air Force believes that refrigerant can be transferred between bases without having to be reclaimed because the Air Force is a single owner.)

A.4.3 Equipment Certification

The EPA has established a certification program for recovery and recycling equipment. Under the program, EPA requires that equipment manufactured on or after 15 November 1993 be tested by an EPA-approved testing organization to ensure that it meets EPA requirements. Recycling and recovery equipment intended for use with AC/R equipment, besides small appliances, must be tested under the ARI 740-93 test protocol. Recovery equipment intended for use with small appliances must be tested under the ARI 740-93 protocol. The EPA is requiring recovery efficiency standards that vary depending on the size and type of AC/R equipment being serviced. For recovery and recycling equipment intended for use with AC/R equipment besides small appliances, the standards are the same as those shown in the second column of Table A-1. Recovery equipment intended for use with small appliances must be able to recover 90 percent of the refrigerant in the small appliance when the small appliance compressor is operating and 80 percent of the refrigerant in the small appliance when the compressor is not operating.

A.4.4 Equipment Grandfathering

Equipment manufactured before 15 November 1993, including home-made equipment, will be grandfathered if it meets the standards in the first column of Table A-1. Third-party testing is not required for equipment manufactured before 15 November 1993 (see Equipment Certification).

A.4.5 Refrigerant Leaks

Owners of equipment with charges of greater than 50 pounds are required to repair substantial leaks within 30 days. If the owner does not want to repair the equipment, a retirement plan must be developed in 30 days and will be implemented in 12 months. A copy of the plan must be available at the equipment location. A 35 percent annual leak rate is established for the industrial process and commercial refrigeration sectors as the trigger for requiring repairs. An annual leak rate of 15 percent of charge per year is established for comfort cooling equipment and all other equipment with a charge of over 50 pounds other than industrial process and commercial refrigeration equipment. Owners must keep records of the quantity of refrigerant added to their equipment during servicing and maintenance procedures. The Air Force Civil Engineer Support Agency (AFCESA) developed Work

Information Management System (WIMS) Refrigerant Management Software which can accomplish the recordkeeping.

A.4.6 Mandatory Technician Certification

The CAAA of 1990, Title VI, Section 608 imposes requirements for the training and certification of technicians involved in the maintenance and service of refrigeration systems.

A.4.6.1 The EPA has developed four types of certification:

Type I	For servicing small appliances.
Type II	For servicing or disposing of high- or very high-pressure appliances, except small appliances and MVAC.
Type III	For servicing or disposing of low-pressure appliances.
Universal	For servicing all types of equipment.

A.4.6.2 Persons removing refrigerant from small appliances and MVACs for purposes of disposal of these appliances do not have to be certified.

A.4.6.3 Technicians are required to pass an EPA-approved test given by an EPA-approved certifying organization. Technicians must be certified by 14 November 1994 to be able to maintain, service, and repair AC/R equipment.

A.4.6.4 EPA will propose an amendment to its final recycling rule that would require technician certification organizations to meet most not all of the requirements in the final rule. This change is required to ensure technicians tested under a voluntary program can be grandfathered as intended. Up to this time no organization who has applied for grandfathering meets all of the requirements. In order to ensure technicians who participated in voluntary programs have sufficient time to take any testing that is required pursuant to EPA review, EPA will propose that technicians who participated in voluntary programs be given six months after finalization of the amended rule to become certified. To be eligible for this extension, programs would have to apply (or have already applied) to grandfather technicians within 30 days of publication of the final amendment. EPA will propose that these technicians be permitted to purchase refrigerant in the interim using the cards issued to them by the voluntary program. Technicians who have not participated in one of the applying programs must still be certified by 14 November 1994. It is recommended that those Air Force technicians who took voluntary tests contact the organizations who administered the exam and ask if they are applying for grandfathering. If the organizations are not applying for grandfathering, then the technicians must be certified under any current, EPA-approved program.

A.4.7 Refrigerant Sales Restrictions

After 14 November 1994, the sale of refrigerant in any size container will be restricted to technicians certified by an EPA-approved program.

A.4.8 Certification by Owners of Recycling and Recovery Equipment

EPA is requiring that persons servicing or disposing of AC/R equipment certify to EPA that they have acquired (built, bought, or leased) recovery or recycling equipment and that they are complying with the applicable requirements of this rule. This certification must be signed by the owner of the equipment or another responsible officer and sent to the appropriate EPA Regional Office by 12 August 1993. A sample form for this certification is Figure A-1, The *United States Environmental Protection Agency (EPA) Refrigerant Recovery or Recycling Device Acquisition Certification Form.* Although owners of recycling and recovery equipment are required to list the number of trucks based at their shops, they do not need to have a piece of recycling or recovery equipment for every truck.

A.4.9 Safe Disposal Requirements

Under EPA's rule, equipment that is typically dismantled on-site before disposal (for example, retail food refrigeration, cold storage warehouse refrigeration, chillers, and industrial process refrigeration) has to have the refrigerant recovered in accordance with EPA's requirements for servicing. However, equipment that typically enters the waste stream with the charge intact (for example, household refrigerators and freezers, room air conditioners) is subject to special safe disposal requirements. Under these requirements, the final person in the disposal chain (for example, a scrap metal recycler or landfill owner) is responsible for ensuring that refrigerant is recovered from equipment before the final disposal of the equipment. However, persons "up-stream" can remove the refrigerant and provide documentation of its removal to the final person if this is more cost-effective. The technician certification is not required for individuals removing the refrigerant from appliances in the waste stream. The disposal requirements take effect on 13 July 1993.

A.4.10 Major Recordkeeping Requirements

The EPA recordkeeping requirements discussed in A.4.10.1 and A.4.10.2 can be met by using the WIMS Refrigerant Management Software. For a detailed description of this software, see Appendix G, *Work Information Management System (WIMS).*

A.4.10.1 Technicians servicing appliances that contain 50 or more pounds of refrigerant must provide the owner with an invoice that indicates the amount of refrigerant added to the appliance. Technicians must also keep a copy of their proof of certification at their place of business.

A.4.10.2 Owners of appliances that contain 50 or more pounds of refrigerant must keep service records documenting the date and type of service, as well as the quantity of refrigerant added.

A.4.11 Hazardous Waste Disposal

EPA has established requirements for the safe disposal of refrigerants.

A.4.11.1 If refrigerants are recycled or reclaimed, they are not considered hazardous under federal law. In addition, used oils contaminated with CFCs are not

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THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (EPA)
REFRIGERATION RECOVERY OR RECYCLING DEVICE
ACQUISITION CERTIFICATION FORM

EPA regulations require establishments that service or dispose of refrigeration or air conditioning equipment to certify [by 90 days after publication of the final rule] that they have acquired recovery or recycling devices that meet EPA standards for such devices. To certify that you have acquired equipment, please complete this form according to the instructions and mail it to the appropriate EPA Regional Office. BOTH THE INSTRUCTIONS AND MAILING ADDRESSES CAN BE FOUND ON THE REVERSE SIDE OF THIS FORM.

PART 1: ESTABLISHMENT INFORMATION

Name of Establishment

Street

(Area Code)Telephone Number

City State Zip Code

Number of Service Vehicles Based at Establishment

PART 2: REGULATORY CLASSIFICATION

Identify the type of work performed by the establishment. Check all boxes that apply.

- ❑ Type A -Service small appliances
- ❑ Type B -Service refrigeration or air conditioning equipment other than small appliances
- ❑ Type C -Disposal of small appliances
- ❑ Type D -Dispose of refrigeration or air conditioning equipment other than small appliances

PART 3: DEVICE IDENTIFICATION

Name of Device(s) Manufacturer	Model Number	Year	Serial Number (if any)	Check Box if Self-Contained
1.				❑
2.				❑
3.				❑
4.				❑
5.				❑
6.				❑
7.				❑

PART 4: CERTIFICATION SIGNATURE

I certify that the establishment in part 1 has acquired the refrigerant recovery or recycling device(s) listed in Part 2, that the establishment is complying with Section 608 regulations, and that the information given is true and correct.

Signature of Ownership/Responsible Officer	Date	Name (Please Print)	Title

Public reporting burden for the collection of information is estimated to vary from 20 munites per response with an average of 40 minutes per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing the collection of information. Send regarding ONLY the burden estimates or any other aspects of the collection of information, including suggestions for reducing the burden to Chief, Information Policy Branch, EPA, 401 M St., S. w. (PM-223Y), Washington, DC 20460, and to the Office of Information and Regulatory Affairs. Office of Management and Budgets, Washington, DC 20503, market 'Attention Desk Officer of EPA'. DO NOT SEND THIS FORM TO THE ABOVE ADDRESS. ONLY SEND COMMENTS TO THESE ADDRESSES.

Figure A-1. The United States Environmental Protection Agency (EPA) Refrigerant Recovery or Recycling Device Acquisition Certification Form

Instructions

Part 1: Please provide the name, address, phone number of the establishment where the refrigerant recovery or recycling device(s) is (are) located. Please complete one form for each location. State the number of vehicles based at this location that are used to transport technicians and equipment to and from service sites.

Part 2: Check appropriate boxes for the type of work performed by technicians who are employees of the establishment. The term "small appliances" refers to any of the following products that are fully manufactured, charged and hermetically sealed in a factory with five pounds or less of refrigerant refrigerators and freezers designed for home use, room air conditioners (including window air conditioners and packaged terminal air conditions), packaged terminal heat pumps, dehumidifiers, under-the-counter ice makers, vending machines and drinking water coolers.

Part3: For each recovery or recycling device acquire, please list the name of the manufacturer of the device, and (if applicable) its model number end serial number.

If more than 7 devices have been acquired, please fill out an additional form and attach it to this one. Recovery devices that are self-contained should be listed first and should be identified by checking the box in the last column on the right. A self-contained device is one that uses its own pump or compressor to remove refrigerant from refrigeration or air conditioning equipment. On the other hand, system-dependent recovery devices rely solely upon the compressor in the refrigeration or air conditioning equipment and/or on upon the pressure of the refrigerant inside the equipment to remove the refrigerant inside the equipment to remove the refrigerant.

If the establishment has been listed as Type B and/or Type D Part 2, then the first device listed in Part 3 must be a self-contained device and identified as such by checking the box in the last column to the right.

If any of the devices are homemade, they should be identified by writing "homemade" in the column provided for listing the name of the device manufacturer. Homemade devices can be certified for establishments that are listed as Type A or Type B in Part 2 until [six months after promulgation of the rule]. Type C or Type D establishments can oertify homemade devices at any time. If, however, a Type C or Type D establishment is certifying equipment after [six months after promulgation of the rule], then it must not use these devices for service jobs classified as Type A or Type B.

Part 4: This form must be signed by either the owner of the establishment or another responsible officer. The person who signs is certifying that the establishment is complying with Section 608 regulations, and that the information provided is true and correct.

EPA Regional Offices

Send your form to the EPA office listed below under the state or territory in which the establishment is located:

Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont

CAA 608 Enforcement Contact: EPA Region 1, Mail Code APC, JFK Federal Building, One Congress Street, Boston, MA 02203

New York, New Jersey, Puerto Rico, Virgin Islands

CAA 608 Enforcement Contact: EPA Region II, Jacob K. Javits Federal Building Room 5000,26 Federal Plaza, New York, NY 10278

Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia

CAA 608 Enforcement Contact EPA Region III, Mail Code 3AT21 , 841 Chestnut Building, Philadelphia, PA 19107

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee

CAA 608 Enforcement Contact: EPA Region IV, Mail Code APT-AE, 345 Courtland St NE, Atlanta, GA 30365

Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

CAA 608 Enforcement Contact EPA Region V, Mail Code AT18J, 77 W Jackson Blvd., Chicago, IL 60604

Arkansas, Louisiana, New Mexico, Oklahoma, Taxes

CAA 809 Enforcement Contact: EPA Region VI, Mail Coda ST-EC, First Interstate Tower af Fountain Place, 1445 ROSS AVe., Suite 1200, Dallas, TX 75202

Iowa, Kansas, Missouri, Nebraska

CAA 608 Enforcement Contact EPA Region VII, Mail Code ARTX/ARBR, 726 Minnesota Ave.. Kansas City, KS 66101

Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming

CAA 608 Enforcement Contact: EPA Region VIII, Mail Code 8AT-AP, 999 18th Street Suite 500, Denver, CO 80202

America Samoa, Arizona, California, Guam, Hawaii, Nevada

CAA 608 Enforcement Contact: EPA Region IX, Mail Code A-3, 75 Hawthorne St., San Francisco CA 94105

Alaska, Idaho, Oregon, Washington

CAA 806 Enforcement Contact: EPA Region X, Mail Code AT-082, 1200 Sixth Ave., Seattle, WA 98101

Figure A-1. The United States Environmental Protection Agency (EPA) Refrigerant Recovery or Recycling Device Acquisition Certification Form (continued)

hazardous if they are not mixed with other waste.

- Contaminated oils are subjected to CFC recycling or reclamation.
- Contaminated oils are not mixed with used oils from other sources.

A.4.11.2 Used oils containing CFCs after the CFC reclamation procedure, however, are subject to specification limits for used oil fuels if these oils are destined for burning.

A.4.12 Enforcement

EPA is performing random inspections, responding to tips, and pursuing potential cases against violators. Under the CAAA, EPA is authorized to assess fines of up to $25,000 per day for any violation of these regulations.

A.5 Air Force Requirements

Air Force requirements are contained in two documents: ETL 91-7 and the Action Memorandum 7 January 1993. These two documents make up the major policy and procedural guidance that AFCESA used to develop the Base Refrigerant Management Program (BRMP).

A.5.1 ETL 91-7

In response to the CAAA of November 1990, AFCESA published ETL 91-7. ETL 91-7 identified strategies on how to contain the emissions of CFCs and replace refrigerant in existing AC/R equipment and when to change out a piece of AC/R equipment. ETL 91-7 prohibited any future purchase of AC/R equipment for HVAC installations which used CFC-11 or CFC-12 and identified acceptable alternative refrigerants to include HCFC-22, HCFC-123, and HFC-134a. Even though two of these alternatives are HCFCs, they are acceptable replacements because the Protocol production ban does not affect them until after 2020 and 2030, respectively. This allows sufficient time for the AC/R equipment containing these HCFCs to operate to the end of their economic life.

A.5.1.1 Existing equipment containing CFCs must be properly operated and maintained to reduce leaks and emissions during routine handling, servicing, and overhaul. Base civil engineer (BCE) personnel must:

- use pump-out/recovery equipment,
- retrofit low-pressure chillers with high-efficiency purge systems,
- identify and correct leaks,
- reclaim contaminated or otherwise unusable refrigerant,
- monitor refrigerant usage, and
- institute conservation practices.

A.5.1.2 Retrofitting (conversion) of existing AC/R equipment, typically centrifugal chillers, should be accomplished when it is economically or *operationally* appropriate. An “engineered conversion” should be made in consultation with the original equipment manufacturer (OEM). They decide the effect on capacity and energy usage. They also determine the proper conversion program to minimize degradation in capacity and increased energy consumption. Consider supplementing lost capacity with an additional chiller by comparing the cost of this approach to the cost of the various conversion options.

A.5.1.3 AC/R equipment should be replaced when it

- reaches the end of its useful mechanical life and overhaul is not cost-effective,
- can no longer meet mission requirements, or
- cannot be economically converted to operate on an alternative refrigerant or conversion is otherwise not cost-effective.

A.5.1.4 ETL 91-7 details how equipment rooms must be modified in accordance with ASHRAE 15-1994, when to replace and use purge and pump-out units, and the appropriate use of absorption equipment and multiple AC/R units.

A.5.2 Secretary and Chief of Staff of the Air Force Action Memorandum, Ban on ODC Purchases

Because of the UNEP decision made in late 1992 to institute a global production ban of CFCs and halons by 1995 and 1994, respectively, the Air Force realized that operations had to change. The sooner the Air Force learns to live without these substances the less likely it will suffer a mission stoppage and contribute to depletion of the earth's ozone layer. The policies established by the Action Memorandum 7 January 1993 apply to all Air Force, Reserve, Air National Guard, and government-owned, contractor-operated activities. The Action Memorandum 7 January 1993 stressed that the Air Force could not allow "business as usual." It established the requirement for waivers to purchase new ODCs or receive them from the Defense Logistics Agency ODC bank for mission-critical applications and directed Air Staff functions to reduce dependence on CFCs.

A.5.2.1 The Action Memorandum 7 January 1993 laid out specific guidance for all Air Force missions which use CFCs. These included acquisition of facility air conditioning systems, air/ground equipment (AGE) and other refrigeration and support equipment, and commercial vehicles. It tasked the Air Force Civil Engineer (AF/CE) to develop installation guidance for managing refrigerant inventory so existing chillers can be maintained until the end of their economic life. This included recovering refrigerant from retired equipment to service remaining CFC systems. In general, the Action Memorandum 7 January 1993 reinforced the guidance contained in ETL 91-7 and was the impetus behind the development of the BRMP.

A.5.2.2 On 14 July 1993, the Assistant Vice Chief of Staff of the Air Force issued a letter detailing the Air Force ODC interim waiver application, approval procedures, and reporting requirements. The letter stated that as of 1 June 1993 waivers were necessary:

- prior to award of any contract that requires the use of a Class I ODC,
- to purchase new or recycled ODCs, or
- to obtain ODCs from the Defense Logistics Agency ODC bank for mission-critical applications.

A.5.2.2.1 Using the letter as a guide, AFCESA developed blanket waiver applications for CY93 and 94 that covered all facility AC/R equipment refrigerant requirements for AF/CE activities including the Air National Guard and Reserves. The applications were approved and AFCESA distributed the approved quantities to all major commands (MAJCOMs).

A.5.2.2.2 An Air Staff approved waiver is required for refrigerant quantities directly related to:

- purchase of CFC refrigerants;
- maintenance and service contracts which require contractors to purchase CFC refrigerants (if the government supplies refrigerant to the contractor, the contract does not require a waiver); and
- purchase of new equipment which uses CFC refrigerants (for example, household refrigerators, ice machines, refrigerating domestic appliances used in the family/unaccompanied housing and lodging facilities, food establishments, medical, and other base facilities).

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Appendix B — Refrigerant Sensors and Monitoring of Equipment Rooms

ABSTRACT: This appendix describes the various refrigerant area monitors available to detect refrigerants within mechanical rooms and refrigerant storage areas. Information is provided on the applications of these monitors. Halogen-sensitive detectors are described in the greatest detail, as they are most appropriate for these applications.

B. 1 Introduction

ETL 91-7 requires all new mechanical equipment rooms be designed in accordance with the most current edition of the ASHRAE standard covering the American National Standard Safety Code for Mechanical Refrigeration. Right now this is ASHRAE Standard 15-1994. ETL 91-7 also requires all existing mechanical rooms must be upgraded to comply with this standard whenever new mechanical equipment is installed or existing mechanical equipment is retrofitted. ASHRAE 15-1994 requires the installation of a refrigerant vapor detector for all types of refrigerants. This appendix provides an overview of these requirements and an introduction to refrigerant leak detection equipment.

B.2 Refrigerant Sensor Terminology

The following terminology and criteria associated with refrigerant sensors and detection allows each type to be compared. These criteria, sensitivity, detection, limits, and selectivity, apply to both portable pinpoint detectors and permanently-mounted area monitors.

B.2.1 Sensitivity
The sensitivity of any device is defined as the amount of input (material being measured) necessary to generate a certain change in output signal. For refrigerant sensors, the input is the refrigerant vapor concentration being measured and the output is the reading from a panel meter, a voltage output, or other display device. Refrigerant sensors with good (high) sensitivity require little material to generate a large change in output signal. Sensors with poor (low) sensitivity require larger amounts to change the output signal. The sensitivity is affected by the method of detection and the material being detected.

B.2.1.1 The sensitivity of an ionization sensor associated with a particular material that demonstrates high sensitivity for CFC-12 may have low sensitivity for HCFC-123 and very low sensitivity for HFC-134a. The variations in sensitivity are due to reduction in chlorine content, very easily ionized and detected, from chlorofluorocarbons (CFC) to hydrochlorofluorocarbons (HCFC) to hydrofluorocarbons (HFC) class compounds. Sensitivity differences of l00X to l000X have been reported when comparing CFC- 12 to HFC- 134a with some ionization-based sensors. Another example of this varying sensitivity is an infrared-based sensor. It has roughly the same sensitivity to CFC-12, HCFC-123, and HFC-134a, which is not the case for an ionization detector.

B.2.2 Detection Limit

Certain analytical techniques have well-defined sensitivity values, but these do not exist for refrigerant sensors. The most common measure of how "sensitive" a sensor can be is the detection limit. This is defined as the minimum amount of material a unit can sense that gives a signal at least two times the background noise level. A sensitive device does not necessarily mean a low-detection limit, although the two usually tend to coincide. Detection limits are measured in parts per million (ppm) for area monitoring applications. Area monitors typically have detection limits as low as 1 ppm, although a more typical value is 3 to 4 ppm for most compounds. For example, a detector with high sensitivity may be able to accurately discriminate concentration levels of 1 ppm or 2 ppm of vapor, while a low-sensitivity detector may only be able to discriminate in increments of 20 ppm or higher. A refrigerant sensor must be matched with the intended application. For example, an ionization detector that claims a detection limit of 2 ppm for CFC-12 does not work very well for HFC-134a detection. Conversely, an ionization detector made specifically for HFC-134a may be too sensitive for CFC- 12 monitoring.

B.2.3 Selectivity

Selectivity is defined as the ability to detect only the refrigerant of interest without interference from other compounds that may be present in the area. Selectivity requirements for area monitoring will vary with each specific installation. It is important because the monitors must work on a continuous basis and are thus exposed to other, more potentially interfering refrigerants at a wider concentration range over a long period of time.

B.2.3.1 Selectivity is a required feature of an area monitor if there are other refrigerants present with vastly different threshold limit values (TLV). The terms TLV and acceptable exposure limit (AEL) are used almost interchangeably in technical literature and tend to cause some confusion. TLVs are the maximum concentration of a chemical vapor in air for which workers can be exposed on a chronic basis (eight-hour work day and a 40-hour work week) without adverse effect over their working lifetime. These values are established by the American Conference of Government and Industrial Hygienists (ACGIH). AELs are defined as the maximum concentration of a chemical vapor in air for which workers can be chronically exposed as defined by the manufacturer of the chemical. In many cases, manufacturers will introduce new chemicals to the marketplace before ACGIH can establish TLVs. In these cases, AELs will be specified by the manufacturer and used until ACGIH can establish TLVs. For practical purposes, these values are used interchangeably to establish chronic exposure limits. In some rare cases, chemical manufacturers may establish AELs lower than ACGIH TLVs. In this case, the lower of the two values should be used. For example, equipment rooms with HCFC-123 chillers (AEL = 30 ppm) may also have chillers with CFC- 11 (TLV = 1,000 ppm). Without being able to distinguish between the two other refrigerants, a nonselective detector will alarm when 30 ppm of either refrigerant is detected. In this case a small leak of CFC- 11 will trigger the alarm. This can lead to concern about excessive HCFC - 123 exposure when, in reality, there may be no exposure to that compound and only inconsequential exposure to the CFC - 11. This can also lead to false alarms and eventual complacency toward alarms. Regardless of this possibility, some operators still prefer nonspecific detection so there is an alarm when any refrigerant is detected. The identity of the refrigerant will be discovered once the leak is pinpointed.

B.3 Electronic Area Monitor Detection Equipment

Electronic area monitor detection equipment can be placed into one of three categories based on selectivity as a criterion:

1) nonselective,
2) halogen-selective, and
3) compound-specific.

B.3.1 Nonselective Sensors

The sensors in this equipment can detect any type of emission or vapor present, regardless of its chemical composition. Detectors in this category are based on electrical ionization, thermal conductivity, ultrasonics, or metal-oxide semiconductors. These detectors are simple to use, very rugged, and, usually inexpensive. Nonselective sensors are best used in leak pinpointing applications.

B.3.2 Halogen-Selective Sensors

Halogen-selective sensors use a specialized sensor that allows the monitor to detect compounds containing fluoride, chloride, bromide, and iodide without interference from other species. The major advantage is a reduction in the number of “nuisance alarms” —false alarms caused by the presence of nonrefrigerant compounds (for example, paint or gas fumes). These detectors are easy to use, feature a higher sensitivity than nonselective detectors (detection limits are typically < 5 ppm), and are very durable. Due to the partial specificity of the detector, these instruments can be calibrated easily.

B.3.3 Compound-Specific Sensors

Compound-specific sensors are the most complex and expensive. These units are capable of detecting the presence of a single species without interference from other compounds. Compound-specific sensors are infrared-based (IR), although some of the newer types are infrared-photoacoustic-based (IR-PAS). These normally have detection limits around 1 ppm, depending upon the compound being detected. Due to recent improvements in technology, the price of compound-specific detectors has dropped but is still in the **$3,500** to **$4,000** range.

B.3.4 Comparing Sensors

These three types of sensors are compared in Table B-1, *Comparison of Refrigerant Sensors.*

Table B-1. Comparison of Refrigerant Sensors

Comments	Nonselective	Halogen-Selective	Compound-Specific
Advantages:	• Simplicity • Ruggedness	• Simple/rugged • Can be calibrated • Good sensitivity • Low maintenance	• Virtually interference-free • Can be calibrated • Good sensitivity
Disadvantages:	• Poor detection limits • Cross-sensitive to other species • Most cannot be calibrated	• Not compound-specific • Detector lifetime/stability	• Complexity/maintenance • Stability questionable • High price
Refrigerants Detected:	• All CFCs, HCFCs, HFCs, blends • Not recommended due to cross-sensitivity and poor detection limits	• All CFCs, HCFCs. HFC-134a, blends	• All CFCs, HCFCs, HFC-134a, blends
Other:	• None	• Where only one refrigerant is used • In moderately clean equipment rooms	• Performance degraded in “dirty” environments • Preferred type for use in multi-refrigerant environments

B. 4 Refrigerant Sensors

AHRAE 15-1994 requires refrigerant sensors/monitors in all mechanical equipment rooms for all refrigerants. The refrigerant sensor has the advantage of providing fast detection of refrigerant leaks. This capability can minimize the loss of valuable refrigerant. Its high cost can be justified by the cost savings associated with avoiding the loss of an entire or partial charge.

B.4.1 Group Al Refrigerants

Group Al refrigerants include CFC-11, -12, -13, -113, -114, -500, and -502; HCFC-22; and HFC-134a. These refrigerants are classified low in toxicity and possess no flame propagation. Their greatest hazard is associated with refrigerant spills and the possibility of asphyxiation. Refrigerant gases are heavier than air and, if undisturbed, tend to fill a room from the floor up, displacing the air.

B.4.2 Other Refrigerant Groups

Other groups of refrigerants are A2, A3, B 1, and B2 (HCFC-123 is a B1 refrigerant). Refrigerant sensors which detect the specific refrigerant in use are required to activate the alarm at no more than the corresponding TLV.

B.4.2.1 A refrigerant sensor can be used to meet ASHRAE 15-1994’s monitoring requirements for Group A 1 refrigerants. Though more expensive than an oxygen deprivation sensor, the refrigerant sensor has the advantage of providing much faster detection of refrigerant leaks. This capability can minimize the loss of valuable refrigerant. The additional cost of a refrigerant sensor may be justified by the cost savings associated with avoiding the loss of an entire or partial charge.

B.4.2.2 Any equipment room containing a mixture of Group A 1 and B 1 refrigerants must meet the requirements of each system individually. This means if an equipment room houses an R-11 chiller and an R-123 chiller, it must also contain both an oxygen deprivation sensor and a refrigerant vapor monitor. Alternatively, two refrigerant vapor sensors (one for R-11 and one for R-123) could be used.

B.5 Continuous Duty Area Monitors

Area monitors are used today to check the refrigerant vapor level on a continuing basis in an equipment room or other locations where exposure can occur. There are several reasons for monitoring, including personnel health and safety protection, conservation of expensive refrigerants, and protection of valuable refrigeration equipment.

B.5.1 Monitor Characteristics

If a monitor is used to continuously sample the air in an equipment room, it should have several qualities that short-term or leak-checking monitors do not require. These include low “O” drift or an “autozeroing” capability and outputs to trigger external alarms to notify the proper base personnel. Continuous monitors should be refrigerant-specific to prevent nuisance alarms, caused by the presence of some compound (for example, gasoline or paints) in the area other than the target compound. Monitors with poor selectivity y will alarm on compounds other than refrigerant, such as cleaning agents or paints.

B.5.2 Monitor Requirements

ASHRAE 15-1994 requires a monitor be able to actuate an alarm and start mechanical ventilation. This corresponds to the basic function of the monitor to alert personnel that the refrigerant level is above the TLV or AEL. Devices used for longterm monitoring should also be stable over the range of temperatures, voltages, humidities, and barometric pressures to which they will be exposed. One of the outputs should notify base emergency personnel in the event of a major release of refrigerant. Last, but not least, they should require minimal maintenance.

B.5.3 Calibration Stability

Calibration stability is a very important aspect of monitors used for long-term monitoring. Stability is provided by the electronics used to read the sensor output. In general, the electronics must be able to correctly interpret sensor output under all equipment room conditions, such as changes in temperature and humidity. Calibration can be performed by the manufacturer of the monitor for approximately $200 to $250. Always recalibrate an area monitor after a repair involving the replacement of a sensor, bridge board, or a main control board. The replacement of any of these three components can significantly affect the calibration of the unit. There are many situations in which more than one type of refrigerant is being monitored. Because all monitors can only be calibrated for a single refrigerant, the following criteria should be used in selecting the refrigerant sensor to use: always use R-123 if that is one of the refrigerants being monitored. R-123 has an AEL of 30 ppm. All other common refrigerants have much higher AELs.

B.5.3.1 Although most area monitors will detect all halogen-based refrigerants, their sensitivity varies with the specific refrigerant type. The commonly used refrigerants can be segregated into four groups, from the highest sensitivity (highest reading for a given concentration) to lowest sensitivity as shown below:

Highest Sensitivity	R-n, -22, -123
Moderate Sensitivity	R-502
Lower Sensitivity	R-12, -500, -114
Lowest Sensitivity	R-134

Choose the refrigerant for which the detector has the lowest sensitivity. For example, if the unit is monitoring a room that has both R-12 and R-22, choose R-12 for the calibration.

B.5.3.2 Typically, all sensors will last for approximately two to five years from the date installed before a new sensor is required. As refrigerant is detected, the sensor loses some amount of its ability to detect refrigerant the next time. The life of a sensor is primarily determined by the amount of refrigerant it senses over a period of time. The average cost to replace a sensor is approximately $300 to $350 each.

B.5.4 Characteristics

Monitors should also have a method of setting the “0” reference point. Those used on a long-term basis should either have a very small “0” drift (ppm) between inspections or an “auto zero” feature.

B. 6 Monitor Alarm Outputs

Monitors must provide a relay to annunciate an alarm signal when the TLV, AEL, or oxygen limit is reached. It can be used to trigger an alarm, light, or bell; signal the condition to other parts of the building; and energize the ventilation system to purge the room. Equipment room alarm signals and start-up of mechanical ventilation systems should be done directly by the monitor. Remote alarm indicators can be connected through a building automation system (BAS). Some monitors provide several relay outputs that can be set to trigger at various levels of refrigerant concentration. These can be used to clearly define the danger of exposure.

B.6.1 First-Stage Alarm

The first stage of alarm must occur at the TLV or AEL (that is, the concentration for eight hours per day, 40 hours per week for their working life, to which nearly all employees can be exposed without adverse effect). At this level, purge rate ventilation of the space should be initiated. Occupants can remain in the room if they are working to contain a leak. Use of National Institute for Occupational Safety and Health (NIOSH)-approved respiratory protection is recommended, but not required.

B.6.2 Second-Stage Alarm

The second-stage alarm should be set at the short-term exposure limit (STEL) which can be up to three times the TLV or AEL. ACGIH allows brief exposure (up to 15 minutes) at this level in a work shift. This level of alarm indicates that the room should only be occupied by personnel, properly equipped with respiratory protection, intent on eliminating the refrigerant source.

B.6.3 Third-Stage Alarm

The third-stage alarm, or alternate second level, is the emergency exposure limit (EEL). The EEL defines a concentration that a worker should only be exposed to rarely in a lifetime. In addition, it will not cause permanent adverse health effects or interfere with a worker's escape. An exposure time is generally given with the concentration (for example, 1000 ppm for one hour); however, at this level it should be mandatory that all occupants exit the space immediately. This level would only be expected when a major spill has occurred.

B.6.4 Self-Monitoring

Many monitors have the capability of detecting failure in their operations. They are provided with an output signal, such as a relay, which can be used to report a sensor failure. Examples of failures include: low airflow through the monitor, circuit failure, and a saturated or absent sensor signal. Loss of the monitor's supply power can also be detected if the alarm contacts of the monitor are normally powered open. This output should signal an alarm condition to the building operator so the monitor can be checked and returned to operation. Upon receiving such a signal, the operator should bring a portable monitoring device to the equipment room when checking the permanent monitor. He should ascertain the level of refrigerant in the mechanical equipment room before entering.

B.6.5 Remote Reset

Some monitors contain a remote reset input that allows the alarm to be reset from a remote location. If the monitor contains this feature, the reset switch should be located outside the equipment room door. This allows an operator to reset the alarm before entering the room. If the alarm can be successfully reset, the buildup of refrigerant has cleared. If the alarm does not reset, additional steps should be taken before the room is entered. The technician should:

- wear a self-contained breathing apparatus (SCBA);
- determine refrigerant concentration level with a hand-held monitor; and
- obtain additional ventilation using existing systems or portable units if high concentration levels are detected.

B.6.6 Serial Signal

Some monitors provide a O to 10 vDC, 4 to 20 mA or serial signal that is proportional to the level of refrigerant sensed by the monitor. This signal can be used to provide a remote indication of the refrigerant level in the equipment room. Example:

> One use of this output could signal a meter located outside the entry door to the equipment room. This will help operating personnel decide if SCBA is necessary or if the refrigerant in the room has been successfully purged by the ventilation system.

SCBAs are required:

- in atmospheres deficient in oxygen (concentrations of oxygen in air < 19.5 percent), or
- if the concentration of chemical vapor in air is equal to or greater than the concentration which is considered immediately dangerous to life and health (IDLH).

IDLH values are specified by NIOSH (see Table C-1, *Physical Properties of Refrigerants*, in Appendix C). This is not intended to be a complete discussion of the requirements established in federal regulations for respiratory protection. The user of this Handbook should consult 29 C.F.R. 1910.134 and ANSI Z88.2- 1980 for detailed requirements. When tied to a building automation system, a signal can be used to alert operating personnel of a leak, initiate ventilation purge of the room, and generate an electronic log of the refrigerant level in the equipment room.

B.6.7 Advantages

Monitoring equipment room refrigerant concentrations with a BAS may eventually become common practice for all refrigerants. This level of control not only monitors refrigerant level and initiates necessary alarms, it also automatically alerts the service order desk responsible for repair of the equipment. This provides an inexpensive means of having a trained expert, who can quickly respond to a problem, constantly oversee the operation of the equipment room.

B.6.7.1 Refrigerant concentration in the equipment room can be logged electronically y and documented. This provides documentation that refrigerant concentrations are maintained below the appropriate AEL. It also allows employees to feel comfortable they are working in a safe environment.

B.6.7.2 A refrigerant vapor monitor can be used for early detection of refrigerant leaks and may prevent significant refrigerant loss.

B.6.7.2.1 Monitoring the purge unit with a BAS for excessive purge unit operating times can also provide valuable information that could lead to early leak detection.

B.6.7.3 Purge unit run times can be automatically logged and plotted in graph form to identify trends. In addition, an alarm message can be triggered to alert the operator if the purge rate exceeds some preset limit. In general, purge unit run times in excess of one hour per week are indicative of excessive leakage. This value is dependent on the capacity of the purge unit and the internal volume of the chiller and is therefore only a guideline. The chiller manufacturer should be consulted to determine the actual maximum, allowable purge unit run times for each chiller which are to be expected of a chiller in good operating condition.

B.7 Sensor Locations

The refrigerant sensors associated with the area monitors must be properly located. Some refrigerant leak detectors are capable of monitoring multiple locations and may use multiple sensors in one unit. Other leak detectors are single-zone units capable of monitoring only one location. Some of the key factors in determining sensor locations are:

- leak source locations,
- air flow patterns, and
- where room occupants are most likely to be exposed to refrigerants through inhalation.

Using occupant safety as a guide, the recommended height for the sensor is 18 inches above the floor. The sensor should always be below the common breathing zone height of five feet. When undisturbed by air currents, refrigerants released into a space fall to the floor and spread out. They are three to five times heavier than air and seek the lowest areas. Once these areas are "full," the space will fill from the bottom up, much as it would if it were being filled with water.

B.7.1 Locating Sensors

"Locate the sensor where refrigerant is likely to concentrate, " is the only direction given by ASHRAE 15-1994 to locate the refrigerant monitor sensor. This recommendation is necessarily vague, due to the wide variety of equipment room configurations. Instructions provided by the monitor manufacturer should be followed when locating the sensor.

B.7.1.1 Because the sensor measures the concentration of refrigerant in the air, each zone inlet tube should be mounted where it is most likely to sense leaking refrigerant, Place the inlet as close as possible to the area of potential leaks; on the downstream side of the air flow pattern in the room. Place the inlet close to the floor, because refrigerants are typically heavier than air. Locate the control unit so the farthest pick-up point will not exceed the manufacturer's recommendations for zone inlet tube length.

B.7.1.2 Moisture can damage refrigerant sensors. Pickup points must be located and protected, where necessary, to prevent water from entering the system.

B.7.1.3 Figure B-1, *Sensor Pickup Points,* shows a general location of the pickup points where sensors should be located in accordance with ASHRAE 15-1994.

B.8 Vendor Listing

The following is a partial listing of companies that sell leak detectors. These are not recommendations and the Air Force does not endorse these companies.

B.8.1 Nonselective Detectors

AIM USA
12919 Southwest Freeway, Suite 170
P.O. Box 720540
Stafford, TX 77477
(713) 240-5020

B.8.2 Halogen-Selective Detectors

Yokogawa Corporation of America
2 Dart Road
Shenandoah Industrial Park
Newnan, GA 30265-1094
(800) 447-9656

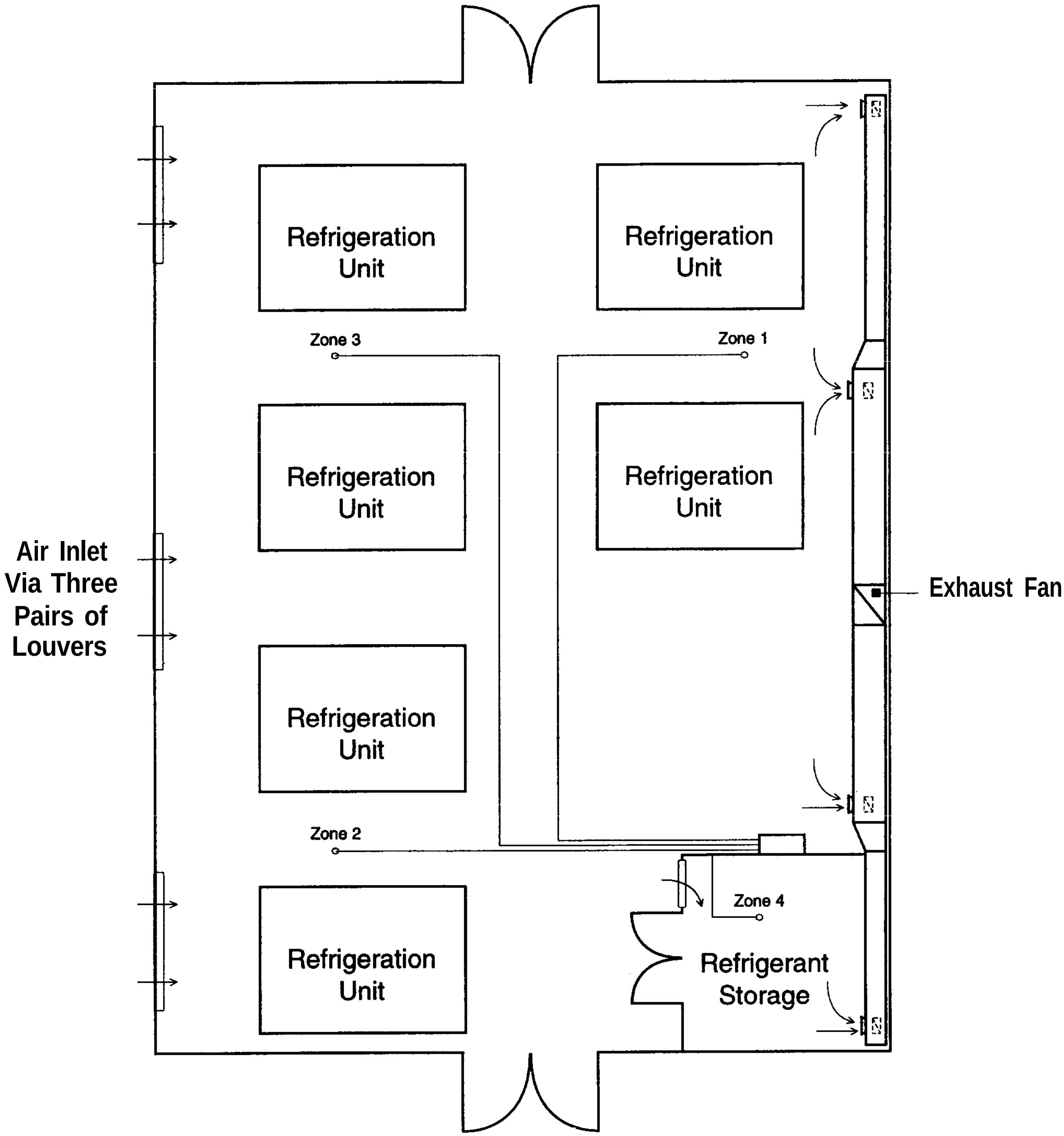

Figure B-1. Sensor Pickup Points

Leybold-Inficon, Inc.
Two Technology Place
East Syracuse, NY 13057
(315) 434-1246

SenTech Corporation
P.O. Box 42905
2020 Production Drive
Indianapolis, IN 46242
(317) 248-1988

B.8.3 Compound-Specific Detectors

Foxboro Corporation
EMO Division, P.O. Box 500
600 N. Bedford Street
East Bridgewater, MA 02333
(508) 378-5400

Gas Tech, Inc.
8407 Central Avenue
Newark, CA 94560
(510) 794-6200

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Appendix C — Refrigerant Storage Recommendations and Requirements

ABSTRACT: This appendix explains the refrigerant storage recommendations and requirements for refrigerant storage facilities, refrigerant storage container types, labels and markings, transportation of refrigerant issues, and the safe handling of refrigerants. It provides health and safety issues for refrigerants.

C.1 Introduction

Refrigerants, whether regulated or non-regulated, should be stored in a controlled environment. From a safety standpoint, it is important to limit access to refrigerants; some refrigerants are very toxic, flammable, or stored in high-pressure containers. With the implementation of production bans of chlorofluorocarbons (CFCs) in 1995, decreasing availability and increasing price, inventory control of refrigerants is very important. If possible, store refrigerants in a single location to provide better control and management. This will simplify managing refrigerant inventories and assure the necessary recordkeeping is being accomplished. If refrigerant is stored within an enclosed space, the area monitor and emergency ventilation system cost savings are significant if only one site is used; otherwise, all storage sites will require these systems.

C.2 Refrigerant Storage Requirements: Enclosed Space

Buildings, or areas within buildings, designed or used specifically as enclosed refrigerant storage facilities shall comply with ASHRAE 15-1994, *Safety Codes for Mechanical Room Design (see* Appendix J, *Application of ASHRAE Equipment Room Design Requirements).* ASHRAE 15-1994 guidelines include, but are not limited to: refrigerant storage facility ventilation and exhaust requirements, refrigerant monitors and alarms, and on-site self-contained breathing apparatus. ASHRAE 15-1994 limits the amount of stored refrigerant in a machinery room to not more than 330 lbs (150 Kg) of refrigerant, in addition to the charge in the equipment plus the refrigerant stored in a permanently attached receiving vessel. Whenever refrigerant is stored within a building, such as a refrigeration shop, it is preferable for it to be in an enclosed room. Otherwise, everyone in the shop is at constant risk of exposure and possible asphyxiation.

C.3 Refrigerant Storage Recommendations: Open Space

Currently, there are no regulations for the storage of refrigerants in a nonenclosed refrigerant storage facility, other than to follow safe refrigerant handling practices. The following practices are recommended.

- All storage areas should be under a roof to protect them from weather extremes and be of such a size as to keep direct sunlight off the refrigerant containers. The area should be enclosed, at a minimum, with a chain-link fence for security purposes.
- An open enclosure should preferably be a stand-alone entity.
- If an enclosure is located adjacent to a building with which it shares a common wall (with the other three sides open), it is recommended no door be installed in the common wall within the confines of the enclosure.

C.4 Other Recommendations

Technicians, or anyone who has the potential to be working with or around refrigerants, should complete a training program which meets the minimum guidelines set forth by OSHA 1910.120, including training on the flammability and toxicity of refrigerants commonly used on the base; and safe work practices and handling of refrigerants, especially when working in an enclosed space (for example, use of self-contained breathing apparatus (SCBA) and refrigerant vapor monitoring). Emergency procedures in response to accidents, spills, and exposure involving refrigerants should be provided during training.

C.5 Refrigerant Health and Safety Issues

There are many health and safety issues associated with both the new, alternative non-CFC refrigerants, and CFC refrigerants. Several of these issues will be addressed in the following sections.

C.5.1 Physical Properties of Refrigerants

Table C-1, *Physical Properties of Refrigerants,* provides a quick overview of the refrigerants used in air conditioning and refrigeration (AC/R) applications, including: type and designation number, chemical formula, boiling point, threshold limit value (TLV), acceptable exposure limit (AEL), short-term exposure limit (STEL), and immediately dangerous to life and health (IDLH) information. Values for some of these items are not readily available or have not been determined.

C.5.1.1 The refrigerants which are CFC, hydrochlorofluorocarbon (HCFC), and hydrofluorocarbon (HFC) compounds have been identified under refrigerant by replacing the “R” designation with the appropriate compound designation. The boiling point refers to the temperature at which the refrigerant will boil off as a gas at atmospheric pressure.

C.5.1.2 The various refrigerant concentration levels at which an individual can be safely exposed are usually time-dependent. These levels are indicated by the TLV, AEL, STEL, and IDLH and are expressed in parts per million (ppm).

C.5.1.2.1 The compound TLVs are established by the American Conference of Government and Industrial Hygienists (ACGIH). TLVs are the maximum chemical vapor concentration in air to which workers can be exposed on a chronic basis (eight-hour work day and 40-hour work week for a working lifetime) without adverse affect. Several years can elapse before the TLVs for a new chemical are established.

Table C-1. Physical Properties of Refrigerants

Refrigerant	Name	Chemical Formula	Boiling Point °C/° F	TLV (ppm)	AEL (ppm)	STEL (ppm)	IDLH (ppm)
Group A1							
CFC-11	Trichlorofluoromethane	CCl_3F	23.9/75	1,000	1,000	--	10,000
CFC-12	Dichlorodifluoromethane	CCl_2F_2	-30/-22	1,000	1,000	--	50,000
CFC-13	Chlorotrifluoromethane	$CClF_3$	-82/-115	--	--	--	50,000
R-13B1	Bromotrifluoromethane	$CBrF_3$	-57.81-72	1,000	1,000	--	--
R-14	Tetrafluoromethane (carbon tetrafluoride)	CF_4	-128/-198	--	--	--	--
HCFC-22	Chlorodifluoromethane	$CHClF_2$	-40.6/-41	1,000	1,000	1,250	--
CFC-113	Trichlorotrifluoroethane	CCl_2FCClF_2	47.8/118	1,000	1,000	1,250	4,500
CFC-114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	3.3/38	1,000	1,000	--	50,000
CFC-115	Chloropentafluoroethane	$CClF_2CF_3$	-38.9/-38	1,000	1,000	--	--
HFC-134a	1,1, 1,2-Tetrafluoroethane	CH_2FCF_3	-26/15.2	--	1,000	--	--
CFC-400	R-12 and R-114	$CCl_2F_2/C_2Cl_2F_4$		1,000	- -	--	50,000
HCFC-401a	R-22/R-152a/R-124 (53%/13%/34% by wt)	$CHC1F_2/CH_3CHF_2/$ $CHClFCF_3$	-32.81-27	--	800	--	--
HCFC401b	R-22/R-152a/R-124 (61%/11%/28% by wt)	$CHClF_2$/CH,$CHF_2/$ $CHC1FCF_3$	-35/-30.5	- -	940	- -	- -
HCFC-402a	R-22/R-125/R-290 (30%/60%/2% by wt)	$CHClF_2/C_3H_8/$ $CHF_2CF_3C_2HF_5$	-49/-56.6	- -	1,000	- -	- -
HCFC-402b	R-22/R-125/R-290 (60%/38%/2% by wt)	$CHClF_2/C_3H_8$ $CHF_2CF_3C_2HF_5$	-47/-53.3	- -	1,000	- -	- -
HFC-404a	R-143a/R-125/R-134a (52%/44%/4% by wt)	$CH_3CF_3/CHF_2CF_3/$ CH_2FCF_3	-46.7/-52	--	1,000	- -	--
CFC-500	R-12/152a (73.8%/26.2% by wt)	CCL_2F_2/CH_3CHF_3	-33.31-28	1,000	1,000	--	--
CFC-502	R-22/l 15 (48.8%/51.2% by wt)	$CHClF_2/CClF_2CF_3$	45/-49.7	1,000	1,000	--	--
CFC-503	R-23113 (40.1%/59.9% by wt)	$CHF_3/CClF_3$	-88/-126	--	--	--	--

Table C-1. Physical Properties of Refrigerants (continued)

Refrigerant	Name	Chemical Formula	Boiling Point ° C / ° F	TLV (ppm)	AEL (ppm)	STEL (ppm)	IDLH (ppm)
HFC-507	R-125/R-143a (50%/50% by wt)	CHF_2CF_3/CH_3CF_3	-46.7/-52	--	1,000	--	--
R-744	Carbon Dioxide	CO_2	-78/-109	5,000	--	30,000	50,000
Group A2							
CFC-142b	l-Chloro-l, 1,-Difluoro-ethane	CH_3CC1F_2	-10/14	--	1,000**	--	--
HFC-152a	1,l-Difluoroethane	CH_3CHF_2	-25/-13	--	1,000**	--	--
Group *A3*							
R-170	Ethane*	C_2H_6	-89/-128	--	--	--	--
R-290	Propane*	C_3H_8	-42.2/-44	1,000	--	--	20,000
R-600	Butane	C_4H_{10}	-0.6/31	800	--	--	--
R-600a	2-Methylpropane (Isobutane)	$CH(CH3)_3$	-11.7/11	--	--	--	--
R-1 150	Ethene (Ethylene)	C_2H_4	-104/-155	--	--	--	--
R-1270	Propene (Propylene)	C_3H_6	-47.81-54	--	--	--	--
Group B1							
HCFC-123	2,2-Dichloro-l,1,l-Tri-fluoroethane	$CHC1_2CF_3$	27.6/81.7	--	30	--	--
R-764	Sulfur Dioxide	SO_2	-10/14	2	--	5	100
Group B2							
R40	Chloromethane (Methyl Chloride)	CH_3Cl	-24.4/-12 -24.4-12	50	--	100	10,000
R-611	Methyl Formate	$HCOOCH_3$	31.7/89	100	--	150	5,000
R-717	Ammonia	NH_3	-33.3/-28	25	--	35	500

* Simple asphyxiant
** Work place Environmental Exposure Limit as defined by American Industrial Hygienists Association

C.5.1.2.2 The compound AEL is determined by the manufacturer of a chemical or substance. It is listed in the material safety data sheet (MSDS) for the substance for guidance of personnel exposure. This value is typically used until ACGIH can establish TLVs. Often the AEL and TLV are equal and used interchangeably.

C.5.1.2.3 The STEL is defined by ACGIH as a 15-rninute time-weighted average exposure which should not be exceeded at any time during a work day, even if the eight-hour time-weighted average is within the TLV. Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times per day. There should beat least 60 minutes between successive exposures at the STEL. STEL represents the concentration to which workers can be exposed continuously for a short period of time without suffering from

- irritation;
- chronic or permanent tissue damage; or
- narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue, or materially reduce work efficiency,

provided the daily TLV is not exceeded. It is not a separate, independent exposure limit. Rather, it supplements the time-weighted average (TWA) limit where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. STELs are recommended only where toxic effects have been reported from high, short-term exposures in either humans or animals. Very few refrigerants have had STEL values developed.

C.5.1.2.4 IDLH values are specified by the National Institute of Occupational Safety and Health (NIOSH). These values represent a vapor concentration level that, when present, results in oxygen concentrations to drop below 19.5 percent.

C.5.1.2.5 The oxygen content of normal air at sea level is approximately 21 percent. Physiological effects of oxygen deficiency in humans are readily apparent when the oxygen concentration in the air decreases to 16 percent. These effects include impaired attention, judgment and coordination, and increased breathing and heart rate. Oxygen concentrations below 16 percent can result in nausea and vomiting, brain damage, heart damage, unconsciousness, and death. To take into account individual physiological responses and errors in measurement, concentrations of 19.5 percent oxygen or lower are considered to be indicative of oxygen deficiency.

C.5.2 Refrigerant Exposure
Refrigerants handled in accordance with the manufacturer's recommended exposure limits pose no acute or chronic inhalation toxicity hazard. However, there are certain precautions which should be undertaken and are as follows.

C.5.2.1 At room temperatures, refrigerant vapors have little or no effect on the skin or eyes. Inhaling high concentrations of refrigerant vapor may cause temporary central nervous system depression with narcosis, lethargy, and anesthetic effects. Other effects may be dizziness, intoxication, and a loss of coordination.

Continued breathing of high concentrations of vapors may produce cardiac irregularities (cardiac sensitization), unconsciousness, and, with gross overexposure, death. If any of the above symptoms are experienced, move to fresh air and seek medical attention.

C.5.2.2 Cardiac sensitization can occur if vapors are inhaled at concentrations well above the AEL. This can cause the heart to become sensitized to adrenaline, leading to cardiac irregularities and possible cardiac arrest. The likelihood of these cardiac problems increases with physical or emotional stress. Immediate medical attention must be provided if exposure to high concentrations of refrigerants occurs. Do not treat with adrenaline (epinephrine) or similar drugs. These drugs may increase the risk of cardiac arrhythmias and cardiac arrest. If the person is having difficulty breathing, administer oxygen. If breathing has stopped, give artificial respiration.

C.5.2.3 Suffocation can occur when a large release of vapor occurs, such as from a large spill or leak. These vapors may concentrate near the floor or in low spots and will displace the oxygen available for breathing, causing suffocation. When a large spill or leak occurs, always wear appropriate respiratory and other personal protective equipment before entering the area.

C.5.2.4 When working with a piece of refrigeration equipment in an equipment room or enclosed area, ensure that the relief and purge vent piping has been routed outdoors, away from air intakes. Make certain the area is well-ventilated. If necessary, use auxiliary ventilation to move refrigerant vapors. Check that air monitoring equipment has been installed to detect leaks. Ensure the area is clear of vapors prior to beginning work.

C.5.2.5 Refrigerants that are liquid at room temperature tend to dissolve the skin's protective fat, causing dryness and irritation, particularly after prolonged or repeated contact. Protective clothing should always be worn when there is a risk of exposure to liquid refrigerants. Where splashing is possible, always wear eye protection and a face shield. If the eyes are splashed, repeatedly flush them with water for at least 15 minutes. When handling refrigerants, always wear lined butyl gloves to avoid prolonged skin contact and chemical splash goggles to avoid eye contact. Provide SCBA for use in the event of a major spill or system failure.

