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REFRIGERANT MANAGEMENT

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This publication provides guidance for implementing procedures in Air Force instruction (AFI) 32-7086, *Hazardous Materials Management*, Chapter 4, "Air Force Ozone Depleting Substances (ODS) Program (ODSP)," as it applies to refrigerants used in real property equipment and does not apply to refrigerants used in motor vehicle air conditioning (MVAC) or aircraft refrigeration systems. This pamphlet replaces the 1994 *Air Force Refrigerant Management Handbook* that provided information and guidance for setting up Base Refrigerant Management Programs (BRMP) throughout the Air Force. The original program focused on chlorofluorocarbons (CFC) with guidance on future issues associated with refrigerant management. This publication provides the base civil engineer (BCE) and staff with a systematic approach to meet the requirements of the BRMP. This publication also includes steps to meet daily and annual record-keeping requirements through the Refrigerant Management System (RMS). Use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this pamphlet does not imply endorsement by the Air Force. This publication applies to Air Force Reserve Command (AFRC) and Air National Guard (ANG) units. Ensure that all records created as a result of processes prescribed in this publication are maintained in accordance with Air Force manual (AFMAN) 33-363, *Management of Records*, and disposed of in accordance with the Air Force Records Disposition Schedule (RDS) located in the Air Force Records Information Management System (AFRIMS). Users should send comments and suggested improvements on AF Form 847, *Recommendation for Change of Publication*, through their major commands (MAJCOM) and AFCEC, 139 Barnes Drive, Suite 1, Tyndall AFB, FL 32403-5319, to HQ USAF/A7C, 1260 Air Force Pentagon, Washington, D.C. 20330-1260. Units may supplement this publication as required; such supplements must be coordinated through the Air Force Civil Engineer Center, Operations Directorate (AFCEC/CO), prior to publication.

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Chapter 1

INTRODUCTION

1.1. Purpose. All installations, regardless of size, with refrigeration and/or comfort cooling equipment using refrigerants, as required by AFI 32-7086, *Hazardous Materials Management*, must set up and maintain a Base Refrigerant Management Program (BRMP). This pamphlet is intended to provide guidance and a methodology to the base civil engineer (BCE) and staff to set up a program, perform daily tasks, and prepare annual reports to meet the requirements of the BRMP. Daily record-keeping can be accomplished with the Refrigerant Management System (RMS) spreadsheet and annual reporting requirements can be accomplished with the Refrigerant Management Plan (RMP). The BRMP was originally required to manage Class I (chlorofluorocarbon [CFC] –based) and Class II (hydrochlorofluorocarbon [HCFC] -based) refrigerants in equipment with a charge of 50 pounds or more. However, with the new focus on phasing out HCFCs, as well as transitioning to alternate refrigerants, it is strongly recommended that all other refrigerants, including hydrofluorocarbon (HFC), be treated and managed identically. A BCE might also choose to include equipment with lower refrigerant charges to maintain mission capability with better inventory management and control. The RMS spreadsheet, RMS User's Guide, and a sample RMP are available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website: https://www.my.af.mil/gcss-af/USAF/ep/contentView.do?contentType=EDITORIAL&contentId=c88B4F00B39C57917013AD0CA469435FB&channelPageId=s2D8EB9D637283B5601377B2CE4030666&programId=t2D8EB9D6386BFB8B01394F5729351F52

1.2. Requirements.

1.2.1. This pamphlet provides guidance for the practical application of the laws and regulations behind the purpose for the BRMP. The initial requirement was published in 1994 as Title 40, Code of Federal Regulations, Part 82 (40 CFR Part 82), *Protection of Environment*, Subpart F, and has been amended over the years. The Air Force incorporated this law on 7 January 1993 via an Action Memorandum from the Secretary and Chief of Staff of the Air Force that, in some cases, provided more stringent requirements than required by law to manage refrigerants.

1.2.2. On 1 November 2004, by order of the Secretary of the Air Force, implementation of AFI 32-7086, *Hazardous Materials Management*, Chapter 4, "Air Force Ozone Depleting Substances (ODS) Program (ODSP)," took effect. On 24 January 2007, Executive Order (E.O.) 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*, was issued. E.O. 13423 states: "It is the policy of the United States that Federal agencies conduct their environmental, transportation, and energy-related activities under the law in support of their respective missions in an environmentally, economically and fiscally sound, integrated, continuously improving, efficient, and sustainable manner."