C.5.3 Flammability Precautions
Typical AC/R refrigerants are nonflammable and nonexplosive. However, mixing refrigerants with flammable gases (such as air) or liquids can result in a flammable solution. Therefore, refrigerants should never be mixed with any flammable gas or liquid. Refrigerants should not be exposed to open flames or electrical heating elements. Though most refrigerants are not flammable at ambient temperatures and atmospheric pressure, tests have shown some types to be combustible at pressures as low as 5.5 psig at 177° C (351° F) when mixed with air at volumetric concentrations of generally more than 60 percent air. At lower temperatures, higher pressures are required for combustibility.

Refrigerants should not be used or allowed to be present with high concentrations of air above atmospheric pressure.

C.6 Disposable and Reusable Refrigerant Cylinders

Refrigerants are contained in both disposable and reusable shipping containers or cylinders. Since the refrigerant-containing cylinders can be pressurized, they are considered pressure vessels. They must comply with federal and state laws regulating transportation and usage of such containers.

C.6.1 Identifying Containers

Both disposable and reusable cylinders are painted (or otherwise distinguished) in a color code system. This code was voluntarily established by the refrigerant manufacturers to identify their products. The common refrigerant colors and identification are:

R-11 Orange
R-12 White
R-13 Light Blue
R-22 Light Green
R-113 Purple
R-114 Dark Blue
R-123 Light Grey (Silver)
R-134a Light Blue (Sky)
R-401a Coral
R-401b Yellow Brown
R-402a Sand
R-402b Olive
R-404a Orange
R-500 Yellow
R-502 Light Purple
R-503 Aquamarine
R-507 Teal
R-717 Silver
NH_3 Silver

The shade of color may vary from one manufacturer to another. Verify contents by means other than color. Every refrigerant cylinder is silk-screened with product, safety, and warning information. Manufacturer technical bulletins and MSDSs are available upon request. Even though cylinders are designed and manufactured to withstand the saturated pressure of R-502 (the base refrigerant), it is not recommended any cylinder be repainted with a different color and used with another refrigerant.

C.6.2 Container Pressure

All refrigerant cylinders come equipped with a pressure-relief valve designed to prevent the cylinder from being overpressurized, either during the filling of the cylinder with refrigerant or during the storage of the cylinder due to possible exposure of the cylinder to elevated temperatures. If the refrigerant pressure inside the cylinder exceeds the preset pressure of the pressure relief valve, the pressure-relief valve allows the automatic venting of refrigerant to reduce the pressure in the cylinder. Pressure-relief safety devices are of the frangible (rupture) disc style, or spring-loaded relief integrated into the valve stem of the cylinder. Neither adjust nor tamper with pressure-relief valves.

C.6.3 Reusable Containers

Reusable cylinders meet Department of Transportation (DOT) specification 4BA-300, with a water capacity of 122.7 pounds. Low boiling point, high vapor pressure refrigerants such as R-13 and R-503 are supplied in cylinders with DOT specification 3AA-180 or 3AA-2015, respectively. These cylinders are characterized by a combined liquid/vapor valve, located at the top of the cylinder. A dip tube feeding the liquid valve is immersed to the bottom to allow liquid removal without inverting the tank. Refrigerant can be removed in either gas or liquid phase through selection of the gas or liquid valve. The large, reusable cylinders bear a stamp on the shoulder which provides the following information:

- OWNER'S NAME (abbreviated),
- DOT SPECIFICATION NUMBER for the cylinder,
- SERIAL NUMBER of the tank,
- TEST DATE (month and year),
- MANUFACTURER'S SYMBOL, and
- WATER CAPACITY (in pounds weight).

C.6.3.1 DOT specifications require disposable refrigerant cylinders be rated for a service pressure of 260 pounds per square inch (psi). Under laboratory tests, one cylinder per 1,000 produced is pressurized to the point of failure. The cylinder must not rupture below 650 psi. These cylinders are constructed of common steel, which is prone to oxidation (rust). Rust can weaken the wall and seams of the cylinder to the point where the cylinder can no longer tolerate the pressure of the refrigerant inside. On the top of disposable cylinders is a single-acting plastic valve. Handles are provided, which can serve as rests for inverted liquid access from the cylinder. Disposable cylinders are to be stored in dry locations to prevent corrosion, and transported carefully to prevent abrasion of painted surfaces. They are not to be refilled. The penalty for transporting a refilled disposable cylinder is a fine up to $25,000 and five years of imprisonment.

Recycle disposable cylinders as scrap metal. When the cylinder is empty, ensure all pressure is released to zero psi. The cylinders should be rendered useless for any purpose.

C. 7 Labels and Markings (DOT Requirements)

Specific container labeling and marking requirements apply for all DOT-regulated hazardous materials. **DOT hazardous materials designations should not be confused with EPA hazardous materials.** They are solely concerned with material transportation issues, not environmental issues. For instance, DOT regulates material as hazardous if it is capable of causing injury or property damage due to an accidental release or failure of its packaging during shipment on public roads, railways, and airways. There are nine classes of DOT hazards. Only Class 2, Division 2.2 (nonflammable gases), is pertinent to the common refrigerants. This rating is attributable to the pressurized nature of the refrigerant in its container. The applicable AC/R refrigerants are R-12, R-22, R-134a, R-401a, R-401b, R-402a, R-402b, R-404a, R-500, R-502, and R-507 shipped in cylinders and ton tanks. They require marking and labeling. R-1 1, R-113, R-1 14, and R-123 are not DOT-regulated hazardous materials; therefore, DOT labeling and marking requirements do not apply.

C.7.1 Labeling

Each cylinder shall display a DOT diamond (square-on-point) "Nonflammable Gas" label. The 4-inch x 4-inch green diamond-shaped label may be printed on a tag and securely attached to the cylinder's valve protection cap prior to shipment. Ton tanks require two DOT Nonflammable Gas labels, one on each end.

C.7.2 Marking

Each container shall be marked with a proper DOT shipping name and appropriate United Nations (UN) four-digit chemical or hazard class identification number.

C.7.3 Precautionary Labels

Each container shall display a precautionary label prepared in accordance with ANSI 2129.1-88 and Compressed Gas Association C7-92. This label will include:

- product identity;
- antidotes;
- signal word;
- notes to physicians;
- statement of hazards;
- instructions in case of contact or exposure;
- precautionary measures;
- instructions in case of fire, spill, or leak; and
- instructions for container handling and storage.

C.7.4 Warning Labels

Since May 1993, warning labels have been required on containers of DOT Class 2 Division 2.1 (flammable gases) and Division 2.2 substances, as well as products containing or made with either of these substances.

C.8 Transportation of Refrigerants

The shipper of recovered refrigerant is responsible for determining if there are any state or local regulations restricting transportation, such as classifying recovered refrigerant and oil mixtures as hazardous wastes. The EPA does not classify these materials as hazardous waste.

C.8.1 Shipping Papers

Shipping papers are required whenever refrigerant is transported using public roadways, railroads, and airways. This includes transfer of refrigerants between Air Force bases. The shipper is required to properly fill out the shipping papers when returning the recovered refrigerant. The shipping papers must always contain:

- the quantity and type of container used (for example, "2-RETURNABLE CYLINDERS");
- the total gross weight of recovered refrigerants;
- the shipping name (for example, Chlorodifluoromethane Mixture);
- the DOT hazard class (for example, "NONFLAMMABLE GAS"); and
- the UN identification number (for example, "UN1018").

For material not regulated by DOT as a hazardous material, the words "Not Regulated by DOT" are recommended, but not required.

C.8.2 Shipping Tags and Placards

When a full or partially-full container is shipped, the shipper will be required to affix a DOT hazard label to the container. Typically, this is a green, 4-inch square tag, reading "NONFLAMMABLE GAS", that can be tied to the valve cover. If a container is empty and has no residual pressure, a DOT hazard tag is not required. If the shipper is sending 1,000 pounds (gross weight) or more of a hazardous material on the truck, DOT regulations require the shipper to provide the motor carrier with four Nonflammable Gas place cards. For materials being transported in ton tanks, the placards must also include the appropriate UN 4-digit identification number. Affixing the placards to the truck is the responsibility of the motor carrier.

Appendix D — Refrigerant Leak Detection Methods and Equipment

ABSTRACT: This appendix addresses refrigerant leak detection methods and equipment. The common leak locations on high- and low-pressure machines are addressed. The leak detection methods include those applicable for high- and low-pressure refrigerants used within both operating and idle equipment. The portable equipment available to pinpoint leak locations are presented with advantages and disadvantages of each type. Sensitivity, detection limits, and selectivity criteria for detectors are discussed.

D.1 Introduction

The Environmental Protection Agency (EPA) has promulgated new regulations, 40 C.F.R. Part 82 (1993), in response to the Clean Air Act Amendments (CAAA). They resulted in an increased emphasis on efforts to reduce the use of refrigerants due to leakage losses. This appendix provides an overview of methods and technologies which are currently available to aid service technicians in the location of refrigerant leak sources.

D.2 Background

A large amount of refrigerant is lost during normal chiller operation. This loss must be reduced significantly. The major chiller manufacturers believe 12 to 13 percent of low-pressure refrigerant emissions are due to the use of inefficient purging equipment. This loss can be as high as seven pounds of refrigerant for every pound of air purged on systems manufactured prior to the mid- 1980s. Refrigerant leakage occurs in high-pressure chillers and direct expansion systems as well, although these losses are primarily due to mechanical failures of piping systems, pressure vessels, and gasket materials. Manufacturers of refrigeration equipment believe that approximately 40 percent of emissions are due to leakage from refrigeration systems caused by normal operation and wear. These types of leaks are most often found in tubing, flanges, O-rings, and other connections. An ongoing program of leak detection is the best solution for managing the amount of refrigerant lost during “normal” operations. This requires a knowledge of the equipment, methods available to the technician, and the advantages of each.

D.3 Leak Test Methods: High-Pressure Refrigerants

There are several methods available for leak-testing equipment containing high--pressure refrigerants. These methods vary depending on the refrigerant charge and operational status and are described in the following paragraphs.

D.3.1 Operating Equipment with Refrigerant Charge

A positive-pressure refrigerant has sufficient pressure within all components of the system to enable most external leaks to the environment to be detected using leak detectors. Use caution whenever leak-testing operating equipment due to the dangers associated with moving and rotating parts. There is no method to directly detect evaporator and condenser tube leaks with the equipment operating.

D.3.2 Idle Equipment with Refrigerant Charge

A positive-pressure refrigerant has sufficient pressure at all reasonable mechanical room or ambient air temperatures to enable most external leaks to the environment to be detected using leak detectors. There is only one method to check for evaporator or condenser tube leaks that use water as the other heat transfer medium. It requires the equipment to be isolated from the water piping, drain the tubes, and remove the tube sheet access plate. An eddy-current analysis or leak detector (electronic or ultrasonic) can be used at this time to locate leaks.

D.3.3 Equipment without Refrigerant Charge

There are situations in which leak-testing is necessary due to a loss of all refrigerant, and it is inappropriate to pressurize the system with refrigerant to ensure all leaks have been repaired. There are also situations where using the system refrigerant pressure as the leak-producing mechanism may be inadequate to detect leaks. These situations may require the refrigerant charge to be evacuated from the entire system or a single component. When leak-testing a system or component which has had the refrigerant removed:

- Do not use a chlorofluorocarbon (CFC) for a trace gas; use a hydrochlorofluorocarbon (HCFC). HCFC-22 is the most commonly used trace gas. Inject the trace gas into the system first, using as little as possible (four pounds maximum) to minimize refrigerant emissions.
- Use compressed dry nitrogen to pressurize the system. Never use compressed air, oxygen, or a flammable gas to pressurize the system! The system may explode. Always use a regulator when adding nitrogen to a system. Add nitrogen slowly, to allow better mixing with the trace gas and prevent sweeping the trace gas away from the access port. To ensure that the rating of the relief valve is not exceeded, a maximum test pressure of 200 pounds per square inch gauge (psig) is recommended.
- When possible, isolate and pressure-test only the part of the system that requires testing.

After a system is pressurized with nitrogen, if possible, allow the system to stand for 12 to 24 hours to allow the tracer gas to disperse uniformly throughout the system. Once the tracer gas has dispersed, any of the methods described in section D.7 may be used to identify leak sources.

D.4 Leak Test Methods: Low-Pressure Refrigerants

To leak test equipment containing low-pressure refrigerants is more difficult than high-pressure refrigerants. The methods available are discussed in the following sections.

D.4.1 Operating Equipment

There is no way to completely leak-test a low-pressure refrigerant system during operation because a large part of the system is under a vacuum. The compressor discharge pipe, condenser, and piping leading to the refrigerant flow control valve are all slightly above atmospheric pressure and can be checked using leak detectors. Use caution when leak-testing operating equipment due to the dangers associated with moving and rotating parts. Evaporator and condenser tube leaks typically involve water leaking into the refrigerant, not the opposite. This is due to the lower refrigerant pressure in comparison with chilled and condenser water system pressures.

D.4.2 Off-Line Equipment Testing

A thorough leak-check can be performed on a low-pressure refrigerant system only when the system is not operating. Base maintenance personnel should schedule a maintenance shut-down period of at least 48 hours for a leak test. The timing of this test should minimize the impact on the facility's mission served by the refrigeration system being tested. A leak check is not a simple process, even with the equipment off-line. The refrigerant pressure in the equipment will usually be under a vacuum at room temperature. With CFC-11, equipment is under a vacuum when the refrigerant temperature drops below 23° C (74° F). With HCFC-123 and CFC-113, equipment is under a vacuum below 28° C (82° F) and 47° C (1 17° F), respectively.

D.4.2.1 The refrigerant pressure must be increased above atmospheric pressure to detect leaks. Equipment containing refrigerant can no longer be pressurized using a noncondensible gas such as dry nitrogen. The only method to increase the refrigerant pressure above atmospheric pressure is to increase the temperature of the refrigerant. In a constant volume system, this will cause a corresponding pressure increase. Increasing the temperature of CFC-11 to 38° C (100° F) will produce a 9 psig system pressure.

D.4.2.2 There are two pressure equalization system types used to increase refrigerant temperature to obtain the desired pressure.

D.4.2.2.1 One system uses an electric-resistance blanket heater (commonly referred to as a "belly heater") with associated temperature controls. The heater mounts on the underside of the evaporator between the shell exterior and the insulation cover. The heat conducts through the shell and into the refrigerant.

D.4.2.2.2 The other system heats the refrigerant by circulating hot water through the evaporator tubes. Using the service valves, the chilled water piping is isolated from the equipment. There must be a hose bib or other valved connection on the inlet and outlet chilled water piping connections. These connections are used to circulate the water in the evaporator through a water heater and back into the evaporator;

the refrigerant temperature is raised, causing the pressure to increase. The hot water source can be permanent, portable, or the facility's domestic water heater.

D.4.2.3 Use caution when raising the temperature of the refrigerant charge. The pressure can not exceed the pressure relief valve and/or rupture disk setting. This would cause refrigerant to escape to the atmosphere. Stop the addition of heat to the refrigerant when a pressure of 8 to 10 psig is achieved.

D.4.2.4 Perform a leak-check at all gaskets, fittings, and penetrations, using the leak detection equipment or substances described later in section D.7.

D.4.3 Idle/Standby Equipment

A low-pressure system will usually be in a vacuum at typical room or ambient temperature when it is not operating. This causes any leakage to be air and water vapor into the chiller in lieu of refrigerant leaking out. The concern is this leakage requires the purge unit to operate to remove these gases and, in so doing, discharges refrigerant vapors. It is recommended that an integral pressure equalization system as described in D.4.2.2.1 and D.4.2.2.2 be used for refrigeration equipment which operates intermittently, especially for equipment used largely for standby. This will control the pressure automatically, so its internal pressure is always equal to the atmospheric pressure while the chiller is idle. This will minimize, if not eliminate, loss of refrigerant. Another option is the removal of the refrigerant charge for chillers that are idle for long durations, such as a winter shutdown.

Refrigerant removed from the chiller will be stored in a leak-tight tank capable of withstanding a range in pressure from 29.8 inches of mercury vacuum to 15 psig. During this idle period the chiller should be charged with dry nitrogen to a pressure of 1 to 2 psig to prevent moisture accumulation in the chiller vessels.

D.4.4 Equipment without Refrigerant Charge

There are two steps to leak test a low-pressure chiller without its charge. The first step is to pressurize the system to allow the leaks to be located and repaired. Upon completion, a vacuum is pulled to ensure the equipment does not leak under its normal negative pressure operating conditions. These steps follow.

D.4.4.1 ***Step 1*** **-** Pressurize the chiller with dry nitrogen and use a soap-and-water solution to check all joints. Leaks will be revealed by "bubbling" of the soap solution. Repair all leaks discovered. If the leaks cannot be discovered, insert a fully halogenated HCFC refrigerant (one to four pounds of HCFC-22) as a trace gas. Use an electronic halogen leak detector to locate leaks. After the completion of this procedure, the mixture of HCFC-22 and nitrogen may be released to the atmosphere.

D.4.4.2 ***Step*** **2-** Evacuate the chiller, using a vacuum pump capable of achieving 1000 microns of mercury absolute. Once evacuated to that level, allow the chiller to stand for 12 hours. Some pressure rise (due to microscopic leaks that cannot be prevented at reasonable cost) is acceptable. The Trane Company suggests if the pressure does not rise above 2500 microns, the unit is acceptable and may be charged with refrigerant. If the vacuum rises above 2500 microns, the unit is unacceptable and further leak-testing is required. The procedure in Step 1 should be repeated and, the vacuum pulled again.

D.4.5 Spectrographic Oil Analysis

Routine spectrographic oil analyses will detect the presence of moisture in the refrigerant circuit. The presence of moisture in the oil is indicative of the existence of a leak source. This technique does not provide indications as to the location or magnitude of a leak. Detailed information on spectrographic oil analyses is in Appendix F, *Refrigerant Leak Mitigation through Equipment Maintenance and Service Practices,* including recommended ceiling values for moisture in oil samples.

D.5 Potential Refrigerant Leak Areas

During inspections, leak-check certain leak-prone areas of the system for integrity. These areas include all penetrations into the refrigerant-occupying area and all nonwelded connections. Specific areas include:

- motor terminals;
- sight glasses;
- shaft seals;
- Schrader cores;
- service, solenoid, and relief valves;
- flare fittings;
- joints with gaskets; and
- filter dryers.

Oil stains on positive-pressure equipment or components are a sign of leak paths.

D. 6 Leak Detection Equipment Terminology

The following terminology and criteria associated with leak detection allows each type of detection equipment to be compared with each other. These criteria are applicable to both portable pinpoint detectors used for locating specific leak sources and permanently-mounted area monitors used to sense a leak of refrigerant within an enclosed area. These criteria are sensitivity, detection limits, and selectivity.

D.6.1 Sensitivity

The sensitivity of any device is defined as the amount of input (material being measured) necessary to generate a certain change in output signal. For leak detection, the material is the refrigerant vapor concentration being measured and the output is the reading from a panel meter, a voltage output, or other display device. Detectors with good (high) sensitivity require very little material to generate a large change in output signal, while detectors with poor (low) sensitivity require larger amounts of material to change the output signal. Sensitivity is affected by the method of detection and the material being detected.

D.6.2 Sensitivity Differences

The sensitivity of an ionization detector associated with a particular material that demonstrates high sensitivity for CFC-12 may have poor sensitivity for HCFC-123 and very poor sensitivity for HFC-134a. The variations in sensitivity are due to reduction in chlorine content, very easily ionized and detected, from CFC to HCFC to hydrofluorocarbon (HFC) compounds. Sensitivity differences of l00X to 1000X have been reported when comparing CFC-12 to HFC-134a with some ionization-based detectors. The impact of refrigerant detection methods on sensitivity is illustrated in that an infrared (IR)-based detector will show roughly the same sensitivity to CFC-12, HCFC-123, and HFC-134a, which is not the case for an ionization detector.

D.6.3 Detection Limit

Certain analytical techniques have well-defined sensitivity values, but these do not exist for leak detectors. The most common measure of how “sensitive” a detector can be is the detection limit, defined as the minimum amount of material a unit can sense that gives a signal at least two times the background noise level. A sensitive device does not necessarily mean a low detection limit (it could have a high background electronic noise level), although the two measures of performance usually tend to coincide. Detection limits for monitors are measured in ounces per year for pinpointing applications. Portable leak pinpointers typically have detection limits around 0.25 ounces per year, although a more typical value is 3 to 4 ppm for most compounds. For example, a detector with high sensitivity may be able to accurately discriminate concentration levels of 1 or 2 ppm of vapor, while a low-sensitivity detector may only be able to discriminate in increments of 20 ppm or higher.

D.6.3.1 Because sensitivity can vary greatly with different compounds, the detector must be carefully matched to the intended application. For example, an ionization detector that claims a detection limit of 0.25 ounces per year for CFC-12 does not work very well for HFC-134a detection. Conversely, an ionization detector made specifically for HFC-134a may be too sensitive for CFC-12 leak pinpointing.

D.6.4 Selectivity

Selectivity is defined as the ability to detect only the refrigerant of interest without interference from other compounds that may be present in the area. Selectivity is not too important for leak pinpointers, because the equipment is attempting to pinpoint leaks, not determine the identity of the refrigerant. Based on selectivity as a criterion, electronic leak pinpointers can be placed into one of the three categories: (1) nonselective, (2) halogen-selective, and (3) compound-specific.

D.6.4.1 Nonselective detectors detect any type of emission or vapor present, regardless of its chemical composition. Detectors in this category are based on electrical ionization, thermal conductivity, ultrasonics, or metal-oxide semiconductors. Ideal for leak pinpointing applications, these detectors are simple to use, very rugged, inexpensive (normally, less than $500), and almost always portable.

D.6.4.2 Halogen-selective detectors use a specialized sensor that allows the monitor to detect compounds containing fluoride, chloride, bromide, and iodide without interference from other species. The major advantage of this detector is a reduction in the number of “nuisance alarms”–false alarms caused by the presence of non-refrigerant compounds such as paint and gas fumes. These detectors are easy to use, feature higher sensitivity than nonselective detectors (detection limits are typically <5 ppm when used as an area monitor and <0.05 oz/yr when used as a leak pinpointer), and very durable. Due to the partial specificity of the detector, these instruments can be calibrated easily.

D.6.4.3 Compound-specific detectors are the most complex and expensive. These units are capable of detecting the presence of a single species without interference from other compounds. Compound-specific detectors are either IR-based or, as some of the newer types, infrared-photoacoustic-based (IRPAS). These normally have detection limits around 1 ppm, depending upon the compound being detected. Due to recent improvements in technology, the price of compound-specific detectors has dropped by about 50 to 60 percent during the last year. IR-based detectors can now be purchased for about $3,500 to $4,000.

D. 7 Leak Detection Methods and Equipment

There are several methods available to pinpoint leaks of refrigerant. They range from simple soap bubbles to more complex electronic detectors. Some detection methods are invasive and must be injected directly into the refrigerant. All the detection methods have advantages and disadvantages.

D.7.1 Ultrasonic Leak Detectors

Ultrasonic leak detectors are nonselective and do not require the use of refrigerant to detect a leak. They employ an ultrasonic method to listen for leaking gas. The gas must be at a higher pressure than the location of the detector. The detector cannot detect the sound of gas being pulled into a vacuum.

D.7.1.1 This technique requires some advance knowledge of the leak location and a fairly low background noise level. Ultrasonic leak detectors provide high sensitivity adjustment. This type of equipment is reliable for outdoor use where air currents can upset the accuracy of other methods of detection.

D.7.2 Electronic Leak Detectors

Electronic leak detectors can be obtained in nonselective, halogen-selective, and compound-specific styles. They require the use of a fully-halogenated refrigerant as a trace gas. The most sensitive leak detectors used are ion source detector, thermistor type (based on change in temperature), and Dielectric type (measures a balance in surrounding air and then responds only to halogen gas). These detectors can be difficult to use in environments with high ambient air velocities because the refrigerant gases can be entrained in the airstream and removed from the leak source before building up a detectable concentration. Finding the leak source can be made difficult by airflows created by purge ventilation systems and condenser fans. These detectors are effective at detecting small leaks, as low as 1/2 oz/yr. A large leak may saturate the element when using leak detectors without a varying sensitivity. This situation will normally clear itself when the instrument is removed from the atmosphere contaminated with refrigerant vapors.

D.7.3 Halide Torches

Halide torches are nonselective detectors based on the principle that alcohol, propane, acetylene, and most other torches bum with an almost colorless flame. This trait is further enhanced by the fact that if copper is placed in this flame, the flame will continue to be almost colorless. However, if even the tiniest quantity of a halogen refrigerant (for example, R-1 1, R-12, R-22) is brought into contact with this heated copper, the flame will immediately take on a light green color. These detectors can be difficult to use in environments with high ambient air velocities because refrigerant gases can be entrained in the airstream and removed from the leak source before building up a detectable concentration. Finding the leak source can be made difficult by airflow created by purge ventilation systems and condenser fans. Some skill in discernment is required, and bright sunlight makes them of little use outdoors. No sensitivity adjustment is available, thus these devices are sometimes unable to discern between refrigerant concentrations in the general area versus a point source at the site of the leak.

D.7.4 Soap Bubbles

Soap bubbles are commonly used to detect leaks in equipment or components under positive pressure. A water-soap solution is sprayed or brushed over an area suspected of leaking. Gas communing through the solution will cause bubbles. The advantages of using the bubble method are its ease of use, low cost, and ease of application (compared to instrumentation). The bubble method can be used with a nitrogen-charged system and is also the best method to be used when trying to check for a leak on a system that is located outdoors, where the wind may limit the use of any other type of leak pinpointer. A disadvantage is that larger leaks will blow through the solution, and no bubbles will appear.

D.7.5 Fluorescent Dyes

Fluorescent dyes are used in refrigeration systems to detect leaks, invisible under ordinary lighting, visible under ultraviolet (UV) light. Fluorescent dyes are available for all refrigerants in use today. The dyes are placed into the refrigeration lubricant when the system is serviced. Select a dye compound compatible with the lubricating oil in the refrigeration system. Contact the refrigerant supplier for recommendation on appropriate dyes to ensure compatibility with the refrigerant. Leaks are detected by using a UV light to search for dye that has escaped from the system. The color of the dye when subjected to UV light is normally an easily-seen bright green or yellow. Fluorescent dyes work very well because large areas can be rapidly checked by a single individual.

D.7.6 Refrigerant Dye

Refrigerant dye in a system will produce a bright red color at the point of leakage. To achieve maximum leak detection, the entire refrigerant charge must be replaced with refrigerant containing the dye. The presence of dye in the refrigerant does not affect the performance of the system. Refrigerant containing dye must be liquid-charged. This method of leak detection pinpoints the leak where it occurs in the system. It is dependent upon the oil circulation rate and can take time to indicate leaks.

Table D-1. Comparison of Leak Detectors

Comments	Nonselective	Halogen-Selective	Compound-Specific	Fluorescent Dyes
Advantages:	• Simplicity • Ruggedness	• Simple/rugged • Can be calibrated • Good sensitivity • Low maintenance	• Virtually interference-free • Can be calibrated • Good sensitivity	• Low price • Rapid detection • Interference-free
Dis-advantages:	• Poor detection limits • Cross-sensitive to other species • Most cannot be calibrated	• Not compound-specific • Detector lifetime/ stability	• Complexity/ maintenance • Stability questionable	• Potential lubricant compatibility problems • Difficult to use in direct sunlight
Refrigerants Detected:	• All CFCs • HFC-134a • HCFC-123, blends	• All CFCs • All HCFCs • HFC-134a, blends	• Not recommended due to high price	• All currently available refrigerants

D.7.7 Visual Equipment Inspection

In many cases, a refrigerant leak can be located with a visual inspection. When refrigerant escapes from a sealed system, lubricating oils are usually entrained with the refrigerant vapor. This oil will, in many cases, leave art oily residue on the piping and equipment in the immediate vicinity of the leak. While this is a crude method, it can often be used to localize suspect components, allowing a more definitive search with one or more of the aforementioned techniques. Often the loss of as little as one pound of refrigerant will result in the deposition of a noticeable oil residue.

D.7.8 Considerations

There are several items which should be considered when selecting leak pinpointing equipment. Table D-1, *Comparison of Leak Detectors*, provides a general check-list to ensure items are not overlooked.

D. 8 Vendor Listing

A partial listing of-companies that produce leak detectors follows. These companies are not recommended or endorsed by the Air Force.

D.8.1 Nonselective Detectors

Thermal Gas System
P.O. Box *803*
Roswell, GA 30075
(404) 667-3865

D.8.2 Halogen-Selective Detectors

Leybold-Inficon, Inc.
Two Technology Place
East Syracuse, NY 13057
(315) 434-1246

SenTech Corporation
P.O. Box 42905
2020 Production Drive
Indianapolis, IN 46242
(317) 248-1988

Yokogawa Corporation of America
2 Dart Road
Shenandoah Industrial Park
Newnan, GA 30265-1094
(800) 447-9656

D.8.3 Compound-Specific Detectors

Foxboro Corporation
EMO Division, P.O. Box 500
600 N. Bedford Street
East Bridgewater, MA 02333
(508) 378-5400

Gas Tech, Inc.
8407 Central Avenue
Newark, CA 94560
(510) 794-6200

D.8.4 Fluorescent Dyes

Spectronics Corporation
956 Brush Hollow Road
P.O. Box 483
Westbury, NY 11590
(800) 274-1988

Appendix E — Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air Conditioning and Refrigeration Systems

ABSTRACT This appendix discusses the equipment available to reduce refrigerant release during operation and servicing. It addresses the Environmental Protection Agency (EPA) requirements for re-use of refrigerant removed from air conditioning and refrigeration (AC/R) equipment.

E. 1 Introduction

EPA requires AC/R equipment owners and maintenance technicians to implement certain practices to minimize refrigerant loss. This appendix discusses equipment that can be added to AC/R equipment or used by maintenance technicians servicing the equipment to meet these requirements. It explains the EPA performance requirements for the equipment. It addresses the EPA requirements for re-use of refrigerant removed from AC/R equipment.

E.2 Recovery and Recycling Equipment

Recovery equipment must meet certain evacuation standards to minimize refrigerant losses during service that requires opening the refrigeration system. EPA is grandfathering equipment manufactured or imported before 15 November 1993, as long as it meets the evacuation requirements listed in Table E-1, Required *Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances.* Currently, there are no requirements to retrofit or replace grandfathered equipment. Recovery and recycling equipment manufactured or imported on or after 15 November 1993 must be tested and certified by a third-party, EPA-approved testing laboratory or organization. EPA is requiring verification of performance for vapor recovery efficiency and efficiency of noncondensible purge devices on recycling machines. All certified recycling and recovery equipment must have a manufacturer's or importer's label indicating that it was certified and showing who certified the equipment (see Appendix A, *Update on Refrigerants: Translating the Laws, Regulations, and Policies into Practice).* Equipment manufactured or imported after 15 November 1993 must meet the evacuation requirements listed in Table E-1.

E.2.1 Evaluation Criteria

Many manufacturers offer a variety of recovery equipment. In making an informed choice, consideration should be given to:

- safety, including cutouts for high pressure, low pressure, and high temperature;
- Underwriters Laboratory (UL) approval;

Table El. Required Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances[1]

Type of Appliance	Inches of Mercury Vacuum" Using Equipment Manufactured: Before 15 Nov 1993	On or After 15 Nov 1993
HCFC-22 appliance- normally containing less than 200 pounds of refrigerant	0	0
HCFC-22 appliance" normally containing 200 pounds or more of refrigerant	4	10
Other high-pressure appliance- normally containing less than 200 pounds of refrigerant (CFC-12, -500,-502, -144)	4	10
Other high-pressure appliance- normally containing 200 pounds or more of refrigerant (CFC-12, -500,-502, -144)	4	15
Very high-pressure appliance (CFC-13, -503)	o	0
Low-pressure appliance (CFC-11, HCFC-123)	25	29

* Relative to standard atmospheric pressure of 29.9" Hg
** Or isolated component of such an appliance
1 Federal Register, Vol. 58, No. 52, Friday, May, 1993, pg. 28

- maintenance requirements (that is, number of parts requiring replacement, the recommended frequency of replacement, and cost);
- versatility in meeting different job functions;
- the cylinder or tank capacity holding the refrigerant while work is being done on the refrigeration system;
- recovery rate of the equipment (should be such that the total charge can be recovered in one hour maximum);
- price of filter replacements;
- whether the unit uses interchangeable storage tanks or can it be used only with tanks supplied by its manufacturer; and
- if the unit is equipped with low-loss fittings.

E.3 Recovery, Recycle, and Reclaim Definitions

The process of removing refrigerant from a refrigeration system is recovery. When equipment operation indicates contamination or refrigerant deficiency, refrigerant can be recovered and recycled on-base. If contamination is severe, or exacting standards must be met, refrigerant must be reclaimed off-base. Once refrigerants are contaminated or mixed, complicated procedures must be used for separation. Reclamation by refrigerant distillation can separate some refrigerants. If the refrigerant is contaminated such that it cannot be separated by distillation, it must be sent to an authorized treatment facility for disposal.

E.3.1 Recovery

Recovery is the act of removing refrigerant, in any condition, from a refrigeration system in either an active or passive manner, arid storing it in an external container. Recovery is mandatory if the system is to be opened to the atmosphere. If an equipment component that requires work can be isolated, then only the isolated section of the equipment needs to be evacuated. Internal refrigerant storage should be used at every opportunity.

E.3.2 Recycling

Recycling is the act of reducing contaminants in the recovered refrigerant by oil separation with single and multiple passes through devices such as replaceable filter core driers. These devices reduce moisture, acidity, and particulate matter. Recycling can be advantageous for drying refrigerants that contain moisture (not water) or removing particulate.

E.3.3 Reclamation

Reclamation is the act of purifying, testing, and certifying used refrigerant to new product specifications by means which may include distillation. Chemical analysis of the refrigerant is required to assure that appropriate product specifications are met. Reclamation of refrigerants from a system that is in the process of repairs (in most cases) is not required. It is mandatory if free water is standing in the system (for example, such as a tube failure) or if motor bum-out has occurred. Refrigerants recovered from equipment are required to be reclaimed if they are being transferred to a new owner (a different base is not considered a new owner).

E.4 Low-Loss Fittings

EPA defines in 40 C.F.R. Part 82 (1993) a low-loss fitting as any device that is intended to establish a connection between hoses, air-conditioning and refrigeration equipment, recovery or recycling machines, and is designed to close automatically or manually when disconnected, minimizing the release of refrigerant from hoses, air-conditioning or refrigeration equipment, and recovery or recycling machines. EPA requires that recovery or recycling machines manufactured or imported after 15 November 1993 possess low-loss fittings. It is recommended that low-loss fittings be added to refrigeration equipment connection points and service equipment hoses.

E.5 High-Efficiency Purge Units

Purge units are used with low-pressure chillers and refrigerant recovery equipment to remove noncondensibles that may enter the system. Traditional purge unit designs can expel large amounts of refrigerant. High-efficiency purge units allow noncondensibles to be vented while releasing relatively small quantities of refrigerant. There are two levels of high efficiency: (1) one group discharges approximately

0.7 to 1.0 pounds of refrigerant per pound of noncondensibles, and (2) ultra high-efficiency units discharge 0.0005 pounds of refrigerant per pound of noncondensibles. With the discharge information, run-time, and amount of refrigerant and noncondensibles processed per unit time, the maintenance technician can determine the run-time needed to cause refrigerant losses in excess of EPA limits. Choose a purge unit that contains a safety system to prevent excessive purging due to malfunction or a large leak. These safety systems limit the time that a purge unit may operate to assure that a control malfunction will not allow the purge unit to operate continuously.

E.5.1 Low-Pressure Chiller Purge Units
EPA has not established any requirements for chiller purge units. However, Air Force policy is to replace older purge units with new, high-efficiency purge units equipped with run-time meters.

E.5.2 Recycling Equipment Purge Units
EPA has established the maximum purge-10ss limit for recycling equipment purge units at five percent of the total refrigerant being recycled. As of 15 May 1995, the purge-loss limit will be reduced to three percent of the total refrigerant being recycled.

E.5.3 Servicing Purge Systems
Most purge systems require regular service. Purge tanks and oil separators must be cleaned, gasket materials must be renewed, purge compressors must be overhauled, and so forth. These functions should be conducted in accordance with the purge system manufacturer's guidelines. To open the purge system for service, isolate it from the chiller refrigeration system and recover the refrigerant from the purge unit. To provide a convenient, efficient means of accomplishing this on an ongoing basis, permanent access and isolation valves should be installed in the system when the new high-efficiency unit is installed.

E. 6 Low-Pressure Systems Pressurization Methods

Low-pressure systems can be under a vacuum when they are not in operation. Their purge systems remain in operation to keep air and moisture out of the system. If the machine leaks, it will cause the purge to operate more often, discharging refrigerant along with noncondensibles. The installation of a pressurization system can solve this problem. There are two types of systems, blanket heater and water heater/pump, both operating on the principle of increasing system pressure through the addition of heat to the refrigerant.

E.6.1 Blanket Heater
The most common pressurization system is an electric-resistant blanket heater installed between the outer shell of the evaporator and its insulation, jacket. Because it is mounted on the underside of the shell, it is commonly known as the "belly" heater. A blanket heater is used to prevent refrigerant air infiltration by heating the refrigerant until the pressure is at or nearly at atmospheric. The blanket heater also can be used to raise the system pressure above atmospheric pressure to allow leak testing. Typically, temperature or pressure sensors monitor the condenser conditions and are

used to control the blanket heater. To prevent system over-pressurization and subsequent loss of refrigerant, the accuracy of temperature or pressure sensors should be checked prior to energizing the blanket heater.

E.6.2 Water Heater/Pump
The second type of system uses a small electric water heater and circulating pump package. It heats and circulates water through the evaporator tubes to raise the refrigerant temperature and, consequently, the system pressure. Prior to initiating the heating process the evaporator should be isolated from the distribution piping system. The heat addition to the water is typically controlled by monitoring the water temperature once it has exited the evaporator. To prevent system over-pressurization and subsequent loss of refrigerant, the temperature sensor should be checked prior to starting the water heater/pump system.

E. 7 Re-Use of Recovered Refrigerants

EPA allows refrigerant remaining on-site to be returned to AC/R equipment or transferred between equipment owned by the same entity with or without being recycled or reclaimed. Refrigerant changing ownership must be reclaimed to ARI 700-88. This standard requires a chemical analysis to verify the purity of the refrigerant before it can be re-used.

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Appendix F — Refrigerant Leak Mitigation through Equipment Maintenance and Service Practices

ABSTRACT: This appendix addresses refrigerant leak mitigation through equipment maintenance and service practices. The Environmental Protection Agency (EPA) has several requirements and recommendations to reduce, if not eliminate, refrigerant loss when maintaining or servicing equipment. These include major changes from the methods used in the past. The new methods are more rigid and tasks will require more time to complete. Personnel who install, service, or repair refrigeration equipment must be certified.

F.1 Background

Many preferred refrigeration service and maintenance practices commonly used in the past resulted in the routine release of significant quantities of refrigerant to the atmosphere. EPA has promulgated new regulations in response to Clean Air Act Amendments (CAAA), Title 6, which are intended to force changes in these practices to minimize the loss of refrigerant. These new laws and regulations have serious implications for air conditioning and refrigeration (AC/R) owners, operators, and maintenance personnel.

F.1.1 Technician Training

The training of chiller operators and maintenance and service personnel is the first line of defense for minimizing refrigerant loss. Service and maintenance personnel should be familiar with procedures to minimize refrigerant emissions, the use of new safety equipment, and techniques for proper refrigerant handling.

F.1.2 Technician Certification

Any person who performs maintenance, service, or repair to AC/R equipment that could reasonably be expected to release chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) into the atmosphere must be certified. Performance of these duties by improperly trained personnel can waste valuable refrigerant and result in violation of the law.

F.1.2.1 EPA requires certification of all individuals who maintain, install, service, or repair AC/R equipment. It has established four categories of technician certification associated with the ability to handle and service refrigerants and associated equipment. Three of these categories are for specific types of equipment. The fourth is an universal category. Technicians must be certified by an EPA-approved certifying organization by 14 November 1994. For more information see Handbook, Chapter 2, *Conservation Efforts for the Base Refrigerant Management Program*, and

Appendix A, *Update on Refrigerants: Translating the Laws, Regulations, and Policies into Practice.*

F.2 Minimizing Maintenance and Service Emissions

Much refrigerant has been lost in past years due to the methods of maintaining and servicing equipment. ASHRAE Guideline 3-1990 states: "Significant loss of refrigerant can be attributed to improper operation and monitoring of equipment operation. Routine operating logs should be kept so that the operator (or technician) knows how much refrigerant and oil are used. " The WIMS Refrigerant Management Software provides the capability to collect and organize maintenance and operating data for all refrigeration systems. The use of this system to replace the existing "paper" maintenance and operation logs will enhance the ability of a base maintenance crew to spot adverse trends and predict future refrigerant needs.

F.2.1 Service Practices

Current service practices revolve around containment of refrigerant within the system. For example, venting refrigerants to the atmosphere is now illegal. It cannot impact the environment if contained. Service practices which keep refrigerants isolated from the environment as much as possible are now required. The following practices are now banned by the CAAA.

- Blowing vapor charge after removal of liquid when opening equipment.
- Refrigerant drums open to the atmosphere.
- Using refrigerants as cleaning solvents.
- Leak-testing with nitrogen if the system contains its refrigerant charge. Leak testing with a trace gas, HCFC-22, is permitted; see Appendix D, *Refrigerant Leak Detection Methods and Equipment.* (This will potentially contaminate the refrigerant charge with non-condensible gases which will subsequently require purging, thus resulting in an additional loss of refrigerant.)
- Operating systems in under-charged or over-charged modes.
- Changing oil filters at intervals more frequently than required by manufacturers' recommendations or as indicated by spectrographic oil analyses.

F.2.1.1 EPA requires low-pressure systems undergoing minor servicing, such as oil changes, to be pressurized to atmospheric pressure to minimize the intrusion and subsequent purging of air. Methods, such as heat, that do not require subsequent system purging must be used.

F.2.1.2 Purge run-time should be monitored. Many manufacturers suggest that purge systems operating in excess of one hour of run-time per week are indicative of excessive leakage.

F.2.1.3 Purge systems require regular maintenance and service to ensure proper operation. Purge tanks and oil separators must be cleaned, gasket material renewed, and purge compressors overhauled. These tasks must now be performed with little or no loss of refrigerant by installing permanent access and isolation valves on the unit to service it with minimal emissions. These valves should be installed the next time the machine is serviced. When servicing the purge unit, the liquid and vapor refrigerant must be evacuated prior to opening it to the atmosphere.

F.2.1.4 Specified high-efficiency purge units should be evaluated as:

- replacements for older, less efficient units on existing chillers, or
- new equipment on replacement chillers.

Some of the high-efficiency purge units currently on the market include high maintenance components like floats and regulating valves. Additional maintenance requirements should be considered in the specification development process for purge systems. See Appendix E, *Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air Conditioning and Refrigeration Systems,* for more information on purge limits.

F.2.1.5 Oil should not be changed on an arbitrary schedule; instead, oil samples should be analyzed on a regular, scheduled basis to check for contamination. This analysis should determine the necessity for an oil and filter change. These tasks must now be performed with minimal refrigerant loss. An oil sample port and isolation valves should be installed around the filter at the first service opportunity.

F.2.1.6 Isolation valves for all equipment sub-components should be installed to isolate them for service and repair. Replace missing system connection and refrigerant cylinder caps and ensure the seal is in good condition. Using a Schrader core replacement tool will allow the replacement of a leaking Schrader core without having to open the system or isolate the refrigerant charge.

F.2.1.7 Refrigeration gauge sets should be rebuilt with new seals, valve seats, and packing to minimize refrigerant losses. Additional features that will further minimize refrigerant loss include:

- quick-connect fittings on hoses;
- four-valve manifolds to minimize the amount of hose and manifold refrigerant purging;
- quality, high-strength hoses to prevent possible rupture; and
- separate refrigeration gauge sets for each refrigerant to avoid cross contamination.

F.2.1.8 Equipment service requiring removal of the refrigerant charge can be done with either a pumpout (active) or a pump-down (passive) method.

F.2.1.8.1 The pumpout method is the most common for system refrigerant removal. It uses a self-contained recovery unit, often referred to as a recovery/recycling machine. These machines are capable of both liquid and vapor removal. It is best to remove as much of the refrigerant in a liquid form as possible. The equipment removes liquid at a much higher rate than that for vapor. The vapor charge must then be removed using the recovery unit. The system or isolated section must be evacuated to the level shown in Table E-1, *Required Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances.* A higher ambient temperature also facilitates more rapid recovery due to increased system internal vapor pressure.

F.2.1.8.2 The pump-down process is preferred. It uses the refrigeration system's compressor to remove the refrigerant from a component and move it to an integral receiver or another component of the system where it can be stored during maintenance. The isolated section must be evacuated to the level shown in Table E-1, *Required Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances.*

F.2.1.9 All preventative maintenance work plans should be modified to include leak-checks of leak-prone areas of the system. Be assured that a brazed or welded fitting will develop leaks. The following items should be checked regularly:

- flanges and gaskets,
- screwed piping at connections,
- compressor seals,
- deteriorated O-rings,
- valves and cylinders,
- missing valve caps,
- purge system leaks,
- receiver leaks,
- flare fittings,
- Schrader cores, and
- sight glasses.

F.2.1.10 Certified technicians should determine the type of service work required before opening the system. Previous service records obtained from the WIMS, or operating logs, can provide background on the equipment. This information can be used to develop a work plan which will ensure that refrigerant losses are held to minimal levels.

F.3 Spectrographic Oil Analysis

Laboratory analysis of chiller oil is a method of analyzing the mechanical condition of equipment and pinpointing when tear-down and visual inspection is needed. A spectrographic oil analysis is inexpensive and usually has a quick turnaround. The cost ranges from $50 to $150 per analysis. An analysis should be performed for comfort cooling applications twice each year or every 2,000 to 2,500 hours of operation. Prior to taking a sample of the oil for analysis, a chiller must be in operation at least one hour. Otherwise, any metals that might be in the oil will not have had sufficient time to be re-entrained from the bottom of the machine and will not be detected by the analysis. With complete and accurate laboratory oil analysis testing, recommendations for appropriate action become more reliable.

F.3.1 Particulate Evaluation

The oil filter is also an important source of information. Just as technicians can spot debris trapped on the falter material, the laboratory can identify these sediments to further evaluate system condition. This evaluation can be just as important as the testing of the liquid oil sample.

F.3.2 Sources for Laboratory Analysis

The following laboratories, as of the date of this document, are capable of performing an oil analysis which will indicate moisture, acid, and various metals content. Only TAI Services and Trane Service First are familiar with equipment oil analysis and, therefore, provide an analysis of the data. The Air Force does not endorse any of the following laboratories; the list is provided for information purposes only.

Advanced Chemistry Labs
3039 Amwiler Rd., Suite 100
Atlanta, GA 30360
(404) 409-1444

Southern Petroleum Labs
8820 Interchange Dr.
Houston, TX 77054
(713) 660-0901

TAI Services Inc.
1900 Lake Park Dr., Suite 300
Smyrna, GA 30080-8874
1-800-554-4127

Trane Service First
4500 Morris Field Dr.
Charlotte, NC 28208
(704) 398-4600

F.3.3 Analysis Readings
Information received from a laboratory analysis of chiller oil should include:

- water suspension,
- viscosity,
- total acid number (TAN),
- dielectric strength,
- color, and
- interracial tension

and an assessment of the condition of the equipment based on these analyses.

F.3.3.1 The amount of water suspended in a lubricant is measured in parts per million (ppm). Water content in the chiller oil sample should not exceed 40 ppm for reciprocating systems and 50 ppm for centrifugal and rotary screw systems.

F.3.3.2 The viscosity, reported in centistoke (cSt) at 40° C (1120 F), measures a fluid's internal resistance to flow at a given temperature in relation to time. Change in viscosity can indicate dilution, oxidation, improper servicing, or lubricant breakdown.

F.3.3.3 The TAN indicates the amount of acidic product present in a lubricant. Generally, an increase in TAN, above that of the new product, indicates oil oxidation or contamination with an acidic product. Total acid should not exceed 0.150 mg KOH per gram of oil sample.

F.3.3.4 The dielectric strength measures the insulating ability of a fluid. A low value can indicate the presence of water or other conducting compounds.

F.3.3.5 Visual determination of a fluid's color serves as an indicator of the presence of contaminants and system operating conditions.

F.3.3.6 The analysis of interracial tension is an indicator of the presence of compounds with a strong affinity for water.

F.3.4 Analysis of Metal Content
The spectrographic analysis of chiller oil will show the metal content within the oil and should indicate possible sources of that particular metal. Typical elements discovered in analyses and their available sources are listed below.

Element	Possible Sources
Iron	Shell/supports/ cylinder/tube sheet
Chromium	Rings/cylinder/crankshaft
Nickel	Tubes/crankshaft
Aluminum	Pistons/bearings/impeller
Lead/Tin	Bearings
Copper	Bearings/tubes/oil lines
silver	Solder/cooler
Silicon	Dirt/sealant/coolant
Boron	Additive/coolant
Sodium	Brine/coolant
Potassium	Additive
Zinc	Anti-wear additive
Calcium/Magnesium	Brine/detergent additive
Barium	Detergent additive

The results of all oil analyses should be preserved in historical maintenance files. In many cases, rapid changes in values may be more indicative of problems than the magnitude of the value at any given point in time. In fact, the real strength of spectrographic analysis is the ability to spot excessive wear rates of given components shown by rapidly increasing concentrations of the elements listed above in relation to operating hours between samples. To properly spot these trends, the analytical laboratory performing the tests must be supplied with previous test data.

F.3.5 Disposing of Contaminated Oil

Federal, state, and local regulations must be followed in the disposal of contaminated oil. Per 40 C.F.R. section 261.3 (1993), used refrigerant oils are not classified as hazardous wastes, providing the following conditions exist:

- used refrigeration oils are not mixed with other hazardous wastes;
- used refrigeration oils will be recycled or reclaimed for future use;
- used refrigeration oils are not mixed with used oils from other sources; and
- used refrigeration oils do not contain any contaminants, such as heavy metals, which will render it a characteristic waste when analyzed using the Toxicity Characteristic Leaching Procedure per 40 C.F.R. section 261.24 (1993).

F.3.5.1 It is the responsibility of the generator of a potentially hazardous waste to determine whether a material should be classified as a hazardous waste. Local and state codes may be even more stringent than federal regulations. Therefore, base environmental officers should be consulted prior to disposing of any potentially hazardous waste.

F.3.5.2 When an oil analysis indicates that the refrigerant oil should be replaced, care should be taken to avoid the atmospheric release of refrigerant which may be in solution in the oil. This can be accomplished by pumping the oil into a sealed, reusable container. A refrigerant recovery system can then be used to pull a vacuum on the head space above the oil in this container. This configuration will cause the refrigerant to “outgas” from the oil. The out-gassed refrigerant will then be captured by the refrigerant recovery system. This recovered refrigerant can then be returned to the refrigeration system or placed in proper storage containers. In no case should refrigerant oil be pumped into a vented container allowing the uncontrolled loss of refrigerant to the atmosphere.

F.4 Chiller Tube-Testing

A vital element of a successful preventive maintenance program that minimizes emissions is a regularly scheduled chiller tube-testing program. It prevents refrigerant contamination caused by tube rupture, ensures tube integrity and efficiency, and can provide early warning.

F.4.1 Eddy Current Tube-Testing

Eddy current tube-testing is a method that measures the thickness of the tube as the probe passes from one end to the other. This method can identify potential leak areas before they occur and prevent unscheduled chiller downtime, lost production or cooling, major chiller damage, and contamination of the refrigerant charge. Refrigerant contaminated by water in-leakage will require reclamation. To protect the refrigerant charge, eddy current tube-testing should be performed at least every three years for a chiller. This analysis, if performed by an outside contractor, costs approximately $1,500 per analysis. An eddy current tube-testing device can be purchased from most refrigeration equipment suppliers for $20,000 to $30,000.

F.5 Additional EPA Requirements

The EPA requires equipment service and refrigerant usage records to be maintained for three years. This applies to all comfort cooling and refrigeration equipment with an operating charge of 50 pounds or greater.

F.5.1 Recordkeeping Satisfied with WIMS

The WIMS Refrigerant Management Software can provide the refrigerant usage and servicing history for each piece of equipment as required by EPA. It will also monitor the progress of the Base Refrigerant Management Program (BRMP) by tracking refrigerant inventory and consumption. Information of the use of the WIMS Refrigerant Management Software can be found in Appendix G, *Work Information Management System (WIMS).*

F.5.2 Repairing Leaks

Commercial refrigeration equipment with over 50 pounds of refrigerant (for example, cold storage plants) must be repaired of all leaks within 30 days if the equipment is leaking at a rate which will exceed 35 percent of the total charge during a 12-month period. Equipment, other than commercial refrigeration, containing 50 or more pounds of refrigerant (for example, comfort cooling) must be repaired of all leaks within 30 days if the unit leaks at a rate exceeding 15 percent of the total charge during a 12-month period. Equipment does not require repair if, within 30 days after leak identification (as described above), a plan is developed for retirement within one year. A copy of the plan must be available at the site of the equipment. Some state or local regulations, codes, and ordinances may impose more stringent requirements than the EPA regulations. Therefore, base environmental officers should be consulted prior to electing a course of action to either repair a leak or replace a piece of equipment.

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Appendix G — AFCESA Work Information Management System (WIMS) Software Release 940715

ABSTRACT: This appendix explains the Work Information Management System (WIMS) and, specifically, the WIMS Refrigerant Management Software. It explains how to use the system to help the base Refrigerant Manager (RM) and technicians implement the Refrigerant Management Plan (RMP).

G. 1 Refrigerant Management System Overview

G.1.1 Purpose of Software

The Refrigerant Management System (RMS) program (module) is made up of several submodules designed to provide the Base Civil Engineer (BCE) with a meaningful way to manage refrigeration equipment and refrigerant supplies. The Refrigerant Management System submodules are listed below and discussed in detail in their individual sections:

- Refrigeration Equipment Inventory (MREQUD)
- Refrigeration Equipment Service (MRESUD)
- Refrigerant Bench Stock Adjustment (MRTRUD)
- Upward Reporting Data Log (MRURUD)

The Refrigerant Management System is designed to aid the Refrigerant Manager (RM):

- Track refrigerant consumption for individual pieces of equipment;
- Monitor refrigerant inventories; and,
- Prioritize equipment repairs.

When used correctly, these applications will fulfill the Environmental Protection Agency (EPA) requirements to record service data on units using chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

G.1.2 Special Features

G.1.2.1 User's Interface

The module's user interface has been altered from the standard WIMS interface. When adding transactions, an equipment item selection (directory) screen is displayed instead of a detail screen. When a record has been selected, all necessary equipment information will be automatically entered by the program onto the detail screen. This reduces typing.

G.1.2.2 Input Data Validation

Numerous information validation checks are performed to ensure meaningful data will be collected. For example, when entering a new transaction, the Refrigerant Quantity file must contain a numeric value. The transaction will not be accepted if the value is greater than the equipment item's capacity.

G.1.2.3 Selectable Fields
Some data fields are selectable fields to prevent invalid entries. These selectors contain lists of valid terminology that can be chosen for a particular field. Place the cursor on the data field, press PF14 (Select) and the selector list will display. Place the cursor next to your choice, place an X in the blank, and press ENTER to commit the selector choice.

G.1.2.3.1 Selectable data lists are a safety feature to prevent invalid entries in the data field while ensuring system-wide consistency of terms. These selector files contain validation lists that prevent misspellings, provide up-to-date lists of equipment, consistently used abbreviations, and other terminology or lists that should be static throughout the entire program.

G.1.2.3.2 Some selectors are neither modifiable nor transactable by the bases or MAJCOMs.

G.1.2.4 Archiving (PF28)
The data from this application should be archived two years from the date it was entered, When the application is first brought on the screen, the module is reviewed for records two or more years old. If they exist, the program will inform the user that records should be archived.

G.1.2.5 Equipment Status
The Equipment Status field will initially reflect the current status per the Equipment Inventory file. If the Status is modified on this screen, the Equipment Inventory submodule will be updated automatically.

G.1.2.6 Data Reporting Requirements
The software allows data to be upward reported to HQ AFCESA/EN through the MAJCOM. PF27 is used by the base and MAJCOM RMs to upward report new transactions to HQ AFCESA/EN. This key will be displayed only after refrigerant service records have been input. Data may not be modified by either HQ AFCESA or the MAJCOM. This data is used for trend analysis only. Upward reporting should be accomplished by the tenth working day following the end of each quarter.

G.1.2.7 Security
The access to change information throughout the Refrigerant Management System is granted through the Generic User Rights system (IRGTUD). Listed below are the rights that can be granted to users of the Refrigerant Management System (RMS) at the discretion of the Base Civil Engineering's (BCE) Refrigerant Manager (RM).

Add (PF11)	Allows the user to add records to the data file.
Modify (PF9)	Allows the user to modify existing records in the data file.
Delete (PF12)	Allows the user to delete existing records from the data file.
Upward Reporting (PF27)	Allows base level users to transmit Refrigeration Manage-Management System transactions to their MAJCOM, and MAJCOM users to transmit the latest base level records to HQ AFCESA/EN.
Archive (PF28)	Allows the user to archive records that are over two years old.

Note: There may be variations in which user rights are granted to each user. Some user rights (modify or delete) bear a great deal of responsibility and care must be taken to issue only those rights necessary to individual users.

G.2 Main Menu

The Refrigerant Management System (RMS) main menu (Figure 1) lists all submodules in the system, and all reports that can be developed in these submodules.

```
HQ Air Force Civil Engineering Support Agency      Tuesday 94/06/14 01:21 PM   * 1*
                                                                               * 2*
Hello  :  Mr Rich Bauman                                                 ENB * 3*
MREFR : Refrigerant Management System - Version 93/11/03                 899 * 4*
                                                                               * 5*
To Select a Function Press (PFKEY) or Position Cursor and Press (ENTER)        * 6*
                                                                               * 7*
 (1) * Refrig Equipment Serviced      Service Reports:                         * 8*
                                      (18) * Refrig Service Log Report         * 9*
 (3) * Refrig Bench Stock             (19) * Refrig Consumption Report         *10*
                                                                               * 1*
                                                                               * 2*
 (5) * Refrig Equipment Inventory     Refer Inventory Reports:                 * 3*
                                      (22) * Refrig Bench Stock Report         * 4*
                                      (23) * Refrig Quantities Report          * 5*
                                      (24) * Refrig Equip Inventory Report     * 6*
                                                                               * 7*
 (9) * Upward Reportig Status         (25) * Refrig Equip Capacity Report      * 8*
                                                                               * 9*
                                                                               *20*
                                                                               * 1*
                                                                               * 2*
                                                                               * 3*
(16) * Exit                                                                    * 4*
                                                                               *  *
```

Figure 1. Refrigerant Management System Main Menu

G.3 Refrigerant Equipment Inventory (MWQUD)

G.3.1 Refrigerant Equipment Inventory (MIREQUD), Main Menu, PF5

This program (module) is a collection of pertinent information on all base refrigeration equipment including, size, refrigerant capacity, and operational status. The information must be accurate because it is used for various calculations and logic checks in other parts of this software.

G.3.2 Screen and Field Descriptions

Data File: MREQ in MMXXDATA

Control File: MREQ in MMXXCTL

The Air Conditioning/Refrigeration Equipment (Figure 2) directory screen lists all the equipment loaded in the file by facility, unit, and model number. Air Conditioning/Refrigeration Equipment transaction data can be manipulated from the Directory screen (Figure 2), or the Input (Detail) screen (Figure 3). PF keys are assigned to data entry functions. See Attachment 1 for a list of all assigned PF keys and their functions. Definitions of specific entries on the Air Conditioning/Refrigeration Equipment Input (Detail) screen are as follows.

Active Air Conditioning/Refrigeration Equipment

	Inst	Facility		Un	Model	Serial	Refrig
±	XLWV	00462	w	01	CGABC606AE10FHK23	J84K81833	R-22
-	XLWV	00462	w	02	CGABC206AD10BFHK13	J84B80295	R-22
-	XLWV	00474	w	01	TTA120A300AA	FH7193855	R-22
-	XLWV	00546		09	CGABC304AC10ABH23	J83E71400	R-22
-	XLWV	00546		12	CGABC304AE00ARBH	J85C80779	R-22
-	XLWV	00548		01	CGABC606AE00FHK23	J85H82124	R-22
-	XLWV	00549		01	CGAA1001EV51AA5A4C361EFR	L84M24395	R-22
-	XLWV	00580		01	RAWC-101CAS	4895G45922688	R-22
-	XLWV	00647	w	01	CGACD111RNNLV623CPRVWF	J92M84032	R-22
-	XLWV	00727		01	CGADC25GAGA1ECRV	J92M84029	R-22
-	XLWV	00729		01	CGADC25GAGA1ECRV	J92M84030	R-22
-	XLWV	00741		01	CGABC206AE0032KHS	J84K81750	R-22
-	XLWV	00747		01	CGACC506KANFF603GPV	J87K82731	R-22
-	XLWV	00845	w	01	CGACC806RANJJ40G3M	J86K72542	R-22
-	XLWV	01001		01	CGAA053HF53CC5C4A361EMF	L84M24435	R-22

Position the cursor and press ENTER to display the entire record.

(1)Keys (5)Next (7)Up (8)Find
(10)Queru (13)Help (14)Path (15)Print (16)Retrn
(29)Info (30)Histry(31)Rpts

Figure 2. Air Conditioning/Refrigeration Equipment Directory Screen (MREQUD)

Air Conditioning/Refrigeration Equipment

Base Name: TYNDALL AFB MAJCOM: ATC
Facility Number: XLWV 462 W
Description: CHILLER, HERMI RECIP Unit #: 1

Capacity: 60. TN (TN, HP) Status: I *IN SERVICE*

Refrigerant Qty: 122. LB Type: R-22

Manufacturer: TRANE Model CGABC606AE10FHK23
Serial #: J84K81833 Date Manufactured: 19841001 (yyyymmdd)
Comments: CHILLER HAS TWO CIRCUIT EACH HAS 61 LB. R-22

- Optional Fields for chilled water units -
AFCESA Condition Assessment: Multi Site Potential:

(1)Keys (3)Desc [5] Next (8)Find
(10) Quey (13)Help (15)Print (16) Retrn
(29)Info (32)Exit

Figure 3. Air Conditioning/Refrigeration Equipment Input (Detail) Screen (MREQUD)

Note: If an entry is incorrect or has changed since initial input, the entire record must be deleted (PF12) in the Air Conditioning/ Refrigeration Equipment program, and re-entered as a new item.

G.3.2.1 Facility Number

Identifies where the AC/R equipment is located.

G.3.2.2 Description

This is a selectable field. To determine the proper entry, a standardized listing can be accessed by pressing **PF14 (Select)** (Figure 4). This is a valid list of all the various types of equipment that can be entered in the description field. To ensure standardization across the Air Force, items cannot be added to this list by the user.

```
Equipment Description

_ CHILLER, HERM ABSORP              DRINKING FOUNTAIN
_ CHILLER, HERM CENTRIF             ICE MACHINE
_ CHILLER, HERM RECIP               REFRIGERATION
_ CHILLER, HERM SCREW               WINDOW AIR CONDITIONER
_ CHILLER, HERM SCROLL
_ CHILLER; OPENED ABSORP
_ CHILLER, OPENED RECIP
_ CHILLER, OPENEND CENTRIF
_ CHILLER, OPENEND SCREW
_ CHILLER, SEMIHERM ABSORP
_ CHILLER, SEMIHERM CENTRIF
_ CHILLER, SEMIHERM RECIP
_ CHILLER, SEMIHERM SCREW
_ DEHUMIDIFIER
_ DIRECT EXPANSION
_ DIRECT EXPANSION RECIP
_ DIRECT EXPANSION ROTARY
_ DIRECT EXPANSION SCROLL
Place an "H" next to an entry and press ENTER to select.
 (1)Keys   (2)First                                      (8)Find
                                (13)Help      (15)Print (16) Retrn
                                (29)Info                 (32)Exit
```

Figure 4. Equipment Description Selector File (MREQUD)

G.3.2.3 Unit

If there is more than one unit in a facility, each unit must have a unique number; for example: 1, 2, 3. Use a local numbering system when available, as long as the combination of the facility number and unit number provide a unique identification.

G.3.2.4 Capacity

Manufacturer-rated capacity for the unit can normally be found on the nameplate. The screen has space for two decimal places. Denote whether the measurement is in tons (TN) or horsepower (HP). Most entries will be in tons.

G.3.2.5 Status

This is a selectable field which can be identified by using **PF14 (Select)** (Figure 5). **The automatic default for adding a piece of equipment is I.**

- **I** is for In Service
- **R** is for Repair
- **D** is for Decommissioned
- **M** is for Mothballed

```
Status Indicators

_ D DECOMMISSIONED
_ I IN SERVICE
_ MMOTHBALLED
_ R UNDER REPAIR
```

Figure 5. Status Indicators Selector File (MREQUD)

G.3.2.6 Refrigerant Qty.

Manufacturer-rated capacity for the unit should be found on the equipment's name plate. The screen can accommodate up to two decimal places: "9999.**99** ."

Note: When entering numbers to the right of the decimal point, enter a number in both fields to place the numbers in the correct position. A number placed in the tenths space will move to the hundredths space when ENTER is pressed. If 0.5_is entered, it will be translated to 0._ 5".

G.3.2.7 Type

Type of refrigerant is a selected field identified through PF14 (Select) (Figure 6). To input new refrigerant types you must access Refrig Bench Stock (PF3) on the Main Menu. Use Add for adding a new bench stock transaction, and then **Add** again to add a new refrigerant.

Refrigerant Types

Inst	Refer Type	Location	MAJCOM
XLWV	Ammonia	TYNDALL AFB	ATC
XLWV	LiBr	TYNDALL AFB	ATC
XLWV	R-11	TYNDALL AFB	ATC
XLWV	R-113	TYNDALL AFB	ATC
XLWV	R-114	TYNDALL AFB	ATC
XLWV	R-115	TYNDALL AFB	ATC
XLWV	R-12	TYNDALL AFB	ATC
XLWV	R-123	TYNDALL AFB	ATC
XLWV	R-134A	TYNDALL AFB	ATC
XLWV	R-22	TYNDALL AFB	ATC
XLWV	R-500	TYNDALL AFB	ATC
XLWV	R-501	TYNDALL AFB	ATC
XLWV	R-502	TYNDALL AFB	ATC

Place an "X" next to an entry and press ENTER to select.

Figure 6. Type Selector File - Locations and Refrigerant Types (MREQUD)

G.3.2.8 Manufacturer, Model, and Date Manufactured

Refer to Figure 7. Data from the nameplate or other reliable source.

G.3.2.9 Serial

This number must be unique for each piece of equipment on the base to ensure the program can uniquely identify each unit. If this number is not available from nameplate data, a random number must be generated, while in Add or Modify mode, by selecting PF17 (Serial) from the Input (Detail) screen.

Note: Do not make up a serial number, since this may lead to more than one unit having the same number.

G.3.2.10 Comments

Used for recording any refrigerant management comments.

G.3.2.11 AFCESA Condition Assessment

The condition is one of four numeric codes. It is an overall condition and should reflect the status of the unit at the time of evaluation. It is the evaluator's

```
                 Air Conditioning/Refrigeration Equipment

      Base Name:  TYNDALL AFB                     MAJCOM: ATC
Facility Number:  XLWU    __462 W_
    Description:  CHILLER, HERM RECIP             Unit #: _1

       Capacity:  ___60 . __ TN (TN,HP)           Status: I  *IN SERVICE*

Refrigerant Qty:  __122 . __ LB                   Type:   R-22

   Manufacturer:  TRANE             Model: CGABC606AE10FHK23
       Serial #:  J84K81833         Date Manufactured: 19841001
                                                       (yyyymmdd)
       Comments:  CHILLER_HAS_TWO_CIRCUIT_EACH_HAS_61_LB._R-22______
                  ___________________________________________________
                  ___________________________________________________
                  ___________________________________________________
              - Optional Fields for chilled water units -
   AFCESA Condition Assessment:         Multi Site Potential:

 (1)Keys              (3)Desc
          (10)Query                   (13)Help  (14)Select  (15)Print  (16)Retrn
(17)Serial                            (29)Info                         (32)Exit
```

Figure 7. Air Conditioning/Refrigeration Equipment Input (Detail) Screen (MREQUD) Data Entry Mode Showing PF17, Serial, Option

impression and should not require any significant work effort to determine. No engineering studies should be needed to determine this code.

G.3.2.12 Multi-Site Potential

This is for chilled water units only. The data field identifies the possibility that the chilled water from this unit, along with other units, could be provided by a new centrally chilled water plant. The number can go up to 9999 (no decimals).

G.3.3 Standard Reports

The software generates two standard reports from data input through the Air Conditioning/ Refrigeration Equipment screen. They are:

G.3.3.1 Main Menu, PF 24 (Figure 8): Refrig Equip Inventory Report - By Facility

Lists every unit by facility and unit number. This report provides general information on the entire refrigeration system at the base.

G.3.3.2 Main Menu, PF 25 (Figure 9): Refrig Equip Capacity Report - By Refer Type

Lists, by type of refrigerant, all units, refrigerant charges for each unit, and total installed charge for all units. This report provides general information on the entire refrigeration system.

G.3.4 Special Features

G.3.4.1 Model and Serial Numbers

The manufacturer's model and serial numbers may be difficult, or impossible to determine. When necessary, the refrigerant manager should generate a new serial number to identify the equipment. A new serial number can be generated using

REPORT DATE 94/06/22 Refrig Equip Inventory Report - By Facility PAGE 1

VERSION 4.01.000.000 93/05/31 (MREQFAC IN MMXXRPT)

FACILITY		DESCRIPTION	UNIT	STATUS	CAPACITY	UM	TYPE	UOLUME
XLWV	115	CHILLER, SEMIHERM CENTRIF	1	I	259.09	TN	CFC-11	640.05
XLWV	115	CHILLER, SEMIHERM CENTRIF	2	I	259.08	TN	CFC-11	640.05
XLWV	147	CHILLER, SEMIHERM CENTRIF		D	120.00	TN	CFC-12	340.00
XLWV	147	CHILLER; SEMIHERM CENTRIF		I	120.00	TN	CFC-12	340.00
XLWV	147	CHILLER, SEMIHERM CENTRIF		I	120.00	TN	CFC-11	340.00
XLWV	147	CHILLER, SEMIHERM CENTRIF	2	I	120.00	TN	CFC-11	340.00
XLWV	147	CHILLER, SEMIHERM CENTRIF		I	120.00	TN	CFC-11	340.00
XLWV	150	CHILLER, SEMIHERM CENTRIF		I	150.00	TN	CFC-113	500.00
XLWV	302	DIRECT EXPANSION RECIP	1	I	40.00	TN	CFC-12	250.00
XLWV	302	DIRECT EXPANSION RECIP		I	40,00	TN	CFC-12	250.00
XLWV	313	CHILLER, SEMIHERM CENTRIF	1	I	210.00	TN	CFC-12	900.00
XLWV	313	CHILLER, SEMIHERM CENTRIF	2	I	2110.00	TN	CFC-12	900.00
XLWV	2521	REFRIGERATION	3	I	5.00	TN	CFC-502	10.00

Figure 8. Refrig Equip Inventory Report - By Facility (MREQFAC)

REPORT DATE 94/06/22 Equipment Capacity Inventory - By Refer Type PAGE 1

VERSION 4.02.000.000 93/12/01 (MREQCAP IN MMXXRPT)

REFER TYPE	CAPACITY	UM	DESCRIPTION	UNIT	FACILITY	STATUS
CFC-11	259.08	TN	CHILLER, SEMIHERM CENTRIF	1	XLWV 115	I
CFC-11	259,08	TN	CHILLER, SEMIHERM CENIRIF	2	XLWV 115	I
CFC-11	120.08	TN	CHILLER, SEMIHERM CENTRIF		XLWV 147	I
CFC-11	120.00	TN	CHILLER, SEMIHERM CENTRIF	2	XLWV 147	I
CFC-11	129.00	TN	CHILLER, SEMIHERM CENTRIF		XLWV 147	I
SUBTOTAL:	878,08					
CFC-113	150.00	TN	CHILLER, SEMIHERM CENTRIF		XLWV 150	I
CFC-113	150.80	TN	CHILLER, SEMIHERM CENTRIF		XLWV 6300	I
SUBTOTAL:	300.00					

Figure 9. Refrig Equip Capacity Report - By Refer Type (MREQCAP)

PF17 (Serial) from the Refrigerant Equipment Serviced Input (Detail) screen. See **Field Description** under **Serial #.** Also, the equipment should be marked with the new number for future reference using stencils or engraved plates.

G.3.4.2 Move Records to History File

Equipment items may be moved to the history file if refrigerant consumption will no longer be monitored. This must be accomplished through the Refrigeration Equipment Serviced, Main Menu, **PF1** file by changing the **Status** field to a **D** for decommissioned.

G.3.4.3 Reactivate (Delete/Move) a History File

To reactivate a history record, use the PF28 (Move) under the Air Conditioning/

Refrigeration Equipment. After the history file is reactivated the record status must be modified from **D,** for decommissioned, to one of the following status indicators. Modify the **Status** to:

- **R** for Under Repair;
- **I** for In Service; or
- **M** for Mothballed.

The reactivated file will also show up on the list under the Refrig Equipment Inventory submodule.

G.3.4.4 Changing Information on Existing Entry

After using PF5 to get to the Air Conditioning/Refrigeration Equipment screen, position the cursor on the entry to modify, and press **Modify (PF9).** This will access the original entry screen. Make the modifications; press **ENTER** to save the modifications.

Note: Manufacturer, Model, and Serial # cannot be modified. To change these entries the entire record must be deleted and a new record added with the necessary changes. The record can be deleted from the Air Conditioning/ Refrigeration Equipment screen or the screen that shows the current information on that specific piece of equipment.

G.4 Refrigerant Equipment Serviced (MRESUD)

G.4.1 Refrig Equipment Services (MRESUD), Menu, PF1

This submodule tracks the amount of refrigerant used to service each piece of equipment in the Refrig Equipment Inventory. It contains the upward reporting capabilities for all the submodules in the Refrigeration Management program.

G.4.2 Screen and Field Descriptions

Data File: MRES in MMXXDATA
Control File: MRES in MMXXCTL

G.4.2.1 The first screen accessed with **PF1 is** Refrigerant Equipment Serviced directory screen (Figure 10). The directory screen lists all the service

```
Active                 Refrigerant Equipment Serviced

   Inst Facility  Unit Manufacture Name  Model Number         Date

 + XLWU 00462  W   01 TRANE          CGABC606AE10FHK23         19940611
 - XLWU 00462  W   01 TRANE          CGABC6069AE10FHK23        19940627
 - XLWU 00546      09 TRANE          CGABC304AC10BH23          19940207
 - XLWU 00548      01    TRANE       CGABC606AE00FHK23         19940325
 - XLWU 01046      01 TRANE          CGACC601KBNGG623G         19940322
 - XLWU 01060      01 TRANE          CGAA1001ED51AA5C361EFR    19940411
 - XLWU 01140      01 TRANE          CGACC306KBNDD303FGPU      19940217
 - XLWU 01801      01 TRANE          CGAA0804RJ51CC4C4C361JRA  19930927
 - XLWU 01801      01    TRANE       CGAA0804RJ51CC4C4C361JRA  19930927

Position the cursor and press ENTER to record.
 (1)Keys                                                          (8)Find
 (9)Modify(10)Query (11)Add  (12)Delete(13)Help (14)Path (15)Print (16)Retrn
                    (27) Upward(28)Archu (29)Info (30)Histry(31)Rpts
```

Figure 10. Refrigeration Equipment Serviced Directory Screen (MRESUD)

transactions that have occurred over the last two years. Two years is an important length of time because EPA requires service records be maintained for three years. With two years of records stored in the Refrigerant Management program and one year in taped storage, EPA requirements are met.

G.4.2.1.1 If more information is needed on an individual transaction, move the cursor to that transaction and press **ENTER.** The Air Conditioning/ Refrigeration Equipment Serviced Input (Detail) screen (Figure 11) will be displayed. From this screen you can **Modify (PF9)** the remarks and the technician's name; **Add (PF11)** a totally new service record; and, access the Air Conditioning/Refrigeration Equipment Inventory using **PF17 (Equip).**

G.4.2.1.2 To view History records, press PF30 (History).

```
            Air  Conditioning/Refrigerant  Equipment  Serviced

    Instl/Bldg:    XLWU /    546          Manufacture:    TRANE
                   TYNDALL AFB            ModelNumber:CGABC304AC10ABH23
    Unit Number: 9                        Serial  Number:  J83E71400

    Refrig  Type:  R-22                        Oil Change:      N (Y/N)
    Trans Type:    I  (I=Install   in   Machine)   Filter Change: N (Y/N)
                     (R=Remove from Machine)   Oil Qty Added:
    Refrig  Cond:  U  (U=Usable,  N=Not  Usable)  Hour Meter:
    Trans  Qty:        64 .      lbs           Equip Status: I


    Remarks:


    Technician:    ROSARIO, ROBERTO            Trans  Date:     19940207
    Signature:

  (1)Keys    (2) First (3)Desc (4)Prev (5)Next                   (8)Find
  (9)Modify(10)Query  (11)Add         (13)Help        (15)Print  (16)Retrn
 (17)Equip                            (29)Info                   (32)Exit
```

Figure 11. Air Conditioning/Refrigeration Equipment Serviced Detail Screen (MRESUD)

G.4.2.2 Most transactions from the Refrigerant Equipment Serviced screen will be accomplished through **Add (PF11).** The Add function can be accessed from either the directory or the Input (Detail) screen. In pressing **Add** from the directory screen, the Select the Equipment Item to be Serviced screen (Figure 12) will be displayed. To pick the piece of equipment for a service transaction, press **PF17 (Equip).** The user will be taken to the Air Conditioning/Refrigeration Equipment Inventory. A **Find (PF8)** key is available to aid the search. After finding the right piece of equipment, press ENTER to display the specific piece of equipment screen.

Note: After accessing the Refrigeration Equipment Inventory, press PF16 (Retrn) to return to the Air Conditioning/ Refrigeration Equipment Serviced screen.

Select the Equipment Item to be Serviced

Instl	Facility	Unit	Manufacture	Model
XLWU	00462 W	01	TRANE	CGABC606AE10FHK23
XLWU	00462 W	02	TRANE	CGABC206AD1OBFHK13
XLWU	00474 W	01	TRANE	TTA120A300AA
XLWU	00546	09	TRANE	CGABC304AC109BH23
XLWU	00546	12	TRANE	CGABC304AE00ABH
XLWU	00548	01	TRANE	CGABC606AE00FHK23
XLWU	00549	01	TRANE	CGAA1001EU51AA5A4C361EFR
XLWU	00588	01	TRANE	RAWC-101CAS
XLWU	00647 W	01	TRANE	CGACD111ANNLU623CPRVWF

Figure 12. Select the Equipment Item to be Serviced Screen (MRESUD)

The next screen is the Air Conditioning/Refrigeration Equipment Serviced Input (Detail) screen (Figure 13). Information on service performed on a specific piece of equipment can be added on this screen. The screen should already have Instl/Bldg, Manufacturer, Unit Number, Model Number, Serial Number, and Refrig Type filled in. The software retrieves this information from the Refrig Equipment Inventory submodule. The remaining screen fields to be filled are listed below.

```
Air Conditioning/Refrigeration Equipment Serviced

Instl/Bldg:     XLWU /   546            Manufacture:    TRANE
                TYNDALL AFB             Model Number:   CGABC304AC10ABH23
Unit Number: 9                          Serial Number:  J83E71400

Refrig Type:  R-22                          O i 1 Change:    N (Y/N)
Trans Type:   I (I= Intstall in Machine)    Filter Change: N (Y/N)
                (R=Remove from Machine)     Oil Qty Added:
Refrig Cond:  U (U=Usable, N=Not Usable)    Hour Meter:
Trans Qty:       64 .    lbs                Equip Status: I

Remarks:

Technician:   ROSARIO, ROBERTO              Trans Date:    1994e2e7
Signature:

(1)Keys   (2) First (3)Desc   (4)Prev   (5)Next                  (8)Find
(9)Modify(10)Query (11)Add             (13)Help       (15) Print (16) Retrn
(17) Equip                             (29)Info                  (32)Exit
```

Figure 13. Air Conditioning/Refrigeration Equipment Serviced Input (Detail) Screen (MRESUD)

G.4.2.2.1 Oil Change

Type in **Y** for yes; **N** for no.

G.4.2.2.2 Filter Change

Type in **Y** for yes; **N** for no.

G.4.2.2.3 Oil Qty Added

Type in number (up to 999; no decimals) of quarts of oil used during the oil change, or amount added during this servicing without an oil change.

G.4.2.2.4 Hour Meter
If the unit has an hour meter, record the time shown. This number goes up to 999,999 (no decimals).

G.4.2.2.5 Trans Type
Type in an I representing the technician installing refrigerant to the unit. Type in an R representing the technician removing refrigerant from the unit.

G.4.2.2.6 Refrig Cond
Type in U for usable; N for not usable.

G.4.2.2.7 Trans Qty
Type in the number of pounds of refrigerant that was either installed or removed during this servicing. The number can be up to 99,999.99. The program will not allow installing or removing more refrigerant in the unit at one servicing than the unit can hold. If it holds 300 pounds per the Refrig Equipment Inventory submodule, then up to 300 pounds can be installed or removed. It is very important to have the correct quantity for every service transaction. The report which computes the unit's refrigerant consumption rate uses these quantities for the final calculation.

Note: When entering numbers to the right of the decimal point, enter a number in both fields to place the numbers in the correct position. A number placed in the tenths space will move to the hundredths space when ENTER is pressed. If 0.5_ is entered, it will be translated to 0._5.

G.4.2.2.8 Equip Status
The computer will display a status on the screen. It will be the status from the last service transaction, and will be either I for In Service, R for Under Repair, or M for Mothballed. It will not show D for Decommissioned. Once a unit is decommissioned, it is moved to the History file automatically, and cannot have a service transaction placed against it. Paragraph G. 3.4.1 on Refrig Equipment Inventory explains how to make a unit active once it has been decommissioned.

G.4.2.2.9 Remarks
A suggested use for this area is to write in what was done during the servicing.

G.4.2.2.10 Technician
This is a selectable field. Use PF14 to show the list of technicians who work at the base. To choose a name, place an X next to the name, and press ENTER.

Note: Modifications can be made to this selector file. Names can be added to the list using PF11, or deleted from the list using PF12.

G.4.2.2.11 Trans Date
This is the date the transaction takes place. You can input service transactions which occurred on dates prior to the current date. It is very important to have the correct date for every service transaction. The report which computes the unit's refrigerant consumption rate uses these dates for the final calculation.

G.4.2.2.12 Signature

This place is reserved for signature of the technician who accomplished the work. Print a hard copy of this screen and give it to the technician to fill out after he/she does the work. The signature indicates the work was completed and signed off, and makes inputting the data to the computer easier. Use of this procedure is a local decision that may be started by the base as part of an overall Refrigerant Management program.

G.4.3 Standard Reports

This module generates two standard reports. They are:

G.4.3.1 Main Menu, PF18 (Figure 14): Refrig Service Log Report (Also Known as the Refrigerant Issue/Receive Log - By Date)

This report lists in chronological order all the issues and receipts with amounts and types of refrigerants identified along with the responsible technician.

```
REPORT DATE 94/06/22          Refrigerant  Issue/Receive  Log - By Date                 PAGE  1
                              VERSION  4,01,000,000  93/02/01     (MRESLOG IN MMXRPT

DATE Y/M/D (I)SSUE AM0UNT RFR TYPE   (U)SABLE/    TO/FROM
---------------- (R)ECEVE ------ ---------- (N)OT USABLE   ---------------------------------

1993/04/29      I       10.00  CFC-11        U       PAT DAUGHERTY
1993/05/055     I       10.00  CFC-11        U       RICHBAUMANNC
1993/05/05      I       30.00  CFC-11        U       PAT DAUGHERTY
1993/10/29      I       30.00  CFC-11        U       PAT DAUGHERTY
1993/11/05      I       15.00  CFC-11        U       PAT DAUGHERTY
1993/11/05      I       40.00  CFC-11        U       RICHBRAUMANNC
1994/01/01      I       10.00  CFC-11        U       RICHBRAUMANNC
1994/01/29      I       10.00  CFC-11        U       PAT DAUGHERTY
1994/02/07      I       64.00  R-22          U       ROSARIO, ROBERTO
1994/02/17      I       44.00  R-22          U       ROSARIO, ROBERTO
1994/03/11      I       10.00  CFC-12        U       PAT DAUGHERTY
1994/04/11      I       18.00  CFC-12        U       PAT DAUGHERTY
1994/04/18      R          00  CFC-12        U       PAT DAUGHERTY
```

Figure 14. Refrigerant Issue/Receive Log (MRESLOG)

G.4.3.2 Main Menu, PF19 (Figure 15): Refrig Consumption Report (Also Known as the Refrigerant Consumption Rates - By Facility, Equipment, and Service Date

This report provides the information necessary to comply with the EPA leak rate restrictions. **IT IS THE MOST IMPORTANT REPORT IN THIS SOFTWARE PROGRAM.**

- The % **used** column is the leak rate for the listed unit based on the most recent service data.
- The information to determine this leak rate comes from the data entered in the Refrig Equipment Serviced file.
- The % **used** is an annual rate.
- If the rate is over 99%, the notation is 99+.
- The % **used** is the percent of total charge the unit will leak in the next twelve months based on the amount leaked over the period between the last two servicing.

Refrigerant Consumption Rates - by Facility, Equipment, & Suc Date

Version 4.02.000.000 93/11/01 MRESFAC MMXXOBJ

Facility	Unit	Description	Suc Date	Charge	Type	x used
XLWU 313	1	CHILLER, SEMIHERM CENTRIF	940611	35.00	CFC-12	23
XLWU 313	1	CHILLER, SEMIHERM CENTRIF	940811	22.00	CFC-12	14
XLWU 313	1	CHILLER, SEMIHERM CENTRIF	941013	10.00	CFC-12	6
XLWU 6300		CHILLER, SEMIHERM CENTRIF	940512	400.00	CFC-113	99 +
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	931105	15.00	CFC-11	9
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	940505	20.00	CFC-11	6
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	940509	60.00	CFC-11	99 +
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	940513	1.00	CFC-11	29
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	940621	639.05	CFC-11	99+
XLWU 115	1	CHILLER, SEMIHERM CENTRIF	940621	38.05	CFC-11	99 +
XLWU 115	2	CHILLER, SEMIHERM CENTRIF	940507	50.00	CFC-11	8
XLWU 147	2	CHILLER, SEMIHERM CENTRIF	940515	340.00	CFC-11	99

Figure 15. Refrigerant Consumption Rates - by Facility, Equipment, & Svc Date (MRESFAC)

The specific calculation used to determine this rate can be found in the Refrigerant Manager's Handbook in Chapter 2. If the unit is used for refrigeration and the rate is higher than 35%, or used for something other than refrigeration and the rate is higher than 15%, EPA regulations are violated. Any units exceeding or violating EPA regulations must be repaired within 30 days, or a retirement plan developed within 30 days which will be completed within twelve months.

G.5 REFRIGERANT BENCH STOCK ADJUSTMENT (MRTRUD)

G.5.1 Refrigerant Bench Stock Adjustment (MRTRUD) Main Menu (PF3)

This module is a listing of the refrigerant issued or received by the Refrigerant Manager (RM). When the RM receives refrigerant from a technician or other source for bench stock, a transaction must be entered to increase the recorded stock level of the refrigerant received. Likewise, when refrigerant is issued to a technician or to someone outside CE, a transaction must be entered to decrease the recorded stock level.

Note: The Refrig Equipment Serviced submodule does not update the Refrig Bench Stock submodule.

G.5.2 Screen and Field Descriptions

Data File: MRTR in MMXXDATA
Control File: MRTR in MMXXCTL

G.5.2.1 The first screen of the Refrigerant Bench Stock Adjustment program is Refrigerant Turn-In and Receiving File directory screen (Figure 16). The screen all transactions accomplished through the **Add** key **(PF11).** If a mistake is made entering a new transaction, it must be deleted using **PF12.** A specific transaction can be called up from this screen by positioning the cursor next to the transaction to review, and pressing ENTER.

Active Refrigerant Turn-In and Receiving File

Inst	Refrigerant	Date	Iran	Cond	Tran Qty	MAJCOM
XLWU	R-11	19940311	R	U	1890.00	ATC
XLWU	R-22	19930924	R	U	100.00	AETC
XLWU	R-22	19940214	R	U	100.00	ATC
XLWU	R-22	19940308	R	U	125.00	ATC
XLWU	R-22	19940323	R	U	125.00	ATC
XLWU	R-22	19940325	R	U	125.00	ATC
XLWU	R-22	19940412	R	U	125.00	ATC
XLWU	R-22	19940412	R	U	125.00	ATC
XLWU	R-22	19940412	R	U	125.00	ATC
XLWU	R-582	19940311	R	U	290.08	ATC

Position the cursor and press ENTER to display the entire record.

(1)Keys (8)Find
(1O)Query (11)Add (12)Delete(13)Help (14)Path (15)Print (16)Retrn
(28)Archu (29)Info (30)Histry(31)Rpts

Figure 16. Refrigerant Turn-In and Receiving File Directory Screen (MRTRUD)

G.5.2.2 Most transactions under the Refrigerant Turn-In and Receiving File directory screen will be accomplished through the **Add (PF11).** When in Add mode, the Refrigerant Stock Adjustment Input (Detail) screen (Figure 17) is accessed. This screen is used every time a refrigerant transaction occurs. With these inputs the computer keeps a running total of the refrigerant in the BCE's inventory. The running total is not updated by any other submodules in the RIMS software.

Refrigerant Stock Adjustment

Installation Code: TYNDALL A Major Command: ATC

Refrigerant Type : R-11 YYMMDD
Transact ion QtY : 1890 . 00 Lbs Transact ion Date: 19948311

Transact ion Type : R (1 = Issue to CE Technican)
(2 = Received from outside of CE)
(3 = Received from CE Technican)
(4 = Issued to Outside CE)
Refrigerant Cond : U (U = Usable, N = Unusable)

Usable Inventory Qty: 1898 . Lbs
Unusable Inventory Qty: Lbs
Name
Issued to Technician:
Received From Outside CE:
Received From Technician:
Issued to Outside CE:

(1)Keys (3)Desc (5)Next (8)Find
(10)Query (11)Add (13)Help (15)Print (16)Retrn
(29)Info (32)Exit

Figure 17. Refrigerant Stock Adjustment Detail Screen Directory Screen (MRTRUD)

Each issue and receipt must be accomplished as a separate transaction under **Add.** The four input definitions for the Refrigerant Stock Adjustment screen are as follows:

1 = Issue to CE Technician
This tracks the refrigerant signed out to each technician. It could be a quantity of refrigerant for a specific unit or for many units. Each issue must be recorded with a separate transaction.

2 = Received From Outside of CE
Any refrigerant that comes to the inventory from other than a CE technician. This could be from Base Supply, Contracting, GOCESS, GOCESS, or interbase transfer. Each receipt must be recorded with a separate transaction.

3 = Received From a CE Technician
This tracks the refrigerant returned to inventory by each technician. The turn-in could be due to base procedures requiring daily turn-in of unused refrigerant, or refrigerant recovered from a mothballed or decommissioned machine for storage or reclaiming. Each receipt must be recorded with a separate transaction.

4 = Issued to Outside CE
This will occur when refrigerant is sent to another base, or to a contractor for reclaiming. Each issue must be recorded with a separate transaction.

Note: Before an Add can occur, all refrigerant types used by the base must be identified.

This is accomplished by selecting PF14 on the Refrigerant Stock Adjustment screen, at the **Refrigerant Type** field. The Locations and Refrigerant Types screen (Figure 6) is accessed. Again, select PF1l to **Add** the refrigerants used by the base.

G.5.2.3 Refrigerant Cond is either Usable (U) or Unusable (N). The program keeps a separate running total on both.

G.5.2.4 Usable Inventory Qty is a current total of good refrigerant in inventory. It is composed of all transactions for a specific refrigerant up to but not including the current transaction.

G.5.2.5 Unusable Inventory Qty is a current total of contaminated refrigerant in inventory. It is composed of all transactions for a specific refrigerant up to but not including the current transaction.

G.5.2.6 Issued to Technician and **Received From Technician** are selectable fields through **PF14 (Select).** Using **PF14** will give you a list of all technicians that the RM can issue refrigerant to or receive refrigerant from.

G.5.3 Standard Reports

This submodule generates two standard reports from data input through the Refrigerant Stock Adjustment screen. They are:

G.5.3.1 Main Menu (PF22) (Figure 18) - Refrig Bench Stock Report
This **Bench Stock Transaction Log - By Date** report provides a listing of all transactions in ascending chronological order, the earliest transaction first.

G.5.3.2 Main Menu (PF23) (Figure 19) - Refrig Quantities Report
This Refrigerant Inventory report gives the current total of each refrigerant used on base and managed by the software.

REPORT DATE 94/06/22 — Bench Stock Transaction Log - By Date — Page 1
From: All Thru 940622
VERSION 4.01.000.000 93/02/01 (MRTRLOG IN MMXXRPT)

AFR TYPE	AMOUNT	T/R	CONO	DATE=Y/M/D	AGENCY
CFC-11	100	1	U	1993/04/29	PATDOUGHERTY
CFC-11	10000	2	U	1994/04/28	INITIAL INVENTORY
CFC-113	10000	2	U	1994/04/28	INITIAL INVENTORY
CFC-12	10000	2	U	1994/04/28	INITIAL INVENTORY
CFC-500	10000	2	U	1994/04/28	INITIAL INVENTORY
CFC-582	10000	2	U	1994/04/28	INITIAL INVENTORY
CFC-11	640	3	U	1994/04/29	PATDOUGHERTY
CFC-113	10000	4	U	1994/04/29	RECLYCLER
CFC-113	100	3		1994/04/29	PATDOUGHERTY
CFC-500	800	3	U	1994/04/09	RICH BAUMAN NC
CFC-11	55	1	U	1994/05/11	PATDOUGHERTY
CFC-11	50	1	U	1994/05/11	PATDOUGHERTY
CFC-11	50	1	U	1994/05/11	PATDOUGHERTY

Figure 18. Bench Stock Transaction Log (MRTRLOG)

REPORT DATE 94/06/22 — Refrigerant Inventory — PAGE 1
VERSION 4.02.000.000 93/12/01 (MRQTINV IN MMXXRPT)

MAJCOM	BASE NAME	RFR TYPE	GOOD QTY	BAD QTY
AETC	TYNDALL	CFC-11	10995.50	0
	TOTAL QTY FOR REFRIGERANT TYPE:		10995.50	0
AETC	TYNDALL	CFC-113	90.00	0
	TOTAL QTY FOR REFRIGERANT TYPE:		90.00	0
AETC	TYNDALL	CFC-12	10000.00	0
USAFE	AVIANO	CFC-12	0	0

Figure 19. Refrigerant Inventory (MRQTIN)

G.5.4 Special Feature: Tracking for Other Bases

For organizations that will be tracking refrigerant usage for other bases/locations (Air National Guard and USAFE), the other base's installation code, base name, and MAJCOM should be entered. Use PF14 (Select) on the Refrigerant Stock Adjustment Screen (Figure 17) to access the Locations and Refrigerant Types Screen (Figure 6). From this screen, use **PF11 (Add)** to add a new installation **(Inst),** refrigerant type (Refer Type), base name, and MAJCOM. This file is used by all the Refrigerant Management sub-modules to ascertain the necessary refrigerant for individual bases. When adding records to track usage for another base, care must be taken to ensure that refrigerant from their bench stock is kept separate.

Note: Always ensure that the installation code is entered correctly.

G. 6 Upward Reported Data Logs (MRURUD)

G.6.1 Upward Reported Data Logs (MRURUD) - Main Menu (PF9)

This submodule is for MAJCOM and AFCESA use. The Refrigerant Management Upward Reporting Results screen (Figure 20) displays the dates files sent from different bases and MAJCOMs to higher headquarters. This helps the MAJCOMs and AFCESA know how current information is in their data files.

G.6.2 Management Benefits

Analysis and interpretation of the WIMS refrigerant reports enable the RM to:

```
            Refrigerant Management Upward Reporting Results

  MAJCOM BASE NAME Merge Date/Time Arrive









 There are no records in the file.

                                              (15)Print   (16)Retrn
                               (29)Info       (31)Rpts
```

Figure 20. Upward Reporting Data Log

- Establish equipment repair priorities based on consumption rates. This allows the concentration of limited labor resources to where they can do the most good.
- Compare projected refrigerant inventories to consumption rates to ensure continued mission support.
- Use the consumption records to help prioritize conversion or replacement of equipment.
- Compare different equipment repair and convert/replace strategies with their effect on estimated refrigerant depletion rates.
- Identify low-use equipment for possible mothballing for extended periods of time to eliminate leakage.
- Estimate the labor requirements needed to maintain equipment at minimum refrigerant consumption levels.
- Develop metrics to measure the success of conservation efforts.
- Provide a list of buildings which, due to their proximity and system types, are potential candidates for replacement with small chilled water plants.

G. 8 Definition of Terms

In-Service: When a unit is operational.

Under Repair: When a unit is temporarily down for repair.

Mothballed: When a unit is taken out of service for the winter or non-air conditioning season, including the removal of its refrigerant, and will be recharged and put back in service at the start of the next cooling season.

Decommissioned: When a unit is permanently removed from service.

Usable: Describes the condition of the refrigerant. Usable refrigerant can be placed in a unit without recovery or reclamation.

Unusable: Describes the condition of the refrigerant. Unusable refrigerant cannot be placed in a unit without first being recovered or reclaimed.

AFCESA Condition Assessment Definitions:

4 - An intolerable condition, where components have failed or failure is imminent.
3 - A serious condition, but conditions are tolerable. Failure is probable but work-arounds can be established.
2 - All equipment is operational. Routine preventive maintenance is required to preserve reliability.
1 - System is fully operational and no work in the infrastructure program is required.

Calculation for Multi-Site Potential:

First, use the procedure for determining possible locations for central chilled water plants detailed in the Refrigerant Management Handbook, Appendix H.

Second, for each possible location determine the approximate supply line length (round off to the nearest hundred feet: 100, 200) needed to connect all units. Assign that same number (distance) to each unit in the group. For example, if there are five units that could be served by one plant, and it would take approximately 1100 feet of supply line to connect all units, assign the number 1100 to the data field for all five units. Follow this procedure for each possible location. If two plants require the same line distance, round up or down to the nearest 100 (1000 or 1200) so each group can be identified separately.

Note: Provide only approximate distances between buildings.

PF Keys

Key	Function	Description
1	Keys	Displays the PF Key functions
5	Next	Displays the next full screen of records
7	up	Moves the display up one record
8	Find	Allows the search for a specific record
9	Modify	Allows modification of a selected record
10	Query	Allows user-designed inquiries
11	Add	Allows addition of new records to the file
12	Delete	Allows deletion of selected record(s)
13	Help	Displays documentation on this application
14	Path	Resorts the data by an alternate path
15	Print	Prints the screen being displayed
16	Retrn	Used to return to the previous screen or exit out of program
17	Serial	Used to select unique equipment serial numbers from the Air Conditioning/Refrigeration Equipment program
17	Equip	Used to access the Air Conditioning/Refrigeration Equipment inventory from the Refrigeration Equipment Serviced program
27	Upward	Upward reports Refrigeration System data from the Refrigeration Equipment Serviced program
28	Move	Used to move records to history, or from history to active
28	Archv	Archives records to history after two years (Refrigeration Equipment Serviced program)
29	INFO	Allows access to all the INFO documents
30	Histry/Active	Switch between Active and History Files
31	Rpts	Displays Reports
32	Exit	Used to Exit the program

Appendix H — AC/R Equipment Survey Guide and Equipment Data Collection Survey Forms

ABSTRACT: This appendix will assist the base Refrigerant Manager (RM) conducting a survey of air conditioning and refrigeration (AC/R) equipment. The purpose of the survey is to assess and record the condition of equipment that uses chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) as a refrigerant. This information will be used to assemble a Refrigerant Management Plan (RMP).

H.1 Introduction

This appendix provides instructions and background information for performing a survey of AC/R equipment using Utilities Data Sheets, the AC/R Equipment Survey Form for Water Chillers, and the AC/R Equipment Survey Form for Air Conditioning & Refrigeration Equipment. Blank copies of these forms are included as attachments to this appendix. They can be photocopied and used to complete the survey.

H.11 Required Items

The following items are required to perform the survey:

- AC/R equipment survey forms,
- a three-ring binder for carrying survey forms, and
- a portable refrigerant leak detector, (see Appendix D, *Refigerant Leak Detection Methods and Equipment.*

H.1.2 Recommended Items

In addition to the required items, the following items are recommended to perform the survey:

- extra battery power for the portable leak detector,
- extra sensors and filters for leak detectors,
- a flashlight, and
- hearing protection (ear plugs).

H.2 Completing the Utilities Data Sheet

Utility bills for electric and natural gas services provide a record of the consumption and cost of these utilities. This information will be useful in evaluating the various electric- and gas-powered retrofit or replacement alternatives discussed in Appendices M, *Evaluating Water Chillers for Replacement or Retrofit Potential,* N, *Chiller Selection Guide, O, Assessing the Potential of Central Chilled Water Plants,* P, *Heat Recovery Alternatives for Refrigerant Chillers,* and Q, *Assessing the Potential of Thermal Energy Storage. The* Utilities Data Sheet (Attachment 1) organizes this information into a useful form. A separate sheet is needed for each separate electric or gas service billed to the base. Complete the Utilities Data Sheet using utility bills for the preceding 12 months. See the base civil engineer's (BCE's) Resource Management group for this information.

H.3 Organizing the Survey

Make one copy of the appropriate blank survey form (either for water chillers or AC/R equipment) for each piece of equipment using CFCs or HCFCs as a refrigerant.

H.3.1 Data Retrieval

Access the Work Information Management System (WIMS) Refrigerant Management Software for data on each piece of equipment that uses CFCs or HCFCs. Record the facility number, unit number, date manufactured, and refrigerant quantity and type on Part I of the survey form.

H.3.2 Sort Forms

Sort the survey forms by refrigerant type, refrigerant quantity, age, and location (optional). This is recommended so units are surveyed in order of importance. Sort in the following order:

- separate the forms for CFC- and HCFC-units into piles;
- sort each pile in descending order by refrigerant quantity;
- retaining this order, sort each pile by age, placing older units on top of younger units of equal refrigerant quantity;
- place the CFC pile on top of the HCFC pile, and
- if more than one person is conducting the survey or to reduce travel time, sort survey forms by location.

H.3.3 Map Locations

On an up-to-date, to-scale Base Site Plan showing the facilities, mark the approximate location of each unit and its unit number. If locations can not be determined prior to the survey, they must be determined during the survey.

H.3.4 Mapping Water Chillers

Using compass or circle template, draw a circle around each chiller (or chiller plant) of radius equal to its capacity in tons. This circle is the "capacity radius" of the chiller. For example, a 1,000-foot radius circle would be drawn around a 1,000-ton chiller (or chiller plant); a 200-foot radius circle would be drawn around a 200-ton chiller (or chiller plant). Overlapping circles indicate a potential to combine these chillers into a central system. Further assessment of this potential will be made during ***the*** survey.

H.4 Performing the Survey

The instructions and additional information in this section relate directly to the AC/R Equipment Survey Form for water chillers (Attachment 2); however, they pertain to the Survey Form for air conditioning and refrigeration equipment (Attachment 3) as well. Both Forms are divided into five parts:

Part I. General Data
Part II. Service Data
Part III. Assessment of Mechanical Room
Part IV. Assessment of Equipment
Part V. Action Items

H.4.1 Complete Part I
Part I is for recording general data that may be available at the site of the equipment. This information is then used to verify and update the WIMS Refrigerant Management Software.

H.4.1.1 ***Line 1*** **-** One of the end-products of this survey is an up-to-date AC/R equipment database. This is accomplished by completing Part I by inspection. Following the survey, any additions and corrections will be input to the WIMS Refrigerant Management Software. Input will be made easier if the additions and corrections are clearly indicated. Refer to equipment by facility number, followed by the unit number, (that is, 4355-l). If the equipment does not have a unit number, assign one to it — for example, "1," "2," "3" – up to the total number of units in the facility. Status of Equipment is either:

- I - In Service,
- D - Decommissioned,
- M - Mothballed, or
- R - Under Repair.

H.4.1.2 The condition assessment of each unit is based on page 3 of the Air Conditioning and Refrigerant Equipment Form (Attachment 3) and page 5 of the Water Chillers Form (Attachment 2).

H.4.2 Complete Part II
Part II is for recording service information that may be available at the site of the equipment. This information is then used to verify and update the WIMS Refrigerant Management Software.

H.4.2.1 ***Line*** 2- Complete Part II, Service Data if this information is available in a service log book kept near the unit. Transfer this information to the WIMS Refrigerant Management Software. An up-to-date service log is required by EPA. If no service log is currently kept, one should be started as soon as possible. See Appendix G, *Work Information Management System (WIMS),* for information on setting up a service log in WIMS and the use of WIMS to track refrigerant consumption.

H.4.2.2 ***Line 2A*** **-** Record the two most recent additions of refrigerant. This information will be used to compute the unit's refrigerant consumption rate. The refrigerant consumption rate will determine what, if any, action is required to comply with the EPA regulations.

H.4.2.3 ***Line 2B*** **-** Use this section to record rebuilds, major repairs, or overhauls performed on the machine over the past five years. This information will be used to gauge the cost of maintaining this machine, and to project future major service work. It will affect the schedule for replacement or retrofit.

H.4.3 Complete Part II
Information recorded in Part 111 is used to assess the condition of the room containing the AC/R Equipment.

H.4.3.1 ETL 91-7 requires ASHRAE 15-1992, Safety Code for Mechanical Refrigeration be followed for new construction or when chillers are retrofitted or replaced (see also Appendix J, *Application of ASHRAE Equipment Room Design Requirements).* A preliminary assessment of the mechanical room is necessary to estimate the cost of renovating the room to meet ASHRAE 15-1992. It is also useful to identify difficulties in replacing the chiller. To complete:

H.4.3.2 ***Line 3*** - If the chiller is located outside, skip to the next section.

H.4.3.3 ***Line 3A*** - Make a quick (free-hand, five-minute maximum time-effort) sketch of the mechanical room containing the chiller, noting the following where they exist (all dimensions should be visual estimates):

H.4.3.3.1 Room dimensions and height - Example: 40'(L) x 25'(W) x 15'(H). This information will be used to estimate ventilation requirements.

H.4.3.3.2 Door locations and sizes - This will indicate a removal path for the chiller and how the room might be modified to comply with ASHRAE 15-1994.

H.4.3.3.3 Louver locations and sizes and Exhaust fan locations and sizes - This will indicate the capacity of the existing ventilation systems for comparison with ASHRAE 15-1994 requirements.

H.4.3.3.4 Open floor area for new equipment - This will indicate the amount of extra space available to locate additional chillers or pumps (if desired).

H.4.3.3.5 Flame-producing equipment - Provide a brief description of the type and location of flame-producing equipment in the room. This is any piece of equipment producing a visible open flame, either internal or external to the equipment. *Examples:* boilers, unit heaters, water heaters, door heaters which are gas- or oil-fired.) Note if: (1) it is separated from the chiller by a wall with a door and (2) its combustion air is ducted in from outside the room.

H.4.3.3.6 Refrigerant or oxygen monitors - Show types, manufacturer, model number, and locations of each refrigerant or oxygen monitor. A refrigerant monitor is an instrument which measures the concentration of refrigerant in the room. It is likely to be mounted on a wall near the chiller and may have remote sensors located at the base of the chiller. An oxygen sensor is an instrument which measures the concentration of oxygen in the room. It is necessary for use with refrigerants such as CFC-11, CFC-12, HCFC-22, CFC-113, CFC-500, and CFC-502 whose predominant exposure hazard is asphyxiation (depletion of oxygen). Oxygen sensors are typically wall-mounted.

H.4.3.3.7 Self-contained breathing apparatus (SCBA) - Show the location of SCBA apparatus. A self-contained breathing apparatus is used for entering the mechanical room in an emergency situation following a release of refrigerant within the room. It should be located in a prominent location near the entrance to the mechanical room.

H.4.3.3.8 Exterior walls - Show exterior walls. They indicate how the mechanical room might be expanded to accommodate more equipment, or modified to comply with ASHRAE 15-1994.

H.4.3.3.9 Chiller location - Show chiller location. Chiller locations indicate the ease of replacement and compliance with ASHRAE 15-1994.

H.4.3.4 ***Line 3B*** (Water Chiller Form only) - Rank the relative ease of replacing the chiller according to the following definitions:

- Easy - little disassembly required and little disturbance to equipment, walls, or structures;
- Moderate - some disassembly required and/or some disturbance to equipment, walls, or structures; and
- Difficult - major disassembly required and/or major disturbance to equipment, walls, or structures.

H.4.3.5 ***Line 3C*** (Water Chiller Form only) - Briefly describe what appears to be the easiest way to get the chiller out of the room. How much disassembly would be required? What equipment would need to be moved out of the way? What building walls or structures would need to be altered, and, if a multi-chiller installation, in what order would they need to be removed?

H.4.4 Complete Part IV

Part IV requires the surveyor to assess the condition of AC/R equipment.

H.4.4.1 ***Line 4*** - Compressor full load amps (FLA) and volts are found on the main equipment tag. These will be used to estimate the existing full load efficiency.

H.4.4.2 ***Line*** **5** - (Water Chiller Form) CFC-11, CFC-113, and HCFC-123 are "low-pressure refrigerants". This means that the operating pressure within the evaporator is less than atmospheric. It is recommended they be equipped with high-efficiency purge units and evaporator heater/pressurization systems.

H.4.4.2.1 ***Line 5A*** - Is the unit equipped with an evaporator heater/pressurization system? An evaporator heater/pressurization system is used to elevate the pressure in the evaporator during idle periods so that air will not be drawn into the machine through any leaks that may be present. (See Appendix E, *Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air Conditioning and Refrigeration Systems,* for further explanation and types of systems.)

H.4.4.2.2 ***Line 5B*** - Is the unit equipped with a purge unit? A purge unit is a device that removes air from the refrigerant in order to improve performance and reduce corrosion of the internal surfaces. (See Appendix E for further explanation on types of purge units and their efficiencies.)

H.4.4.2.2.1 ***Line 5B1***- The efficiency of purge units (ability to contain refrigerant while extracting air) varies greatly among individual units. Older units are, typically, far less efficient than newer units. The tag data you provide will help determine if the purge is losing excessive refrigerant and should be replaced.

H.4.4.2.2.2 ***Line 5B2*** - Knowing how the purge unit is being operated is essential to estimating the leakage on the low-pressure side of the machine.

H.4.4.2.2.3 ***Line 5B3*** - The discharge of a purge unit is capable of a significant refrigerant release. For this reason it must be piped to the outdoors.

H.4.4.2.2.4 ***Line 5B4*** - If "high efficiency" is stated somewhere on the purge, note it here. (See Appendix E for more information on purge units and purge unit efficiency.)

H.4.4.2.3 ***Line 5C*** **-** The hour meter on a purge unit records the time the unit was actively venting. Logging of purge run-time is highly recommended.

H.4.4.2.3.1 ***Line 5C1*** **-** Record current reading of the hour meter.

H.4.4.2.3.2 ***Line 5C2*** **-** A recent record of purge unit operation will be useful in estimating the leakage on the low-pressure side of the machine. (See Appendix F, *Refrigerant Leak Mitigation through Equipment Maintenance and Service Practices,* for more information on acceptable purge unit run-time.)

H.4.4.3 ***Line 6*** **-** Record the current reading on the chiller run-time hour meter, if available. A record of the run-time will be useful in estimating load and operating costs for the evaluation of replacement or retrofit alternatives.

H.4.4.4 ***Line 7*** **-** A pressure-relieving device is installed on all water chillers to prevent over-pressurization. This can be either a rupture disk or a combination rupture disk and pressure relief valve.

H.4.4.4.1 ***Line 7A*** **-** Pressure relief for water chillers is required to be piped to the outside. Exposure to refrigerants is a health hazard.

H.4.4.4.2 ***Line 7B*** **-** A pressure-relief valve is recommended in the vent piping. It should automatically reseat after activation to prevent loss of a total refrigerant charge should the rupture disk fail.

H.4.4.4.3 ***Line 7C*** **-** A rupture disk is a pressure-relieving device incapable of reseating itself.

H.4.4.4.4 ***Line 7D*** **-** A properly installed vent system will have a rupture disk between the chiller and a self-reseating pressure-relief valve. The purpose of the rupture disk is to protect the valve from corrosion and possible reseating problems. There should be a way to tell if the rupture disk has burst so that it can be replaced.

H.4.4.5 ***Line 8*** **-** An important outcome of this survey is the identification of refrigerant leaks. All potential leak points, such as brazed and welded joints, gaskets, flanges, shaft seals, and valve stems, should be tested. Identify the leak locations on the chiller with either a marker or a tag. EPA defines a “major” leak repair as involving the removal of major components such as the compressor, condenser, evaporator, or auxiliary heat exchanger coil. A “minor” leak repair does not entail the removal of major components. Major leaks require immediate action as discussed in line 14J. Minor leak repairs should be performed by maintenance personnel as soon as possible.

H.4.4.5.1 ***Line 8A*** **-** List the number of minor leaks found. A minor leak is defined above.

H.4.4.5.2 ***Line 8B*** **-** List the number of major leaks found. A major leak is defined above.

H.4.4.5.3 ***Line 8C*** **-** Provide a brief description of the leak (for example, compressor shaft seal, liquid line filter-drier, valve stem on compressor service shut-off valve, inlet flange on condenser, tubing connection). Indicate whether the leak requires "major" or "minor" repair, as defined above.

H.4.4.6 ***Line*** **9 -** The type of facility served by this chiller indicates the system load profile, or the cooling load demand over time. This information will be used in the selection and staging of replacement alternatives.

H.4.4.7 ***Line 10*** **-** It is useful to know if the chilled water system is already a central plant (serving more than one facility). Identifying central plants by circling them on the plan will assist in the analyses to follow.

H.4.4.8 ***Line 11*** **-** Whether or not this chiller is part of a multi-chiller plant is significant in the selection and scheduling of replacement or retrofit alternatives. Multi-chiller plants can be identified by a shared, chilled water supply header.

H.4.4.8.1 ***Line 11A*** **-** Enter the unit numbers of all other units sharing the same chilled water supply header. Check to see they are correctly located on the Base Site Plan.

H.4.4.8.2 ***Line 1123 - This*** information will be used to estimate the least-cost replacement or retrofit scenario for the chiller plant.

H.4.4.9 ***Line 12*** **-** Water-cooled chillers have condenser water piping leading to a cooling tower. Air-cooled chillers have refrigerant piping leading to a condensing unit, usually mounted on the same frame.

H.4.4.9.1 ***Line 12A*** **-** A "dedicated" cooling tower serves only this chilled water system. A "central" cooling tower serves more than one chilled water system.

H.4.4.9.2 ***Line 12B*** **-** Provide a brief description of the type and number of towers. Copy important tag data such as manufacturer, model, serial no., unit no., and year manufactured.

H.4.4.9.3 ***Line 12C*** **-** Assess the general condition of the cooling tower(s) using assessment codes as defined on the survey form.

H.4.4.9.4 ***Line 12D*** **-** Provide a brief description of the type of condensing unit and its condition. For example: Are all fans operational? Are finned surfaces straight and clean? Is the unit structurally sound? Copy important tag data such as manufacturer, model, serial number, unit number, and year manufactured.

H.4.4.9.5 ***Line 12E*** **-** Assess the general condition of the condensing unit using assessment codes as defined in line 12C of the survey form.

H.4.4.10 ***Line 13*** **-** Use this space to continue your responses to this section, or to make additional comments regarding your inspection of the equipment.

H.4.5 Complete Part V

Part V is for noting specific conditions which contribute to leakage or are a risk to health and safety and should be corrected as soon as possible.

H.4.5.1 ***Line 14*** **-** By following the instructions on the survey form, most of the "Action Items" applicable to this chiller should be checked by the completion of this survey. Facility Number, Unit Number, Surveyor, Date, and Base information need to be repeated at the top of page 6. This page can then be distributed separately from the other pages of the form. Each of these action items contribute directly to refrigerant leakage or as a risk to health and safety. Every action item "checked" should be corrected by maintenance personnel as soon as possible.

H.4.5.1.1 ***Line 14A*** - For line 5A, an inspection was made to determine whether the low-pressure machine had an heater/-pressurization system on the evaporator. Check this box if line 5A was marked "No. "

H.4.5.1.2 ***Line 14B*** - For line 5B, the purge unit was surveyed. If this is a low-pressure chiller, and does not have a purge unit, one must be installed. Check this box if line 5B was marked "No. "

H.4.5.1.3 ***Line 14C*** - For line 5B3, whether or not the purge discharge was piped to the outside was determined. Check this box if line 5B3 was marked "No."

H.4.5.1.4 ***Line 14D*** **-** For line 5B4, it was determined whether or not the purge was a high-efficiency type. Check this box if line 5B4 was marked "No. "

H.4.5.1.5 ***Line 14E*** **-** For line 7A, it was determined whether or not the pressure relief for the evaporator and condenser was piped to the outside. Check this box if line 7A was marked "No. "

H.4.5.1.6 ***Line 14F*** **-** For line 7B, it was determined whether or not a pressure relief valve was installed in the vent pipe for the evaporator and condenser. Check this box if line 7B was marked "No."

H.4.5.1.7 ***Line 14G*** **-** For lines 7C and 7D, it was determined whether or not a rupture disk was installed in (1) the vent pipe for the evaporator and condenser and (2) whether or not it was installed between the chiller and the pressure relieve valve. Check this box if either line 7C or 7D was marked "No. "

H.4.5.1.8 ***Line 14H*** **-** Check this box if information was obtained for lines 2A and 2B, or if service data for this unit is not currently being logged on the WIMS Refrigerant Management Software.

H.4.5.1.9 ***Line 14I-*** Check this box if any "minor" leaks were found (refer to line 8A).

H.4.5.1.10 ***Line*** 14J **-** Check this box if any "major" leaks were found (refer to line 8B). Determine whether the leaks requiring a major repair effort are significant in terms of refrigerant loss. If leaks are obviously significant, mark the unit for immediate retirement. If the significance of the leak cannot be determined, mark the unit for further evaluation (fixing all minor leaks and closely tracking consumption). If EPA leak rate requirements cannot be met, schedule the equipment for immediate retirement (that is, develop a plan for retirement and have it retired in one year per EPA requirements).

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AC/R EQUIPMENT SURVEY - UTILITIES DATA SHEET

****
UTILITY USE AND COST DATA FOR THE PRECEDING 12 MONTH PERIOD
****

Your Name: ______________________ Base: ________________ Date: ____________

Description of Service: ____

Name & Address of Utility: ____

____

____

Service Rep.: _________________________ Phone No.: ________________________

BILLING PERIOD			CONSUMPTION	DEMAND	COST	
FROM	TO	# DAYS	UNITS: _______	________	(NEAREST $)	$/UNIT
TOTALS				XXXXXXXXX		

Attach a copy of the rate schedule effective for the prcedeing 12 month period.

Remarks: ____

____

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AC/R EQUIPMENT SURVEY FORM

FOR WATER CHILLERS

Surveyor: ____________________ Date: ______________ Base: ________________

****

I. GENERAL DATA

****

1. Complete the following.

Facility Number: _________________ Unit No.: ___________________

Description: _____________________ Status of Equipment: ________

Capacity: _____________ (Tons, HP) Date Mfg'd: _________________

Refrigerant Qty: ___________ (lb) Refrigerant Type: R - _______

Manufacturer: ____________________ Model: ______________________

Serial #: ________________________

Condition Assessment (See 12.C for Definitions) : _______________

Description of Load: [ ]Comfort Cooling [ ]Process Cooling

Is chiller located correctly on the Base Site Plan? [No, Yes]
Make correction on the plan <___________________________|

Remarks: ____

____

____

****

II. SERVICE DATA

****

2. Complete the following for service work performed recently.

A. Refrigerant Added:

Quantity: ______ (lb) Hour Meter: _______ Date: _________

Quantity: ______ (lb) Hour Meter: _______ Date: _________

B. Major Service Work (rebuilds, major repairs, overhaul):

____

____

____

****

III. ASSESSMENT OF MECHANICAL ROOM

****

3. Is the chiller located in a mechanical room? . . . . . . [No, Yes]
   Skip to 4 <—— (No)

   Yes ——> A. Sketch the room below. Note the following.

   * Room dimensions & height
   * Door locations & sizes
   * Louver locations & sizes
   * Exhaust fan locations & sizes
   * Open floor area for new equip.
   * Flame-producing equipment
   * Refrig. or oxygen monitors
   * Self-contained breathing App.
   * Exterior walls
   * Chiller location

   ——> B. Ease of Replacement: [ ]Easy [ ]Moderate [ ]Difficult

   ——> C. Briefly describe the work required to replace chiller:

   ____

   ____

AC/R EQUIPMENT SURVEY FORM

FOR WATER CHILLERS

****
IV. ASSESSMENT OF EQUIPMENT
****

4. Compressor Full Load Amps (FLA): ____________ volts : ____________

5. Is chiller low-pressure (R-n, or R-113)? . . . . [No, Yes]

   A. Heater/Pressurization System on Evaporator?. . . . . . . [No, Yes]
      Check Action Item A (last page) <—

   B. Does chiller have a purge? . . . . [No, Yes]
      Check Action Item B (last page) <—

      1. Manufacturer: ________________ Year Built: __________

         Model: ____________________ Serial #: ________________

         Other: ____

      2. Mode of operation: . . . . [Manual, Off, Auto, ?]

      3. Is discharge piped to outdoors? . . . . [No, Yes]
         Check Action Item C (last page) <—

      4. Is purge high-efficiency type? . . . . [No, ?, Yes]
         Check Action Item D (last page) <—

   C. Does purge have an hour meter? . . . . [No, Yes]
      If yes:

      1. Current reading: ________________

      2. Past three readings (if logged):

         Date: _____________ Reading: ________________

         Date: _____________ Reading: ________________

         Date: _____________ Reading: ________________

6. Does chiller have a run-hour meter? . . . .[No, Yes]
   Current reading: ____________ <—

AC/R EQUIPMENT SURVEY FORM

FOR WATER CHILLERS

7. Pressure-relief for evaporator and condenser:

   A. Vent piped to outside? . . . . [No, Yes]
   Check Action Item E (last page) <——

   B. Pressure-relief valve (PRV) installed? . . . .[No, Yes]
   Check Action Item F (last page) <——

   C. Rupture disk installed? . . . . . . [No, Yes]
   Check Action Item G (last page) <——

   D. Rupture disk installed between chiller & PRV? . . .[No, Yes]
   Check Action Item G (last page) <——

8. Survey the chiller with portable leak detector. Mark each leak location with a tag or marker. (See Survey Guide for definition of major and minor leaks.

   A. How many minor leaks were found? _____
   Check Action Item I (last page) if any <——

   B. How many major leaks were found? _____
   Check Action Item J (last page) if any <——

   C. Briefly describe the leaks: ______________________________

   ____

   ____

   ____

   ____

9. Identify each & every type of facility served by this chiller.

   _____ Storage
   _____ Club
   _____ Dining
   _____ Community
   _____ Hospital
   _____ Living Quarters
   _____ Retail Store
   _____ Maintenance Shops
   _____ Assembly Halls
   _____ Training/School
   _____ Clinics & Dispensaries
   _____ Large Offices (> 8,000 SF)
   _____ Small Offices (< 8,000 SF)
   _____ ______________________________

10. Is chiller serving more than one building? . . . . [No, Yes]
    Circle buildings served on base plan <——

11. Are other chillers serving the same load? . . . . [No, Yes]
    If yes:

    A. Enter their unit numbers: ______________________________

    B. Are they located in the same room? [No, Yes]

AC/R EQUIPMENT SURVEY FORM

FOR WATER CHILLERS

12. Is the chiller water cooled? . . . . [No, Yes]

> A. Cooling tower(s) serves this system only? . . . . . [No, Yes]

> B. Describe the cooling tower(s): ______________________

____

____

> C. Condition Assessment Code for Cooling Tower(s): _____

1 = Fully Operational Condition. System is reliable and fully functional.
2 = Operational Condition. Routine preventive maintenance is required to preserve reliability.
3 = Serious but Tolerable Condition. Failure is probable, but work-arounds can be established.
4 = Intolerable Condition. Major components have failed or failure is-imminefit.

> D. Briefly describe condensing unit: ___________________

____

____

> E. Condition Assessment Code for Condensing Unit: ____

13. Remarks: ____

____

____

____

____

____

____

____

____

AC/R EQUIPMENT SURVEY FORM

FOR WATER CHILLERS

Facility Number: __________ Unit Number: _____

Surveyor: ____________________ Date: ______________ Base: __________________

****

V. ACTION ITEMS

****

14. Check items below which require immediate action. Give a copy of this page to the Base Refrigerant Manager.

A. ☐ Install a Heater/Pressurization System on Evaporator

B. ☐ Install High-Efficiency Purge Unit

C. ☐ Pipe Purge Discharge to Outside

D. ☐ Verify if Purge is High-Efficiency Type. If Not, Replace with a High-Efficiency type.

E. ☐ Pipe Pressure-Relief Vent for Evaporator and Condenser Outside

F. ☐ Install Pressure Relief Valve (PRV) in Vent Pipe for Evaporator and Condenser

G. ☐ Install Rupture Disk in Vent Pipe for Evaporator and Condenser. Install Upstream of PRV.

H. ☐ Start/update an equipment service log on the WIMS.

I. ☐ Repair Minor Refrigerant Leaks

J. ☐ Major leaks found - repair, retire, or schedule retirement of the unit within 30 days. See Appendix B of the Refrigerant Management Handbook for more information.

AC/R EQUIPMENT SURVEY FORM

FOR AIR CONDITIONING AND REFRIGERATION EQUIPMENT

Surveyor: ____________________ Date: ______________ Base: ___________________

****

I. GENERAL DATA

****

1. Complete the following.

Facility Number: ____________________ Unit No.: ___________________

Description: _________________________ Status of Equipment: _____

Capacity: _______________ (Tons, HP) Date Mfg'd: ________________

Refrigerant Qty: _____________ (lbs) Refrigerant Type: R - ____

Manufacturer: ________________________ Mode 1: ______________________

Serial #: ____________________________

Condition Assessment (See Page 3 for Definitions): _______________

Description of Load: [ ]Air Conditioning [ ]Refrigeration

Is unit located correctly on the Base Site Plan? [No, Yes]
Make correction on the plan <————————————————————┘

Remarks: ____

____

____

****

II. SERVICE DATA

****

2. Complete the following for service work performed recently.

A. Refrigerant Added:

Quantity: _______ (lb) Hour Meter: ________ Date: ________

Quantity: _______ (lb) Hour Meter: ________ Date: ________

B. Major Service Work (rebuilds, major repairs, overhaul) :

____

____

____

AC/R EQUIPMENT SURVEY FORM

FOR AIR CONDITIONING AND REFRIGERATION EQUIPMENT

****

III. ASSESSMENT OF MECHANICAL ROOM

****

3. Is the unit located in a room? . . . . [No, Yes]
   Skip to 4 <—— (No)

—> (Yes) A. Sketch the room below. Note the following.

- * Room dimensions & height
- * Door locations & sizes
- * Louver locations & sizes
- * Exhaust fan locations & sizes
- * Flame-producing equipment
- * Refrig. or oxygen monitors
- * Self-contained breathing App.
- * Exterior walls
- * Unit location

AC/R EQUIPMENT SURVEY FORM

FOR AIR CONDITIONING AND REFRIGERATION EQUIPMENT

****

IV. ASSESSMENT *OF* EQUIPMENT

****

4. Compressor Data (if separate from other components):

Manufacturer: ____________________ Model No.: ______________

Serial No.: ______________________ Year Built: _____________

Full Load Amps (FLA): ____________ volts : _________

Condition Assessment (See Code Descriptions Below): _______

Remarks: ____

____

5. Evaporator/Air Handling Unit Data (if separate from other components) :

Manufacturer: ____________________ Model No.: ______________

Serial No.: ______________________ Year Built: _____________

Condition Assessment (See Code Descriptions Below): _______

Remarks: ____

____

6. Condensing Unit/Cooling Tower Data (if separate from other components) :

Manufacturer: ____________________ Model No.: ______________

Serial No.: ______________________ Year Built: _____________

Condition Assessment (See Code Descriptions Below): _______

Remarks: ____

____

*********** Condition Assessment Code Descriptions ***********

1 = Fully Operational Condition. System is reliable and fully functional.

2 = Operational Condition. Routine preventive maintenance is required to preserve reliability.

3 = Serious but Tolerable Condition. Failure is probable, but work-arounds can be established.

4 = Intolerable Condition. Major components have failed or failure is imminent.

****

7. Survey each component of the system with portable leak detecto. Mark each leak location with a tag or marker.

   A. How many leaks were found? ______
   Check Action Item B (last page) if any <—

   B. Briefly describe the leaks: ____________________________

   ____

   ____

   ____

   ____

Facility Number: __________ Unit Number: _____

Surveyor: ____________________ Date: ______________ Base: ___________________

****

V. ACTION ITEMS

****

8. Check items below which require immediate action. Give a copy of this page to the Base Refrigerant Manager.

   A. ☐ Start/update an equipment service log on the WIMS.

   B. ☐ Repair Refrigerant Leaks

Appendix I — Funding Alternatives for Base Refrigerant Management Program

ABSTRACT: This appendix provides information on obtaining alternative funding for projects in support of the Base Refrigerant Management Program (BRMP). The three specialized programs are the Energy Conservation Investment Program (ECIP), the Federal Energy Management Program (FEMP), and the Pollution Prevention Program (PPP).

I. 1 Introduction

This chapter contains information on funding sources for equipment, tools, management initiatives, and facility contracts supporting a BRMP. The three specialized programs to support such projects are ECIP, FEMP, and PPP. This appendix provides a description of these three programs, as well as specific examples on how to accomplish the paperwork to justify a project for any of these funding avenues. These programs have specific advocates and points of contact (POC) at each base and major command (MAJCOM). All actions involving these programs must be coordinated with these advocates.

1.2 Program Definitions

1.2.1 Energy Conservation Investment Program

The ECIP is a Military Construction (MILCON)-funded program to improve the energy efficiency of existing Department of Defense (DoD) facilities. The projects funded through ECIP improve the living and working environment of DoD personnel, enhance mission capabilities, and greatly decrease the negative environmental effects of DoD energy systems. In the Air Force, the specific purpose is to help bases reduce energy consumption and costs, provide savings in operating costs, and achieve the energy goals. This includes construction of new, high-efficiency energy systems or the improvement and modernization of existing systems. Public Law 102-486 makes each military service responsible for identifying and accomplishing all energy conservation measures with a payback period of ten years or less.

1.2.2 Federal Energy Management Program

The FEMP is a MILCON and/or Operations and Maintenance-funded program that covers energy conservation, renewable energy, and water efficiency projects. It also covers the identification and design of these projects and the program support, such as training and awareness. FEMP can be used to fund Military Family Housing (MFH) projects.

1.2.3 Pollution Prevention Program

The PPP program includes all work necessary to eliminate or reduce undesirable impacts on human health and the environment to include the use of processes, practices, products, or management actions. PPP requirements span the Air Force budget with finding in such appropriations as: Military Construction (3300); Operations and Maintenance (O&M) (3400); Research, Development, Testing, and Evaluation (RDT&E) (3600); Aircraft Procurement (3010); Missile Procurement (3020); and Other Procurement (3080). Program and budget pollution prevention project requirements in accordance with the associated rules for each appropriation. The functional offices of primary responsibility (OPRs) are responsible for requirement advocacy with civil engineering as the lead agency for PPP consolidation, tracking, and management.

1.3 Criteria for Each Program

1.3.1 ECIP and FEMP Programming Criteria

Priority is given to projects that produce the highest savings-to-investment ratio (SIR) and the discounted payback (DPB) period. SIR and DPB are terms used with life-cycle cost analyses. For more detail see section I.4, *Justification and Documentation.* Projects must have a SIR greater than 1.25 and a DPB of ten years or less. Additional consideration can be given to projects that substitute renewable energy for nonrenewable energy. Because there is uncertainty over future force levels and base structure, a sensitivity analysis must be conducted to determine if there is likelihood that expected changes might alter the economic benefits. Increased risk identified as the result of a sensitivity analysis may be used to lower a project's programming priority.

1.3.2 PPP Programming Criteria
PPP requirements can be divided into recurring and nonrecurring categories.

1.3.2.1 Recurring: pollution prevention operations and services (O&S). Annual recurring, "must do" services and projects are associated with "keeping the gates open. " Recurring, "must do" requirements include:

- periodic updates of management plans and analyses of pollution prevention initiatives required by law or policy;
- baseline survey updates;
- other overhead costs;
- education, training, and awareness programs;
- operations and maintenance costs for PPP tracking systems and hazardous material pharmacies;
- pollution prevention opportunity assessments; and
- environmental certifications and licenses, only as part of a mandatory training course.

1.3.2.2 Nonrecurring requirements are divided into three levels: **P1**, P2, and P3. **P1** includes projects and services that:

- eliminate dependence on ozone depleting chemicals;
- satisfy federal, state, and local pollution prevention laws and regulations; and
- satisfy pollution prevention Executive Orders.

P2 requirements are those required to meet future federal or DoD legal requirements or Air Force Pollution Prevention Action Plan goals, objectives, and sub-objectives.

P3 projects and services go beyond Air Force Pollution Prevention Action Plan goals, DoD goals, and legal requirements. The BRMP requirements will probably fall under level PI. The following are nonrecurring projects and services.

- Projects which reduce/eliminate the Air Force demand for ozone depleting compounds (ODCs). Typical ODC projects include: halon and refrigerant recyclers and reclamation costs, air conditioner purge units/heaters, aqueous parts washers, storage containers for ODC banking, limited air conditioner retrofits from chlorofluorocarbon (CFC) to hydrochlorofluorocarbon (HCFC) (if they are cost-effective; no ODC inventory exists and no recyclable ODC market exists), leak detectors, and automatic shutoff valves.
- Pollution prevention management plans, where required by law.
- Projects to find acceptable materials and processes to replace existing materials and processes in facilities.

I.3.2.3 Requirements not eligible for PPP include, but are not limited to the following types of projects.

- Nonenvironmental projects-projects primarily justified for nonenvironmental reasons which include environmental requirements in scope.
- Maintenance projects-resulting from poor infrastructure maintenance.
- Air conditioning projects—replacing air conditioning equipment using CFCs with HCFCs, unless criteria in paragraph 1.3.2.2 is met.
- Depot-level equipment-the Defense Business Maintenance Area (DBMA) in the Defense Business Operations Fund has been established to pay for the replacement of depot-level equipment costing more than $25,000. Equipment meeting this definition should be budgeted through the DBMA capital asset budget.
- Acquisition projects.
- Energy conservation MILCON projects.

1.4 Justification and Documentation

I.4.1 ECIP and FEMP Justification and Documentation Process

Facility energy conservation retrofit projects costing $300,000 or more are administered through the ECIP program as MILCON projects. FEMP follows these same roles but also includes O&M. Projects are evaluated on the basis of highest SIR, as calculated by the life-cycle cost method contained in this guidance. Projects must meet the following programming criteria.

- Projects are ranked on the basis of the greatest potential life-cycle cost payback, as indicated by the SIR and payback period. Additional consideration is given to projects that substitute renewable energy for nonrenewable energy.
- Projects must have a SIR greater than 1.25 and discounted payback period of ten years or less.
- The basic objectives of ECIP are energy conservation and energy cost savings. In order for a project to be eligible for the program, at least 20 percent of its annual dollar savings must be attributed to energy British thermal unit (Btu) savings.

I.4.2 Economic Analysis

Each discrete portion of the project must be life-cycle cost-effective or essential to accomplishment of the other portions of the project. Care must be taken to ensure energy savings are not credited to multiple projects.

I.4.2.1 Life-cycle cost (LCC) analysis must follow the criteria and standards contained in "Tri-Service Memorandum of Agreement on Criteria/Standards for Economic Analysis/Life-Cycle Costing for MILCON Design," Attachment 1. The Construction Engineering Research Laboratory (CERL) computer program *Life Cycle Cost in Design* (LCCID), is recommended. The program was mailed to the MAJCOM Energy engineers on 27 May 1993.

I.4.2.2 Other tools that can assist in the economic analysis are:

- "Life-Cycle Costing Manual for the Federal Energy Management Program, " NIST *Handbook 135* (current version 1987), and
- NIST *Building Life-Cycle Cost* (BLCC) computer program, version 4.1 (1994).

Available by calling Advance Sciences, Inc., at (703) 243-4900. Also helpful is the document

Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense, NISTIR 4942-1 (current version 1994). Included in this document is a Memorandum of Agreement on *Criteria/Standards for Economic Analysis/Life Cycle Costing for MILCON Design,* dated March 18, 1991, which includes further information on the basic life-cycle analysis assumptions and criteria.

I.4.2.3 A recommended simplified economic analysis summary format is provided in Attachment 2 of this appendix. In using this form all costs are determined as of the date the analysis is made.

I.4.2.4 A LCC analysis for each overall project and for each discrete retrofit action (for example, storm windows, insulation, economizer) included within the project will be performed and included with the DD form 1391 project documents submitted for consideration. In preparing an analysis:

- base it on an economic life of 25 years or the anticipated life of the retrofit action or facility, whichever is less (Attachment 3);
- use the actual current cost of energy at the facility;
- for the purpose of ranking qualified projects, all discounted dollar savings (100 percent) will be used for computing the SIR;
- the estimated construction cost. labor and material costs, and the actual current unit costs of the energy at the facility analyzed (cost to the government, not stock fund prices) will be used as the basis for all LCC calculations.

I.4.3 Project Documentation

Project submittal will include the following.

I.4.3.1 DD Form 1391 with the normal MILCON line item detail. DD Form 1391 will include the notation ECIP at the beginning of the title block and a line item identification, description, location, current working estimate (CWE), total project SIR, annual dollar savings, and energy savings in million British thermal units (MBtu).

I.4.3.2 Classification of projects under one of the ten categories listed in Attachment 3. A project is classified in a category if 75 percent of the scope of the project falls into the category. Projects which do not contain 75 percent on any one category shall be identified as "Facility Energy Improvement."

I.4.3.3 A copy of all the life-cycle analyses for each discrete portion and for the overall project. Use the format provided in Attachment 2 for reporting the LCC analysis on DD Form 1391c.

I.4.3.4 Supporting documentation consisting of basic assumptions and basic engineering and economic calculations showing how savings were determined. Computer-generated summaries are acceptable, provided they conform to the above guidance.

I.4.3.5 Use metric units in support of the goals established under the Executive Order 12770 *Metric Usage in Federal Government Programs,* dated 25 July 1991.

I.4.3.6 Clearly defined conservation measures that will provide the energy savings and the specific facilities affected by the project.

I.4.3.7 A statement regarding whether or not the installation affected by the project is being considered for closure or realignment. If so, provide an explanation why the project should be considered in light of the closure or realignment.

I.4.3.8 A detailed statement on how you plan to verify savings after the project is operational/installed.

I.4.3.9 Electronic input via 'PDC,' consisting of the program initial input screen with Program Type - 'ECP' and PDP = ECIP, plus DD Form 1391.

I.4.4 Program Credibility
To maintain the program credibility of the ECIP and FEMP and provide and explain current project data which are not in agreement with data as approved by Congress, it is essential that documentation be diligently maintained by installations, MAJCOMS, and design and construction agents. This documentation should include, for example, scope and scope changes, design projections, and auditable trails of cost, cost avoidance, energy savings, SIRS, and simple amortization. Each level of command should assist in maintaining the audit trails to provide quick, positive responses to DoD and Congress.

I.4.5 Management Responsibilities
Each organization, within its area of responsibility, ensures:

- Projects are included in the ECIP and FEMP at a rate appropriate to accomplish the objectives of the National Energy Conservation Policy Act and the objectives of DoD criteria.

- All projects are designed and constructed within the original scope as submitted to Office of the Secretary of Defense (OSD) and Congress.
- Adherence to this guidance will not decrease the program efforts to continue accomplishment of all cost-effective, low cost/no cost, energy conservation actions which might serve to reduce the scope of an ECIP or FEMP project.
- Funds authorized and appropriated for ECIP and FEMP projects are not diverted or reprogrammed without specific approval from DoD.
- Savings estimates and program criteria compliance are recomputed, and reported to Systems Engineering Directorate Headquarters Civil Engineer Support Division (HQ AFCESA/EN), whenever scope, savings, or cost estimates are changed by more than ten percent.
- Readily auditable supporting documentation, including basic engineering and economic calculations, are maintained for each project.

I.4.6 Energy Savings Conversion Factors

For the purpose of calculating energy savings, use the following conversion factors:

Purchased electricity		
	3,413 Btu/kWh	3.6 MJ/kWh
Purchased steam		
	1,340 Btu/lb	1.41 MJ/lb
Distillate fuel oil		
	138,700 Btu/gal	38.6 MJ/L
Natural gas		
	1,031,000 Btu/ Cu ft	38.85 MJ/cu m
LPG, propane, butane		
	95,000 Btu/gal	24.6 MJ/L
Bituminous coal		
	24,580,000 Btu/ short ton	28,592 MJ/metric ton
Anthracite coal		
	25,400,000 Btu/ short ton	29,546 MJ/metric ton
Residual fuel oil		
	Average thermal content of oil at each installation	

I.4.6.1 Purchased energy is defined as being generated off-site. For special cases, where electric power or steam is obtained from on-site sources, use the actual average gross energy input to the generating plant.

I.4.6.2 The term "coal" does not include lignite. Where lignite is involved, use the Bureau of Mines average value for the source field.

I.4.7 PPP Documentation Process

PPP is a new program, being held to line-item approval through the Air Staff resource allocation process. As such, line-item validation and avocation by the appropriate Air Staff oversight office is required so they can provide advocacy for this program.

I.4.7.1 The required PPP documentation is included in the WIMS-Environmental System Pollution Prevention (WIMS-ES PP) module.

I.4.7.2 No new PPP requirements can be submitted to Prevention Division, Directorate of Environmental Quality, Headquarters U.S. Air Force (HQ USAF/CEVV) without a corresponding A-106 listing. The WINS-ES PP module includes additional data fields needed to manage projects.

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ATTACHMENT 1

MEMORANDUM OF AGREEMENT
ON
CRITERIA/STANDARDS FOR ECONOMIC ANALYSES/LIFE-CYCLE COSTING FOR MILCON DESIGN

I. PURPOSE

1.1 The purpose of this Memorandum of Agreement (MOA) is to establish criteria and standards for performing economic analyses and life-cycle cost studies used in support of design decisions for projects in the Military Construction (MILCON) Program (that is, to support the selection from various alternatives of components/systems being considered as elements in facilities design). These criteria and standards apply to all design decisions regardless of when they are made in the planning, programming, design, and procurement process. This agreement does not apply to economic analyses and life-cycle studies used to make project-justification decisions during the planning and programming process.

II GENERAL

2.1 Economic analyses shall be conducted as part of the design process to ensure that the selection/rejection of design alternatives is not based solely on construction costs, but also on least life-cycle costs (LCC), that is, lowest total cost of ownership. The depth and degree of formality of these analyses shall be determined on a case-by-case basis to ensure that the cost of performing an analysis is clearly outweighed by the potential benefits derived. Results of generic studies or results of previous analyses of alternatives similar to those currently under consideration may be used in lieu of performing a new study, provided the previous study was based on similar design conditions, criteria, and methods. Previous studies should be updated only as required to reflect changes of conditions significant enough to impact the design decision. All economic analyses and other justification for the selection of a design alternative, whether a previous study or a new one, shall be clearly documented in the appropriate section of the project design analysis.

III. METHODS

3.1 All analyses shall consider the total LCC for design alternatives, where the LCC includes all costs and benefits associated with an alternative over its expected life, including but not limited to construction/procurement, energy, maintenance, operation, repair, replacement, alteration, disposal costs, and retention values. The present value discounting approach shall be used to adjust for the differences in timing of costs and benefits unless otherwise specified by other directives or by public law. The basic discount factor for finding the present value of a future amount is calculated as follows:

$$\text{Discount Factor} = \frac{1}{(1 + d)^{n}}$$

where: d = appropriate discount rate, and
n = the time period over which the discounting is done.

Discounting should be applied to all costs and benefits over the appropriate analysis period. Specific criteria include:

a) **Discount Rates:** The discount rates are expressed in "real" terms (i.e., over and above the rate of inflation for the economy as a whole).

1) **Nonenergy-Related Studies:** An annual "real" discount rate of 10 percent should be used in evaluating all nonenergy-related economic studies.

2) Energy-Related Studies: All energy-related economic studies (studies in which energy costs are relevant, regardless of their magnitude relative to other costs) shall use the current discount rate published by the National Institute of Standards and Technology (NIST) in their annual supplement to NIST Handbook 135 and disseminated by the appropriate Service Headquarters Office.

b) Analysis Period: The analysis period shall be the date of the study (DOS) through the economic life of the facility as a whole. The economic life shall not be taken beyond 25 years from the scheduled beneficial occupancy date (BOD) for the project unless specifically approved by the appropriate Service Headquarters Office. Such approval cannot be granted for energy-related studies as it is precluded by statute.

c) Cash Flow: In general, cash flow used in the analysis will be based on the estimated calendar dates on which the events and costs/benefits are projected/scheduled to occur. Construction/procurement costs may be assumed to be incurred as a single lump sum, preferably at the time corresponding to the midpoint of the construction/procurement process. Other cash flows that occur periodically throughout the year (for example, cost of fuel, electricity, water, maintenance) may be assumed to be incurred as a single lump sum, preferably at midyear. In the circumstances where the above assumptions add unnecessarily to the complexity of the calculations, all cash flows maybe assumed to occur at the end of the year in which they are actually scheduled/projected to occur.

d) **Benefits and Costs:** All benefits and costs will be expressed in terms of constant dollars that reflect the purchasing power of the dollar on the DOS (i.e., constant DOS dollars). The rate of inflation of the economy as a whole will be excluded from all LCC calculations. (The rate of inflation is irrelevant to the LCC analysis results since all benefits and costs are expressed in terms of constant DOS dollars and discounted using a "real" discount rate which reflects the time value of money over-and-above the general rate of inflation.)

e) **Future Benefits and Costs:** In projecting future benefits and costs, an allowance for future price-level changes will be made only for particular benefits and costs expected to change at rates higher or lower than the general rate of inflation. In such cases, the rates of change used in the analysis will be the "differential" rates (i.e., the anticipated differences between the actual projected rates of change and the general inflation rate).

1) **Nonenergy Studies:** For nonenergy studies, the differential rate of future price-level change shall generally be assumed to be zero, except in those cases where there is reliable information/data to the contrary.

2) **Energy Studies:** Fuel/energy costs shall have differential escalation rates as published by NIST in Handbook 135 and disseminated as indicated in paragraph 3.1.a (2) above. All nonenergy costs shall have a zero differential escalation rate.

IV. COMPUTER-AIDED CALCULATIONS

4.1 All computer-aided calculations for MILCON design economic studies will be accomplished using the Life-Cycle Cost In Design (LCCID), a computer program for economic analysis developed by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) or a version thereof which has been certified by CERL as equivalent.

signed
RICHARD C. ARMSTRONG
Chief Engineering Division
Directorate of Military Program
HQUSACE

signed
RUSSELL T. RESTON, Colonel
SAF/FMCE
HQ USAF

signed
H. ZIMMERMAN
Assistant Commander for
Engineering and Design
NAVFACENGCOM

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ATTACHMENT 2

LIFE-CYCLE COST ANALYSIS SUMMARY
Energy Conservation Investment Project (ECIP) Program

LOCATION: ________ REGION NO. ________ PROJECT NUMBER: ________
PROJECT TITLE: ________ FISCAL YEAR: ________
DISCRETE PORTION NAME: ________
ANALYSIS DATE: ________ ECONOMIC LIFE: ____ YEARS
PREPARED BY: ________

1. INVESTMENT
   A. CONSTRUCTION COST $______
   B. SIOH $______
   C. DESIGN COST $______
   D. SALVAGE VALUE COST $______
   E. TOTAL INVESTMENT (1A + lB + lC - lD) $______

2. ENERGY SAVINGS (+) / COST (-)
   ANALYSIS DATE, ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	UNIT COST $/MBtu (1)		SAVINGS MBtu/YR (2)		ANNUAL $ SAVINGS (3)		DISCOUNT FACTOR (4)		DISCOUNTED SAVINGS (5)
A. ELECT	$ ______	x	______	=	$ ______	x	______	=	$ ______
B. DIST	$ ______	x	______	=	$ ______	x	______	=	$ ______
C. RESID	$ ______	x	______	=	$ ______	x	______	=	$ ______
D. NAT G	$ ______	x	______	=	$ ______	x	______	=	$ ______
E. COAL	$ ______	x	______	=	$ ______	x	______	=	$ ______
F. TOTAL			______		$ ______				$ ______

3. NON-ENERGY SAVINGS (+) / COST (-)
   A. ANNUAL RECURRING (+/-) $______
      (1) DISCOUNT FACTOR (TABLE A) ______
      (2) DISCOUNTED SAVINGS/COST (3A X 3A1) $______

   B. NON-ENERGY SAVINGS (+)/COST (-)

ITEM	SAVINGS (+) COST (-) (1)	YEAR OF OCCUR (2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVING(+) COST (-) (4)
(1) ______	$ ______	______	______	$ ______
(2) ______	$ ______	______	______	$ ______
(3) ______	$ ______	______	______	$ ______
(4) TOTAL	$ ______			$ ______

   C. TOTAL NON-ENERGY SAVINGS (+)/COST (-) (3A2+3B44) $______

4. FIRST YEAR DOLLAR SAVINGS 2F3 +3A+(3B44/(YRS ECONOMIC LIFE)) $______

5. TOTAL NET DISCOUNTED SAVINGS (2F5 +3C) $______

6. SAVINGS TO INVESTMENT RATIO (SIR) = (5/1E) = ______

7. SIMPLE PAYBACK PERIOD (ESTIMATED) (SPB) = (lE/4) = ______

LOCATION: Price Support Ctr REGION NO. 2 PROJECT NUMBER: 38806
PROJECT TITLE: ECIP: Insulate Steam Lines FISCAL YEAR: YR1992
DISCRETE PORTION NAME: Insulate Warehouse Steam Distribution Lines
ANALYSIS DATE: AUG 1991 ECONOMIC LIFE: 25 YEARS
PREPARED BY: J. Hooten

1. INVESTMENT

A. CONSTRUCITON COST	$200,800
B. SIOH	$ 12,048
C. DESIGN COST	$ 12,048
D. SALVAGE VALUE COST	$
E. TOTAL INVESTMENT (1A + lB + lC - lD)	$224,896

2. ENERGY SAVINGS (+) / COST (-)
ANALYSIS DATE, ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	UNIT COST $/MBtu (1)	SAVINGS MBtu/YR (2)	ANNUAL $ SAVINGS (3)	DISCOUNT FACTOR (4)	DISCOUNTED SAVINGS (5)
A. ELEECT	$ 16.23	x 11 =	$ 179	x 15.85 =	$ 2,830
B. DIST	$	x =	$	x =	$
c. RESID	$ 6.61	x 27,919 =	$ 184,545	x 28.23 =	$ 5,209,694
D. NAT G	$	x =	$	x =	$
E. COAL	$	x =	$	x =	$
F. TOTAL		27,930	$ 184,724		$ 5,212,524

3. NON-ENERGY SAVINGS (+) / COST (-)

A. ANNUAL RECURRING (+/-)		$ 0
(1) DISCOUNT FACTOR (TABLE A)		
(2) DISCOUNTED SAVINGS/COST (3A X 3A1)		$

B. NON-ENERGY SAVINGS (+)/COST (-)

ITEM	SAVINGS (+) COST (-) (1)	YEAR OF OCCUR (2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVING(+) COST (-) (4)
(1)	$			$
(2)	$			$
(3)	$			$
(4) TOTAL	$			$

C. TOTAL NON-ENERGY SAVINGS (+)/COST (-) (3A2+3B44) $

4. FIRST YEAR DOLLAR SAVINGS 2F3 + 3A+ (3B44/(YRS ECONOMIC LIFE)) $ 184,724

5. TOTAL NET DISCOUNTED SAVINGS (2F5 +3C) $5212,524

6. SAVINGS TO INVESTMENT RATIO (SIR) = (5/lE) = 23.18

7. SIMPLE PAYBACK PERIOD (ESTIMATED) (SPB) = (lE/4) = 1.22

SAMPLE FORMAT
LIFE-CYCLE COST ANALYSIS FOR ENERGY CONSERVATION INVESTMENT PROGRAM PROJECTS

1992 38806 S REVISION DATE: 07 NOV 1991
MCA (AS OF 11/22/1991 AT 07:41:48) 09 AUG 1991
LFA= 1.08
DATE 09 AUG 1991 FY 92 PROGRAM
PROJECT NUMBER 38806
PROJECT. TITLE: ECIP: Insulate Stream Lines
INSTALLATION: Charles Melvin Price Spt Ctr
LOCATION: Illinois

SECTION 11- ECONOMIC ANALYSIS

11C CONSIDERATION OF ALTERNATIVES

Maintain Status Quo
Insulate Steam Distribution System

11D ECONOMIC JUSTIFICATION SUMMARY

Life-Cycle Cost Analysis Data Base

1. Investment costs were calculated using R. S. Means estimating publications. Total investment costs, including contingency and SIOH= $224,896

2. Energy savings were calculated using various energy conservation publications.

   a. Documents included:

      (1) Architects & Engineers Guide to Energy Conservation in Existing Building, DOE, 1979

      (2) ASHRAE Fundamentals, 1985

      (3) The 1975 Energy Management Guidebook, published by editors of Power Magazine, McGraw Hill Inc, NY, NY, 1975

   b. Distillate fuel oil will not be affected by the project. Initial firing of the boilers uses #2 fuel oil. Firing up procedures at the beginning of the heating season will not change.

      Distillate fuel oil savings = O

   c. Residual fuel oil (#6 fuel oil) is the primary fuel used in the central heating plant steam distribution system.

      (1) Data base:

         (a) Boiler data -- temperature at 100 psi = 170° C (338° F), 80 psi = 162° C (324° F)

         (b) Assume average steam/condensate temperature in the line = 116° (240°) to 121° C (250° F)

         (c) To be conservative, assume some of the lost heat from the pipes will find its way to the ground level, due to both the large amount of heat lost and the circulation built up by both the temperature gradient and the unit heater blowers. Assume 25 percent of the lost heat is returned to the floor level.

(2) Current situation -- No insulation on steam or condensate line in warehouse 2. No insulation on the condensate lines in warehouse 3. The steam line in warehouse 3 does have insulation installed.

(a) Heat loss calculations:

Q (bare) = T x L
where Q (bare) = bare pipe seasonal heat loss
HL = unit heat loss

T = 7-month heating season = 5040 hours
L = unit length of pipe

(b) Heat loss

Pipe Size	BtuH/10'	10' Lengths (L)	Q(MBtu/season)
1/2 in.	1125	226.8	1,285.956
3/4 in.	1350	154.0	1,047.816
1 1/2 in.	2300	226.8	2,629.066
2 1/2 in.	3250	913.7	14,966.406
4 in.	5160	446.4	11,609.257
6 in.	7360	12.0	445.133
	Total Q (bare = HL x T x L=		31,983.634

(3) Proposed Situation: Install 2 inches of insulation on all bare steam and condensate lines in warehouse 2 and 3.

(a) Heat loss calculations:

Pipe Size	BtuH/11	Length (LF)	Q(MBtu/season)
1/2 in.	12	2268	137.169
3/4 in.	13	1340	100.901
1 1/2 in.	20	2268	228.614
2 1/2 in.	26	9137	1,197.312
4 in.	55	4464	1,237.421
6 in.	75	120	45.360
	Total Q (insulated) = HL x T x L=		2,946.777

(4) Residual fuel savings = Q (bare) - Q (insulated)

Q (lost) = 31,983.634 MBtu/yr - 2,946.777 MBtu/yr = 29,036.857 MBtu/yr

Not all heat lost from the pipes will be lost to the facility. Even though the warehouses have high bays, we can assume 20 percent of the heat is recycled through the buildings.

Therefore, Q (lost) = 29,037 MBtu/year x 0.75 = 21,777 MBtu/yr.

Considering boiler efficiency of 78 percent, this equates to a residual fuel input equal to 21,777 MBtu/yr/0.78 = 27,919 MBtu/yr.

ATTACHMENT 3

ENERGY CONSERVATION PROJECT TYPES
(Recommended Economic Analysis Life)

Category	Title	Description
1.	EMCS or HVAC Controls (10 years)	Projects which centrally-control energy systems with the ability to automatically adjust temperature, shed electrical loads, control motor speeds, or adjust lighting intensities.
2.	Steam and Condensate Systems (15 years)	Projects to install condensate lines, cross connect lines, distribution system loops, repair or install insulation, and repair or install stream flow meters and controls.
3.	Boiler Plant Modifications (20 years)	Projects to upgrade or replace central boilers or ancillary equipment to improve overall plant efficiency; this includes fuel switching or dual fuel conversions.
4.	Heating, Ventilation, Air Conditioning (HVAC) (20 years)	Projects to install more energy-efficient heating, cooling, ventilation, or hot water heating equipment; this includes the HVAC distribution system (for example, ducts and pipes).
5.	Weatherization (25 years)	Projects improving the thermal envelope of a building; this includes building insulation (wall, roof, foundation, doors), windows, vestibules, earth berms, and shading.
6.	Lighting Systems (15 years)	Projects to install replacement lighting systems and controls; this would include day lighting, new fixtures, lamps, ballasts, photocells, motion sensors, IR sensors, light wells, and highly reflective paint.

ENERGY CONSERVATION PROJECT TYPES
(Recommended Economic Analysis Life)

Category	Title	Description
7.	Energy Recovery (20 years)	Projects to install heat systems exchangers, regenerators, or heat reclaim units, or recapture energy lost to the environment.
8.	Electrical Energy Systems (20 years)	Projects that will increase the energy efficiency of an electrical device or system or reduce costs by reducing peak demand.
9.	Solar Systems (10 years active) (20 years passive and PV)	Any project utilizing renewable energy; this includes active solar heating, cooling, hot water, industrial process heat, photovoltaic (PV), wind, biomass, geothermal, and passive solar applications.
10.	Facility Energy Improvements (20 years)	Multiple-category projects or those that do not fall into any other category.

Appendix J – Application of ASHRAE Equipment Room Design Requirements

ABSTRACT: This appendix discusses the mechanical equipment room design requirements for refrigeration systems covered by ASHRAE 15-1994, "Refrigerant Quality Rule 4". Specifically, this appendix discusses refrigeration system placement within the mechanical equipment room; ventilation requirements; doors, passageways and access; open flame devices; and pressure-relief piping.

J.1 Introduction

ETL 91-7 requires all new mechanical rooms be designed to meet the requirements of ASHRAE 15-1994. ETL 91-7 also requires existing mechanical rooms to be upgraded to comply with this standard when existing equipment is either retrofitted or replaced. ASHRAE 15-1994 defines a set of minimum requirements to ensure the safety of personnel working within equipment rooms. The standard also defines requirements that ensure the operability and maintainability of equipment located in equipment rooms. Most of the equipment rooms located in Air Force facilities will be subjected to ASHRAE 15-1994, "Refrigerant Quality Rule 4" due to the quantity and type of refrigerants encountered in these facilities. This rule applies to all low-probability systems, in all occupancy classifications, using either a Group Al or B1 refrigerant (see Table C-1, *Physical Properties of Refrigerants,* in Appendix C, *Refrigerant Storage Recommendations and Requirements).* Other mechanical equipment room operational requirements, such as safety equipment and placement of leak detection devices, are discussed in more detail in Appendix B, *Refrigerant Sensors and Monitoring of Equipment Rooms.*

J.2 Refrigeration System Placement

Placement of chillers in a mechanical equipment room depends on various factors, including:

- access for service work,
- proximity to other equipment in the mechanical equipment room, and
- air flow through the mechanical equipment room for ventilation.

Clearances should be considered as minimum requirements for normal operation, maintenance, service, and repair of equipment. ASHRAE 15-1994 calls for clear head room of 7.25 feet below equipment situated over passageways. This requirement is designed to prevent piping and equipment from being installed in a location which will constitute a physical hazard to people or equipment moving through aisleways. While these clearances are generally the guiding factor for positioning the chillers in the mechanical equipment room, attention must also be paid to air flow patterns resulting from interaction of the ventilation system and the equipment in the mechanical equipment room to avoid areas of stagnation.

J.2.1 Chiller Placement

Chillers should be placed between the ventilation inlet and outlet and should not create areas of air stagnation. Figure J-1, *Multiple Chiller Equipment Room Layouts,* shows both good and bad examples of configurations for multiple chiller mechanical equipment rooms. Arrangement A in the figure is an example of how chillers should be placed, whereas Arrangement B exemplifies an arrangement which would create stagnant areas between the chillers.

J.3 Ventilation Volume Requirements

Mechanical equipment room volume requirements are covered in ASHRAE 15-1994. This standard splits ventilation air requirements into **Natural** and **Mechanical** ventilation based on location of the equipment.

J.3.1 Natural Ventilation

ASHRAE 15-1994 states:

> When a refrigeration system is located outdoors more than 20 feet from any building opening and is enclosed by a penthouse, lean-to or other open structure, natural ventilation may be employed as an alternative to mechanical ventilation.

The outdoor structure must not be connected to any occupied building by any means to include doorways, pipe tunnels or electrical conduit raceways, ventilation, or ductwork. Figure J-2, *Remote Mechanical Equipment Room,* shows an example of a remote mechanical equipment room.

J.3.1.1 ASHRAE 15-1994 also states:

> The free-aperture cross section for ventilating the machinery room should amount to at least:
>
> $F = G^{0.5}$
>
> Where:
>
> F = The free opening area in square feet.
>
> G = the weight of refrigerant in pounds in the largest system, any part of which is located in the machinery room.

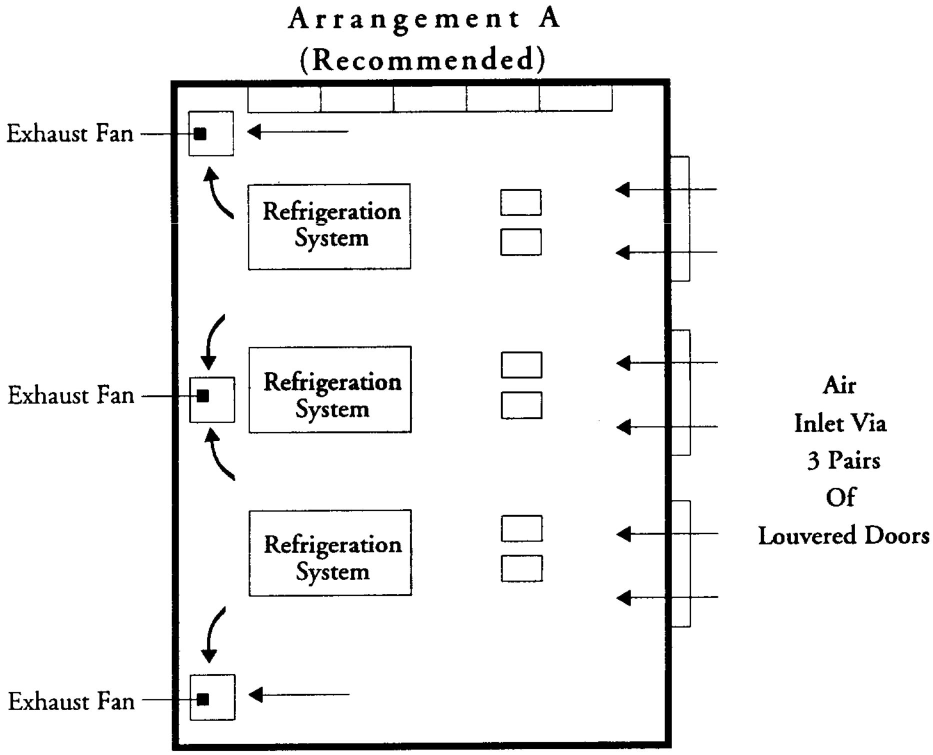
The location of the opening (or openings) shall consider the density of the refrigerant. For example: if the refrigerant in use is heavier than air (that is, the specific gravity of the refrigerant is greater than one) the opening(s) should be located at or close to floor level. If the refrigerant is lighter than air, the opening(s) should be located close to the ceiling of the mechanical room for maximum ventilation effect. As an example, consider a chiller with an 800 lb charge. The free opening area in square feet would be calculated as follows:

$F = 800^{0.5} = 28 \text{ ft}^2$

Thus, a five-foot by six-foot opening would slightly exceed this square footage requirement.

J.3.2 Mechanical Ventilation

When mechanical rooms do not meet the requirements described above as a natural ventilation system, then mechanical



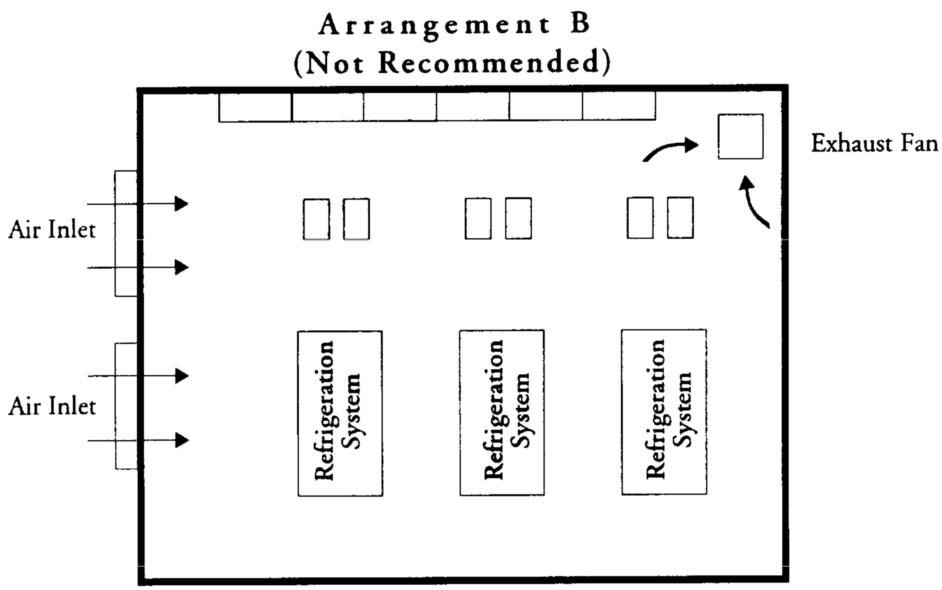


Figure J-1. Multiple Chiller Equipment Room Layouts

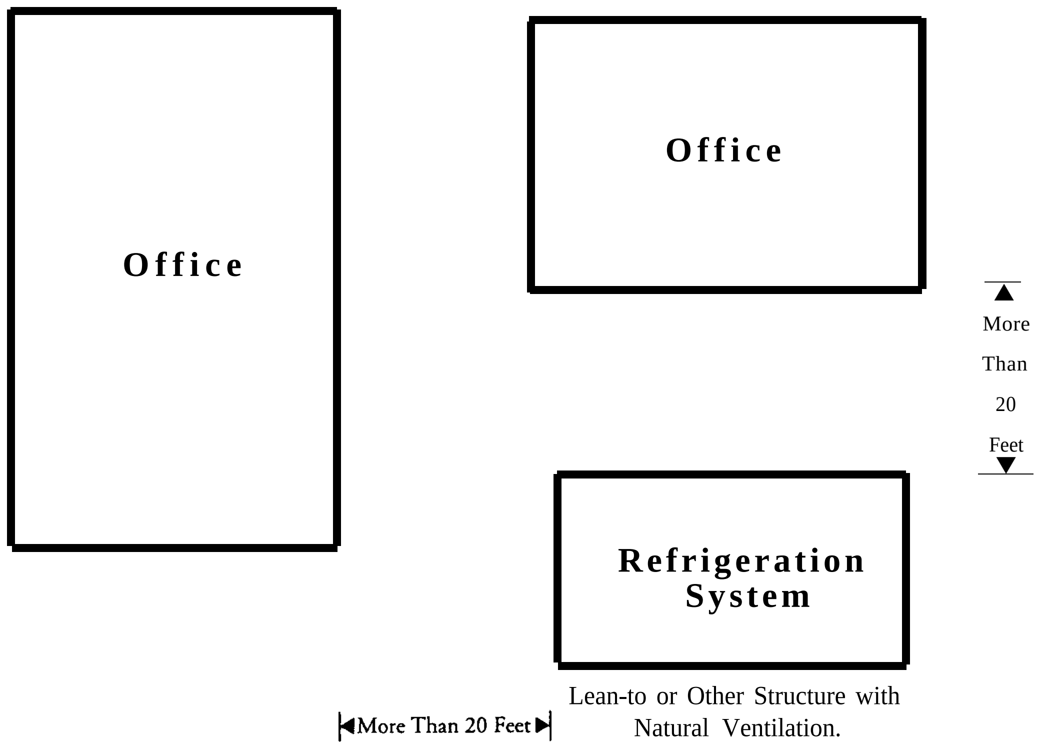


Figure J-2. Remote Mechanical Equipment Room

ventilation must be provided. ASHRAE 15-1994 states the following with respect to mechanical ventilation:

> . . . The minimum mechanical ventilation required to exhaust a potential accumulation of refrigerant due to leaks or a rupture of the system shall be capable of removing air from the machinery room in the following quantity:
>
> $Q = 100 \times G^{0.5}$
>
> Where:
>
> Q = the air flow in cubic feet per minute in purge mode
>
> G = the weight of refrigerant in pounds in the largest system, any part of which is located in the machinery room.

Using the same example charge of 800 lb, the air flow in cubic feet per minute would be calculated as follows:

Q = 100 x 800°5 = 2800 CFM

"Q" represents the minimum air flow the ventilation system must provide to purge the mechanical equipment room of refrigerant vapors. According to ASHRAE 15-1994, it is not necessary to continuously run the ventilation at this volume, provided:

a) Ventilation is provided when occupied at least at 0.5 cfm per square foot of machinery room area or 20 cfm per person; and,
b) Operable, if necessary for operator comfort, at a volume required to maintain a maximum temperature rise of -80 C (180 F) based on all of the heat-producing machinery in the room.
c) Mechanical room ventilation must also be designed to remove sensible heat loads generated by the equipment located in the room. This flow rate should be designed to maintain the temperature in the room no higher than -80 C (180 F) higher than the outdoor ambient temperature. Note that most electrical devices (motors, switchgear, for example) are designed to operate in an environment where the ambient temperature does not exceed 40° C (104° F). This requirement must be met whether or not the equipment room is occupied and may impose the requirement for higher ventilation flow rates than those required for dilution ventilation of refrigerant gases.

J.3.2.1 Two distinct ventilation rates are defined for the mechanical equipment room: (1) **normal ventilation** at a rate of 0.5 cfm per square foot (or more, if excessive heat is produced in the room), and is required any time the mechanical equipment room is occupied and (2) the **purge ventilation** rate, based on the weight of refrigerant in the refrigeration system.

J.3.2.2 If the mechanical equipment room is occupied, the ventilation system must be operated to provide the normal ventilation rate. This can be accomplished by running the fan continuously, starting it automatically by a motion detector, or by providing a fan switch near the mechanical equipment room entrance(s). If a switch is provided, a sign or other prompt should be used to indicate the requirement for ventilation during occupancy. A simple method of assuring operation of the purge ventilation system would be to interlock the ventilation system with the room lighting.

J.3.2.3 The purge ventilation rate is required whenever there is a build-up of refrigerant in the mechanical equipment room, as indicated by the refrigerant vapor monitor. Ventilation at purge volume must be automatically initiated by the monitor's alarm contacts. A switch for manual initiation is also suggested and should be located outside the main entrance to the mechanical equipment room.

J.3.2.4 A single ventilation system can be designed to serve both purge ventilation and normal ventilation requirements. If the normal ventilation flow rate requirements are higher than the purge ventilation flow rate requirements, no additional purge requirement is needed since the ventilation system will operate constantly when the room is occupied. If the purge ventilation flow rate is higher than the normal ventilation flow rate, two-speed fan motors, variable-speed fan motors, or additional exhaust fans can be employed to increase the flow rate from the normal ventilation flow rate to the purge ventilation flow rate when the mechanical room is occupied. Again, the initiation of this higher flow rate can be accomplished by the use of motion detectors or interlocks with area lighting circuits.

J.4 Location of Vents

Locations for the ventilation system's inlet and discharge must be properly positioned to provide efficient ventilation of the mechanical equipment room. ASHRAE 15-1994 generally addresses this requirement as follows:

> . . . The discharge of air shall be to the outdoors in such a manner as not to cause inconvenience or danger. Opening for supply air shall be positioned to avoid intake of exhaust air. Provision shall be made for supply air to replace that being exhausted. Air supply and exhaust ducts to the machinery room shall serve no other area.

J.4.1 Separate Ventilation System
The equipment room ventilation system must be separate from the systems that provide ventilation to other parts of the building. The fans and ductwork used to ventilate the equipment room must not supply any other part of the building, and the discharge must not interfere with any fresh air intakes. Because some of the fans may not run continuously, it is important to locate the discharge of each fan where it will not be inadvertently blocked while the fan is off. Make-up or outside air must be properly conditioned to avoid damage from large, rapid temperature swings or freezing temperatures.

J.4.2 Exhaust Fan Provides Purging
The exhaust fan must provide purging of refrigerant from the equipment room. To remove refrigerants, which are heavier than air, the exhaust fan inlet should be located near the equipment (if possible) and close to the floor, rather than at ceiling height. Refrigerants released into an equipment room tend to drop to the floor and fill the room from the bottom, unless disturbed by air turbulence. Maximum protection for equipment room occupants is provided when the intake of the exhaust

fan is located below the normal breathing zone as shown in Figure J-3. *Suggested Exhaust Fan Location.* It is important that the ventilation provide for an “air sweep” across all refrigeration equipment.

J.4.2.1 When exhaust fans are used to keep the equipment room cool or remove smoke from accidental fire, they are typically installed in the ceiling because heat and smoke both rise. However, if the ventilation system is used to exhaust refrigerants and remove heat or combustion products from the mechanical equipment room, provisions must be made for inlets at both floor and ceiling levels. This can be accomplished using either separate fans or a ducted fan with inlets at the floor and ceiling, as shown in Figure J-4, *Dual Duct Exhaust.*

J.4.2.2 The total ventilation volume required during refrigerant purging could come from the sum of both the ceiling and floor-level fans. However, to provide the most effective purge of refrigerant, the floor-level fan should be capable of meeting the calculated refrigerant purge rate. A ducted system can be used with or without flow control dampers. If dampers are used, they should be designed and controlled to provide maximum exhaust from the floor-level inlet when a refrigerant alarm condition is detected. The inlet to the fan should be located near the potential leak source and away from the fresh air intake. This arrangement will produce a sweeping action that draws fresh air across the leak source on its way to the exhaust fan.

J.4.2.3 Figure J-5, *Modifying an Existing Ventilation System,* is a sketch of a mechanical equipment room located in the comer of a building. In Arrangement A, ventilation is provided via six louvered service doors along one wall (fresh air inlet) and an exhaust fan mounted four feet above the floor in an adjacent wall. Continuous ventilation is provided at the refrigerant purge volume. While this arrangement provides adequate air movement past the chiller, it also creates a stagnant area in one comer of the room. Ducting the exhaust fan inlet across the opposite wall, as depicted by Arrangement B, would provide better air flow across the entire room.

J.5 Mechanical Equipment Room Doors, Passageways and Access

ASHRAE 15-1994 requires that:

> Each refrigerating machinery room shall have a tight fitting door or doors opening outward, self closing if they open into the building, and adequate in number to ensure freedom for persons to escape in an emergency. There shall be no openings, other than doors, that will permit passage of escaping refrigerant to other parts of the building.

Note that the louvered doors shown in Figure J-5 were used to provide the necessary service clearance for the chillers, and also to provide a direct exit to the outdoors. Access to the machinery room is specifically y restricted to authorized personnel by ASHRAE 15-1994.

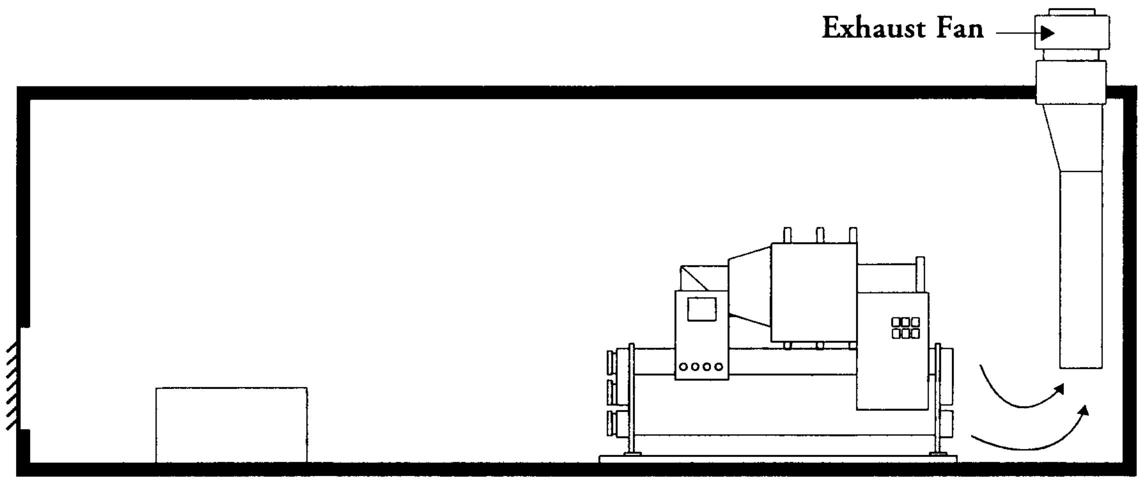


Figure J-3. Suggested Exhaust Fan Location

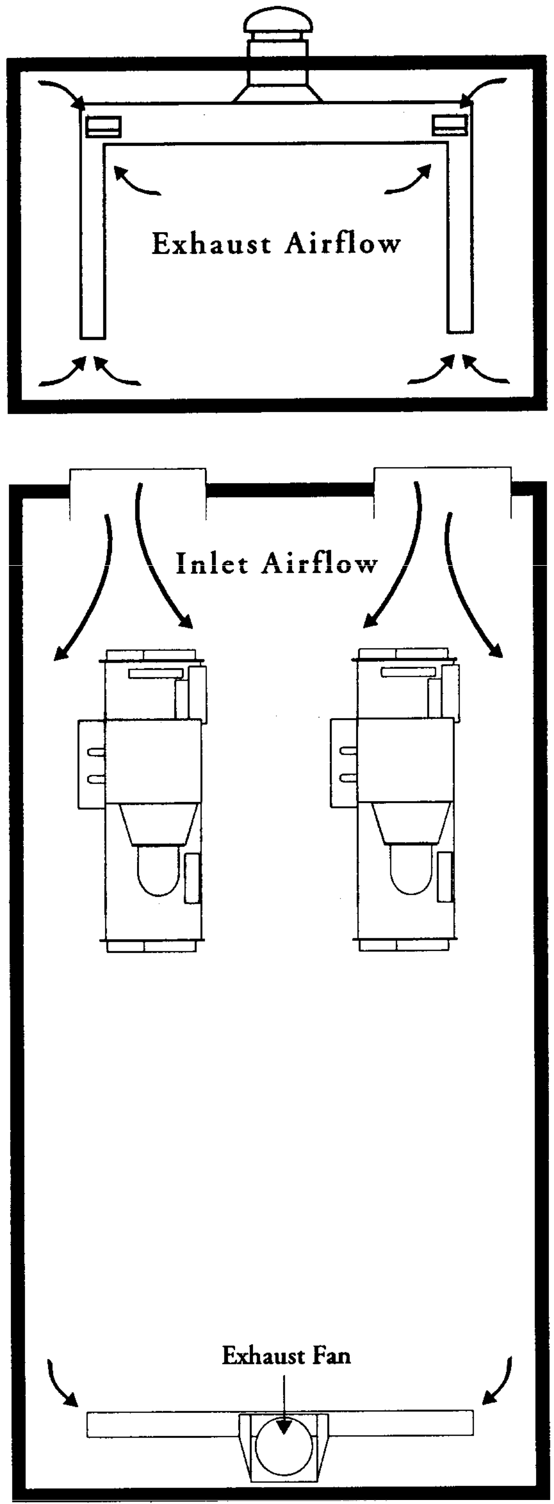
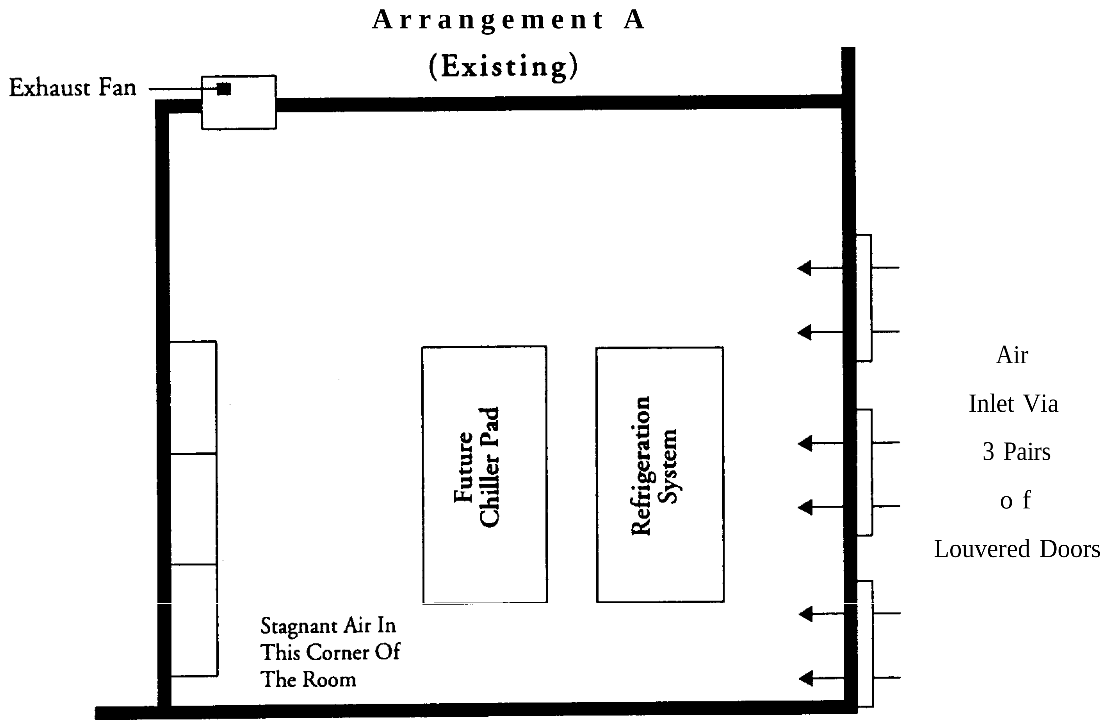


Figure J-4. Dual Duct Exhaust



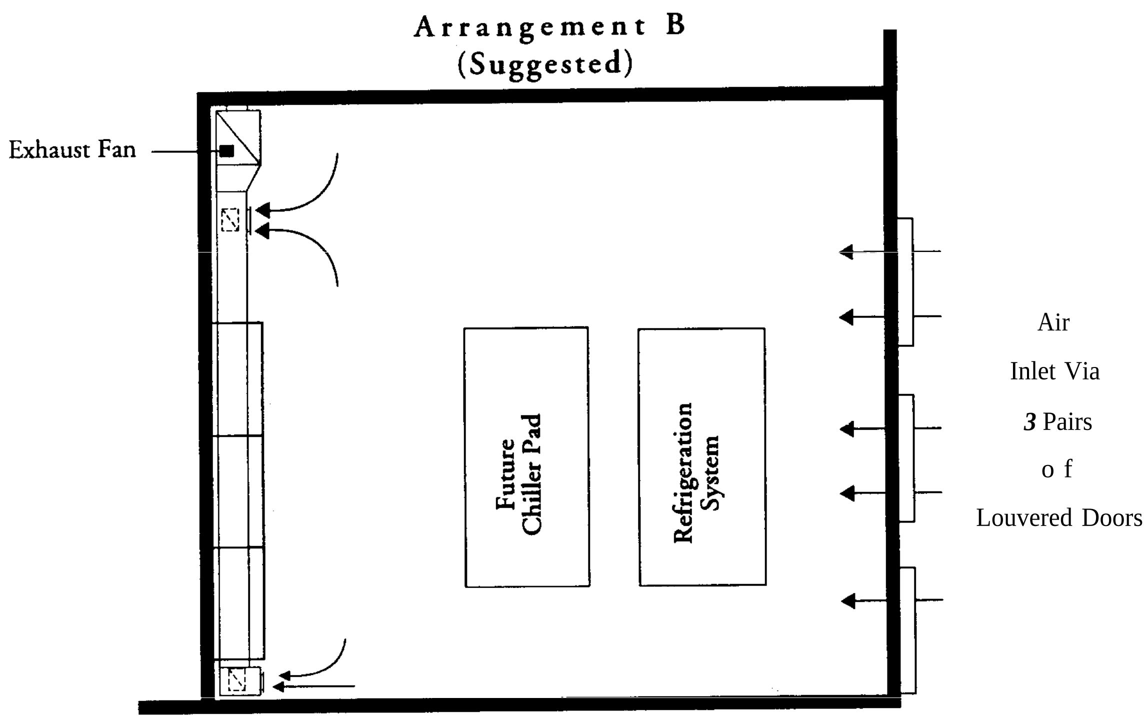


Figure J-5. Modifying An Existing Ventilation System

J. 6 Open Flame Devices

Where a mechanical equipment room contains a flame-producing device, as well as a refrigeration system, compliance with ASHRAE 15-1994 recommends:

- Ducting combustion air to the boiler from outside the equipment room to prevent air and refrigerants present in the equipment room from entering the boiler.
- Erecting a partition wall which will physically isolate the flame-producing device from the refrigerant-containing equipment, should space and egress path constraints permit.
- Using the refrigerant sensor to shut down the flame producing device should the equipment room concentration of refrigerant vapor exceed the refrigerant's Allowable Exposure Limit (AEL).

J. 7 Pressure-Relief Piping

ASHRAE 15-1994 contains these general requirements for pressure-relief

> Every refrigeration system shall be protected by a pressure-relief device or some other means designed to safely relieve pressure due to fire or other abnormal conditions.

ASHRAE 15-1994 also includes very specific descriptions for determining when pressure-relief devices are necessary and how to size them. The original equipment manufacturer generally provides such devices on packaged systems, as well as on the major components of systems that are built-up in the field. However, ASHRAE 15-1994 should be reviewed in all cases to ensure compliance with the standard.

J.7. 1 Piping Rupture Devices
Once the equipment is installed, each of the rupture devices must be piped to a safe location in accordance with the following guidelines from ASHRAE 15-1994:

> Pressure-relief devices and fusible plugs on any system containing a Group A3 or B2 refrigerant, and on any system containing more than 110 lb of a Group Al refrigerant shall discharge to the atmosphere at a location not less than 15 feet above the adjoining ground level and not less than 20 feet from any window, ventilation opening, or exit in any building. A list of A3 and B2 refrigerants can be found in Appendix B of this document. The discharge termination shall be fashioned in such a manner to prevent direct spray of discharged refrigerant on personnel in the vicinity and foreign material or debris from entering the discharge piping. Discharge piping connected to the discharge side of a fusible plug or rupture member shall have provisions to prevent plugging the pipe in the event the fusible plug or rupture member functions.

J.7.1.1 It is critical that the materials used in the pipe and joints of the relief device piping are compatible with the refrigerant that will be vented. Commonly used and acceptable materials include steel or copper pipe. Use of PVC piping is not recommended. Many adhesives employed in this type of piping construction have not been tested for refrigerant compatibility. Flexible connection devices used for vibration isolation must also be compatible with the vented refrigerant. A flexible stainless steel pump connector (or its equivalent) is recommended.

J.7.1.2 Vent pipes should also be equipped with a drip leg capable of holding up to one gallon of liquid. Provide a standard 1/4" FL x 1/4" NPT capped refrigerant service valve to facilitate liquid removal. Accumulated liquid should be removed from the drip leg on a regular maintenance schedule, at least once every six months. Use appropriate refrigerant oil handling procedures when draining the vent since refrigerant oil may be discharged in the exhaust from the purge unit. This oil may, over time, accumulate in the drip leg. An example of a correctly piped vent pipe is shown in Figure J-6, *Suggested Refrigerant Vent Piping. NOTE:* 1 gallon = 231 cubic inches. The following equation should be used to find the length "L," in inches, of pipe required for the drip leg:

$$L = 294/d^2$$

Where:

d = the inside diameter, in inches, of the pipe.

J.8 Purge Discharge

Purge units used to remove noncondensable gas from the refrigeration system should have discharge lines piped according to the requirements for relief piping. Generally, the most convenient way to properly exhaust the purge discharge to the atmosphere is to route it into the valve (rupture disc) vent pipe, The purge discharge line must not contain any liquid traps and should be sloped away from the purge unit to prevent liquid from collecting at the purge unit. Additionally, care should be taken to ensure that no liquid from the purge discharge can collect at the pressure-relief valve or rupture disc. Connect the purge discharge pipe on the chiller side of any vibration isolation as shown in Figure J-6. Consult the manufacturer of the purge equipment for proper sizing of the purge discharge line.

J.8.1 Minimize Loss

Purge-related refrigerant loss should be kept as low as possible to minimize refrigerant discharge to the atmosphere and avoid the expense of replacing lost refrigerant. To minimize purge-related refrigerant loss:

- Choose a purge unit with a low refrigerant-to-noncondensable-gas discharge ratio that can operate while the chiller is off. The Environmental Protection Agency (EPA) has not established a definition of "high efficiency" as it applies to purge units. However, several units are now commercially available which are capable of achieving 0.0005 pounds of refrigerant discharged per pound of air purged. See Appendix E, *Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air Conditioning and Refrigeration Systems,* for a more detailed discussion of purge systems.
- Routinely monitor the refrigeration system for leaks and properly repair any that are found. Routine logging of purge operation and chiller run-time provides an excellent indicator of system integrity.

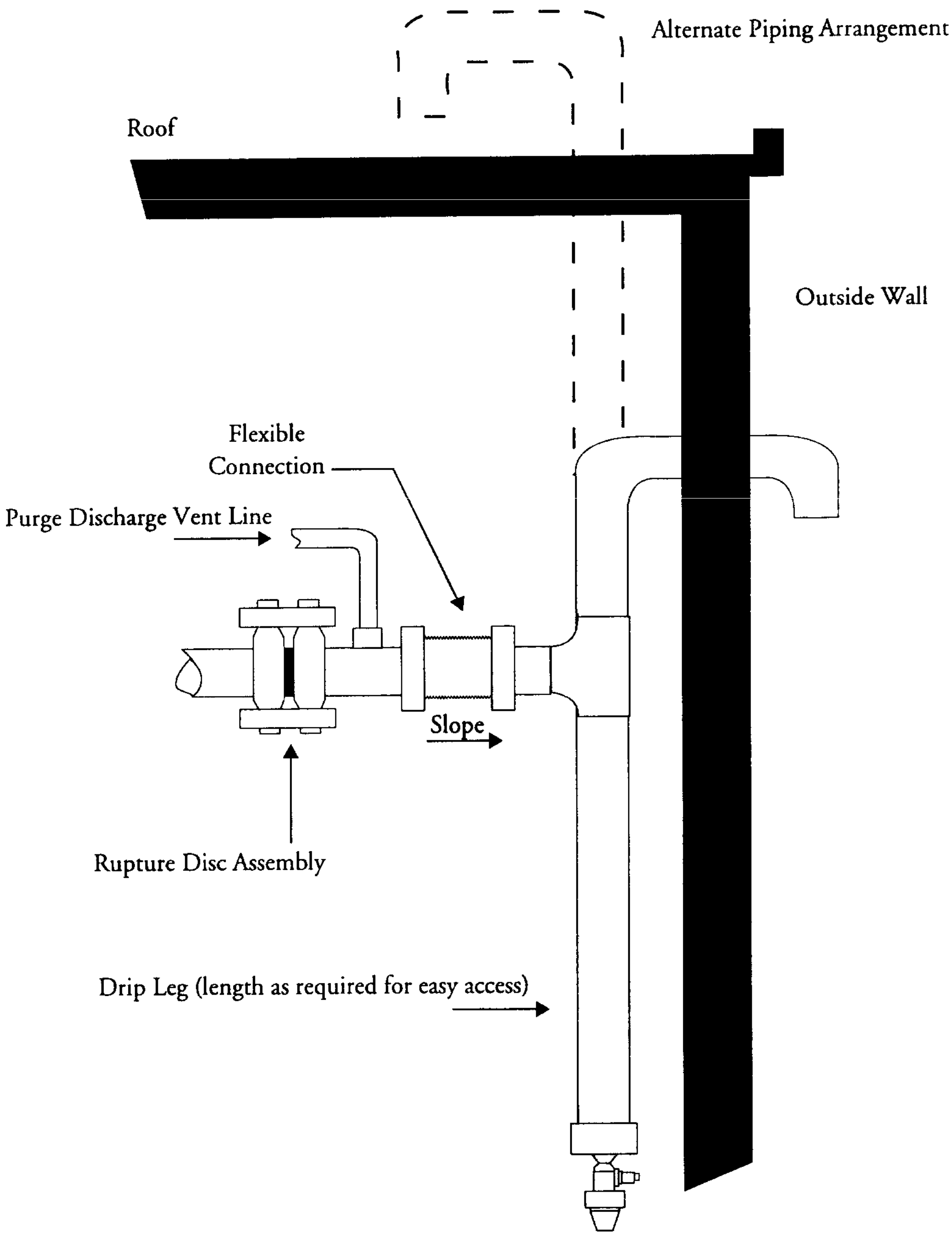


Figure J-6. Suggested Refrigerant Vent Piping

J. 9 Occupied Space Contamination

ASHRAE 15-1994 requires all access panels in ductwork or air handling equipment located in a mechanical equipment room containing refrigeration equipment to be sealed and gasketed. This will prevent the possible spread of refrigerant vapor to the occupied space of the building in case of a catastrophic refrigerant loss.

Appendix K — AC/R Energy Conservation Devices

ABSTRACT: The Air Force objective is cost reduction through energy conservation and improved energy efficiency whenever possible. This appendix explores energy conservation devices, and their application to both new and existing air conditioning and refrigeration (AC/R) systems.

K.1 Introduction

The phase-out of ozone-depleting compounds (ODC) will result in the systematic replacement of existing refrigeration equipment. The replacements will be either new equipment using alternative refrigerants or the retrofit of existing equipment to allow the use of alternative refrigerants. During this period of replacement and retrofit, numerous opportunities will arise to specify and install devices to enhance the energy efficiency of these new and retrofitted units. This appendix describes several devices which may be considered for installation and explains how they affect the performance of refrigerant systems.

K.2 Conservation Devices

The following is a list of refrigeration accessories that should be considered when retrofitting or replacing an existing air conditioning (A/C) system. These items have been proven to increase, to some extent, the efficiency of a typical refrigeration cycle. The original equipment manufacturer (OEM) should be contacted when considering each of these devices:

- desuperheaters,
- liquid-suction heat exchangers,
- variable speed motor drives,
- liquid subcoolers,
- plate and frame heat exchangers, and
- liquid pressure amplification.

K.2.1 Desuperheaters

The primary function of a desuperheater (sometimes referred to as a gas intercooler) is to recover waste heat normally rejected by the A/C equipment and use it to heat domestic or process water.

K.2.1.1 The energy savings are significant. A typical 40-ton, air-cooled system can heat 192 gallons of water per hour. If the 40-ton load is continuous and the electrical rate is five cents per kWh, a desuperheater can save $37 per day, or $4,400 over 120 days of operation.

K.2.1.2 Desuperheaters are most commonly used in direct expansion systems that range in size from 10 to 100 tons. They can be used on a variety of equipment such as: rooftop units, split systems, self-contained units, and air-cooled condensing units.

K.2.1.3 A desuperheater is simply a heat exchanger designed to transfer heat from the superheated refrigerant vapor downstream of the compressor to a water stream. This heated water can be used for domestic hot water or for space or process heating.

K.2.1.4 Some special considerations exist in the application of desuperheaters. Local plumbing codes may require double-walled heat exchangers or a secondary heat exchanger. They ensure a leak between the refrigerant and water side of the heat exchanger does not result in the contamination of the potable water supply. Local plumbing codes should be consulted to determine local requirements. Additionally, the physical location of the desuperheater and the water pipelines may be vulnerable to freezes. Heat tracing and pipe insulation may be necessary to prevent potential freeze damage.

K.2.1.5 Circulating distribution is used in applications that have a varying demand for hot water or a need for extra hot water. After being heated by the desuperheater, the water flows into a water storage tank. As long as the compressor is in operation, a pump continuously circulates water from the storage tank through the desuperheater, raising the water temperature with each pass.

K.2.1.6 Preheat distribution is used in applications with continuous compressor operation and a constant demand for hot water. Water flows directly from the desuperheater into the building's water heater.

K.2.1.7 The desuperheater is installed by placing it directly into the equipment's refrigerant piping system (in the hot gas line between the compressor and condenser). A minor adaptation to the hot water system is required, as well as a tap into the compressor discharge line. Depending on the application, the addition of a pump and water storage tank may also be required. Contact the OEM for more detailed information on desuperheaters for a specific application.

K.2.2 Liquid-Suction Heat Exchangers
Generally, liquid-suction heat exchangers subcool the liquid refrigerant and superheat the suction gas. They are used for one or more functions.

K.2.2.1 The efficiency of the thermodynamic cycle for certain halocarbon refrigerants can be increased when the suction gas is superheated by removing heat from the liquid. This increased efficiency must be evaluated against the effect of pressure drop through the suction side of the exchanger, forcing the compressor to operate at a lower suction pressure. Liquid-suction heat exchangers are most beneficial at low-suction temperatures. The increase in cycle efficiency for systems operating in the air-conditioning range (down to about 10 C (30° F) evaporating temperature) usually does not justify their use.

K.2.2.2 To subcool the liquid refrigerant to prevent flash gas at the expansion valve, the heat exchanger should be located near the condenser or receiver to achieve subcooling before pressure drop occurs.

K.2.2.3 In certain applications, small amounts of liquid refrigerant will return from the evaporator to the compressor. In these situations, a suction-line accumulator and liquid-suction heat exchanger arrangement can be installed to trap liquid floodbacks and slowly vaporize them. Heat pumps are susceptible to trapping liquid refrigerant in the compressor suction lines during the reversal of the refrigerant cycle. Additionally, if the design of an evaporator makes a deliberate slight overfeed of refrigerant necessary either to improve evaporator performance or to return oil out of the evaporator, a liquid-suction heat exchanger is needed to evaporate the refrigerant. This overfeed is controlled by adjusting thermostatic expansion values for minimal superheating of the refrigerant leaving the evaporator.

K.2.3 Variable Speed Motor Drives

Variable frequency motor drives operate by converting normal 60 Hz alternating electrical energy into direct current and, then, inverting the electricity back to an alternating wave form of variable frequency. This variable frequency electrical output allows the speed of a standard induction motor to vary with the change in the frequency of the output. Thus, energy-consuming devices such as pumps and fans can be easily converted to operate within a range of speeds, therefore, matching performance capabilities to dynamic operating conditions rather than at a single design point. The speed of centrifugal pumps and fans is directly proportional to the cube of the power input. A reduction to 50 percent of full speed equates to a corresponding reduction of input power to 12.5 percent of full-speed requirements.

K.2.3.1 Conventional, fixed-speed pumps and fans are "throttled" by control valves, dampers, or inlet-guide vanes. When centrifugal pumps, fans, and chillers service a wide range of flow rates, they operate much more efficiently when driven by variable speed drives at reduced flow conditions. The savings can be significant in applications such as hot water supply systems, chilled water supply systems, and variable air volume (VAV) distribution systems.

K.2.3.2 An additional benefit of a variable speed drive is to "soft start" large mechanical equipment. By starting motors at reduced speed, gradually increasing motor speeds to full operating condition, the dynamic torque induced in mechanical components during startup is reduced significantly.

K.2.4 Liquid Subcoolers

Subcooling is a term used to describe the cooling of a liquid refrigerant, at constant pressure, to a point below the temperature at which it was condensed. When a liquid refrigerant can be subcooled, either by cold water or by some other means external to the refrigeration cycle, the refrigerating effect of the system will be increased. The subcooler can be a coil or a loop of tubing immersed in a spray tank. It can also be additional surface on the air intake side of the condensing coil. The use of a desuperheater may result in subcooling of liquid refrigerant by allowing a portion of the condenser to function as a subcooler.

K.2.4.1 The effect of subcooling is illustrated in Figure K-1, *Pressure-Enthalpy Chart.* Refrigerant vapor is condensed at a temperature of 38° C (100° F), and point B represents subcooled liquid at 24° C (76° F). Liquid throttled from A to the

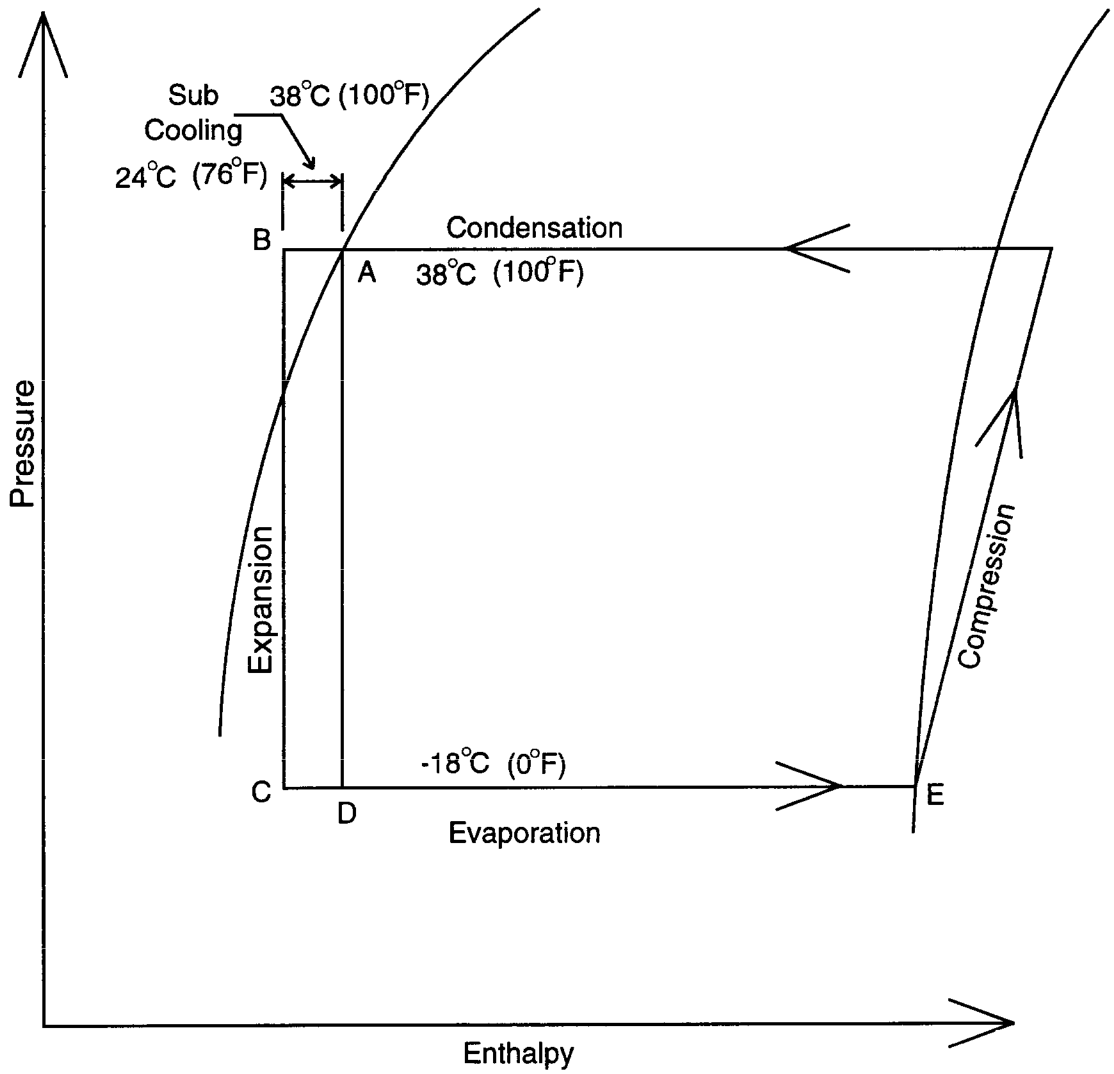


Figure K-1. Pressure-Enthalpy Chart

evaporator pressure will be at condition D, while C represents liquid throttled from point B. The refrigerant leaves the evaporator as saturated vapor at point E. The additional distance between C and D represents gained refrigeration capacity. The gain for this particular example can be shown to be over 11 percent of the original refrigeration effect. As a general rule, a one percent gain in system capacity can be anticipated for each -17° C (2° F) of liquid subcooling obtained from outside the refrigeration cycle.

K.2.5 Plate and Frame Heat Exchangers

A plate and frame heat exchanger consists of a number of pattern-embossed, gasketed channel plates held together in a frame. Every other channel plate is turned 180 degrees so the herringbone pattern gives rise to a lattice of contact points serving as supports for a complex system of channels. Gaskets are placed in grooves around the outer edge of the plate and around two of the punched holes in the comers of the plate. The plate spaces are screened off both from the atmosphere and from the adjacent spaces, enabling two different media to flow in two separate systems of channels in true countercurrent operation, completely separated from each other.

K.2.5.1 Fixed-surface plate and frame exchangers have no moving parts. Alternate layers of plates, separated and sealed (referred to as the heat exchanger core), form the heat-rejecting and heat-receiving fluid passages. Flat-plate heat exchangers (sometimes referred to as “plate and frame”) are considered to be the most efficient type of heat exchangers. The typical engineered performance allows the leaving temperature of the heated fluid stream to be within -17° C (1° F) of the entering temperature of the heat-rejecting fluid stream.

K.2.5.2 Simplicity and no moving parts add to the reliability, longevity, minimum pressure loss, and safe performance of these exchangers. The heat exchanger is designed to be easily dismantled and reassembled. For high-fouling media, the heat exchanger plates can easily be disassembled for cleaning to remove fouling which would inhibit heat transfer.

K.2.5.3 The number of plates in the heat exchanger can also be changed to enable it to work under different operating conditions. Plate and frame heat exchangers can be manufactured with channel plates of acid-resistant stainless steel or less reactive materials such as titanium and hastelloy. Standard gasket materials include Nitrile and EPDM, but other materials such as Viton can also be supplied. Frames are produced in mild steel and stainless steel versions.

K.2.5.4 Today, industry recognizes the plate and frame heat exchanger as the most efficient type of heat transfer equipment available. No other type of heat exchanger delivers the high thermal efficiency, easy maintenance, reduced fouling, low cost, and close approach temperature.

K.2.5.5 Plate and frame heat exchangers are often used for cooling tower isolation. For instance, hydronic heat pump systems (see Figure K-2, *Hydronic Heat Pump with Open Cooling Tower)* may use open circuit

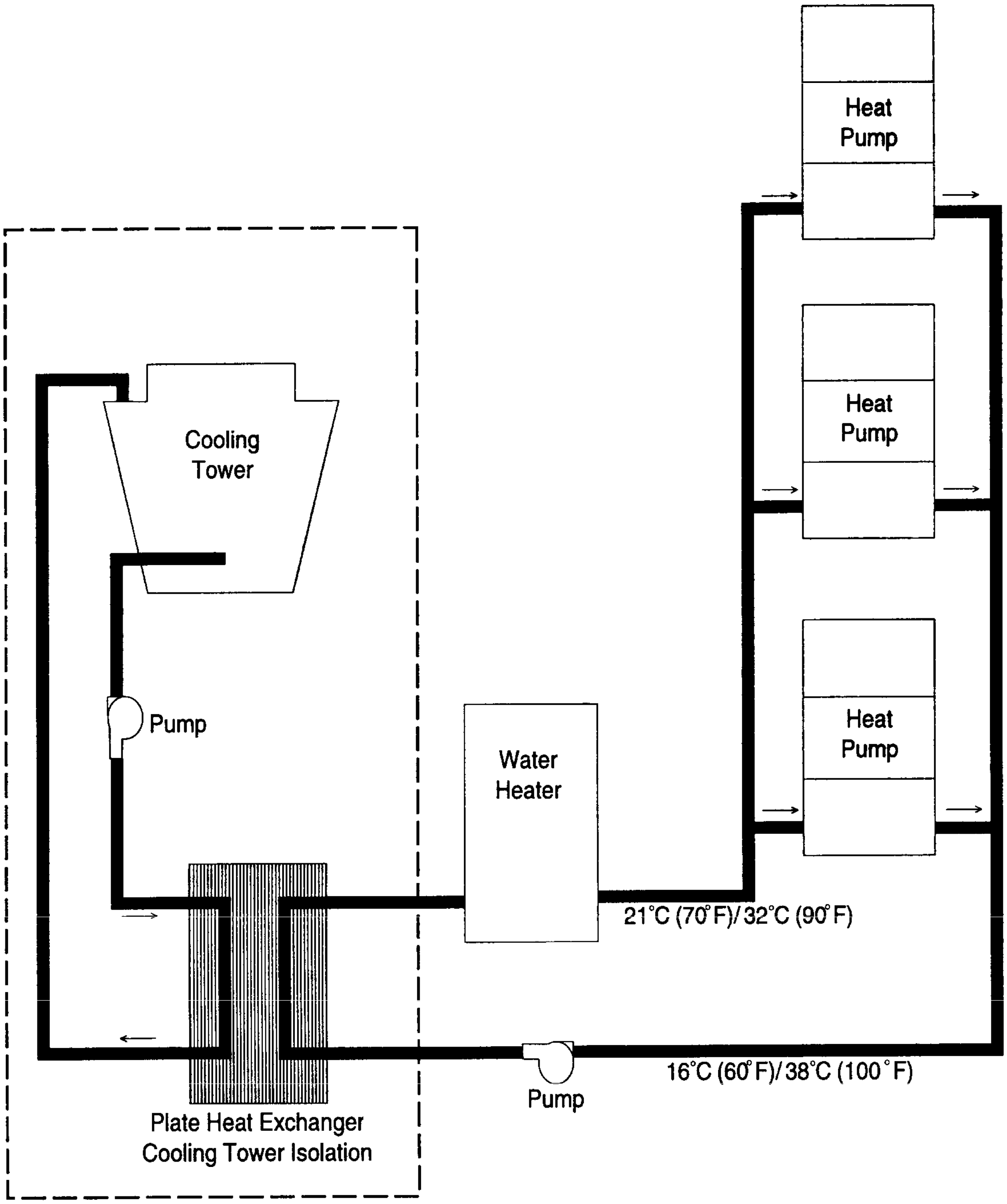


Figure K-2. Hydronic Heat Pump with Open Cooling Tower

cooling towers to reject heat when in the cooling mode. The size of their fluid passages make the individual water-side heat exchangers in the heat pumps subject to fouling by leaves, grass cuttings, and similar debris; the fouling can be controlled with minimal loss of thermal efficiency by using a plate and frame heat exchanger to isolate the water from the cooling tower side.

K.2.5.6 Plate and frame heat exchangers can also be used to allow an evaporative cooling tower to serve as a cooling source. Figure K-3, *Free Cooling (Water-Side Economizer) - Temperature Change,* and Figure K-4, *Free Cooling (Water-Side Economizer) - Flow Rate,* schematically represent two configurations of a chiller bypass system using condenser water to cool the chilled water stream by transferring heat using a flat-plate heat exchanger. To accomplish this, the chiller is bypassed and shut down, conserving significant energy and the cooling tower controls are reset to allow condenser water to be supplied at a lower temperature.

K.2.5.7 The evaporative cooling process, accomplished by a cooling tower, is limited by the wet bulb temperature of the ambient air. Theoretically, the condenser water can be cooled to equal the wet bulb temperature of the ambient air. As a practical matter, most evaporative cooling towers are only designed to cool the condenser water to within -15° C (5° F) to -14° C (6° F) of the ambient wet bulb temperature. Therefore, this type of arrangement has the capability to supply chilled water for space or process cooling load at a temperature from -14° C (6° F) to -13° C (8° F) above ambient wet bulb temperature using a plate and frame heat exchanger selected for a -17° C (1° F) to -17° C (2° F) approach. Figure K-3 represents a configuration with full chilled water flow at an elevated chilled water supply temperature. Figure K-4 represents the same system reset to supply chilled water at normal temperature at a reduced flow rate. Either of these configurations are feasible. The ability to use this type of system is only limited by the availability of suitable ambient wet bulb conditions, coincident with the need for chilled water.

K.2.5.8 Plate and frame heat exchangers are also used in thermal storage systems. This configuration, shown in Figure K-5, *Thermal Storage,* uses a plate and frame heat exchanger to isolate a circulated chilled water loop from a closed water loop circulating through cold water storage banks and a water chiller. The chiller controls have been set to produce a leaving water temperature of 3° C (38° F). This 3° C (38° F) water is stored in a water storage tank which, in effect, acts as a "thermal capacitor. " When demand for cooling is low, the chiller can continue to operate to cool this large mass of water. Eventually, both of the cool water storage tanks will be cooled to 3° C (38° F). When the cooling load rises, the 3° C (38° F) chilled water from the first tank will be supplied to the plate and frame heat exchanger where it will gain heat from the chilled water loop. It will be heated to a leaving temperature of 9° C (48° F), resulting in the cooling of the chilled water from 17° C (62° F) to 6° C (42° F). The 9° C (48° F) water leaving the heat exchanger will blend with the cold

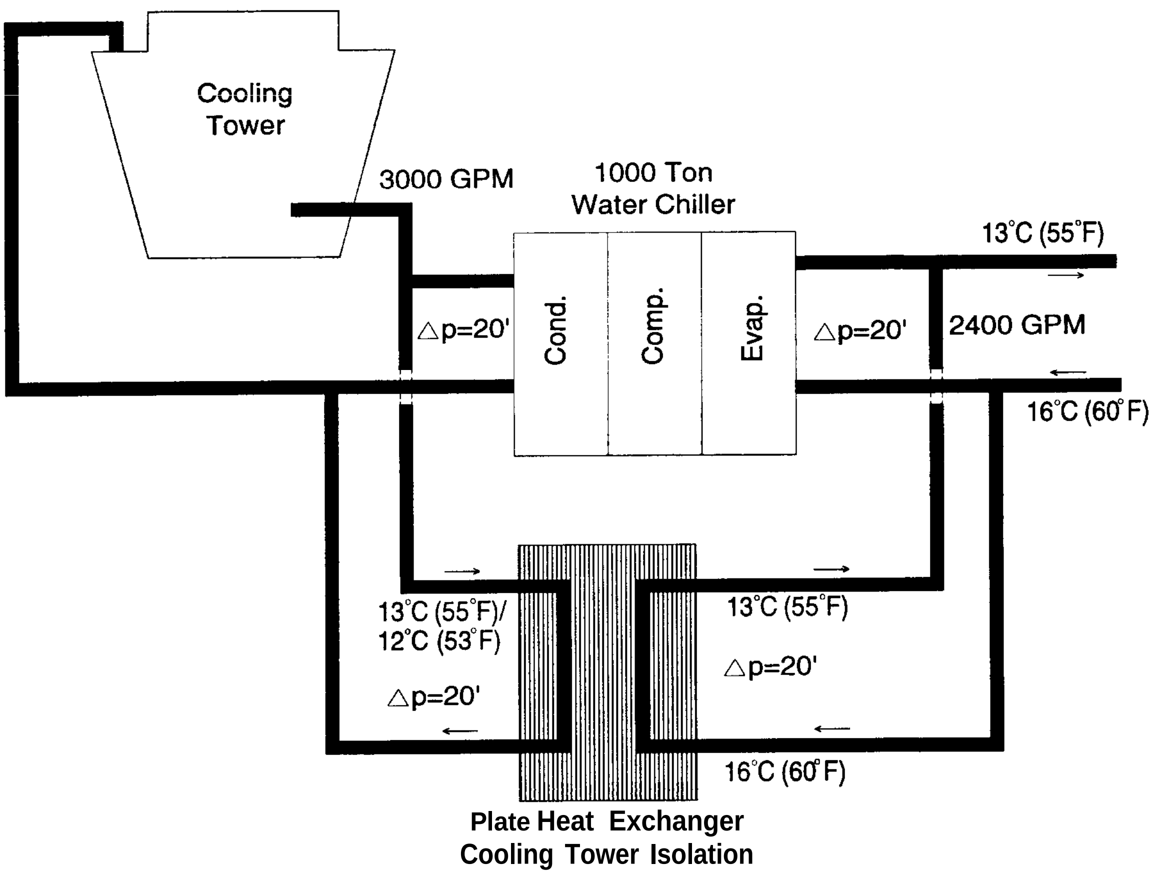


Figure K-3. Free Cooling (Water-Side Economizer) - Temperature Change

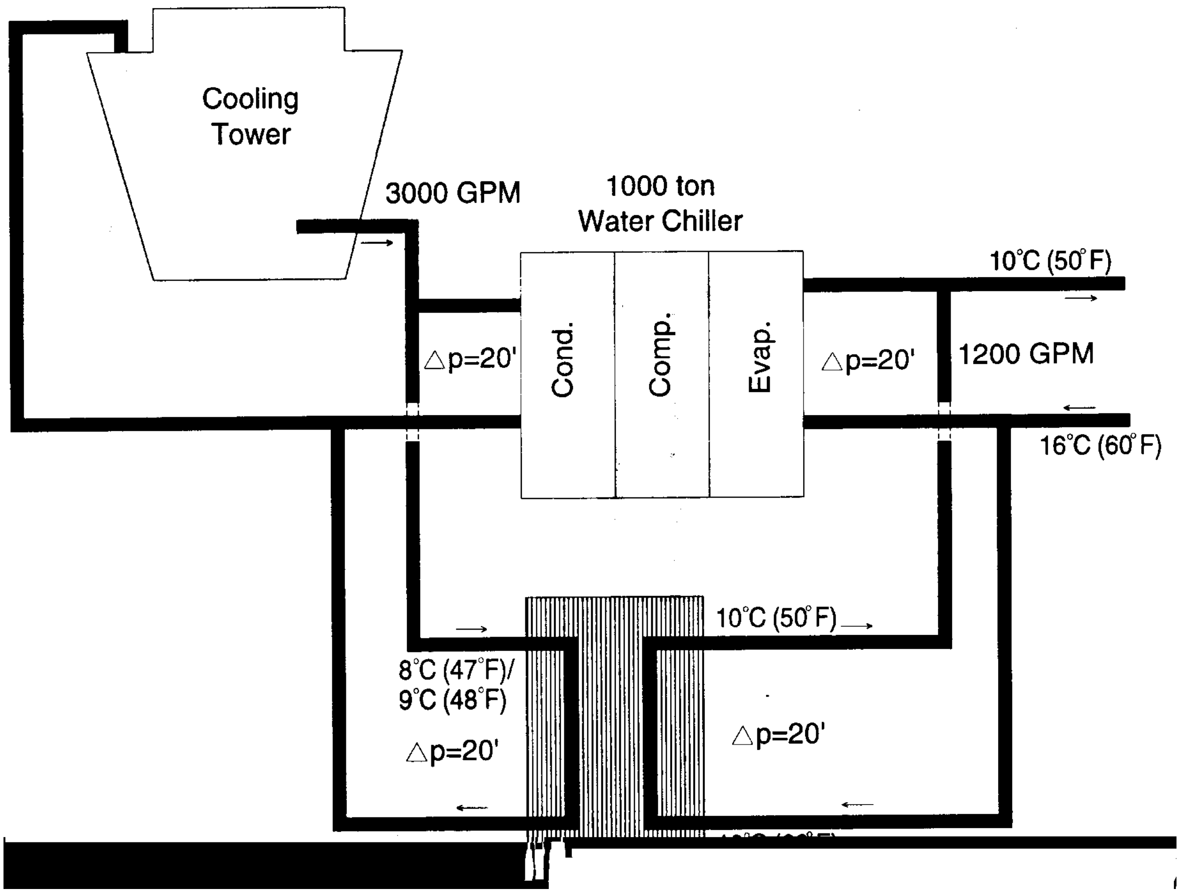


Plate Heat Exchanger
Cooling Tower Isolation

Figure K-4. Free Cooling (Water-Side Economizer) - Flow Rate

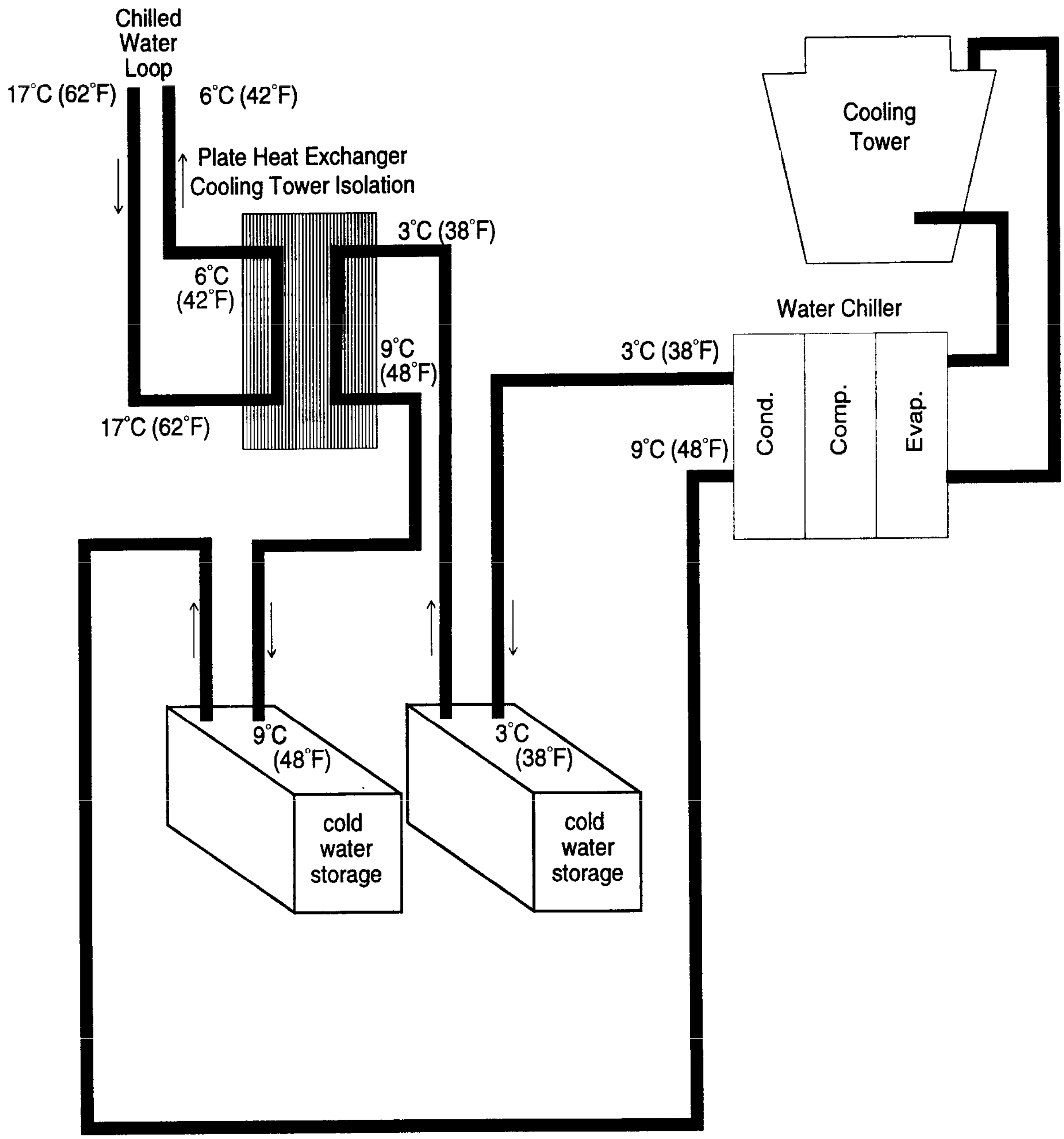


Figure K-5. Thermal Storage

water stored in the second cold water storage tank. The blended water from the second tank is recirculated to the chiller where it is again cooled to 3° C (38° F) before returning to the first cold water storage tank.

K.2.5.9 A thermal storage system like the one shown in Figure K-5 does not actually conserve energy. In fact, this type of system will actually consume more energy than a simple closed chilled water loop directly connected to a chiller. This is due to a loss in chiller efficiency resulting from the production of chilled water at a lower (3° C (38° F) versus 6° C (42° F) in this case) temperature water. Systems like this can, however, save energy dollars by cooling the thermal mass during off-rate peak-time periods. In many locations, local utility companies will charge significantly lower rates for electricity during off-peak hours. If the rate structure at a given base is structured in this way, sufficient energy dollars may be saved to make this a financially-attractive alternative.

K.2.5.10 Electrical utility companies have devised these off-peak rate structures to encourage consumers to use energy at times when the demand is low. Electricity produced to meet peak demands is often generated using natural gas-fired turbines. They are more expensive to operate than normal baseline sources (such as hydro-electric, nuclear, coal-fired).

K.2.5.11 Plate and frame heat exchangers can also be used as shown in Figure K-6, *Condenser Water Heat Recovery,* to recover waste heat energy from the discharge of a chiller cooling water stream. This scenario allows this waste heat energy to be recovered rather than be rejected at the cooling tower. Schemes like this are particularly viable in situations where large volumes of hot water are used, such as hospitals, cafeterias, and laundries.

K.2.6 Liquid Pressure Amplification
A significant amount of energy may be wasted if vapor is delivered to the expansion valve due to pressure losses in the liquid line from the condenser (for example, through hand valves, elbows, branch tees, and the pipe itself). Flash gas occurs when an undesirable mix of liquid and gas is triggered by these pressure losses. The effect of flash gas in a refrigeration system will reduce the cooling efficiency of the coil. Gas will occupy space within the pipe that would otherwise be occupied by the liquid.

K.2.6.1 In the past, this problem was avoided by raising the pressure of the refrigerant entering the liquid line. This was accomplished by increasing and maintaining a high pressure in the condenser. To do this, more energy input is required at the compressor and the overall cycle efficiency is lowered. A method has been designed to reduce power consumption and also provide a method of reducing the amount of “flash gas” in the liquid line by overcoming the pressure losses within the refrigeration system.

K.2.6.2 Liquid pressure amplification reduces “flash gas” in the liquid line by the installation of a small centrifugal pump in the liquid refrigerant line. The pump increases pressure to compensate for these pressure losses with very little power

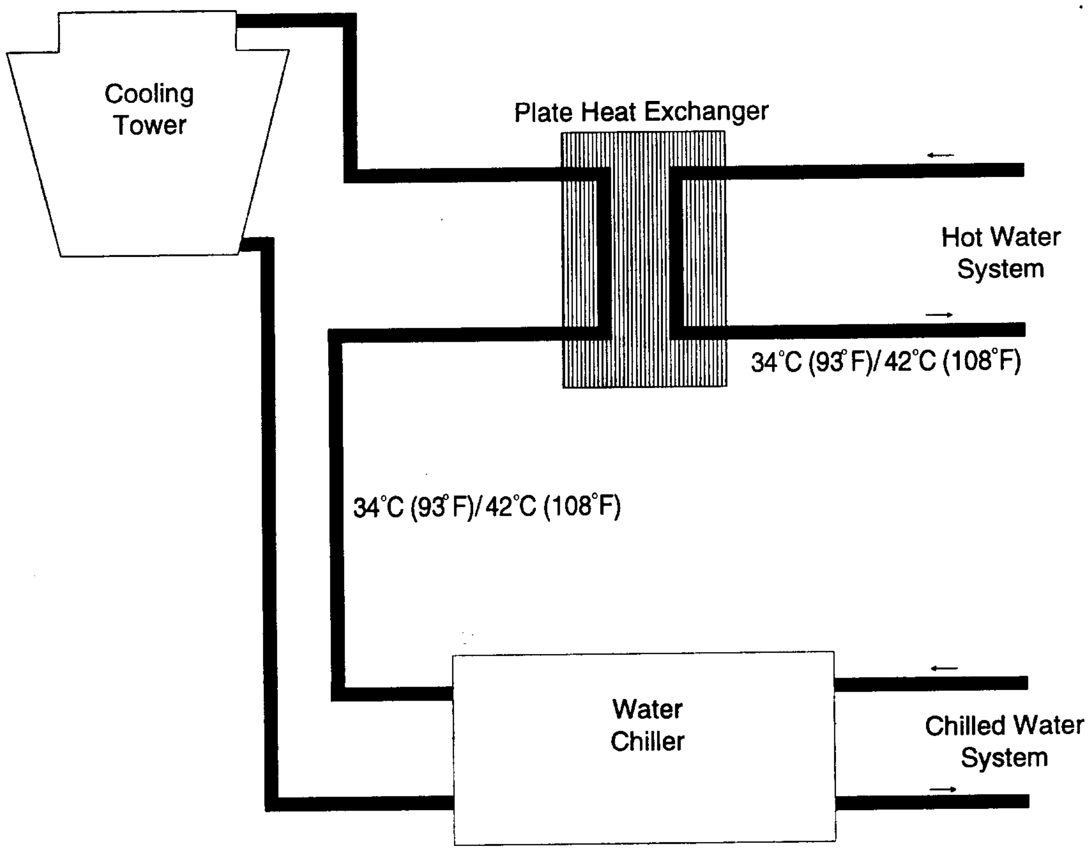


Figure K-6. Condenser Water Heat Recovery

consumption. When compared to elevating the discharge pressure of the compressor, this can cut energy costs up to 40 percent, thus increasing the system's working capacity. This type of system modification is particularly applicable to direct expansion systems where the liquid receiver is located at extreme distances from the evaporator or when the liquid refrigerant line is subjected to unusually high temperatures.

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Appendix L — Fundamentals of Cooling Load and Energy Analysis

ABSTRACT: This appendix outlines the process for analyzing a building's cooling load requirements and annual energy usage. An accurate and comprehensive cooling load and annual energy usage profile is the basis for a properly-sized and -selected chilled water system.

L.1 Introduction

Energy conservation measures and building function changes since the design of the existing cooling system may have changed the maximum required cooling load for the air conditioning equipment. Over the next five years, additional conservation measures may effect more changes. These changes must be kept in mind when targeting air-conditioning equipment for replacement or retrofit. The size of the equipment should be analyzed to correctly meet the demand of today and the future. Load and energy analyses are necessary for buildings that have undergone a significant change since the chiller serving the building was installed. If the building function has not changed, but the chiller is never fully loaded or is overloaded a substantial amount of the time, an analysis is needed to accurately size and economically select a new chiller. By performing a detailed cooling load and energy analysis, a clear understanding of the building's cooling needs can be determined. Accurate load matching of the chiller(s) will reduce initial capital cost and annual energy usage.

L.1.1 Building Survey

To properly analyze a building and determine its cooling load, a physical survey of the building is required. It is necessary to know:

- building material,
- type and quantity of heat-generating equipment,
- occupancy,
- orientation,
- air handling system types, and
- zoning.

This information is determined by both reviewing construction drawings and physically surveying the building.

L.1.2 Cooling Load Calculation

To determine the maximum cooling capacity required from the chiller, a building peak cooling load calculation must be performed. This type of analysis can be performed by following the guidelines . in the ASHRAE Handbook -1993, Chapter 26. Cooling load and energy analysis calculations range from the simple to complex.

L.1.3 Energy Analysis

An energy analysis determines the annual energy consumption, usually on an hourly basis. System part-load requirements can be summarized in a cooling load profile. These data are used to determine the best available alternative for cooling. The three elements that, together, define the annual energy usage are:

1) Space load - energy required to maintain thermal comfort in the space.
2) Equipment load - energy required by the equipment that distributes the heating or cooling medium to the conditioned space (for example, air handling units, pumps, fans).
3) Plant load - energy required by the central plant equipment that converts fuel or electricity to cooling effects (for example, chillers and cooling towers).

L.1.3.1 A cooling load profile provides information allowing optimization of the chiller selection. The profile will identify the amount of time the chiller is at 100 percent (peak), 75 percent, 50 percent, and 25 percent of full load. These values, along with energy cost data, are used to estimate the annual energy cost for the system. Because part-load efficiency varies between chiller types, these values should be used when selecting a chiller. Matching chiller characteristics to the load profile increases overall system efficiency.

L.1.4 Procedure

The following sections outline the basic steps to determine the design load and annual cooling load profile for a given building. This analysis determines:

- required capacity of the chiller(s),
- total annual energy usage, and
- the number of hours at part-load conditions, defined as 100 percent (peak), 75 percent, 50 percent, and 25 percent of peak load.

L.2 Conduct Building Survey

Before conducting the survey, obtain construction drawings of the building. While performing the physical survey, talk to the building occupants and a building manager or maintenance technician to obtain information not shown on the drawings. A building cooling load survey includes the activities listed and discussed below.

L.2.1 Indoor and Outdoor Conditions

Record the desired temperature and humidity for all spaces. These values may appear on the construction drawings, but they should be verified before proceeding.

L.2.2 Wall, Roof, Glass, and Partition Data

Record the construction, dimensions, and orientation. Shaded or glazed glass may have been added and should be noted. Much of this information can be found on the drawings, but a spot check should be performed to verify the information.

L.2.3 Occupancy

Record the number of people who occupy each space and the activity level they maintain. Determine the schedule of occupants, as it can impact the cooling load.

L.2.4 Lighting

Record the number of fixtures, type, watts/fixture, and the usage schedule, if applicable. Determine if fluorescent lighting system lamps or ballasts may have been upgraded from the original installation. Lower wattage lamps or new T-8 style lamps may have been installed. Remember that wattage ratings on T-8 lamps do not correlate with actual input power. For example, a four, 32-watt T-8 lamp fixture with ballast draws approximately 110 watts of power.

L.2.5 Other Internal Heat Sources

These sources include computers, monitors, photocopying machines, coffee makers, refrigerators, vending machines, and cooking equipment, among others. Record the number, type, and heat dissipated to the space. Consider both sensible and latent heat. This information can be determined from amp-meter readings or estimated from nameplate data. Use caution when taking nameplate data. These values are peak current requirements and may not represent steady-state current draw.

L.2.6 Ventilation

Measure and record the rate of the outside air entering the building through the air handling systems. Design values will probably be shown on the drawings, but if possible, the value(s) should be field verified. The ventilation quantity should conform to ASHRAE 62-1989 and any local requirements.

L.2.7 Infiltration

It is practically impossible to record infiltration rates; however, they can be estimated by surveying for inleakage and building pressure differences. A review and understanding of ASHRAE methods for estimating infiltration will allow an engineer to accurately survey an existing building.

L.2.8 System Operational Characteristics

Determine if:

- chiller(s) is(are) shutdown during the winter months and the shutdown period,
- air handling systems use air-side economizers,
- air handling systems use night setback or shutdown, and
- chiller(s) is(are) integrated with an operation schedule for duty cycling.

L.3 Conduct Cooling Load Calculation

The method used to determine the cooling load is detailed in ASHRAE Handbook - 1993, Chapter 26. The cooling load can be calculated manually for small buildings. Calculating the peak cooling load may also be estimated by taking measurements at the appropriate time on an existing system (see section L.3.3). A computer program should be used for large buildings.

L.3.1 Computer Software

Developing load calculations for buildings of moderate or greater complexity can become laborious. Using a computer program can be of great benefit. In addition to saving time, computer programs for large building analyses provide the additional calculations that would be impractical to perform manually. For example, the cooling load may be calculated for each hour of the design day so a load profile may be plotted for that particular day. Some energy calculations are simply an extension of the load calculation. The loads are calculated for each hour of each day of the year (or some representative sample) and building cooling loads are accumulated over an annual period.

L.3.1.1 A list of companies offering cooling load analysis software follow. Any computer programs used to conduct cooling calculations should use any of the ASHRAE methods.

Elite Software Development, Inc.
P.O. Drawer 1194
Bryan, TX 77806
(409) 846-2340

Carrier Air Conditioning Company
Syracuse, NY
(315) 432-6000

The Trane Company
Commercial Systems Group
3600 Pammel Creek Road
La Crosse, WI 54601-7599
(608) 787-2000

Simulation Research Group 90-3147
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720
(510) 486-5711

L.3.2 Simplified Cooling Load Calculation

The building maximum cooling load calculation is presented in a simplified manner in Figure L-1, *Cooling Load Calculation.* (Details of each equation are published in ASHRAE reference material directed at the novice as well as the experienced engineer.)

L.3.3 Measure/Validate Maximum Cooling Load

The calculated maximum cooling load may be validated by taking measurements on an existing system. For this method to be accurate, measurements should be taken on a day that closely represents a design cooling day (maximum load conditions). For most systems, the peak load occurs on a hot, humid, sunny day with full internal occupancy and equipment usage.

L.3.3.1 Peak cooling weather conditions are usually easily recognized. Be careful to consider the wet-bulb temperature. Internal conditions may be more difficult to identify, but can be accurately estimated. When design-day conditions occur, a measurement of chiller loading will define the maximum building cooling load. Measure and record:

- chiller voltage across all phases;
- chiller amperage readings of all phases;
- outdoor conditions at the time of readings (dry-bulb and wet-bulb temperatures, cloudiness, date, and time of day); and
- entering and leaving chilled water conditions and flow if available.

This information can be compared to the rated capacity of the chiller to determine maximum cooling load. For example, if the chiller is 95 percent loaded (electrically), then the actual heat transfer can be determined from the manufacturer's data. Alternatively, the chilled water flow, entering temperature, and leaving temperature will define the heat transfer in Btu/hr. by:

$$Q = \text{Flow (gal/min)} \times (T_{ENTERING} - T_{LEAVING}) \times 500$$

If desired, additional data may be compiled for part-load weather conditions to estimate the cooling load profile.

1) The overall building cooling load (Q) can be expressed as:

$$Q = Q_{SPACE} + Q_{RA} + Q_{SA}$$

Where:

Q_{SPACE} = heat gain to the conditioned space,
Q_{RA} = heat gain to the return air side of airflow,
Q_{SA} = heat gain to the supply side of airflow.

Each element of this equation may have both sensible and latent heat gain components.

2) Q_{SPACE} can be further defined as:

$$Q_{SPACE} = Q_{W\&R} + Q_{GLASS} + Q_{PAR} + Q_{INT}$$

Where:

$Q_{W\&R}$ = heat gain through walls and roofs, both conduction and solar effects
Q_{GLASS} = heat gain through glass, both conduction and solar effects
Q_{PAR} = heat gain through partitions,
Q_{INT} = heat gain internal to the apace.

The elements of this equation, with the exception of Q_{INT}, will have sensible heat components only. If the space under consideration has several zones (separately controlled areas), then Q_{SPACE} will be a summation of all zone space loads.

Furthermore, Q_{INT} can be expressed as:

$$Q_{INT} = Q_{PEOPLE} + Q_{LIGHTS} + Q_{EQUIP} + Q_{INFIL}$$

Where:

Q_{PEOPLE} = heat gain from people within the space,
Q_{LIGHTS} = heat gain from lighting within the space,
Q_{EQUIP} = heat gain from equipment within the space,
Q_{INFIL} = heat gain from infiltration.

Each element of this equation, with the exception of Q_{LIGHTS}, may have both sensible and latent heat gain components.

3) Heat gain to the return side of airflow can be expressed as:

$$Q_{RA} = Q_{PLENUM} + Q_{RAFAN} + Q_{VENT}$$

Where:

Q_{PLENUM} = heat gain to any return plenums or ductwork,
Q_{RAFAN} = heat gain from any return air fans and motors
Q_{VENT} = heat gain from fresh air ventilation.

Heat gain to return air plenums may include additional wall, roof, or floor heat gain, as well as a percentage of lighting heat gain. Heat gain to return air ductwork may also be present, although the significance is usually small.

Heat gain from fresh air ventilation is usually a very significant heat gain and should be carefully considered. Although minimizing the amount of outside air can reduce the cooling load, extreme caution must be exercised because of problems that may develop with indoor air quality. (For additional information regardiug indoor air quality, refer to ASHRAE 62-1989.)

Figure L-1. Cooling Load Calculation

4) Heat gain to the supply side of air flow may be expressed as:

$$Q_{SA} = Q_{PLENUM} + Q_{SAFAN}$$

Where:

Q_{PLENUM} = heat gain to any supply plenums or ductwork
Q_{SAFAN} = heat gain from the supply fan and motor

Heat gain to supply air plenums may include additional wall, roof, or floor heat gain. Heat gain to supply air ductwork may also be present, although the significance is usually small.

NOTE: For non-air systems (for example, packaged terminal air conditioners), Q_{SA} and Q_{RA} do not apply.

Figure L-1. Cooling Load Calculation (continued)

L.4 Perform Energy Analysis

The energy analysis determines how long, during a calendar year, the chiller is within certain ranges of its full load capacity. Knowing this information will assist the engineer in calculating energy costs for different chiller selection alternatives. Four ranges of operation are sufficient for most analyses. More ranges will provide additional accuracy. Energy calculations, especially computer-generated ones, will usually be able to output more than four; however, chiller performance is usually given at four points -25, 50, 75, and 100 percent of full-load capacity. In some cases, especially when evaluating a retrofit, the peak load will not equal 100 percent of the chiller capacity. When this is the case, the ranges describing the building's part-load requirements will have to be aligned to corresponding capacity ranges for the chiller under consideration. This type of adjustment also applies when multiple chillers are being used, such as in a central chilled water plant.

L.4.1 Types of Energy Analyses

There are several types of energy analyses, some of which are more complex (and accurate) than others. The degree-day and bin methods are simple and can be calculated manually. Both are accurate for performing an energy analysis on simple buildings. A dynamic method requiring the use of a computer program is essential for performing an energy analysis of complex buildings.

L.4.1.1 The degree-day method uses the concept of balance point. The balance point for a building is the outside temperature at which the rate of heat transmission to or from the building is zero. When outside temperatures are different than the balance point temperature, there will be some correlation between the temperature difference and energy usage. The accuracy of this type of calculation will vary based on the building's operational characteristics. The degree-day method works best when most of the load results from variations in the outdoor temperature.

L.4.1.2 The bin method uses the balance point concept, but breaks temperature data for a locality into ranges or bins. Typically, five-degree bins are used. Each bin will include the number of hours per year the locality experiences that particular temperature range. For example, Nashville will experience 650 hours of 10° C (50° F) to 12° C (54° F) conditions during a typical year.

L.4.1.2.1 The accuracy of the bin method is somewhat higher that the degree-day method. Hours are used as an increment instead of days. Because the balance point concept is used, the same problems will occur if the building load does not closely follow the outdoor temperature. Some enhancements exist for both the degree-day method and the bin method. The variable degree-day method and the modified bin method are attempts to adjust for variables such as solar gain, thermostat settings, and internal loads.

L.4.1.2.2 Heating and cooling degree days have been published for most localities. A source for this data is the Air Force Manual AFM88-29, Engineering Weather Data.

L.4.1.3 Although the simplified methods mentioned above can be accurate for simple buildings, they will not be acceptable for buildings of complexity (high internal loads and sophisticated system operational characteristics). Also, it is difficult to accurately predict energy consumption with simplified methods when the efficiency of the cooling or heating plant varies significantly with load. When simplified methods are not acceptable, a dynamic method simulating hourly load calculations, and system and plant interaction should be used. This method requires a computer program because of the complexity and repetitive nature of the calculations.

L.4.1.3.1 Energy analysis programs require the building to be modeled. The program will operate on the building model with hourly weather data to calculate cooling (and heating) load for each hour of the year. The resultant loads are related to the system model (for example, air handlers and VAV boxes) to determine energy requirements for the heating/cooling plant. The system energy requirements are then related to the plant model (for example, chillers and boilers) to determine ultimate energy usage. While these programs are very accurate and can simulate many types of systems and plants, they are complex and require a significant amount of time to learn and become proficient.

L.5 Establish Annual Cooling Load Profile

Once an hourly load profile has been developed, a simplified cooling load profile should be established. For example, the hourly load data can be grouped in ranges of O to 25 percent, 25 to 50 percent, 50 to 75 percent, and 75 to 100 percent of peak cooling load. The actual ranges used should be selected to coincide with known ranges of chiller efficiency. These hourly values will be used through the remainder of the chilled water system selection and comparison process.

L.5.1 Energy Conservation Impact on Chiller Selection

Energy conservation improvements can have a significant impact on the cooling load of a building. Improvements implemented within the previous five years and planned over the next five years must be considered. Conservation projects can reduce the required capacity of the retrofit or replacement chiller. In addition, if an energy conservation project can be tied into the replacement of an existing chiller, it is possible. to obtain Energy Conservation Investment Program/Federal Energy Management Program (ECIP/FEMP) funding for both. Future energy conservation projects may reduce the required chiller capacity. In the meantime, peak loads will still occur at existing levels. This situation must be addressed by the engineer. If a chiller is oversized, optimizing that chiller for the actual load when changing to a new refrigerant can result in significant first cost savings. A newly optimized retrofit may be comparable in efficiency to a new, high-efficiency chiller.

Appendix M — Evaluating Water Chillers for Replacement or Retrofit Potential

ABSTRACT: This appendix provides procedures and guidelines for evaluating replacement and retrofit alternatives for existing water chillers based on their age, mechanical condition, operating efficiency, and criticality to the building(s) or system(s) they serve. The decision to replace or retrofit a chiller is to be made based on comparing life-cycle costs (LCC) for both options.

M.1 Introduction

The purpose of this appendix is to describe a procedure for evaluating existing chlorofluorocarbon (CFC) water chillers for replacement or retrofit to environmentally-friendly refrigerants.

M.1.1 Assumptions

This analysis procedure assumes:

- The equipment inventory survey has been completed and the field survey data sheets are available for use in this analysis.
- The chiller life expectancy for all alternatives and the study life of the LCC analysis is 20 years.
- Any existing chiller older than 15 years is not to be considered for retrofit due to its limited remaining life and lower operating efficiencies common to chillers of that age.
- The building maximum cooling load and the building annual cooling load profile have been estimated by the procedure described in Appendix L, *Fundamentals of Cooling Load and Energy Analysis.*
- *The* interest (discount) rate used in the life-cycle cost analysis is obtained from *Energy Prices and Discount Factors for Life Cycle Cost Analysis* (NISTIR-3273-7, 1994), available from the National Institute of Standards and Technology (NISI'). The interest rate currently used for federal energy conservation projects is four percent (excluding inflation).

M.1.2 Applicability

This procedure is applicable to existing water chillers using CFC-11, CFC-12, CFC-113, CFC-114, CFC-115, and CFC-500 refrigerants.

M.2 Evaluation Procedure

The following six components will be evaluated:

1) age assessment;
2) load assessment;
3) original equipment manufacturer (OEM) analysis request;
4) new equipment data requests;
5) cost estimates for retrofit, new equipment, existing equipment/equipment room modifications; and
6) LCC analysis of alternatives selected.

In addition, chilled water systems located near other systems should be evaluated for potential central chilled water plant development (see Appendix O, *Assessing the Potential of Central Chilled Water Plants).*

M.2.1 Age Assessment
The age of a chiller may be obtained from the Work Information Management System (WIMS) Refrigerant Management Software, equipment survey forms, manufacturer's data, or from the manufacturer's local representative. If the chiller is more than 15 years old, it is probably too old for a cost-effective retrofit and should not be considered.

M.2.2 Load Assessment
The capacity of chiller replacements or retrofits should closely match the maximum building cooling load (estimated by procedures described in Appendix L, *Fundamentals of Cooling Load and Energy Analysis).* A change in chiller capacity will apply to situations where installed system capacity is oversized or where users have undertaken energy conservation project(s) reducing the cooling demand on the chiller.

M.2.2.1 There are two circumstances supporting the cost-effectiveness of a new chiller.

1) The capacity of the existing chiller exceeds the maximum system cooling load. In this situation, a smaller chiller can be installed, resulting in lower first-cost (replacement option), and likely lower operating costs.
2) The efficiency of the existing chiller is low (higher kW/ton) compared to chillers currently available. In this situation, a more efficient chiller can be installed which will result in lower operating costs.

M.2.2.2 Four conditions favor a retrofit.

1) The chiller has significant useful service life left, with newer chillers being the more favorable candidates.
2) The chiller requires repair. Retrofits accomplished at the time of scheduled repairs will be more cost-effective because some of the scheduled repairs will be performed as a result of the retrofit.
3) The chiller is servicing facilities/operations that cannot tolerate lengthy downtime of the cooling system. A retrofit may be accomplished sooner, and with less downtime, than replacement. In this situation, the cost of downtime may encourage a retrofit.
4) The chiller is relatively new and has been manufactured for ease of retrofit. In many cases, conversion will result in a loss of efficiency and/or capacity when a new refrigerant is installed. In most cases, it is most cost-effective to continue to operate the chiller (because of its high operating efficiencies) with the CFC refrigerant and take advantage of its efficiency as long as possible. Ensure it is equipped with a high-efficiency purge unit on low-pressure chillers (for example, CFC- 11 and CFC-113 machines).

M.2.3 OEM Analysis Request
Chillers less than 15 years of age should be analyzed for retrofit potential. Contact the OEM with regard to chillers of their manufacture. OEM analysis requests should be made only for chillers that are considered probable candidates for retrofit

because some manufacturers may charge for the analysis. Allow eight weeks lead-time in making requests because some manufacturers will have a backlog.

M.2.3.1 The OEM analysis should include performance data for a "drop-in" retrofit, a "maintained capacity" retrofit, a "maintained efficiency" retrofit, and "optimize to meet current cooling load" retrofit. A drop-in retrofit is the most basic of the four. The old refrigerant is replaced with new refrigerant and any changes necessary to accommodate the new refrigerant are made (for example, seals, lubricating oil). A maintained capacity retrofit includes all components of a drop-in retrofit, as well as any mechanical changes necessary to maintain the original refrigeration capacity. The maintained capacity retrofit typically results in a loss of efficiency. A maintained efficiency retrofit is similar to the maintained capacity retrofit, except the original efficiency of the chiller is maintained, typically at some loss of refrigeration capacity. The "optimize to meet current cooling load" retrofit optimizes by derating a chiller with excess capacity. This can result in greater efficiencies due to the large heat exchange areas in comparison to the load. Be aware that any or all four of these retrofit types can be accomplished for a chiller, but will not necessarily produce the required chilled water supply temperature or use the existing condenser water temperature. Therefore, be diligent to request the OEM analysis with specific water temperatures, not just capacity.

M.2.4 New Equipment Data Request

If chiller replacement is a viable option, a preliminary selection should be made. Refer to Appendix N, *Chiller Selection Guide,* for assistance in making this selection. More than one selection may need to be considered. Engineering data for new chillers should be requested from the local manufacturer's representative. The engineering data should, at a minimum, contain the chiller cost; design operating conditions (capacity and efficiency); part-load efficiency at 25, 50, and 75 percent of full-load capacity; and delivery time for each chiller.

M.2.5 Cost Estimates

Cost estimates must be prepared for the various options under consideration. Costs for chiller retrofit, equipment room modifications, new chillers, and related system modifications must be determined before an LCC analysis of all options can be completed.

M.2.5.1 The cost estimate for chiller replacement and retrofit options should include chillers, their components, and accessories. These estimates may be determined through manufacturer's representatives, construction cost estimating guides, or similar completed construction projects.

M.2.5.2 The work and cost required to modify mechanical rooms to comply with the ASHRAE 15-1994 must be determined. This cost is essentially identical for the replacement and retrofit options. Appendix J, *Application of ASHRAE Equipment Room Design Requirements,* contains a summary of ASHRAE 15-1994. Examples of these modifications include new or upgraded ventilation systems, refrigerant leak detection and monitoring systems, isolation from open-flame equipment, and piping of the refrigerant system relief and purge discharge to the outdoors.

M.2.5.3 A preliminary design of the entire system covering the cooling tower, and chilled water and condenser cooling water distribution systems may be necessary if a smaller replacement chiller is being considered. Budget pricing for the chiller may be obtained from one or more chiller manufacturers. Cost estimates for the rest of chiller plant components will be based on existing equipment that can be used as-is, existing equipment that will require some changes for reuse, and equipment that requires replacement.

M.2.6 LCC Analysis

Once the potential retrofit and replacement alternatives for the chiller have been reduced to a manageable number (two or three), it will be necessary to perform a detailed LCC analysis of these alternatives to select the one most cost-effective. The LCC analysis will require calculating the annual energy cost for each of the alternatives. This calculation method is described in the example in section M. 3.

M.3 Example of Evaluation

The following assumptions, figures, and tables provide the necessary information to assess whether an existing chiller should either be retrofitted or replaced. Table M-1, *Chiller Operating Profile,* summarizes the chiller operating profile for one year. Table M-2, *Chiller Part-Load Efficiencies and Initial Costs,* provides the chiller efficiencies and chiller costs for the various alternatives considered in this example. For this example, three alternatives, (1) a drop-in retrofit, (2) a same-capacity retrofit, and (3) a new unit will be considered feasible alternatives.

M.3.1 Assumptions

The following assumptions were made in developing the examples in this appendix.

M.3.1.1 From the utilities data sheets, the average energy cost is $0.051/kWh.

M.3.1.2 The estimated cost to upgrade the mechanical room to meet ASHRAE 15-1992 is $10,200.

M.3.2 Feasible Alternatives Energy **Cost ($ENERGY)**

The first step in the evaluation is to calculate the annual energy cost for all alternatives for retrofit or replacement. The calculations are shown in Figure M-1, *Calculate $ENERGY.*

M.3.3 Present Value ($PV) Formula

A review of the present value formula is presented prior to calculating the LCC of the feasible alternatives. This analysis assumes a 20-year study period and an expected life of 20 years for all equipment. Because the useful life of all equipment is assumed to be the same and only lasts through the study period, $REMAIN is zero. None of the capital equipment is replaced during the study period, so $REPLACE is also zero. Because maintenance is assumed identical among the alternatives, it will not impact the PV for any alternative. This formula is shown in Figure M-2, *Present Value ($PV) Formula.*

Table M-1. Chiller Operating Profile

Annual Cooling Four-Point Load Profile								
Unit No.	25% of Maximum		50% of Maximum		75% of Maximum		Maximum Load	
	Tons	Hours	Tons	Hours	Tons	Hours	Tons	Hours
Chiller 1	65	1,000	130	2,500	195	3,000	260	500

Table M-2. Chiller Part-Load Efficiencies and Initial Costs

Alternative	Full Load Capacity (tons)	Part-had Efficiency				Initial Cost[1] ($)
		25%	50%	75%	100%	
0. Unchanged	260	0.71	0.58	0.58	0.61	-–-
1. Drop-in[2]	260	1.34	0.81	0.73	0.70	22,000
2. Same Capacity	260	1.04	0.66	0.60	0.58	38,000
3. Same Efficiency[3]	N/A	N/A	N/A	N/A	N/A	N/A
4. New Unit[4]	260	1.04	0.66	0.60	0.58	72,000

(1) Initial cost includes installation, but not costs to modify the mechanical room to meet ASHRAE 15-1962.

(2) This unit was manufactured to be directly convertible to HCFC-123. The original capacity ratings were based on its performance using HCFC-123. Therefore, there is no capacity penalty for the drop-in retrofit alternative.

(3) Not available.

(4) New chiller using HCFC-123, selected to operate at original conditions. The part-load efficiencies are the same as Alternative 2 because they are essentially identical machines.

$$\$ENERGY = \{(EFF_{25\%})(HRS_{25\%})(LOAD_{25\%}) + (EFF_{50\%})(HRS_{50\%})(LOAD_{50\%}) + (EFF_{75\%})(HRS_{75\%})(LOAD_{75\%}) + (EFF_{100\%})(HRS_{100\%}))(LOAD_{100\%})\}(\$/kWh)$$

Where:

- $ENERGY = estimated annual energy cost for chiller operation ($/year)
- $EFF_{xx\%}$ = chiller efficiency at xx% of maximum capacity (kW/ton)
- $HRS_{xx\%}$ = hours of chiller operation at xx% of maximum capacity (hours/year)
- $LOAD_{xx\%}$ = cooling load at xx% of maximum capacity (tons)
- $/kWh = average cost of electricity from the utilities data sheets

For Alternative 1: Drop-In Retrofit:

$$\$ENERGY_{Alt1} = \{(1.34)(1,000)(65) + (0.81)(2,500)(130) + (0.73)(3,000)(195) + (0.70)(500)(260)\}\ (0.05\ 1)$$

$$\$ENERGY_{Alt1} = \$44,290$$

For Alternative 2: Same Capacity Retrofit:

$$\$ENERGY_{Alt2} = \{(1.04)(1,000)(65) + (0.66)(2,500)(130) + (0.60)(3,000)(195) + (0.58)(500)(260)\}\ (0.051)$$

$$\$ENERGY_{Alt2} = \$36,130$$

For Alternative 4: New Unit:

$$\$ENERGY_{Alt4} = \{(1.04)\ (1,000)(65) + (0.66)(2,500)(130) + (0.60)(3,000)(195) + (0.58)(500)(260)\}\ (0.05\ 1)$$

$$\$ENERGY_{Alt4} = \$36,130$$

Figure M-1. Calculate $ENERGY

$$\$PV = \$INITIAL + \$REPLACE(P/F,i\%,N) + (\$ENERGY + \$MAINT)(P/A,i\%,N) - \$REMAIN(P/F,i\%,N)$$

Where:

- $PV = present value of the life-cycle costs associated with a particular alternative ($)
- $INITIAL = total initial cost of a particular alternative ($), including the cost for upgrading the mechanical room
- $REPLACE = future replacement cost (assumed as zero ($))
- (P/F, i%,N) = present value of a future cash flow at an interest rate of i% for N years[1,2]
- (P/A, i%,N) = present value of an annually-recurring cash flow at an interest rate of i% for N year[1,2]
- i% = interest rate (discount rate) for federal energy conservation projects (%)[2]
- N = study period (years)
- $ENERGY = estimated annual energy cost of chiller operation ($/year)
- $MAINT = annual maintenance costs ($)
- $REMAIN = remaining value of equipment at the end of N years (assumed to be zero ($))

1 This factor is obtained from any engineering economics text
2 NISTIR 85-3272-7

Figure M-2. Present Value ($PV) Formula

$$\$PV = \$INITIAL + \$ENERGY(P/A,i\%,N)$$

For Alternative 1: Drop-in Retrofit:

$$\begin{aligned}\$PV_{Alt1} &= \$22,000 + \$10,200 + \{\$44,290X\ (P/A,4\%,20)\}\\ &= \$32,200 + \$44,290(13.59)\\ &= \$32,200 + \$601,900\\ \$PV_{Alt1} &= \$634,100\end{aligned}$$

For Alternative 2: Same Capacity Retrofit:

$$\begin{aligned}\$PV_{Alt2} &= \$38,000 + \$10,200 + \{\$36,130X\ (P/A,4\%,20)\}\\ &= \$48,200 + \$36,130(13.59)\\ &= \$48,200 + \$491,000\\ \$PV_{Alt2} &= \$539,200\end{aligned}$$

For Alternative 4: New Unit:

$$\begin{aligned}\$PV_{Alt4} &= \$72,000 + \$10,200+ \{\$36,130X\ (P/A,4\%,20)\}\\ &= \$82,200 + \$36,130(13.59)\\ &= \$82,200 + \$491,000\\ \$PV_{Alt4} &= \$573,200\end{aligned}$$

Figure M-3. Calculate $PV

M.3.4 Feasible Alternatives for Present Value of LCC ($PV)

The next step in evaluating water chillers for replacement or retrofit is to calculate the present value of the LCC for the feasible alternatives. These calculations are shown in Figure M-3, *Calculate $PV.*

M.3.5 Example Conclusion

Select the alternative with the lowest present value of the LCC. Select Alternative 2: Same Capacity Retrofit.

M.4 List of Major Manufacturers

For further information on replacement and retrofit, contact the following:

Carrier Air Conditioning Company
Carrier Pkwy., P.O. Box 4808
Syracuse, NY 13221
(315) 432-6000

Snyder General Corporation
13600 Industrial Park Blvd.
P.O. Box 1551
Minneapolis, MN 55440
(612) 553-5330

The Trane Company
Commercial Systems Group
3600 Pammel Creek Road
La Crosse, WI 54601-7599
(608) 787-2000

York International Corporation
631 South Richard Ave.
P.O. Box 1592
York, PA 17405-1592
(717) 771-7890

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Appendix N — Chiller Selection Guide

ABSTRACT: This appendix provides guidelines and procedures for selecting water chillers. There are a variety of chillers available for consideration. Each application will require attention to such items as efficiency, availability of fuel sources, load matching, initial cost, annual maintenance cost, and annual operating cost.

N.1 Introduction

This appendix is a guide for engineers selecting and optimizing water chillers. The selection of a chiller is the most important component of chilled water system optimization. All options for each situation must be examined and a selection made based on the lowest life-cycle cost (LCC). Because site-specific conditions-lack of a waste heat source, or a low cost of electricity relative to natural gas–certain alternatives can immediately be eliminated. Figure N-1, *Chiller Selection Flowchart,* illustrates a broad summary of the chiller selection process. Table N-1, *Chiller Selection Guide Summary,* provides a summary of various chiller types, including typical costs, sizes, and efficiencies.

N.1.1 Applicability

The selection process discussed in this appendix applies to chilled water systems consisting of single or multiple chiller installations. Chiller types considered in the selection process should include absorption chillers - steam, hot water, and direct-fired; electric chillers - scroll, reciprocating, rotary screw, and centrifugal; ammonia chillers; and natural gas engine-driven chillers.

N.1.2 Selection Procedure

The guidelines for selecting the most effective chiller(s) are broken down into two parts.

N.1.2.1 Part one describes various types of chillers, discusses the advantages and disadvantages of each, and suggests when each chiller type should be considered. The chiller information in this appendix is general in nature. More detailed information should be sought from chiller manufacturers. A partial list of major chiller manufacturers can be found in N.5.

N.1.2.2 Part two describes a general selection procedure.

N.1.2.3 Chiller efficiency is expressed by the ratio of energy input divided by cooling capacity. Typical units are kilowatts per ton (kW/ton) of refrigerant capacity or pounds of steam per hour per ton (steam/hr/ton) of refrigeration capacity.

N.1.2.4 Chillers are heat “pumps” that are designed to transfer heat from one source to another. The energy required to “pump” the heat is usually less than the cooling capacity available. Because this concept is somewhat different from the traditional definition of efficiency, the term “coefficient of performance” (COP)

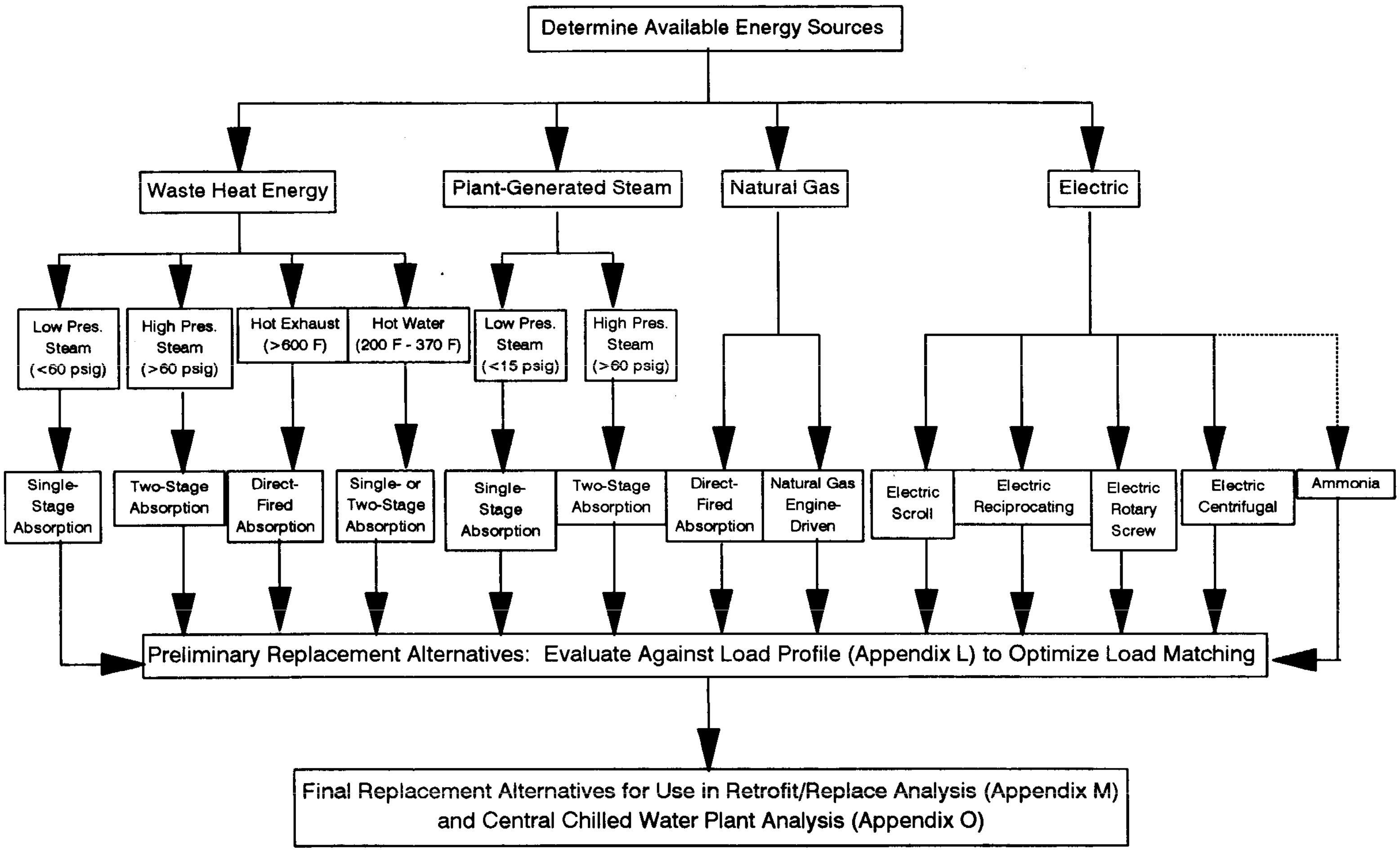

Figure N-1. Chiller Selection Flowchart

Table N-1. Chiller Selection Guide Summary

Chiller Selection Guide				
Equipment Type	**Available Tonnage Range**	**Equipment Cost (chiller only) $/Ton**	**Full Load Efficiency**	**COP**
Single-stage Steam Absorption	100-1700	260-650	15-20 lb/hr/ton	0.85-0.63
Two-stage Steam Absorption	100-1500	460-600	5-10 lb/hr/ton	0.95-1.05
Direct-fired Absorption	100-1500	530-860	10-15 Mbh/ton(1)	1.2-0.80
Electric Scroll	20-80	340-380	0.85 -2.0 kW/ton	4.0 -1.8
Electric Reciprocating(3)	20-200	340-470	0.90-1.10 kW/ton	3.9 -3.2
Electric Rotary Screw(2)	70-500	200-400	0.75-0.85 kWlton	4.7 -4.1
Electric Centrifugal	100-1500	210-300	0.55-0.80 kW/ton	6.4 -4.4
Natural Gas Engine-driven	100-500	750->1000	8-9 Mbh/ton(1)	1.4 -1.3

(1) Mbh = 1000 Btu/hr
(2) Available with ammonia refrigerant in 30 to 300 tons
(3) Available with ammonia refrigerant in 20 to 400 tons

is often used to relate efficiency. COP is simply the cooling capacity divided by the energy input. When equivalent units are used, the COP will be a dimensionless number, usually greater than one.

N.1.2.5 Chiller efficiency and performance can not always be evaluated for peak load. Most cases require that chillers be evaluated based on part-load performance. Part-load performance is the mechanical efficiency of the machine operating at various percentages of full load.

N.2 Chiller Descriptions and Performance Characteristics

The following sections describe the commonly available chiller types and their applications.

N.2.1 Single-Stage Steam or Hot Water Absorption Chiller (Water-Lithium Bromide Solution)

Single-stage steam or hot water absorption chillers should be considered only when there is sufficient excess heat energy in the form of steam or hot water. Steam inlet pressures at the chiller can not exceed 12 to 14 psig with maximum temperatures of 1710 C (340° F). Hot water must be available at 93° C (200° F) to 188° C (370° F). Cooling capacities range from 100 to 1700 tons with chilled water supply temperatures in the range of 4° C (40° F) to 10° C (50° F).

N.2.1.1 A single-stage steam or hot water absorption chiller uses this heat energy to boil a dilute solution of lithium bromide and water. The resulting refrigerant vapor

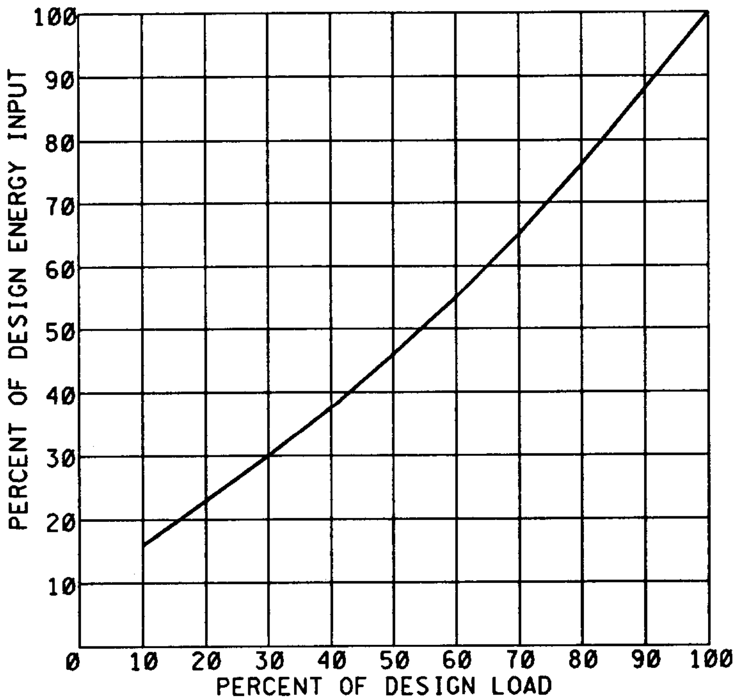

Figure N-2. Single-Stage Steam Absorption Chiller Part-bad Performance

is condensed in the condenser section. The liquid refrigerant then passes through a throttling device and enters the evaporator as a saturated liquid at approximately 4° C (40° F). The liquid refrigerant is collected within and continuously sprayed over the evaporator tube bundles, thereby cooling the water. The resulting refrigerant vapor migrates to the absorber section where it is again condensed on the absorber tube bundles. Cooling tower water is used to remove heat from the absorber tubes. The diluted solution is then pumped back to the concentrator.

N.2.1.2 Single-stage absorption chillers are approximately 20 percent more expensive than a comparable electric centrifugal chiller. However, if excess waste heat energy is available, there is a potential for energy cost savings.

N.2.1.3 Single-stage absorption chillers cost from $260 to $650 per ton of refrigeration capacity. Their efficiencies range from 15 to 20 lb/hr/ton with COPS ranging from 0.85 to 0.63. Figure N-2, *Single-Stage Steam Absorption Chiller Part-Load Performance,* shows a single-stage absorption machine can operate as low as ten percent of its maximum capacity. The chiller is most efficient at 50 to 80 percent of maximum capacity.

N.2.2 Two-Stage Steam or Hot Water Absorption Chillers (Water-Lithium Bromide Solution)

Two-stage steam or hot water absorption chillers are similar to single-stage, with the

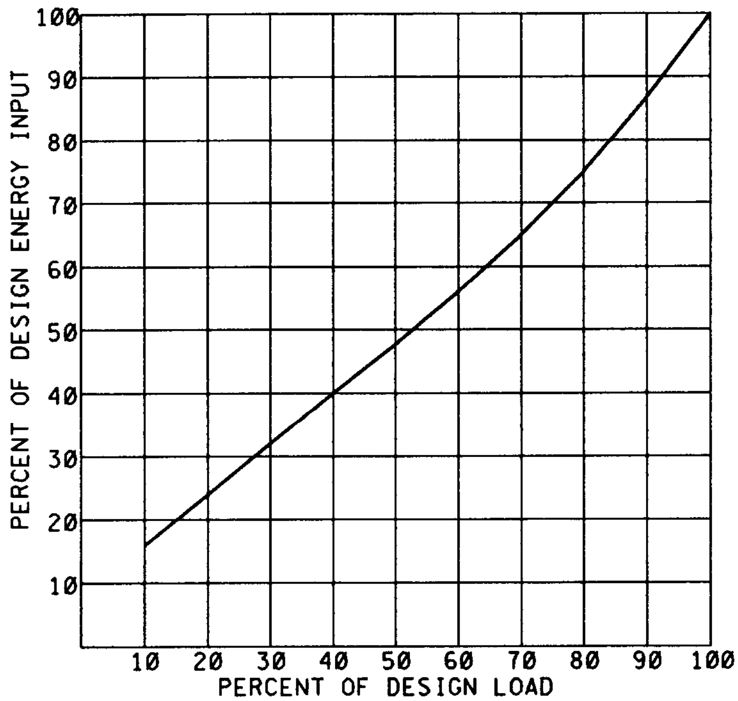

Figure N-3. Two-Stage Steam Absorption Chiller Part-Load Performance

exception that a two-stage machine uses higher steam pressures or hot water temperatures and two concentrator stages. For these machines, steam pressures in the range of 60 to 115 psig and hot water temperatures up to 188° C (370° F) can be used. Cooling capacities range from 100 to 1500 tons.

N.2.2.1 Two-stage absorption chillers cost from $460 to $600 per ton. They re- *quire waste* heat *energy to* be cost-effective and are approximately 2 to 2.5 times as expensive as a comparable electric centrifugal chiller.

N.2.2.2 Full-load efficiencies range from 5-10 lb/hr/ton with COPS ranging from 2.7 to 1.3. Figure N-3, *Two-Stage Steam Absorption Chiller Part-Load Performance,* shows a two-stage absorption machine can operate as low as ten percent of its maximum capacity. The chiller is most efficient at 60 to 80 percent of maximum capacity.

N.2.3 Direct-Fired Absorption Chiller (Water-Lithium Bromide Solution)

Direct-fired chillers use natural gas, fuel oil, or waste heat in the form of clean exhaust gases (T> 316° C (600° F)) from sources such as gas turbines and diesel engines. Direct-fired gas absorption chillers are available only in two-stage configurations. They bum approximately 10 to 15 cubic feet of natural gas per hour per ton of cooling. These machines range in size from 100 to 1500 tons.

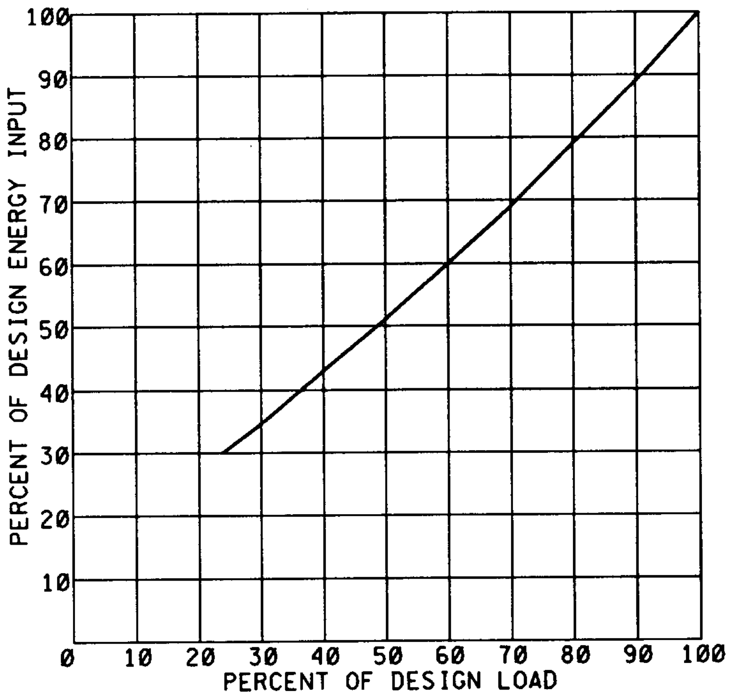

Figure N-4. Direct-Fired Absorption Chiller Part-Load Performance

N.2.3.1 Direct-fired absorption chillers have, in general, the same configuration and processes as two-stage steam or hot water absorption chillers with the exception of the input energy source. A unique feature of most direct-fired absorption chillers is they also act as a heater. Most manufacturers refer to a direct-fired absorption chiller as a chiller-heater.

N.2.3.2 The heater portion of the direct-fired chiller operates by the energy source in the first-stage generator heating the diluted lithium-bromide solution. This drives off refrigerant vapor and leaves concentrated solution. The hot refrigerant vapor's heat is transferred to the building's hot water system via an auxiliary heat exchanger or a heat exchanger internal to the unit. The condensed refrigerant liquid returns to the first-stage generator and completes the cycle.

N.2.3.3 A direct-fired absorption chiller is approximately 2.5 times more expensive than a comparable capacity electric centrifugal chiller, but is competitive with two-stage steam or hot water absorption chillers.

N.2.3.4 Direct-fired absorption chillers range in price from $530 to $860 per ton of refrigeration capacity. Their fill-load efficiencies are approximately 12,000 Btu per hour per ton (12 Mbh/ton) of refrigeration capacity with COPS ranging from 1.2 to 0.80. Figure N-4, *Direct-Fired Absorption Chiller Part-Load Performance,* shows a direct-fired machine can operate as low as 25 percent of its maximum capacity.

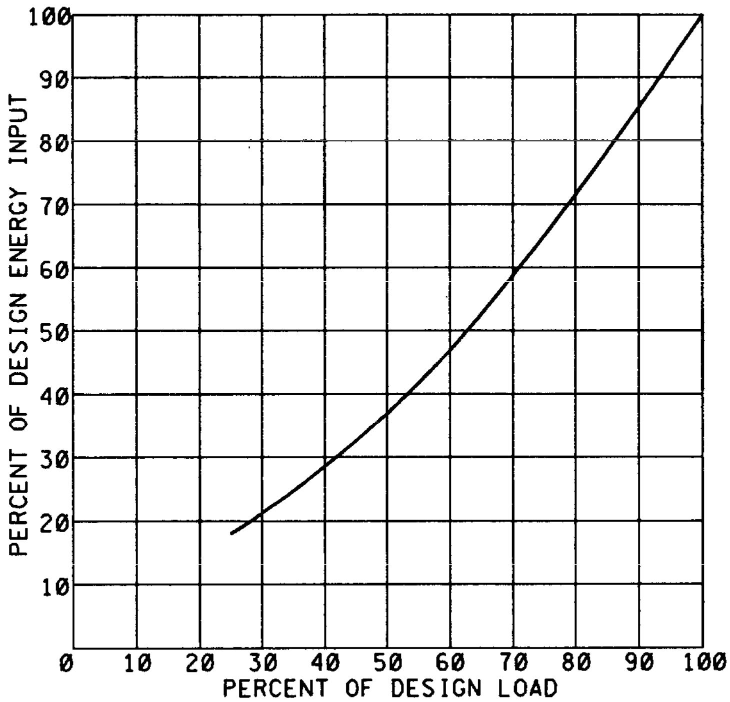

Figure N-5. **Electric Scroll Chiller Part-Load Performance**

The chiller is most efficient at 70 to 90 percent of maximum capacity.

N.2.4 Electric Scroll Chiller

The electric scroll chiller is the smallest of the electrical chillers. It is available in both water-cooled and air-cooled configurations. Sizes range from 20 to 80 tons of refrigeration capacity. Due to their small size, scroll chillers should not be considered for central plant applications. Good applications for scroll chillers include areas that have special temperature and humidity requirements that packaged direct-expansion equipment can not meet.

N.2.4.1 The general operating characteristics are similar to a reciprocating chiller. The main difference is, in lieu of a piston-type compressor, the scroll uses a rotary-type compressor. The compressor operates by rotating a spiral-shape scroll, compressing the vapor as it is forced through the scroll.

N.2.4.2 Scroll chillers can be manifolded together to provide multiple staging and load matching capability. Manifolded scroll chillers can be used as an alternative to reciprocating units. This is most effective when the maximum load exceeds a single-scroll chiller capacity but falls in the range of a reciprocating chiller.

N.2.4.3 Scroll chillers cost $340 to $380 per ton of refrigeration capacity. Their full-load efficiencies range from 0.85 to 2.0 kW/ton with COPS in the range of 4.0 to 1.8. Figure N-5, *Electric Scroll Chiller Part-Load Performance,* shows an electric

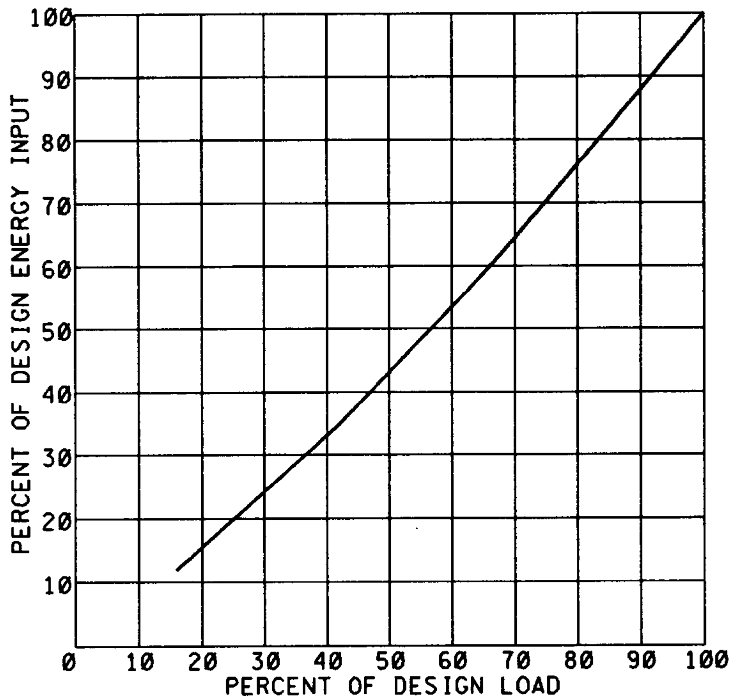

Figure N-6. Electric Reciprocating Chiller Part-Load Performance

scroll machine can operate as low as 25 percent of its maximum capacity. The chiller is most efficient at 25 to 50 percent of maximum capacity.

N.2.5 Electric Reciprocating Chiller

Of the chillers considered, the reciprocating chiller has the lowest first cost, but also the lowest efficiency. Initial cost is from $340 to $470 per ton with full-load efficiencies from 0.90 to 1.10 kW/ton. Reciprocating chillers are available only with HCFC-22 or ammonia as the refrigerant (see section N.2.8). Reciprocating chillers are available in either air-cooled or water-cooled configurations.

N.2.5.1 Air-cooled reciprocating chillers range in capacity from 20 to 130 tons. Water-cooled chillers range in capacity from 50 to 200 tons. The full-load efficiency of an air-cooled system is usually less than a water-cooled system despite the energy required by the water cooler and condenser water pump. An air-cooled system requires more space than a water-cooled system, because an air-cooled condensing unit requires more surface area than a water-cooled condensing unit. Figure N-6, *Electric Reciprocating Chiller Part-Load Performance,* shows an electric reciprocating machine can operate as low as 15 percent of its maximum capacity. The chiller is most efficient at 30 to 50 percent of maximum capacity.

N.2.6 Electric Rotary Screw Chiller

The rotary screw chiller is similar to the scroll chiller; neither use piston compressors. The rotary screw chiller uses two

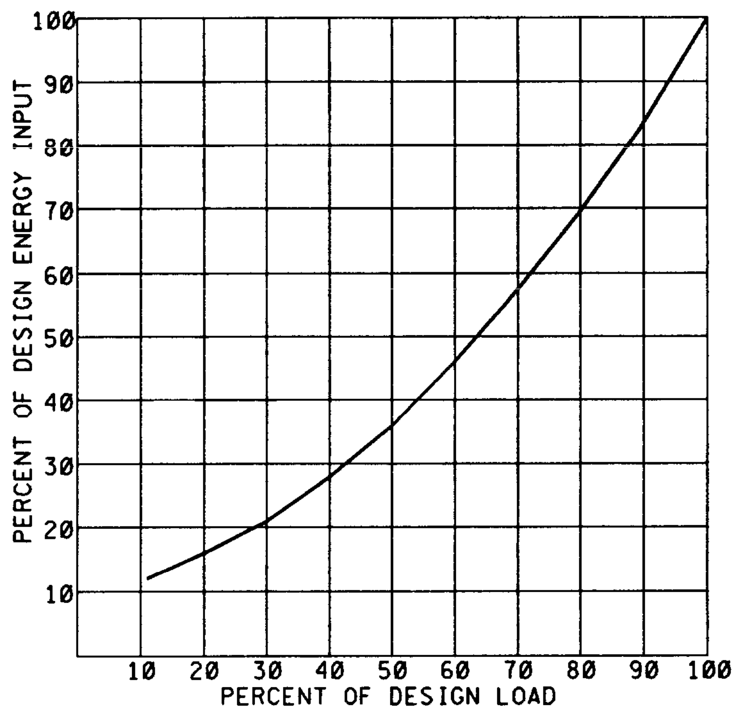

Figure N-7. Electric Rotary Screw Chiller Part-Load Performance

rotors for the compression cycle. A male rotor is driven by the motor which compresses refrigerant gas between a female rotor.

N.2.6.1 Rotary screw chillers offer higher efficiencies than reciprocating chillers of equal capacity, although they will be somewhat more expensive. Screw chillers are available only with either HCFC-22 or ammonia as the refrigerant.

N.2.6.2 Screw chillers are available in either air-cooled or water-cooled configurations. The air-cooled machines range in capacity from 70 to approximately 400 tons. The water-cooled type ranges in capacity from 100 to 500 tons. The full-load efficiency of a screw chiller is generally around 0.80 kW/ton with COPS ranging from 4.7 to 4.1. Among comparable-size machines, the part-load efficiency of a screw chiller is better than the part-load efficiency of a reciprocating chiller. When load matching can not be accomplished through staging individual chillers, this favorable efficiency characteristic of the screw chillers should be considered. Based on energy efficiency, a water-cooled screw chiller is a better selection than an air-cooled chiller. Figure N-7, *Electric Rotary Screw Chiller Part-Load Performance,* shows an electric screw machine can operate as low as ten percent of its maximum capacity. The chiller is most efficient at 35 to 55 percent of maximum capacity.

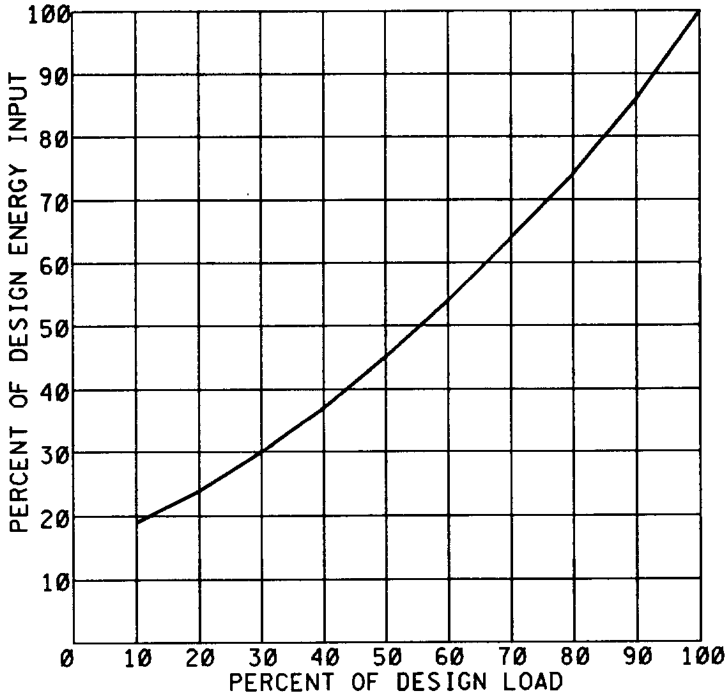

Figure N-8. Electric Centrifugal Chiller Part-Load Performance

N.2.7 Electric Centrifugal Chiller
Electric centrifugal chillers use hermetically sealed or open-drive compressor/motor assemblies. They come with single-, two-, or three-stage compression cycles. Refrigerant vapor is accelerated through the impeller, increasing the pressure and temperature. The high-temperature vapor enters the condenser (a shell and tube heat exchanger) where it is cooled to saturation by condenser water passing through the tubes. The liquid refrigerant then passes through a metering device, such as an orifice plate, which lowers the pressure. The low-pressure liquid refrigerant enters the evaporator (a shell and tube heat exchanger) where it evaporates by heat transfer from the chilled water passing through the tubes, thereby chilling the water. Finally, the low-pressure refrigerant vapor returns to the compressor.

N.2.7.1 Electric centrifugal chillers have the highest full-load efficiency of the electric chillers discussed. The average full-load efficiency will be approximately 0.55 to 0.80 kW/ton with COPS ranging from 6.4 to 4.4, depending on capacity and water temperatures. First cost of electric chillers ranges from $210 to $300 per ton. Centrifugal chillers can operate with many of the environmentally friendly refrigerants, such as HCFC-123 and HFC-134a. Electric centrifugal chillers range in size from approximately 100 to 1500 tons. The only available configuration is water-cooled. Figure N-8, *Electric Centrifugal Chiller Part-Load*

Performance, shows an electric centrifugal machine can operate as low as ten percent of its maximum capacity. The chiller is most efficient at 55 to 85 percent of maximum capacity,

N.2.8 Specialty Chillers
Two specialty chillers are discussed in the following sections. These chillers are variations of the electric chillers.

N.2.8.1 Ammonia chillers use ammonia in lieu of HCFC-22 as a refrigerant. Ammonia is available for use in reciprocating or screw chillers, either air- or water-cooled. The screw chillers range in size from 30 to 300 tons. The reciprocating chillers range in size from approximately 20 to a maximum of about 400 tons. Due to the toxicity of ammonia, these chillers should be considered only if they can be located in a remote area away from the building(s) they serve.

N.2.8.2 Natural gas engine-driven chillers use a natural gas-fired engine rather than an electric motor. Engine-driven chillers are only available with screw compressors at the present time, but may be available with reciprocating compressors in the near future. These chillers are water-cooled and sizes range from 100 to 500 tons. The refrigerant used is HCFC-22. The efficiency is approximately 9.0 cubic feet/hour of natural gas per ton of cooling capacity. Engine-driven chillers are more expensive than motor-driven chillers of comparable capacity and require more maintenance.

N.3 Chiller Selection Procedure

This section outlines a step-by-step procedure for selecting chiller(s) for use in support of Appendix M, *Evaluating Water Chillers for Replacement or Retrofit Potential* and/or Appendix O, *Assessing the Potential of Central Chilled Water Plants.* Figure N-1 shows the flow logic for this selection process.

N.3.1 Cooling Load Profile
It is essential that the cooling load profile be determined (see Appendix L, *Fundamentals of Cooling Load and Energy Analysis). The* site should be surveyed to determine the available utilities. The following is a step-by-step procedure.

N.3.1.1 ***Step 1***- Determine available input energy sources. There are four potential input energy sources which should be evaluated:

- Waste heat energy
  - Low-pressure steam (< 60 psig)
  - High-pressure steam (> 60 psig)
  - Hot water (93° C (200° F) to 188° C (370° F))
  - Hot gas (>316° C (600° F))
- Plant-generated steam
  - Low-pressure steam (12 to 15 psig)
  - High-pressure steam (60 to 115 psig)
- Natural gas
- Electric

Survey the site and determine all available energy input types, including the opportunity for extending such services as natural gas, steam, and electric from adjoining sites. The cost of extending utility services from distant sites may be prohibitive.

N.3.1.2 ***Step 2-*** Because certain input energy services may not be available, a variety of chillers can be eliminated after analyzing their economic feasibility based on the utility rate structures. Examples:

1) If natural gas is not available, then natural gas, direct-fired absorption and natural gas, engine-driven chillers should not be considered.
2) If waste heat energy in the form of steam, hot gas, or hot water is not available, then additional chiller types, such as single- and two-stage absorption chillers can be eliminated.

N.3.1.3 ***Step 3-*** Collect all possible alternatives and compare each chiller's unique characteristics to items such as load matching, space requirements, and special humidity and temperature requirements- By the process of elimination, certain chillers will be unacceptable. Example:

If the load profile shows a peak load requiring 1000 tons, the use of scroll or reciprocating chillers would not be considered cost-effective.

This step in Figure N-1 is not intended to produce a single refined chiller system selection, but a set of possible alternatives to be used in support of Appendices M and O. Example:

The chiller selection is to support a retrofit or replacement of a single 250-ton centrifugal chiller. The only available input source is electric. The available chiller options are limited to a single electric centrifugal, rotary screw, reciprocating, or a multiple chiller installation using rotary screws and reciprocating chillers.

Proper chiller selection matches the performance of single or multiple chillers to the required load profile. Load matching requires the profile be scrutinized and dissected such that optimum chiller load performance is used.

Example:

If the load profile reflects a 1000-ton peak load, but a constant base load of 250 tons exists, the use of multiple chillers should be considered. For this example, further assume electric chillers are the only available alternatives. Therefore, potential chiller selections could be a single centrifugal or rotary used to match the constant 250 tons and two 375-ton centrifugal or rotary chillers to match the remaining 750 tons.

Characteristics for consideration in selecting and matching chillers to load profiles are part-load performance, peak-load performance, initial cost, space requirements, utility rate structures, and the availability of alternative energy input sources.

Example:

If natural gas is available and the electric utility rate structure is such that high rates and demand charges are imposed, natural gas becomes attractive. But in areas where the electric utility rate and demand charges are low, relative to other energy sources, natural gas or fuel oil becomes less attractive.

N.3.1.4 ***Step 4-*** Once chiller alternatives have been refined, further analysis of economic feasibility should be continued as outlined in Appendices M and O.

N.4 Recommendations for Further Study

To further optimize chiller selection, there are several areas which can be considered. Some gas and electric utility offer rebates and purchase incentives for selecting chiller and chiller plant accessories with high-efficiency performance.

N.4.1 Gas Utility Rebates

Some gas utility companies provide rebates and incentives for converting electric-driven chillers to natural gas engine-driven chillers.

N.4.2 Chiller Heat Recovery

Heat dissipated from a natural gas engine-driven chiller should be considered for heat recovery. The available heat from the engine cooling fluid could be used to preheat domestic water or process heating water. Utilization of this waste heat can result in significant reduction in LCC.

N.5 List of Major Manufacturers

Carrier Air Conditioning Company
Syracuse, NY
(315) 432-6000

McQuay/Snyder General Corporation
13600 Industrial Park Blvd.,
P.O. Box 1551
Minneapolis, MN 55440
(612) 553-5330

The Trane Company
Commercial Systems Group
3600 Pammel Creek Road
La Crosse, WI 54601-7599
(608) 787-2000

York International Corporation
P.O. Box 1592
York, PA 17405-1592
(717) 771-7890

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Appendix O– Assessing the Potential of Central Chilled Water Plants

ABSTRACT: This appendix provides guidelines for determining the potential of replacing chillers in multiple locations with a single chilled water plant. The new plant can be a combination of retrofit and new chillers. The new, central location can either be a new structure, or an expanded, existing mechanical room. The concept can even include remotely located chillers tied into a common distribution system and operated as a combined plant.

O.1 Introduction

The purpose of this appendix is to provide guidelines for determining the potential of replacing multiple chilled water systems with a centralized chilled water plant.

O.1.1 Assumptions

The following assumptions have been used in the development of this appendix.

- The equipment inventory survey has been performed as described in Appendix H, *AC/R Equipment Survey Guide and Equipment Data Collection Survey Forms,* and the completed equipment survey forms are available for use in the assessment,
- The chiller life for the life-cycle cost (LCC) analysis and study life are 20 years.
- The annual cooling load profile for each existing chiller water system has been estimated by the procedure described in Appendix L, *Fundamentals of Cooling Load and Energy Analysis.*
- The interest (discount) rate used in the LCC analysis is obtained from NISTIR-3273-7. The interest rate currently used for federal energy conservation projects is four percent (excluding inflation).

This evaluation procedure applies to individual chilled water systems located so they can be economically combined to develop a central chilled water plant. The option of a new building to house the equipment will be evaluated along with the possibility of expanding one or more existing mechanical rooms.

O.1.2 Advantages

Several advantages for conversion to a central plant follow.

1) The potential for lower installation cost. Larger chillers cost less per ton and only one mechanical room would need to be established or upgraded to meet ASHRAE Standard 15-1994 (ETL 91-7 requires ASHRAE 15-1994 be followed for new construction, or when chillers are retrofit or replaced).
2) The potential for lower energy cost due to controlled load matching and improved operating efficiency.
3) The potential for lower maintenance cost (fewer chillers to maintain and maintenance will be centralized).

4) Increased system reliability (equipment redundancy in multi-unit installations).
5) The centralization of condenser cooling water system and water treatment system.
6) Total installed capacity of the central plant may be significantly less than for the separate systems.

O.2 Evaluation Procedure

The first requirement is to identify chiller clusters. Chiller clusters representing proposed chilled water plants are identified by overlapping "capacity radius" circles developed by following the instructions in Appendix H. The information from the field survey, including the base map, should be reviewed. Each central chilled water plant that has a lower LCC than the sum of the individual chillers (as determined from Appendix M, *Evaluating Water Chillers for Replacement or Retrofit Potential)* should be programmed for implementation. Further analysis may be warranted as described in Appendix P, *Heat Recovery Alternatives for Refrigerant Chillers* arid Appendix Q, *Assessing the Potential of Thermal Storage.* The basic procedure for assessing the potential of chilled water plants is as follows.

O.2.1 Obtain Data

Obtain data from equipment survey forms and Appendix M for each chiller whose capacity radius overlaps another's indicating a potential to combine. The capacity radius circles are based upon a radius of one foot per ton. Example: a 100-ton chiller would have a 100-foot capacity radius (200 foot diameter). This rule of thumb is based upon experience involving typical costs associated with installing a central system.

O.2.2 Determine Central Plant Capacity

The maximum cooling load on the central plant will likely be less than the sum of the individual loads if the buildings are dissimilar in construction, orientation, or usage. Dissimilarities such as these cause variation between the time of peak cooling for each separate system and for the central plant. This variation will allow a lesser maximum load on the central plant than the sum of the loads for the separate systems—a concept commonly referred to as load diversity. Load diversities (reductions) of 10 to 20 percent from the sum of the separate loads are common for central chilled water plants. To calculate the maximum central plant load electronically, merge the input data files from the separate systems into one file for the central system and rerun the load analysis software. This will produce the most accurate results. The other method to determine this load is by performing hand calculations. Although not as accurate as the computer method, the results can be close enough for an analysis of this level (see Appendix L, for manually-calculating load).

O.2.3 Select Central Plant Chillers

Refer to Appendix N, *Chiller Selection Guide,* for information concerning types, performance ratings, and costs for various chillers. Use this guide to make a reasonable, preliminary selection of the central plant chillers for this analysis.

O.2.4 Determine Central Plant Location

Survey the site area, as defined by capacity radius circles, to determine a location for the potential central chilled water plant. Evaluate the re-use of an existing mechanical room. the expansion of an existing mechanical room, or the construction of a new central plant building, and determine reasonable pipe routing. Potential modifications to the equipment room should be determined (Appendix J, *Application of ASHRAE Equipment Room Design Requirements)* and conceptual sketches of the equipment layout and pipe routing produced. The purpose of the sketches and the determination of equipment room modifications is to estimate the initial costs of the central chilled water plant.

O.2.5 Determine Distribution System Routing

The decision must be made concerning the installation of above-ground or underground distribution piping. Aesthetic concerns may always dictate underground piping.

O.2.5.1 Above-ground piping should only be a consideration if there would be no probability of freezing. If above-ground piping is required in areas with a freezing potential, freeze protection methods such as heat tracing or a glycol solution should be considered. If glycol is proposed, the negative effect on chiller capacity and performance must be included in the evaluation of the chillers.

O.2.5.2 Three underground piping systems should be considered when estimating system costs. They are field-insulated steel, pre-insulated, and high-density plastic.

O.2.5.2.1 The first underground method is simply black steel pipe that is field-insulated by the contractor, using a foamed-glass type of insulation with a waterproof covering to protect the pipe from corrosion.

O.2.5.2.2 The second system is pre-insulated pipe as supplied by a piping manufacturer. The carrier pipe in a pre-insulated piping system can be steel, copper, stainless steel, aluminum, or polyvinyl chloride (PVC), to name a few. Jacket material is either PVC or polyethylene. The annular space between the carrier pipe and the jacket is filled with polyurethane insulation. Polyurethane provides the most efficient insulation of commonly-used materials for tempemtures to 1210 C (250° F). Typically, the material price for field-insulated piping is less than for pre-insulated piping, but pre-insulated piping is less expensive to install. Contractors have different views on which is the lowest cost system but, from a performance perspective, they are equal.

O.2.5.2.3 The third piping system is a high-density (HD) plastic piping system. Plastic piping offers a cost saving on initial piping costs, but it must still be field-insulated like the black steel pipe. Pipe sizes < 2½" are available on rolled spools for ease of installation and lower installation costs.

O.2.6 Determine Pumping/Piping Arrangement

New primary pumps must be added for the central chilled water plant. Evaluate re-using existing chilled water pumps to serve as secondary pumps. Some pump modifications, such as trimming the pump impeller, may be required. Evaluate piping modifications that must be made at the existing pumps for this new use. Refer to Bell & Gossett Bulletin Number TEH-775, *Primary/Secondary Pumping Application Manual,* for guidelines on primary/secondary pumping. The secondary pumping loop, which serves individual buildings, should use only two-way control valves at the end users (air-handling units) so the chilled water flow can vary with the cooling load. Consider the possibility of installing variable-speed drives on the secondary pumping system.

O.2.7 Engineering Analysis

The engineering analysis consists of comparing the LCC analysis of the individual chillers in the cluster to the proposed central chilled water plant. The annual energy usage and projected maintenance costs must be included. The analysis will include engineering and construction cost estimates. The construction cost estimate must include:

- all new and modified pumps,
- piping,
- equipment room modifications,
- cooling towers,
- chemical treatment systems, and
- controls.

O.2.8 Perform LCC Analysis

Perform an LCC analysis for the central chilled water plant based on the engineering analysis. Compare it to the total LCC of the individual chilled water systems. The following items outline the procedure to follow in performing the simplified LCC analysis. Refer to section 0.3 for a detailed example,

O.2.8.1 Contact the equipment manufacturers to obtain equipment (for example, cooling towers, chillers, pumps) pricing and chiller efficiencies at 100, 75, 50, and 25 percent of full-load capacity.

O.2.8.2 Determine the mechanical room modifications and associated costs required to meet ASHRAE Standard 15-1994 for the selected chiller/refrigerant combination. Refer to Appendix J, *Application of ASHRAE Equipment Room Design Requirements,* for equipment room modification requirements based on ASHRAE 15-1992.

O.2.8.3 Calculate the annual energy cost for each of the chillers being considered for integration into a central plant. Refer to the example in section 0.3 for guidance in calculating the annual energy cost for each of the chillers.

O.2.9 Central Plant Selection

The central chilled water plant is a candidate for funding if it has a LCC less than the sum of the individual chilled water systems.

O.3 Example of Evaluation

The following assumptions, figures, and tables provide the necessary information to assess the feasibility of clustering several chillers into a single, central chilled water plant. Table O-1, *Existing Chiller Operating Profiles,* summarizes the existing chillers' operating profiles during one year. Table O-2, *Results from Replace or Retrofit Analysis,* shows the results of the retrofit/replace for analysis completed prior to this calculation for the group of chillers to be clustered together. Table O-3, *Central Chilled Water Plant*

Table O-1. Existing Chiller Operating Profiles

Annual Cooling Four-Point Load Profile								
	25% of Max		50% of Max		75% of Max		Max Load	
Unit Number	Tons	Hours	Tons	Hours	Tons	Hours	Tons	Hours
Chiller 1	60	900	120	2,200	180	3,200	240	200
Chiller 2	70	1,000	140	2,100	210	3,000	280	100
Chiller 3	70	1,100	140	2,300	210	3,300	280	200
Chiller 4	80	1,200	160	2,400	240	2,600	320	50

Table O-2. Results from Replace or Retrofit Analysis

Unit Number	Selected Alternative	Present Value of Life-Cycle Costa
9110-1	Same Capacity Retrofit	$710,500
9210-1	Same Efficiency Retrofit	$771,700
9310-1	Same Efficiency Retrofit	$771,700
9410-1	Drop-In Retrofit	$853,400

Table O-3. Central Chilled Water Plant Operating Profile

Annual Cooling Load Profile for Central Plant							
25% of Max		50% of Max		75% of Max		Max Load	
Tons	Hours	Tons	Hours	Tons	Hours	Tons	Hours
250	1.500	500	2.500	750	2,000	1,000	1,000

Operating Profile, summarizes the central chilled water plant operating profile.

O.3.1 Assumptions
The following assumptions were made in the example shown in this appendix.

O.3.1.1 Average energy cost from the utilities data sheets is: $0.05 l/kWh.

O.3.1.2 The average maintenance savings with the central plant will be approximately $2000 annually.

O.3.1.3 The four chillers (Chillers 1, 2, 3, and 4) listed in Table O-1 were identified as a cluster of chillers with the potential of incorporation into a central chilled water plant. These units were chosen for consideration of a central system because their capacity-radius circles overlap (Appendix H).

O.3.1.4 Table O-2 is an example of results expected from performing the chiller replace or retrofit analysis (Appendix M).

O.3.1.5 The annual cooling load profile for the central system was computed electronically by merging the load profiles for the separate units. This procedure is discussed in Appendix L. A four-point load profile is assumed for the central system as shown in Table O-3.

O.3.1.6 Develop a conceptual design for the central system. The central plant chillers will be housed in a newly-constructed block building. A primary/secondary piping/pumping system will be used. The primary piping, connecting each user with the central plant building, will be contained in a below-grade, concrete trench. New primary pumps will be purchased and housed in the central plant building. The existing chilled water pumps and piping will remain in place and become the secondary piping/pumping system. The existing cooling towers and condenser water pumps are assumed to be in good condition and will be consolidated at the central plant building and reused. Appendix N contains a discussion on chiller selection criteria. After reviewing this data, a 750-ton electric centrifugal and a 250-ton electric rotary screw chiller is selected for the central plant. The rotary screw chiller will operate during periods of loads less than 250 tons and greater than 750 tons. The centrifugal chiller will operate during all other loads. This sequence of operation takes advantage of the screw chiller's superior operating efficiency at part-load conditions and the centrifugal chiller's superior operating efficiency at mid-to-full loads.

O.3.1.7 Assume the following information for new equipment was obtained from a manufacturer.

Equipment	**Cost Estimate**	**Performance Data**
750-ton chiller (electric centrifugal)	$225,000	25 %: 1.00 kW/ton 50%: 0.75 kW/ton 75%: 0.65 kW/ton 100%: 0.60 kW/ton
250-ton chiller (rotary screw)	$90,000	25%: 0.85 kW/ton 50%: 0.75 kWlton 75%: 0.70 kWlton 100 %: 0.75 kWlton

O.3.1.8 Estimate the initial cost of the central plant alternative.

Description	Cost Estimate	Source
750-ton chiller	**$225,000**	Manufacturer
250-ton chiller	90,000	Manufacturer
Primary pumps	10,000	Manufacturer
Controls	15,000	Manufacturer
Piping & specialties	90,000	Cost Estimate Guide
Bldg (30' x 30')	110,000	Cost Estimate Guide
Electrical service	50,000	Cost Estimate Guide
Concrete trench	160,000	Cost Estimate Guide
Labor	290,000	Cost Estimate Guide

Total of Initial Costa $1,040,000

O.3.1.9 The following annual energy cost assumptions were used in estimating the annual energy cost for the central plant alternative. The load profile is linear between the four reference points, therefore:

25% - The average load between O and 250 tons is 125 tons and is served entirely by the screw chiller. On average, the screw chiller will operate for 1,500 hours/year at 50% of fill load (0.75 kW/ton).

50% - The average load between 250 and 500 tons is 375 tons and is served entirely by the centrifugal chiller. On average, the centrifugal chiller will operate for 2,500 hours/year at 50% of full load (0.75 kW/ton).

75% - The average load between 500 and 750 tons is 625 tons and is served entirely by the centrifugal chiller. On average, the centrifugal chiller will operate for 2,000 hours/year at 83% of full load (approx. 0.63 kW/ton).

100% The average load between 750 and 1,000 tons is 875 tons and is served by both chillers. On average, the centrifugal chiller will operate for 1,000 hours/year at 100% of full load (0.6 kW/ton). The screw chiller will operate for 1,000 hours/year at 50% of full load (0.75 kW/ton); simultaneously for a total of 1,000 hrs.

O.3.1.10 The primary pumps will operate continuously during the cooling period.

O.3.2 Calculate Annual Energy Cost ($ENERGY)

The first step in the evaluation is to calculate the annual energy cost for the proposed central chilled water plant. This calculation is shown in Figure O-1, *Calculate $ENERGY.*

O.3.3 Present Value ($PV) Formula

A review of the present value formula is presented prior to calculating the LCC of a central plant. This analysis assumes a 20-year study period and an expected life of all equipment of 20 years. Because the useful life of all equipment is assumed to be the same and only lasts through the study period, $REMAIN is zero. Because none of the capital equipment is replaced during the study period, $REPLACE is also zero. This formula is shown in Figure O-2, Present *Value ($PV) Formula.*

O.3.4 Calculate the Present Value of LCC for Central Plant ($PV)

The next step in assessing the potential of a single, central chilled water plant is to calculate the present value of the LCC for the central plant. This calculation is shown in Figure O-3, *Calculate $PV.*

$$\$ENERGY = \{(EFF_{25\%})(HRS_{25\%})(LOAD_{25\%}) + (EFF_{50\%})(HRS_{50\%})(LOAD_{50\%}) + EFF_{75\%})(HRS_{75\%})(LOAD_{75\%}) + (EFF_{100\%})(HRS_{100\%})(LOAD_{100\%}) + (kW_{pump})(HRS_{pump})\} (\$/kWh)$$

Where:

- \$ENERGY = estimated annual energy cost for chiller operation (\$/year)
- $EFF_{xx\%}$ = chiller efficiency at xx% of maximum capacity (kW/ton)
- $HRS_{xx\%}$ = hours of chiller operation at xx % of maximum capacity (hours/year)
- $LOAD_{xx\%}$ = cooling load at xx% of maximum capacity (tons)
- \$/kWh = average cost of electricity from the utilities data sheets (\$/kWh)
- kW_{pump} = energy input to primary pumps = (40 hp)(0.746 kW/hp) = 29.8 kW
- HRS_{pump} = hours of primary pump operation

$$\$ENERGY_{plant} = \{(0.75)(1,500)(125) + (0.75)(2,500)(375)+ (0.63)(2,000)(625) + ((0.60)(1000)(750) + (0.75)(1,000)(125)) + (29.8)(7,000)\} (0.051)$$

$$\$ENERGY_{plant} = \$121,560$$

Figure O-1. Calculate \$ENERGY

$$\$PV = \$INITIAL + \$REPLACE(P/F,i\%,N) + (\$ENERGY + \$MAINT)(P/A,i\%,N) - \$REMAIN(P/F,i\%,N)$$

Where:

- \$PV = present value of the life-cycle costs associated with a particular alternative (\$)
- \$INITIAL = total initial cost of a particular alternative (\$), including the cost for upgrading the mechanical room
- \$REPLACE = future replacement cost (assumed as zero (\$))
- (P/F,i%,N) = present value of a future cash flow at an interest rate of i% for N years[1,2]
- (P/A,i%,N) = present value of au annually-recurring cash flow at an interest rate of i % for N year s[1,2]
- i% = interest rate (discount rate) for federal energy conservation projects (%)[2]
- N = study period (years)
- \$ENERGY = estimated annual energy coat of chiller operation (\$/year)
- \$MAINT = annual maintenance costs (\$)
- \$REMAIN = remaining value of equipment at the end of N years (assumed to be zero (\$))

1 This factor is obtained from any engineering economics text
2 NISTIR 85-3272-7

Figure O-2. Present Value (\$PV) Formula

$$\$PV = \$INITIAL + (\$ENERGY + \$MAINT)(P/A,i\%,N)$$

$$\$PV_{Central\ Plant} = \$1,040,000 + (\$121,560 + (-2000))(PA,4\%,20)$$
$$= \$1,040,000 + \$119,560(13.59)$$
$$= \$1,040,000 + \$1,624,800$$
$$\$PV_{Central\ Plant} = \$2,664,800$$

Figure O-3. Calculate \$PV

O.3.5 Compare LCCs

Compare the LCC of the central plant with the sum of the LCCs for separate selections calculated in the retrofit versus replace analysis (Appendix O). Select the alternative with the least LCC. For $PV of the existing individual chillers, refer to Table O-2. The summation to compare the LCC of individual systems with the LCC of a central plant is presented in Figure O-4, *LCC Comparison.*

$$\$PV_{Chiller1} = \$710,500$$
$$\$PV_{Chiller2} = \$771,700$$
$$\$PV_{Chiller3} = \$771,700$$
$$\$PV_{Chiller4} = \$853,400$$

$$\$PV_{Total\ Individual\ Systems} = \$3,107,500$$

$$\$PV_{Central\ Plant} = \$2,664,800$$

Figure O-4. LCC Comparison

O.3.6 Example Conclusion

In comparing total LCC of the individual units with the LCC of a central chilled water plant, the central plant is preferred.

O.4 List of Major Manufacturers

For further information presented in this appendix, contact the following:

Carrier Air Conditioning Company
Syracuse, NY
(315) 432-6000

McQuay/Snyder General Corporation
13600 Industrial Park Blvd.
P.O. Box 1551
Minneapolis, MN 55440
(612) 553-5330

The Trane Company
Commercial Systems Group
3600 Pammel Creek Road
La Crosse, WI 54601-7599
(608) 787-2000

York International Corporation
P.O. Box 1592
York, PA 17405-1592
(717) 771-7890

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Appendix P — Heat Recovery Alternatives for Refrigerant Chillers

ABSTRACT: This appendix provides guidelines for determining when heat recovery chillers may be economically feasible. The decision to integrate heat recovery into a chilled water system is based on comparing the life-cycle cost (LCC) of both alternatives.

P.1 Introduction

The purpose of this appendix is to optimize water chiller selection through consideration of heat recovery to convert waste heat into useful energy. This analysis should be performed by an engineer familiar with building mechanical systems and economic analyses.

P.1.1 Applicability

This evaluation procedure is applicable to chiller installations where heat recovery chillers may be economically feasible. Before heat recovery can be considered a viable alternative, the following questions must first be answered: Is there heat to recover? Is there a use for the recovered heat? A building is a likely candidate for heat recovery if it can pass this two-part test. However, a building may not be a good candidate for heat recovery even if it does satisfy the two criteria. In-depth analyses of the heating and cooling load profiles of the building, as well as the equipment used may be necessary. Typical uses of recovered heat from chillers are:

- reheat for process air conditioning systems;
- reheat for comfort air conditioning systems;
- perimeter zone heating for comfort air conditioning systems;
- outdoor air preheating;
- domestic hot water (HW) systems in dormitories, dining halls, kitchens, shower rooms, and locker rooms;
- preheat for boiler make-up water systems; and
- any hot water process or comfort load.

P.1.1.1 A cooling load must exist for heat recovery systems to work. Buildings with simultaneous heating and cooling loads are candidates. Buildings with high internal loads are generally the best suited for this application. This situation requires the chilled water system to operate year-round, increasing the feasibility of heat recovery systems.

P.1.2 Advantages/Disadvantages

The potential advantage of heat recovery is the reduced energy cost achieved by recovering waste heat from the refrigerant loop within the chiller and converting it into useful energy. A heat recovery chiller operates at a lower efficiency (higher kW/ton) than a cooling-only chiller. The total energy required for providing both heating and cooling from a single piece of equipment can be significantly less than the energy required from two separate pieces of equipment.

P.1.2.1 It should be noted the initial cost of a heat recovery chiller is higher than a cooling-only chiller. This is due to the increased refrigerant pressures and temperatures required to elevate the condenser water temperatures. Another item that adds to the cost of a heat recovery chiller is a second condenser shell dedicated to the heat recovery loop.

P.1.2.2 Heat recovery systems may not eliminate the need for an auxiliary heat source. This will depend on the required HW temperature. Due to the special construction requirements of a heat recovery chiller, manufacturers typically do not support the retrofit of an existing cooling-only chiller to a heat recovery chiller. Even if a retrofit is being performed on a cooling-only chiller for the purpose of converting to a new refrigerant, it is not cost-effective to retrofit for the purpose of adding heat recovery.

P.2 Analysis

This section provides guidance for determining whether a heat recovery system should be incorporated into a potential chilled water system. An end-user of the recovered heat must exist for the system to be considered for evaluation. Each chilled water system using heat recovery chillers that has a lower LCC than the existing or proposed cooling-only chilled water system should be considered for implementation (see Appendix M, *Evaluating Water Chillers for Replacement or Retrofit Potential,* or Appendix O, *Assessing the Potential of Central Chilled Water Plants).*

P.2.1 Obtain Data

Obtain data from equipment survey forms and either Appendix M or Appendix O for each chilled water system to be evaluated. Determine the total cooling load on the chilled water system being considered for heat recovery. Further data gathering and evaluations of the building are typically necessary to determine its HW daily needs along with the actual usage schedule. If a given chilled water system is not a candidate for the heat recovery evaluation, it may still be a candidate for thermal energy storage.

P.2.2 Engineering Analysis

The engineering analysis should consist of comparing the LCC analysis of the existing or potential chilled water system to the proposed chilled water system which will use heat recovery. The analysis should include engineering and construction cost estimates, as determined in Appendix M or Appendix O, and additional costs for HW Pumps, piping, equipment room modifications, energy usage controls, and projected annual maintenance costs for the proposed heat recovery system.

P.2.3 Perform LCC

Perform an LCC estimate for the chilled water system using heat recovery. Compare it to the total LCC of the existing or potential chilled water systems. The following items outline the procedure to follow in performing the LCC analysis.

P.2.3.1 Equipment Pricing - Contact the chiller manufacturer to obtain the cost of the proposed heat recovery chiller, heat recovery rating (heat dissipation), and chiller performance efficiencies at 100, 75, 50, and 25 percent of full loading. Gather further cost information for all additional or modified equipment to support the heat recovery distribution system. Items for consideration should include heat exchangers, pumps, and HW storage tanks.

P.2.3.2 Annual Energy Cost - The LCC analysis will require calculating the annual energy cost for each of the chillers being considered for integration. The following is a summary of methods described in Appendix L, *Fundamentals of Cooling Load and Energy Analysis,* for estimating annual energy costs. Calculate the annual energy cost ($ENERGY) for each of the chillers. Depending on the number of chillers in the system and the need for heat recovery during cooling periods, perform an individual calculation for each chiller.

P.2.3.3 Heat Reclaim Energy Savings - Determine the heat reclaim energy savings ($BOILER-ENERGY). The amount of usable reclaim energy savings will depend largely on the compatibility of the hourly cooling load profile and the hourly heating load profile as previously discussed in Appendix L. Typically, the cooling load profile will be estimated based on groups of hours representing 25, 50, 75, and 100 percent of part-load conditions. The annual heating load profile will need to be estimated in a similar fashion. The evaluator will need to group the annual hourly heating demand into estimated groups of hours matching those of the chiller operation. Once the bins of operation have been determined, contact the chiller manufacturer and request the part-load heat reclaim performance of each chiller being evaluated. Request the part-load performances that match the cooling only chiller. Once the amount of usable heat reclaim has been determined, the annual energy savings can be determined.

P.2.3.4 Compute the present value ($PV) of the LCC. The $PV of the LCC is an equivalent cost, computed for the comparison of mutually exclusive alternatives.

P.2.3.5 If the proposed heat recovery chilled water system has a lower LCC than the proposed chilled water system, the heat recovery chilled water system should then be implemented.

P.3 Example of Evaluation

The following assumptions, figures, and table provide the necessary information to assess whether a chiller slated for replacement is a candidate for a heat recovery chiller in lieu of a cooling-only chiller.

P.3.1 Assumptions

The following assumptions have been made in developing a representative example of heat recovery chiller engineering and LCC analyses.

P.3.1.1 Average energy cost from the utilities data sheet is: $0.051/kWh.

P.3.1.2 The chiller to be replaced is part of an existing central plant but is the only chiller in the plant that is under consideration to be replaced. Total central plant peak cooling load is 1,000 tons with a constant year-round base cooling load of 400 tons. The central plant was previously determined to consist of two 500-ton chillers based on the LCC analysis. The heat is to be recovered 9 hours/day, 5 days/week (2,340 hours/year). The rest of the year the chiller will operate in a cooling-only mode (6,420 hours/year). The proposed heat recovery chiller will provide the base cooling load of 400 tons. A nominal 500-ton heat recovery chiller will be selected.

P.3.1.3 A year-round process heating load of 5,300 Mbh (1,000 Btu/hour) exists. This load is present 9 hours/day, 5 days/week (2,340 hours/year). The heat reclaimed from the heat recovery chiller will supply this load.

P.3.1.4 The existing heating source for the process load is an electric HW boiler. The boiler provides the required 5,300 Mbh load, 9 hours/day, 5 days/week. Electrical input to the boiler is 1,550 kW.

P.3.1.5 The heat recovery water loop and the process heating water loop will be independent circuits. Heat will be transferred through a plate and frame type heat exchanger.

P.3.1.6 The present value ($PV) for the cooling only replacement chiller is: $1,510,000 (see Appendix M for the procedure to determine the $PV for a cooling only replacement chiller).

P.3.1.7 Estimate the initial cost of the heat recovery system.

Description	Cost Estimate	Source
500-ton H-R chiller	$180,000	Manufacturer
Pump	1,400	Manufacturer
Heat exchanger	4,200	Manufacturer
Controls	12,000	Manufacturer
Piping & specialties	8,000	Cost Estimate Guide
Labor	65,000	Cost Estimate Guide

Total of Initial Costs $270,600

P.3.2 Heat Recovery Chiller Annual Energy Cost ($ENERGY)

The first step in the evaluation is to calculate the annual energy cost $\$ENRGY_{Heat\ Recovery}$ for the proposed heat recovery chiller. This calculation is shown in Figure P-1, *Calculate $ENERGY.*

P.3.3 Boiler Annual Energy Costs

Calculate the energy costs to provide the required process heat output with the existing electric hot water boiler ($BOILER-ENERGY). This calculation is the energy dollars saved by providing the required heat from the heat recovery chiller instead of the electric boiler. Figure P-2, *Calculate $BOILER-ENERGY,* illustrates this calculation.

P.3.4 Chiller and Boiler $PV

For comparison to the heat recovery option, calculate the LCC for the cooling-only replacement chiller and HW boiler. This requires the calculation of the HW boiler $PV and adding it to the previously determined chiller $PV. It is shown in Figure P-3, *Calculate Chiller and Boiler $PV.*

$$\$ENERGY_{Heat\ Recovery} = \Sigma\ \{(EFF_{xx\%})(HRS_{xx\%})(LOAD_{xx\%})\}\ x\ (\$/kWh)$$

Where:

$\$ENERGY_{Heat\ Recovery}$ = estimated annual energy cost for heat recovery chiller operation ($/year)
$EFF_{xx\%}$ = chiller efficiency at xx% of maximum capacity (kW/ton)
$HRS_{xx\%}$ = hours of chiller operation at xx% of maximum capacity (hours/year)
$LOAD_{xx\%}$ = cooling load at xx% of maximum capacity (tons)
$/kWh = average cost of electricity from the utilities data sheds ($/kWh)

Since the chiller is operating at a constant base load of 400 tons year-round, referring to Table P-1, xx% =80%.

$$\$ENERGY_{Heat\ Recovery} = \{(0.645)(6{,}420)(400) + (0.750)(2{,}340)(400)\}\ X\ (0.051)$$
$$\$ENERGY_{Heat\ Recovery} = \$120{,}280/year$$

Figure P-1. Calculate $ENERGY

$$\$BOILER\text{-}ENERGY = \Sigma\ (INPUT_{xx\%})(HRS_{xx\%})(\$/kWh)$$

Where

$BOILER-ENERGY = annual energy cost to operate boiler ($/year)
$INPUT_{xx\%}$ = electrical input at xx% of maximum capacity (kW)
$HRS_{xx\%}$ = hours of boiler operation at xx% of maximum capacity (hours/year)
$/kWh = average cost of electricity from the utilities data sheets ($/kWh)

The boiler is operating at a constant load 9 hours/day, 5 days/week (2,340 hours/year).

$BOILER-ENERGY = (1,550)(2,340)(0.051)
$BOILER-ENERGY = $184,980/year

Figure P-2. Calculate $BOILER-ENERGY

$$\$PV_{Replacement} = \$BOILER\text{-}ENERGY(P/A,i\%,N) + \$PV_{Chiller}$$
$$= (184{,}980)(13.69) + 1{,}510{,}000$$
$$= 2{,}532{,}400 + 1{,}510{,}000$$
$$\$PV_{Replacement} = \$4{,}042{,}400$$

Figure P-3. Calculate Chiller and Boiler $PV

Table P-1. Heat Recovery Chiller, Energy Consumption Analysis

Heat Recovery Chiller Energy Consumption Analysis						
Cooling Capacity		**Cooling-only Operation**(1)		**Heat Recovery Operation**(2)		
% Load	Tons	kW	kW/ton	Heat Recovered (Mbh)(3)	kW	kW/ton
100	500	328	0.656	- 0 -	- 0 -	- 0 -
90	450	291	0.647	6605	337	0.749
80	400	258	0.645	5875	300	0.750
70	350	226	0.646	5159	267	0.763
60	300	197	0.657	4451	236	0.787
50	250	169	0.676	3746	206	0.824
40	200	142	0.710	- 0 -	- 0 -	- 0 -
30	150	115	0.767	- 0 -	- 0 -	- 0 -
20	100	89	0.896	- 0 -	- 0 -	- 0 -

(1) Water entering condenser shell at 29° C (85” F) at maximum capacity. Entering condenser water temperature decreases as load decreases to a minimum temperature of 21° C (70° F).

(2) Water entering heat recovery shell at 35° C (95° F) and maximum amount of heat is extracted. Leaving water temperature from this shell is 40.4° C (104.8° F) at 450 tons and decreases to 38.5” C (101.3° F) at 250 tons.

(3) Where "- 0 -" appears, no heat is available to be recovered.

(4) Chat is based on 1500 gpm evaporator flow leaving the evaporator at 7° C (44° F) and returning at 12° C (54° F). Condenser flow rate and heat recovery flow rate is 1200 gpm each circuit.

P.3.5 Present Value ($PV) Formula

A review of the present value formula is presented prior to its application with the heat recovery chiller LCC. This analysis assumes a 20-year study period and an expected life of all equipment of 20 years. The useful life of all equipment is assumed to be the same and only lasts through the study period ($REMAIN is zero). None of the capital equipment is replaced during the study period ($REPLACE is zero). Maintenance for the heat recovery system is assumed to be approximately $2,000 more per year than that required for the chiller/boiler combination. Part of the maintenance cost is attributed to the plate and frame heat exchanger. A simplified $PV formula is used to perform the calculation. This formula is shown in Figure P-4, *Present Value ($PV) Formula.*

P.3.6 Calculate the Present Value of LCC for Heat Recovery Chiller ($PV)

Compute the present value of the life-cycle costs for the heat recovery chiller ($PV). This calculation is shown in Figure P-5, *Calculate $PV.*

P.3.7 Comparison and Selection

Compare the LCC of the heat recovery chiller with the LCC for the cooling-only chiller system. Select the alternative with the least LCC.

$$\$PV_{Replacement} = \$4,042,400$$

$$\$PV_{Heat\ Recovery} = \$1,932,400$$

Select the heat recovery chiller.

P.4 List of Major Manufacturers

Carrier Air Conditioning Company
Syracuse, NY
(315) 432-6000

McQuay/Snyder General Corporation
13600 Industrial Park Blvd., Box 1551
Minneapolis, MN 55440
(612) 553-5330

The Trane Company
Commercial Systems Group
3600 Pammel Creek Road
La Crosse, WI 54601-7599
(608) 787-2000

York International Corporation
P.O. Box 1592
York, PA 17405-1592
(717) 771-7890

$PV = $INITIAL + $REPLACE(P/F,i%,N) + ($ENERGY + $MAINT)(P/A,i%,N) - $REMAIN(P/F,i%,N)

Where:

$PV	=	present value of the life-cycle costs associated with a particular alternative ($)
$INITIAL	=	total initial cost of a particular alternative ($), including the cost for upgrading the mechanical room
$REPLACE	=	future replacement cost, assumed as zero ($)
(P/F,i%,N)	=	present value of a future cash flow at an interest rate of i% for N years[1,2]
(P/A,i%,N)	=	present value of an annually recurring cash flow at an interest rate of i % for N years[1,2]
i%	=	interest rate (discount rate) for federal energy conservation projects (%)’
N	=	study period (years)
$ENERGY	=	estimated annual energy cost of chiller operation ($/year)
$MAINT	=	annual maintenance costs ($)
$REMAIN	=	remaining value of equipment at the end of N years, assumed to be zero ($)

1 This factor is obtained from any engineering economics text
2 NISTIR 85-3272-7

Figure P-4. Present Value ($PV) Formula

$PV = $INITIAL + ($ENERGY + $MAINT)(P/A,i%,N) - ($REMAIN)(P/F,i%,N)

For the heat recovery chiller system,

$$\$PV_{Heat\ Recovery} = \$270,600 + (\$120,280 + \$2,000)(P/A,4\%,20)$$
$$= \$270,600 + \$122,280(13.59)$$
$$= \$270,600 + \$1,661,800$$
$$\$PV_{Heat\ Recovery} = \$1,932,400$$

Figure P-5. Calculate $PV

Appendix Q — Assessing the Potential of Thermal Energy Storage

ABSTRACT: This appendix provides guidelines for determining when thermal energy storage systems (TESS) may be an economically feasible alternative for integration into an existing or proposed chilled water system.

Q.1 Introduction

The purpose of this appendix is to provide guidelines for the consideration of TESS within the chiller selection process. TESSs lower annual energy costs and allow a reduction in the selected chiller's capacity. This analysis should be performed by an engineer familiar with mechanical building systems and economic analyses.

Q.1.1 Consideration of Advantages and Disadvantages

This evaluation procedure applies to existing or proposed chilled water systems into which a TESS can be integrated. The feasibility of incorporating thermal energy storage will be determined by identifying and analyzing various situations that may favor its success. Potential advantages of integrating a TESS into an existing or proposed chilled water system include lower initial costs and lower operating costs. A potential disadvantage is greater space requirements.

Q.1.1.1 Lower initial costs are possible when the maximum cooling load is of a short duration and the thermal storage recovery time is of a long duration before the load returns. Examples are buildings which have relatively large loads for less than six hours per day or only for a day or two per week. A relatively small chilled water system can operate for the extended duration and meet the storage needs.

Q.1.1.2 Lower operating costs are possible because the production of the cooling storage media (ice, chilled water, or a brine solution) occurs during off-peak hours. The local utility rates must be structured such that off-peak rates are less expensive. This will also create a reduction in demand costs.

Q.1.1.3 One potential disadvantage of integrating thermal storage into an existing or proposed chilled water system is the space required for storage tanks. Tank storage can be either above or below grade, but will require significant space.

Q.1.2 Definitions

Terms used in this appendix are defined as follows.

Q.1.2.1 Ton-hour **-** the amount of cooling (in tons) provided in a given amount of time (in hours).

Examples: a chiller operating at 100 tons for one hour would produce the equivalent of 100 ton-hours. A chiller operating at 150 tons for two hours and 50 tons for six hours would produce an equivalent of 600 ton-hours.

Figure Q-1, *Building Cooling Load Served by Convetional System,* provides a graphical representation of this concept.

Q.1.2.2 Off-peak - time period of the day when energy costs ($/kWh) are reduced due to a lower demand for power from a utility.

Q.1.2.3 on-peak - time period of the day when energy costs ($/kWh) are higher due to a greater demand for power from a utility.

Q.1.2.4 Demand charge - a charge assessed by an electric power company ($/kW) for the highest electrical energy usage rate (kW).

Q.1.2.5 Charging - activity of creating the thermal energy to be stored.

Q.1.2.6 Discharging - activity of depleting the thermal energy that was stored during charging.

Q.1.2.7 Thermal efficiency of the storage tank - the rate of heat transfer across the surface of the storage tank expressed as a percentage of energy lost in storage.

Q.2 System Descriptions

There are several different types of thermal storage systems. System types range from chilled water storage to ice storage to phase change material storage (other than water and ice) as defined below.

Q.2.1 Chilled Water Storage

Chilled water storage is conceptually the simplest type of thermal energy storage. The storage tanks can either be located above or below grade. The storage volume is proportional to the required thermal storage capacity and inversely proportional to the chilled water supply-to-return temperature difference. For cost-effectiveness, the storage system should be designed with a -7° C (20° F) AT between the supply and return water temperatures. As a rule, chillers should produce 4° C (40° F) water and coils should, at maximum load, be able to return water at a minimum of 16° C (60° F).

Q.2.1.1 The following equation can be used as a rule of thumb to determine the required tank size:

$$\text{Volume} = (\text{Capacity} \times 1000) / \Delta T$$

Where:

Volume is in gallons,
Capacity is in ton-hours,
ΔT is in °C, and
1000 is a factor which incorporates the specific heat of water and an 8 percent efficient storage tank.

Q.2.1.2 An installation strategy that is unique to chilled water storage is integrating the chilled water storage tank with the fire water storage tank. In doing so, the capital costs for storage is essentially cut by 50 percent.

Q.2.2 Ice Storage

Ice storage uses thermal energy which can be stored as the latent heat of fusion of ice. Latent heat of fusion is the heat required to change between a solid and a

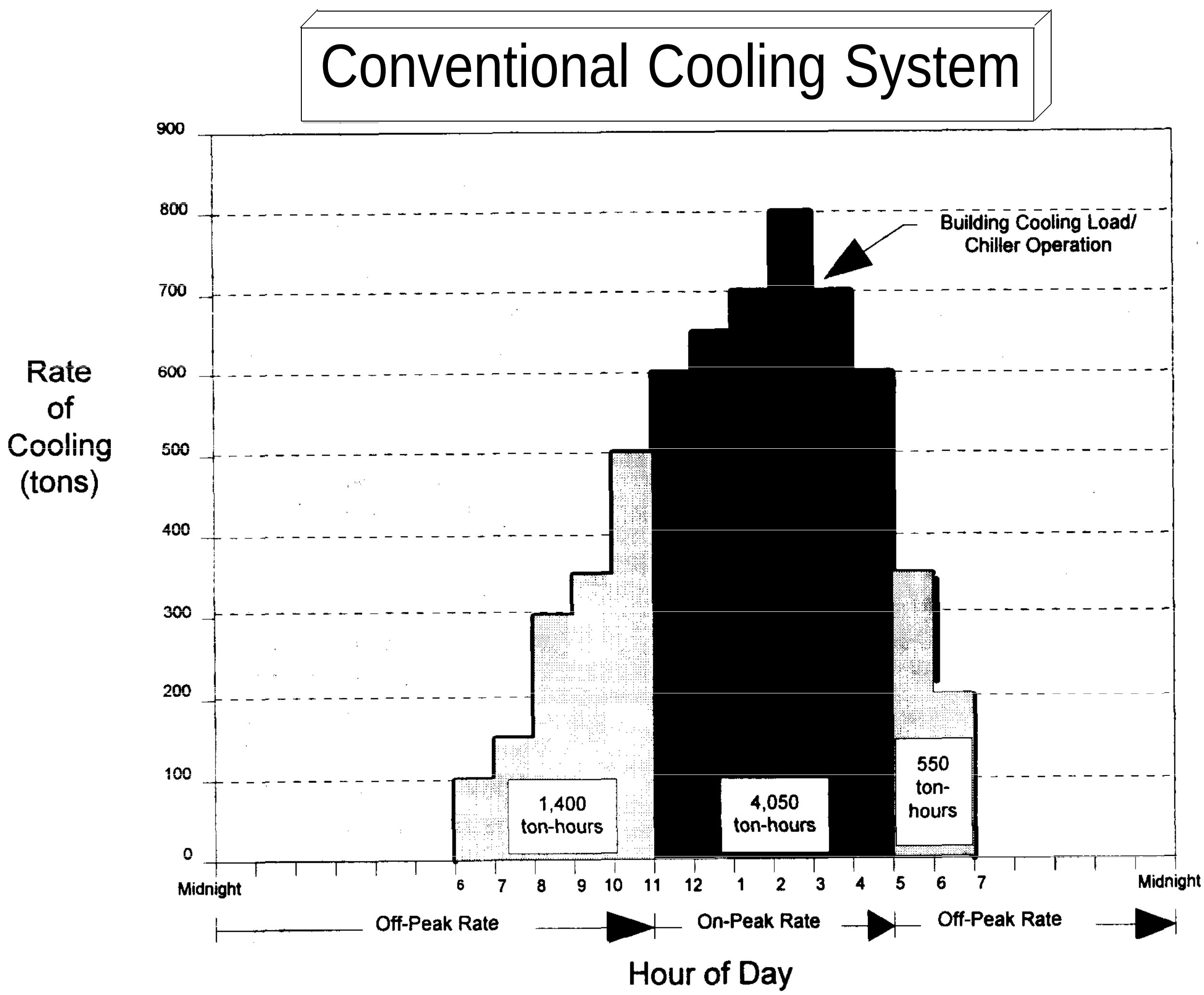

Figure Q-1. Building Cooling Load Served by Conventional System

liquid phase. Water, which has the highest latent heat of fusion of all common materials, is 144 Btu/lbm. Because of this high latent heat of fusion, the required tank size for ice storage systems is approximately 15 to 20 percent of that required for chilled water storage.

Q.2.2.1 There are several types of ice storage systems available. Most of these systems are available as off-the-shelf type components. In some instances, a storage tank may need to be field erected or custom made. The reduced discharge temperature required during charging poses a penalty on the operating efficiency of a chiller. Therefore, it is the required capacity during charging, not the required capacity during normal operation, that sets the chiller size. For a typical ice storage system, the nominal chiller size required will be approximately 50 to 80 percent larger than for a chilled water storage system. For example, in Figure Q-2, *Building Cooling Load Served by Partial Storage System*, a 250-ton output is required from the chiller. A nominal chiller size of 375 to 450 tons will be required to achieve the 250-ton output needed during ice building. Table Q-1, *Equipment Costs*, lists the approximate costs of major system components. The costs are based on the rate of cooling required, not the nominal chiller size. For example, the equipment cost for a chiller able to operate at 250 tons during ice building will be:
(250 tons) x ($650/ton) = $162,500.
The actual chiller size will be in the range of 375 tons to 450 tons. It is advisable to seek assistance from a manufacturer's representative when selecting a chiller for ice building capabilities.

Table Q-1. Equipment Costs

System	Chiller $/Ton	Thermal Storage[1] $/Ton-Hr
Chilled Water[1]	350	65
Ice-on-Coil	650	65
Ice-in-Container	650	60
Solid Ice Brine Coil	650	60
Ice Harvester	650	50
Eutectic Salts	350	95

(1) Based on a storage capacity of approximately 5,000 ton-hours, chilled water storage systems typically involve field erected storage tanks. Therefore, labor is included, but costs for site preparation is not included.

Q.2.2.2 The most common ice storage method is the ice-on-coil system. This system generates ice by submerging refrigerant or brine coils in a tank of water. Water is frozen on the face of the coil to a thickness of approximately 2.5 inches. The ice is stored until needed. Return water is then chilled as it passes through the ice, supplementing or replacing chiller output. This system uses two independent piping systems: one containing the low-temperature brine solution, the other containing the chilled water and ice-water mixture in the storage tank. These two fluids do not mix. Additionally, it may be desirable to design the chilled water loop as a primary/secondary distribution system.

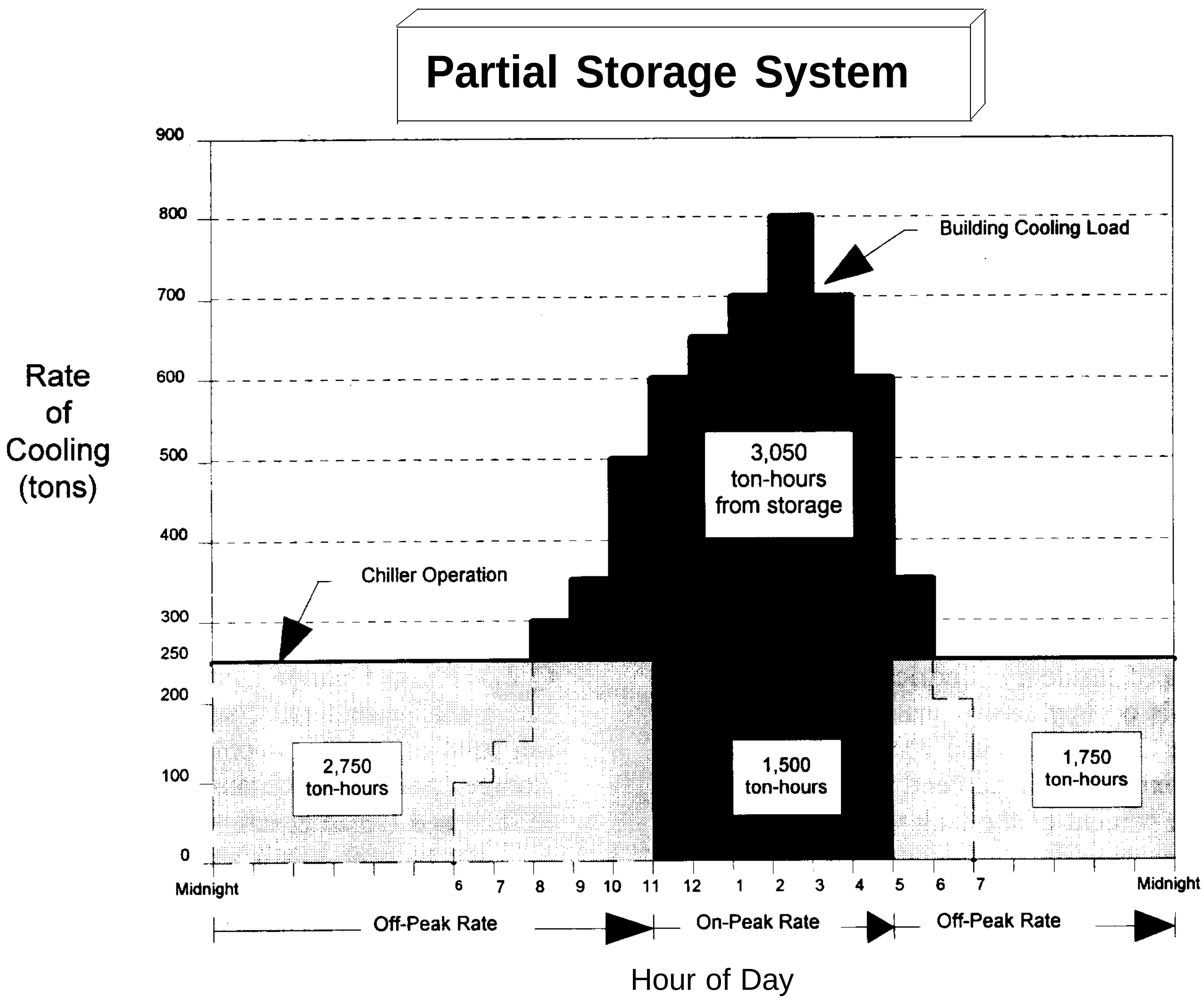

Figure Q-2. Building Cooling Load Served by Partial Storage System

Q.2.2.3 The ice-in-containers method uses high-density polyethylene containers filled with deionized water and an ice nucleating agent. The containers are commercially available in either spherical or rectangular configurations. These containers are placed in storage tanks where a cooled (-4° C to -3° C (24° F to 26° F)) brine solution is pumped through the tank, freezing the containers. During discharge, the return water is chilled as it is pumped through the tank. For this strategy, a single closed piping system is all that is required. This piping system can be either a single piping loop or a primary/secondary piping arrangement. Unlike the ice-on-coil system, the low temperature fluid and the high temperature fluid are the same. If it is undesirable to have a brine solution pumped throughout a system, a heat exchanger can be installed between the primary and secondary loop.

Q.2.2.4 Commercially available solid ice brine coils are a method of storage where plastic mats with integral brine coils are placed inside a cylindrical tank. These coils occupy approximately ten percent of the tank volume and water occupies approximately 80 percent. The remaining ten percent of the tank volume allows for expansion during the charging cycle. A brine solution (-4° C to -3° C) from a chiller is circulated through the coils to freeze the water during the charging cycle. During the discharging cycle (typically when the chiller is not operating), the brine solution is returned from the end-users and pumped through the brine coils and is re-chilled. The piping arrangements for the solid ice brine coils are similar to the ice-in-containers.

Q.2.2.5 Ice harvesting is a method of thermal storage where ice is formed on the face of evaporator coils at a thickness of 0.25 to 0.40 inches. The evaporator coils contain refrigerant at -4° C to -3° C (24° F to 26° F) and are located above an ice and water bath storage tank. Water is sprayed onto the coils until a predetermined thickness of ice is formed. The ice is then discharged from the coils and dropped into a storage tank until a predetermined level of ice is formed. The storage tank is an integral part of the ice harvester machine. The tank will contain a 0° C (32° F) ice and water mixture. This system requires an independent closed loop piping circuit containing the refrigerant. A separate open piping circuit will distribute water from the storage tank to the individual users. The chilled water in this loop is circulated directly through the ice and water mixture in the storage tank. The piping circuit serving the end-users (0° C (32° F) water) can be installed as a primary/secondary piping system if desired.

Q.2.3 Phase Change Materials

Phase change materials, such as a eutectic salt solution, are commonly used for cold storage applications because of their ability to melt and freeze at temperatures of 8° C (47° F). Eutectic salt is a mixture of inorganic salts, water, and nucleating and stabilizing agents. The eutectic salt solution is encapsulated in a high-density polyethylene container. These containers are rectangular in shape and measure approximately 24" x 8" x 1-3/4" and are self-stacking. Because of their 8° C (47° F) freezing point, conventional chilled water temperatures of 6° C (42° F) can be used. This allows for increased flexibility in chiller selection and better mechanical efficiency during charging. This system is very similar to the ice-in-containers method, except the fluid in the container is different and low water temperatures are not required. The piping system for this method is the same as the ice-in-containers system. The volume required for eutectic salts is approximately 30 percent of that required for chilled water storage.

Q.2.4 Equipment Costs

Table Q-1 provides estimated costs of thermal storage systems based on a system storage capacity of approximately 5,000 ton-hours. Except for the chilled water storage system, costs are for materials only and do not include installation, piping, and pump costs. The cost per ton-hour of storage space varies inversely with the storage requirements. This is especially true for the chilled water storage systems. Exercise caution when using the $65/ton-hour value for chilled water storage systems. For example, a 25,000 ton-hour chilled water storage tank would cost about $35/ton-hour. Installation costs will vary depending whether the tank is above grade or below grade. Costs for the glycol or brine solution in the low temperature systems (ice storage) will vary greatly depending on piping arrangements.

Q.2.5 Operating Strategies

The following are descriptions of three thermal storage system operating strategies. The physical size of the storage system will depend on:

- the method used (for example, water or ice storage),
- building cooling load profile, and
- the operating strategy chosen for shifting the electrical load.

The example used through the rest of this appendix will be based on a building with a cooling load profile requiring 6,000 ton-hours of cooling capacity (shown in Figure Q-1). A conventional chiller system serving this load would require an 800-ton chiller operating at various percentages of full capacity for 13 hours per day. The building cooling load and chiller operating profiles are identical.

Q.2.5.1 Partial storage is a strategy where sufficient thermal energy is stored during the off-peak hours to provide a flat energy usage curve from the chiller during a twenty-four hour period. Based on the same building cooling load profile of Figure Q-1, the building cooling load and chiller operating profiles for the partial storage strategy are shown in Figure Q-2. Of the total 6,000 ton-hours required, 3,050 are provided from the stored thermal energy. This strategy imposes a constant 250-ton load on the system. An advantage of partial storage is that it requires the smallest chiller of the three operating strategies, as well as that required for a conventional cooling system. A disadvantage is the chiller continues to operate during the on-peak hours.

Q.2.5.2 Demand limited storage is a strategy where sufficient thermal energy is stored during the off-peak hours to prevent the chiller from operating during the on-peak hours. Figure Q-3, *Building Cooling Load Served by Demand Limited Storage System,* illustrates this operating strategy using the same 6,000 ton-hour per day load. Of the total 6,000 ton-hours

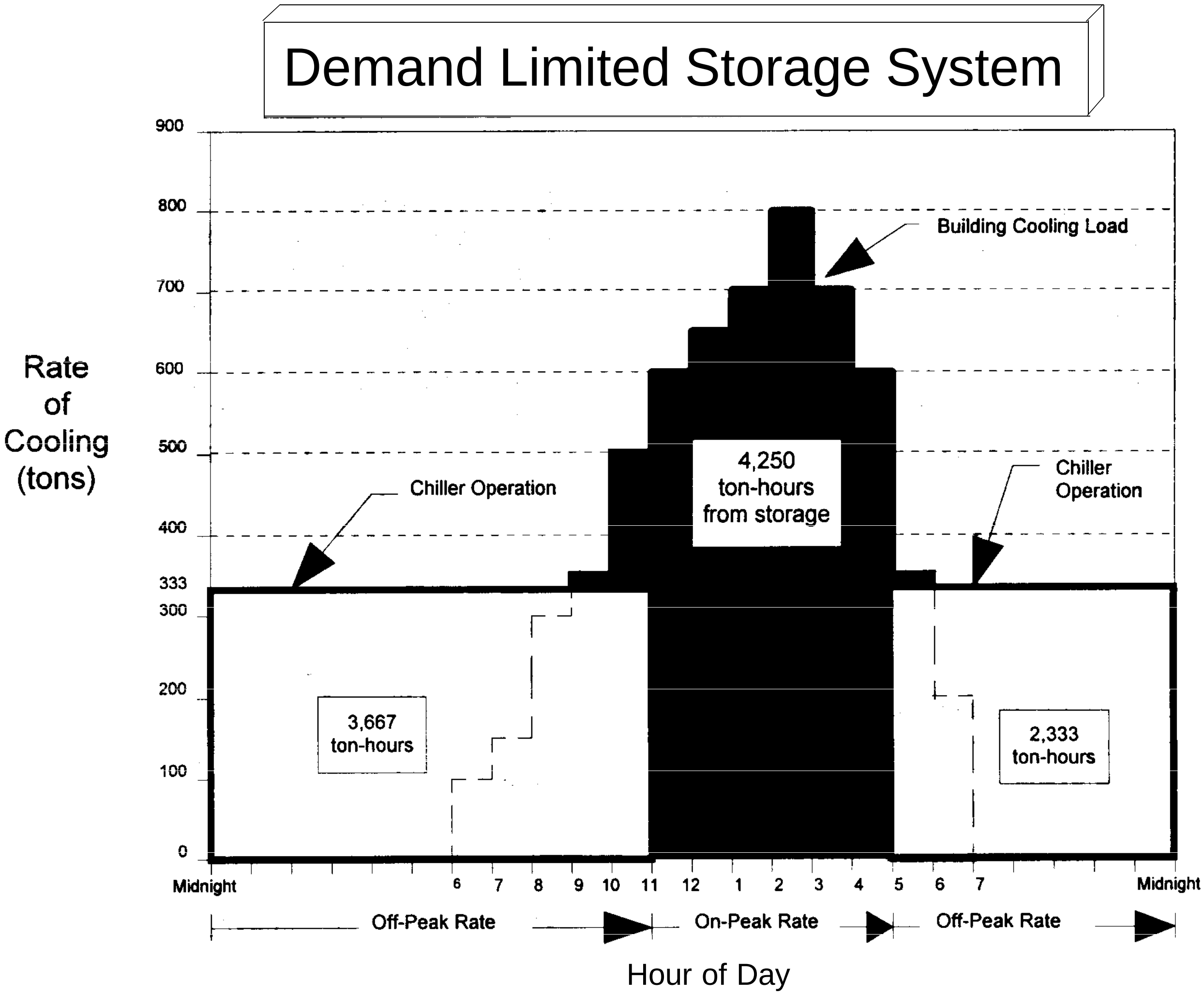

Figure Q-3. Building Cooling Load Served by Demand Limited Storage System

required, 4,250 ton-hours are provided by the stored thermal energy. This strategy imposes a 333-ton load on the system for 18 hours per day. An advantage of demand limited storage is the chiller does not operate during the on-peak hours, thereby reducing electrical demand cost. A disadvantage is it requires a larger chiller and more thermal energy storage space than a partial storage system (4,250 ton-hours versus 3,050 ton-hours).

Q.2.5.3 Full storage is a strategy where sufficient thermal energy is stored during periods of no load to prevent the chiller from operating during periods of load. Using the 6,000 ton-hour per day load profile, the chiller operating profile is shown in Figure Q-4, *Building Cooling Load Served by Full Storage System.* All cooling ton-hours are provided by the stored thermal energy. This strategy imposes a 545-ton load on the system for 11 hours per day. An advantage of full storage is the chiller only operates during the evening hours when building energy usage is typically less. A disadvantage is this arrangement requires a larger chiller and more energy storage space than the other two strategies. For a chilled water storage system, this strategy will allow a smaller chiller than a conventional chiller system. For an ice storage system, chiller size may be the same, or even larger, than a conventional chiller system.

Q.3 Selection Procedure

This section provides guidance for determining whether a TESS can be incorporated into an existing or new chilled water system and selecting the system type. The following paragraphs briefly describe the steps required to perform this analysis. Equations and a detailed example are provided in section Q.4.

Q.3.1 Assess Conditions

Before thermal storage can be considered as an alternative, two basic conditions must exist:

1) the average building cooling load profile is cyclical, with periods of high load occurring during the day, and low load occurring during the night, and
2) the utility company assesses a demand charge as well as significantly different on-peak and off-peak rates.

Q.3.2 Obtain Data

Obtain a completed copy of the AC/R Equipment Survey Form for water chillers (Appendix H, *AC/R Equipment Survey Guide and Equipment Data Collection Survey Forms),* a cooling load analysis of the building (Appendix L, *Fundamentals of Cooling Load and Energy Analysis),* utility rates and rate schedules (Appendix H), and any replacement analyses so far performed (Appendix M, *Evaluating Water Chillers for Replacement or Retrofit Potential,* or Appendix O, *Assessing the Potential of Central Chilled Water Plants).*

Q.3.3 Determine the Peak Hourly Cooling Load Profile

To accurately size the TESS, the load profile should reflect the 24-hour cooling requirements for the peak cooling day. The peak cooling day will typically be the day that requires the greatest number of ton-hours. This information can be graphically represented by aligning the rate of cooling (tons) along the ordinate, and the hour of

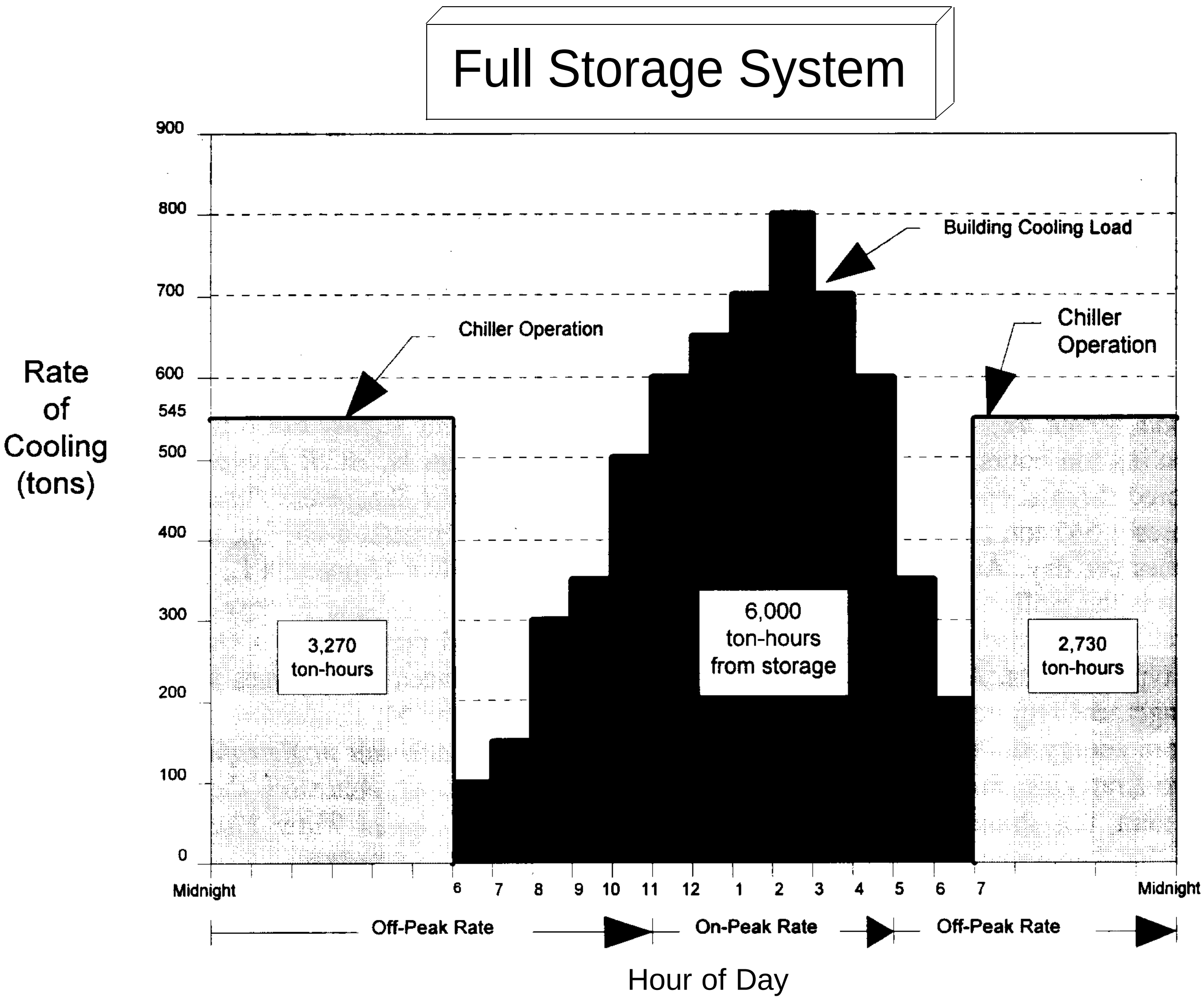

Figure Q-4. Building Cooling Load Served by Full Storage System

day along the abscissa of a Cartesian coordinate system as illustrated in Figure Q-1. This graph will clearly show the twenty-four hour building load profile and allow the evaluator to determine the on-peak and off-peak ton-hours. Repeat this procedure for both peak and typical days for all months of the cooling season (see section Q.4).

Q.3.4 Determine the Annual Energy Cost

The next step is to determine the annual energy cost of the conventional chilled water system. A simplified approach to determining the annual energy cost follows.

1) The electrical utility rate structure must be thoroughly reviewed. If the electrical utility rates are divided into consumption charges and demand charges, calculate the demand charge. Demand charges are based on the highest recorded demand for electricity, measured over a brief period, usually 1 to 15 minutes. Compute the demand charge for each monthly peak load profile by multiplying the peak demand (kW) by the demand charge ($/kW).
2) If a non-racheting billing rate structure is used for demand charges (demand charge is based on peak kW each month), repeat the peak demand charge calculation for each cooling month and add to determine the annual cost.
3) If demand charges are based on a racheting billing structure (demand charge is based on the peak kW in the past 12 months), use the greatest demand charge in the past year and multiply by the number of cooling months to determine the annual demand cost.
4) Compute the average monthly base energy usage cost as follows. Multiply the energy used (ton-hours) during the off-peak hours (the area under the chiller operation curve bound by the start and stop time of the off-peak electrical rates) by the off-peak electrical rates ($/kWh) and chiller efficiency (kW/ton). Perform a similar calculation for the on-peak period. Repeat calculations for each month in which cooling is required. Add up the usage costs from each month to get a yearly base energy-use cost ($).
5) Add the annual base energy-use costs and the annual demand costs to get the total annual energy cost.
6) Using the load profile for the three possible thermal storage operations (partial, demand limited, and full storage), evaluate the energy cost as described above.

Q.3.5 Compute Life-Cycle Costs (LCC) and Compare Alternatives

Once the annual cooling energy costs have been calculated, the initial cost, maintenance cost, replacement cost, and remaining value should be evaluated on a LCC method to determine the best alternative. The optimum thermal storage system will minimize the LCC.

Q.4 Example of Evaluation

The following assumptions, figures, and tables provide a method of determining if a thermal storage system is economically viable. Refer to Figure Q-1 for a graphical presentation of the yearly peak cooling load profile used in this illustration. This example compares a conventional chiller system to a solid ice brine coil thermal storage system operating at each of the three operating strategies described.

Q.4.1 Assumptions

This analysis procedure assumes:

- On-peak hours:
  11:00 a.m. to 5:00 p.m.
- Off-peak hours:
  12:00 midnight to 11:00 a.m. and
  5:00 p.m. to 12:00 midnight
- On-peak demand charge:
  ($\$DEMAND_{on}$) = $8.72/kW
- On-peak base energy charge:
  ($\$BASE_{on}$) = $0.0607/kWh
- Off-peak base energy charge:
  ($\$BASE_{off}$) = $0.0486/kWh
- Rate Structure: non-racheting (demand charge is reset each month to highest demand occurring during the month)

Q.4.2 Calculate Annual Demand Cost ($DEMAND)

The first step in assessing the potential of thermal energy storage is to calculate annual demand cost, This is shown in Figure Q-5, *Calculate $DEMAND. This* calculation is repeated for each month and for each storage system strategy.

Q.4.3 Calculate Annual Base Energy Costs ($BASE)

The second step is to calculate annual base energy costs. This calculation is shown in Figure Q-6, *Calculate $BASE. This* calculation is repeated for each type of storage system strategy.

Q.4.4 Calculate Annual Energy Costs ($ENERGY)

The third step is calculating the annual energy costs. This calculation, shown in Figure Q-7, *Calculate $ENERGY, is* performed for each storage system strategy.

Q.4.5 Determine Maximum Cooling Rate Thermal Storage Required

Referring to Figures Q-1, Q-2, Q-3, and Q-4, the maximum rate of cooling (tons) required and maximum amount of thermal storage (ton-hours) required are as follows:

System	Rate of Cooling	Required Storage
Conventional	800 tons	0 ton-hr
Partial storage	250 tons	3,050 ton-hr
Demand limited storage	333 tons	4,250 ton-hr
Full storage	545 tons	6,000 ton-hr

Q.4.6 Determine Capital Equipment Costs ($CAPITAL) for Each System

Step five requires the determination of the capital equipment costs for each system. Figure Q-8, *Calculate $CAPITAL,* illustrates this calculation. Table Q-1 provides the budget pricing numbers.

Q.4.7 Determine Installation Costs ($INSTALL) for Each System

Refer to published cost-estimating guides, recent in-house projects, and equipment vendors for guidelines. In this example, the following determination was made.

$\$INSTALL_{conventional}$ = $210,000
$\$INSTAL_{partial}$ = $213,400
$\$INSTALL_{demand}$ = $289,800
$\$INSTALL_{full}$ = $445,700

Q.4.8 Determine Initial Costs ($NITIAL) for Each System

Step seven in the assessment is calculating the initial cost. Figure Q-9, *Calculate $INITIAL,* illustrates this calculation and provides the costs for the conventional system and each storage system strategy.

$\$DEMAND = (TONS_{on=peak})(EFF_{\#\#\%})(\$DEMAND_{on})$

Where:

$EFF_{\#\#\%}$ = chiller efficiency at ##% of maximum capacity (kW/ton) (refer to Table Q-2)

For the conventional chiller system (refer to Table Q-3):

$\$DEMAND_{conventional}$ = ((350)(1.06) + (600)(1. 18) + (750)(1.33) + (800)(1.33) + (650)(1.33) + (300)(0.93))kW x (8.72)$/kW

$\$DEMAND_{conventional}$ = $37,360

Repeating for each type of storage system strategy (refer to Tables Q-4, Q-5, and Q-6):

$\$DEMAND_{partial}$ = $10,400 for partial storage system

$\$DEMAND_{demand}$ = $0 for demand limited storage system (shifted to off-peak hours)

$\$DEMAND_{full}$ = $0 for full storage system (shifted to off-peak hours)

Figure Q-5. Calculate $DEMAND

Table (O-2. Chiller Efficiencies at Various Operating Points

System Description and Chiller Size	Chiller Efficiency - kW/Ton					
	20%	40%	60%	80%	100%	Ice Making
Conventional System - 800 Tons Maximum Load Air-cooled Rotary Screw	1.00	0.93	1.06	1.18	1.33	n/a
Partial Storage System - 250 Tons Maximum Load Air-cooled Rotary Screw	1.01	0.95	1.08	1.20	1.35	1.51
Demand Limited Storage System - 333 Tons Maximum Load Air-cooled Rotary Screw	1.01	0.94	1.07	1.19	1.34	1.51
Full Storage System - 545 Tons Maximum Load Air-cooled Rotary Screw	1.00	0.93	1.06	1.18	1.33	1.51

Table Q-3. Chiller Operating Schedule for Conventional Chiller System

800-Ton Peak Load (Nominal 800-Ton Chiller) Values for Monthly Peak Day												
	Monthly Peak		On-Peak Ton-Hours					Off-Peak Ton-Hours				
Month	**Tons**	**kW**	**20%**	**40%**	**60%**	**80%**	**100%**	**20%**	**40%**	**60%**	**80%**	**100%**
May	350	357	0	1770	0	0	0	610	220	0	0	0
June	600	648	0	0	900	2140	0	335	750	375	0	0
July	750	998	0	0	0	1730	2050	230	460	1130	0	0
Aug	800	1064	0	0	0	1200	2850	250	500	700	500	0
Sept	650	865	0	0	940	1670	650	360	770	410	0	0
Ott	300	294	0	0	1520	0	0	590	190	0	0	0
Totals			0	1770	3360	6740	5550	2375	2890	2615	500	0

Table Q-4. Chiller Operating Schedule for Partial Storage System

250-Ton Peak Load (Nominal 375-Ton Chiller) Value for Monthly Peak Day						
	Monthly Peak (During On-Peak Hours)			Off-Peak **Ton-Hours**		
Month	**Tons**	**kW**	**On-Peak Ton-hours**	**Thermal Storage Charging**	**Thermal Storage Discharging**	**Total Peak Day Ton-Hours**
May	108	106	650	1335	615	2600
June	188	192	1125	2290	1085	4500
July	233	252	1400	2855	1345	5600
Aug	250	270	1500	3050	1450	6000
Sept	200	204	1200	2440	1160	4800
Oct	96	94	575	1140	585	2300

Table Q-5. Chiller Operating Schedule for Demand Limited Storage System

233-Ton Peak load (Nominal 500-Ton Chiller) Values for Monthly Peak Day						
	Monthly Peak (During On-Peak Hours)			Off-Peak Ton-Hours		Total Peak Day Ton-Hours
Month	Tons	kW	On-Peak Ton-Hours	Thermal Storage Charging	Thermal Storage Discharging	
May	o	0	0	1850	750	2600
June	o	0	0	3185	1315	4500
July	o	0	0	3975	1625	5600
Aug	o	0	0	4250	1750	6000
Sept	o	0	0	3410	1360	4800
Ott	o	0	0	1610	690	2300

Table Q-6. Chiller Operating Schedule for Full Storage System

545-Ton Peak Load (Nominal 820-Ton Chiller) Values for Monthly Peak Day						
	Monthly Peak (During On-Peak Hours)			Off-Peak Ton-Hours		Total Peak Day Ton-Hours
Month	Tons	kW	On-Peak Ton-Hours	Thermal Storage Charging	Thermal Storage Discharging	
May	0	0	0	2600	0	2600
June	0	0	0	4500	0	4500
July	0	0	0	5600	0	5600
Aug	0	0	0	6000	0	6000
Sept	0	0	0	4800	0	4800
Oct	0	0	0	2300	0	2300

$BASE = {{ Σ ((TONHRS)$_{\#\#}(EFF)_{\#\#\%}$) x ($BASE$_{on}$)}$_{on\text{-}peak}$ + { Σ ((TONHRS)$_{\#\#}$(EFF)$_{\#\#}$%) x ($BASE$_{off}$)}$_{off\text{-}peak}$ } x Σ ((AVGTONHRS/PEAKTONHRS) x DAYS)

Where:

TONHRS$_{\#\#}$ = ton-hours at specific efficiency ratings (refer to Tables Q-3, Q-4, Q-5, Q-6)

EFF$_{\#\#\%}$ = chiller efficiency at ##% of maximum capacity (kW/ton) (refer to Table Q-2)

AVGTONHRS = Average number of ton-hours in a day (refer to Table Q-7 for this example)

PEAKTONHRS = Peak number of ton-hours occurring one day during the month (refer to Table Q-7 for this example)

DAYS = days in the month

For the conventional chiller system (refer to Table Q-3):

$BASE$_{conventional}$ = {((1770)(0.93) + (3360)(1.06) + (6740)(1.18) + (5550)(1.33))kWh x (0.0607)$/kWh + ((2375)(1.00) + (2890)(0.93) + (2615)(1.06) + (500)(1.18))kWh x (0.0486)$k/wh} x {((1800 + 3200 + 3900 + 4200 + 3400 + 1600)/(2600 + 4500 + 5600 + 6000 + 4800 + 2300)) x (31 + 30 + 31 + 31 + 30 +31)}

$BASE$_{conventional}$ = $213,810

Repeating for each type of storage system strategy (refer to Tables Q-4, Q-5, and Q-6):

$BASE$_{partial}$ = $223,700 for partial storage system
$BASE$_{demand}$ = $217,510 for demand limited storage system
$BASE$_{full}$ = $244,360 for full storage system

Figure Q-6. Calculate $BASE

Table O-7. Ton-Hour Usage Summarization

Month	Peak Day Ton-Hours	Average Day Ton-Hours	Days In Month	Monthly Ton-Hours
May	2600	1800	31	55,800
June	4500	3200	30	96,000
July	5600	3900	31	120.900
August	6000	4200	31	130,200
September	4800	3400	30	102,OOO
October	2300	1600	31	49,600

$ENERGY = $DEMAND + $BASE

For the conventional chiller system

$ENERGY$_{conventional}$ $213,810 = $251,170

Repeating for each type

$ENERGY$_{partial}$ = $234,100 for partial storage system

$ENERGY$_{demand}$ = $217,510 for demand limited storage system

$ENERGY$_{full}$ = $244,360 for full storage system

Figure Q-7. Calculate $ENERGY

For the conventional chiller system

$CAPITAL$_{conventional}$ 800 tons)(350 $/ton) + (0 ton-hours)(0 $/ton-hour)

$CAPITAL$_{conventional}$ = $280,000

Repeating for each type of storage system strategy:

$CAPITAL$_{partial}$ = $345,500 for partial storage system

$CAPITAL$_{demand}$ = $471,450 for demand limited storage system

$CAPITAL$_{full}$ = $714,250 for full storage system

Figure Q-8. Calculate $CAPITAL

$INITIAL = $CAPITAL + $INSTALL

For the conventional chiller system

$INITIAL$_{conventional}$ = $280,000+ $210,000= $490,000

Repeating for each type of storage system strategy:

$INITIAL$_{partial}$ = $ 558,900

$INITIAL$_{demand}$ = $ 761,250

$INITIAL$_{full}$ = $1,159,950

Figure Q-9. Calculate $INITIAL

$PV = $INITIAL + $REPLACE(T/F,i%,N) + ($ENERGY + $MAINT)(P/A,i%,N) - $REMAIN(WF,%,N)

Where

$PV	=	present value of the life-cycle costs associated with a particular alternative ($)
$INITIAL	=	total initial cost of a particular alternative ($)
$REPLACE	=	future replacement cost (assumed as zero)
(P/F,i%,N)	=	present value of a future cash flow at an interest rate of i% for N years[1,2]
(P/A,i%,N)	=	present value of an annually-recurring cash flow at an interest rate of i% for N years[1,2]
i%	=	interest rate (discount rate) for federal energy conservation projects (%7
N	=	study period (years)
$ENERGY	=	annual energy costs ($)
$MAINT	=	annual maintenance costs ($)
$REMAIN	=	remaining value of equipment at the end of X years (assumed to be zero)

1 This factor is obtained from any engineering economics text
2 NISTIR 85-3272-7

Figure Q-10. Present Value ($PV) Formula

$PV = $INITIAL + ($ENERGY + $MAINT)(P/A,i%,N)

For the conventional chiller system

$PV_{commercial}$ = 490,000 +((251,170 + 1600) x (P/A,4,20))
= 490,000 + (252,770X 13.59)

$PV_{commercial}$ = $3,925,100

Repeating for each type of storage system alternative:

$PV_{partial}$ = $3,774,300
PV_{demand} = $3,764,800
PV_{full} = $4,551,500

Figure Q-n. Calculate $PV

Q.4.9 Determine Annual Maintenance Costs ($MAINT) for Each System

For this example, the following determination of annual maintenance costs for each system were made.

$MAINT_{conventional}$ = $1,600
$MAINT_{partial}$ = $2,500
$MAINT_{demand}$ = $3,500
$MAINT_{full}$ = $5,200

Q.4.10 Present Value ($PV)

A review of the present value formula is presented prior to calculating the LCC of the alternatives. This analysis assumes a 20-year study period and an expected life of all equipment of 20 years. The useful life of all equipment is assumed to be the same and only last through the study period, thus $REMAIN is zero. None of the capital equipment is replaced during the study period, thus $REPLACE is zero. This PV formula is shown in Figure Q-10, *Present Value ($PV) Formula.*

Q.4.11 Calculate the Present Value of LCC for Each System ($PV)

The $PV is an equivalent cost, computed for the comparison of mutually exclusive alternatives. Figure Q-11, *Calculate $PV*, illustrates this calculation.

Q.4.12 Determination

Based on the calculations and determinations provided in the example, the system selected would be the demand limited storage system.

Q.5 List of Major Manufacturers

Q.5.1 Ice Harvester Method

Baltimore Aircoil Company
P.O. Box 7322
Baltimore, MD 21227
(410) 799-6200

Turbo Refrigeration Company
1815 Shady Oaks Drive
P.O. Box 396
Denton, TX 76205
(817) 387-4301

Q.5.2 Solid Ice Brine Coil Method

Calmac Manufacturing Corp.
101 W. Sheffield Ave.
Englewood, NJ 07631
(201) 569-0420

Q.5.3 Chilled Water Storage Method

Chicago Bridge & Iron Technical Services Company
1501 North Division Street
Plainfield, IL 60544
(815) 439-6000

Q.5.4 Ice-on-Coil Method

Snyder General Corporation
13600 Industrial Park Blvd.
P.O. Box 1551
Minneapolis, MN 55440
(612) 553-5330

Q.5.5 Eutectic Salts Method

Transphase Systems, Incorporated
15572 Computer Lane
Huntington Beach, CA 92649
(714) 893-3920

Q.5.6 Ice-in-Containers Method

York International Corporation
P.O. Box 1592
York, PA 17405
(717) 771-7890

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Appendix R — Glossary of Terms, Definitions, and Bibliography

R. 1 Glossary of Terms and Definitions

A/C: air conditioning

ACGIH: American Conference of Government and Industrial Hygienists

AC/R: air-conditioning and refrigeration

AEL: allowable or acceptable exposure limits

AFB: Air Force Base

AF/CE: Air Force Civil Engineers

AFCESA: Air Force Civil Engineer Support Agency

ALR: actual leak rate

ANSI: American National Standards Institute

APLV: Application Part-Load Value. A single kW/ton value which modifies the IPLV for the chilled and condenser water supply temperatures required in a specific application. The same IPLV schedule for operational hours is used in producing this value.

Appliance: Any device which contains a Class I or Class II chlorofluorocarbon as a refrigerant and is used for household or commercial purposes (for example; air conditioner, refrigerator, chiller, or freezer).

ARI: Air-Conditioning and Refrigeration Institute or American Refrigeration Institute

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASME: American Society of Mechanical Engineers

BAS: building automation system

BCE: base civil engineer

BLCC: building life-cycle cost

BRMP: Base Refrigerant Management Program

Btu: British Thermal Unit. A unit of heat; the heat required to raise the temperature of one pound of water, at its maximum density, one degree Fahrenheit: also, the heat to be removed in cooling one pound of water one degree Fahrenheit.

Btu/hr: British thermal unit per hour

CAA: Clean Air Act

CAAA: Clean Air Act Amendments

CE: civil engineer

Central Chilled Water Plant: Multiple chilled water systems combined and served from a single piping network.

CERL: U.S. Army Construction Engineering Research Laboratory

CerTest: U.S. Air Force-administered certification test

CFC: chlorofluorocarbon

Challenging Alternative: Proposed optimization of the defending alternative with the purpose of trying to establish an alternative that is more energy efficient with a lower LCC.

Chilled Water System: also Chiller System. One or more chillers that serve a single piping network.

CLTD: cooling load temperature difference. An ASHRAE method that simplifies the solar heat gain calculation for a cooling load on a building. It substitutes a one-step conduction calculation for the solar heat transfer through walls, roofs, and glass using an equivalent temperature difference.

Cluster: Individual chilled water systems within close proximity of each other that may be considered for incorporation into a central chilled water plant.

Commercial Refrigeration: Refrigeration appliances used in retail food and cold storage warehouse sectors.

COP: coefficient of performance

CR: consumption rate. The annual rate at which a refrigerant is being lost to leaks and emissions, typically given in pounds per year.

CRR: critical refrigerant reserve. The single, largest charge, in pounds, for each refrigerant used at an AFB.

CWE: current working estimate

DBMA: Defense Business Maintenance Area

Defending Alternative: Lowest LCC chiller alternative from the previous analysis.

Demand Charge: A charge assessed by a utility for the largest amount of power used during a specified period of time.

DERA: Defense Environmental Restoration Account

Disposal: The process leading to the disassembly of any appliance for re-use of its component parts; the disassembly of any appliance for discharge, deposit, dumping or placing of its discarded component parts into or on any land or water; the discharge, deposit, dumping or placing of any discarded appliance into any land or water.

DLA: Defense Logistics Agency

DoD: Department of Defense

DPB: discounted payback

EC: environmental compliance

ECIP: Energy Conservation Investment Program

EEL: emergency exposure limit. The concentration from which escape is feasible without any irreversible effects on health in an emergency situation where recurrence is expected to be rare in an individual's lifetime.

Enhanced Retrofit: The enhanced retrofit involves re-engineering the chiller to be compatible with the properties of the new environmentally friendly refrigerant. Re-engineering includes minimizing loss of cooling capacity and maximizing chiller efficiency. The redesigned components consist of but are not limited to gaskets, O-rings, resized compressor impeller, and revised refrigerant expansion orifice system.

EPA: Environmental Protection Agency

EPAMLR: EPA maximum leak rate. The maximum percentage of the total charge a machine can lose based on a 12-month period without exceeding EPA leakage limitations. Exceeding this rate does not constitute a violation unless the leak is not repaired, or a plan to replace the equipment has not been established within 30 days.

ESCO: Energy Conservation Service Company

ESF: Equipment Survey Form

ETL: Engineering Technical Letter

FAR: Federal Acquisition Regulation

FEMP: Federal Energy Management Program

FLA: full-load amps

Handbook: the Refrigerant Management Handbook

HCFC: hydrochlorofluorocarbon

HD: high density

HFC: hydrofluorocarbon

High-Pressure Appliance: Uses refrigerant with a boiling point between -500 C (-58° F) and 10° C (50° F) at atmospheric pressure.

Household Refrigeration: Refrigerators and freezers intended primarily for household use. This equipment may be used outside the home.

HQ AFCESA/EN: Systems Engineering Directorate, Headquarters, Air Force Civil Engineer Support Agency

HQ USAF/CEVV: Prevention Division, Directorate of Environmental Quality, Headquarters U.S. Air Force

HVAC: heating, ventilating, and air conditioning

HW: hot water

Industrial Process Refrigeration: Complex customized appliances used in the chemical, pharmaceutical, petrochemical, and manufacturing industries. The sector is also defined to include industrial ice machines and ice rinks.

IPLV: integrated part-load value. A single kW/ton value that describes part-load efficiency of a chiller at 25, 50, 75, and 100 percent full load conditions based on a "typical" number of operational hours at each. It is based on 7° C (44° F) chilled water and 29° C (85° F) condenser water temperatures. It is defined in ARI Standard 550-92 by the equation IPLV = 0.05 (100% kW/ton) + 0.3 (75% kW/ton) + 0.4 (50 % kW/Ton) + 0.25 (25% kW/ton),

IR: infrared-based

IR-PAS: infrared-photoacoustic-based

kW: kilowatt

kWh: kilowatt-hour

LCC: life-cycle cost. The total cost associated with the purchase, installation, operating, and maintenance of a system or equipment over its expected life.

LCCID: Life-Cycle Cost in Design

Load Diversity: To allow a lesser maximum load on the central plant than the sum of the loads for separate systems.

Low-Loss Fitting: Any device intended to establish a connection between hoses, air conditioning and refrigeration equipment, or recovery or recycling equipment that will close automatically or must be manually closed before disconnecting, thereby minimizing the release of refrigerant to the atmosphere

Low-Pressure Appliance: Appliances that use a refrigerant with a boiling point above 10° C (50° F) at atmospheric pressure.

Major Maintenance, Service, or Repair: Maintenance, service, or repair that involves removal of the compressor, evaporator, or auxiliary heat exchanger coil.

MAJCOM: Major command

MBtu: 1,000 Btu/hr

MFH: military family housing

MILCON: Military Construction

MOA: Memorandum of Agreement

MRR: marginal refrigerant reserve. The sum of the appropriate EPAMLRs (15% or 35%) for each machine plus the CRR for each refrigerant.

MSDS: material safety data sheets

MVAC: motor vehicle air conditioning

NEMA: National Electric Manufacturers Association

NEPA: National Environmental Policy Act

NIOSH: National Institute for Occupational Safety & Health

NIST: National Institute of Standards and Technology

ODC: ozone-depleting compounds

ODP: ozone-depletion potential

OEM: original equipment manufacturer

Off-peak: Time period of the day when energy costs are reduced by a utility due to below-normal demand.

On-peak: Time period of the day when energy costs are raised by a utility due to above-normal demand.

O&M: operations and management or operations and maintenance

O&S: operations and services

Opening an Appliance: Any service, maintenance, or repair on an appliance that could be reasonably expected to release refrigerant to the atmosphere, unless the refrigerant was previously recovered from the appliance.

OPR: offices of primary responsibility

OSD: Office of the Secretary of Defense

OSHA: Occupational Safety and Health Administration

Partition: Any wall, ceiling, or floor assembly which is not exposed to outside ambient conditions.

POC: point of contact

PPBS: planning, programming, and budgeting system

PPM: parts per million

PPP: Pollution Prevention Program

PRO-ACT: PRO-ACT stands for proactive and is an information clearinghouse located at Brooks APB, Headquarters Air Force Center for Environmental Excellence, HQ AFCEE, commercial phone number (800) 233-4356 and DSN 240-4214.

Primary Chilled Water Pump: Pump which distributes chilled water between the chiller plant and the secondary chilled water pumps serving the load.

PRV: pressure relief valve

PSIG: pounds per square inch gage

Push/Pull Method of Recovery: The push/pull refrigerant recovery method is defined as the process of transferring liquid refrigerant from a refrigeration system to a receiving vessel by lowering the pressure in the vessel and raising the pressure in the system, and by connecting a separate line between the system liquid port and the receiving vessel.

PVC: polyvinylchloride

RDT&E: Research, development, testing and evaluation

RCRA: Resource Conservation and Recovery Act

Reclaim: Reprocessing of refrigerant to new product specifications. The purity of the final product must be chemically verified to meet ARI 700 standards.

Recover: Removal of refrigerant from a system. Testing the condition of the refrigerant is not necessary.

Recycle: To clean refrigerant for re-use without chemical purity verification.

Retirement: The ability to recover refrigerant from a machine by means of retrofit or replacement.

Retrofit: The conversion of equipment containing a CFC refrigerant to use a more environmentally friendly refrigerant.

RM: refrigerant manager, An individual selected to manage the BRMP and be responsible for the RMP development.

RMP: Refrigerant Management Plan: a schedule with the associated costs required to eliminate CFC refrigerants in AC/R equipment at an AFB. The ideal Schedule allows existing equipment to operate until the end of its economic life while maintaining sufficient refrigerant reserves. Reserves are maintained through inter-base refrigerant transfers, purchase waivers, and recovery of equipment refrigerant charges upon retirement.

SC: shading coefficient

SCBA: self-contained breathing apparatus

Schedule: Equipment Retirement Schedule. A pre-determined plan developed to establish the specific dates and order which AC/R equipment retirements should be conducted to maintain sufficient refrigerant inventories and maintain annual funding requirements as level as possible.

SCL: shading cooling load

Secondary Chilled Water Pump: Pump which serves the end users. Pump is sized to overcome only the piping losses in the secondary piping loop and in the end users.

Self-Contained Recovery Equipment: Self-contained recovery equipment that has its own means to draw refrigerant out of an appliance.

SIOH: supervision, inspection, and overhead

SIR: savings-to-investment ratio

Small Appliance: Air conditioner, refrigeration equipment, or freezers which are fully manufactured, charged, and hermetically sealed in a factory with a charge of five pounds or less.

SPB: simple payback

Standard Contaminated Refrigerant Sample: A mixture of new and/or reclaimed refrigerant and specified quantities of identified contaminants which are representative of field obtained, used refrigerant samples and which constitute the mixture to be processed by the equipment under testing.

System-Dependent Recovery Equipment: System-dependent recovery equipment relies on the compressor of the appliance or the pressure of the refrigerant in the appliance to extract the refrigerant from the appliance.

TAN: total acid number

TDS: technical data (TechData) sheet

Technician: Any person who performs maintenance, service, or repair to air conditioning or refrigeration equipment that could reasonably be expected to release **CFCs** or HCFCs to the atmosphere.

TESS: thermal energy storage system

TIC: total installed charge

TLV: threshold limit value

Ton of Refrigeration: 12,000 Btu/hr of cooling capacity

Ton-Hour: the amount of cooling (in tons) provided in a given amount of time (in hours).

UL: Underwriters' Laboratory

UN: United Nations

UNEP: United Nations Environment Programme

VAV: variable air volume

Very High-Pressure Equipment: Air conditioning and refrigeration equipment which contains refrigerant with a boiling point below -50° C (-580 F) at atmospheric pressure.

WIMS: Work Information Management System

WIMS-ES PP: Work Information Management System—Environmental System Pollution Prevention

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