1.3. Air Force Goal. The Air Force goal is to manage the inventory of regulated refrigerants and air-conditioning/refrigeration (AC/R) equipment to ensure uninterrupted mission support while operating the equipment until the end of its economic life. Maintenance procedures used by base civil engineering (CE) personnel must be compatible with the Environmental Protection Agency's (EPA) environmental compliance regulations. The objective of this pamphlet is to provide guidance for managing the base's inventory of regulated refrigerants and AC/R equipment, and to provide information for refrigerant servicing procedures. This pamphlet also assists the BCE in developing a BRMP for managing refrigerant resources and operating 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 existing refrigerant supplies and prioritize equipment retirement. Although the emphasis is on CFCs and HCFCs, this pamphlet's procedures to standardize operations and maintenance (O&M) practices can be applied to all refrigerants. It is also recommended that base CE staff use this pamphlet to develop the RMP. Following the guidelines provided in this pamphlet, base CE staff will be able to successfully complete all essential elements of the BRMP.

1.4. Replaces 1994 Handbook. This pamphlet replaces the 1994 *Air Force Refrigerant Management Handbook* that provided directions and guidance for setting up the original BRMPs throughout the Air Force. The original program focused on CFCs with guidance on future (at that time) issues associated with HCFCs. This pamphlet provides up-to-date guidance on these HCFCs and HFCs as directed by E.O. 13423, which is interpreted to include management of all refrigerants, in addition to Class I and Class II. Guidance on accounting and reporting for greenhouse gases is found in E.O. 13514, *Federal Leadership in Environmental, Energy, and Economic Performance,* 8 October 2009. The program outlined in this pamphlet provides updated guidance for meeting the requirements of the BRMP and managing refrigerant inventories and equipment to meet EPA requirements. The BCE should ensure the CE staff is familiar with this pamphlet.

1.5. Background. There is no requirement to eliminate any equipment type based on its class. This makes for a thoughtful decision on whether to maintain or eliminate a piece of equipment. This decision should be based on an economic analysis, considering the condition of the equipment, efficiency of the equipment, and availability of the refrigerant considered.

1.5.1. **Class I and Class II Refrigerant Equipment Phase-out.** The manufacture of all Class I refrigerant-containing equipment ceased in the mid-1990s. The phase-out of Class II refrigerant-containing equipment started 1 January 2010 when the manufacture of HCFC-22 -containing equipment ceased. This commonly used direct expansion (DX) and smaller chiller equipment product line has been replaced with similar equipment using HFC-410a refrigerant. The only remaining Class II refrigerant-containing equipment still being manufactured is HCFC-123 chillers. The manufacture of this equipment will cease in 2020.

1.5.1.1. **CFC Refrigerant Equipment Replacement.** Though not required by law or Air Force policy, most CFC refrigerant-containing equipment has been replaced due to condition and/or age. In many cases, the CFC equipment was retrofitted to corresponding non-CFC refrigerants. There is no requirement to phase-out Class I refrigerant-containing equipment simply for the sake of eliminating them from the equipment or refrigerant inventory.

1.5.1.2. HCFC Refrigerant Continuation.

1.5.1.2.1. **HCFC Availability.** Though HCFC-22 equipment is no longer manufactured, the refrigerant itself is still available for purchase. HCFC-22 refrigerant is expected to remain relatively plentiful, though production levels will be reduced to the levels in Table 1.1. HCFC-123 refrigerant will continue production through 2029 (with no production allowed in 2030) and at present does not have a mandated production rate reduction schedule.

Table 1.1. HCFC-22 Production Levels.

Year	Production Level
2010	25% of 1996 level
2015	10% of 1996 level
2020	No production

1.5.1.2.2. **Refrigerant Considerations.** There is no imminent regulatory reason to make equipment replacement decisions based on whether equipment contains an HCFC versus HFC refrigerant. There are other factors to consider when determining whether to retain or select equipment with a particular refrigerant. The most important selection criteria include equipment efficiency and condition. Based on past phase-outs of refrigerants such as R-12 and R-11, the refrigerant inventory or availability will not be an issue if refrigerants are recovered and reused as aging equipment is decommissioned. Therefore, with common refrigerants still in production today, the selection criteria should be heavily weighted towards equipment efficiency and condition factors. The total impact on the environment is inconsequential between the two DX-type HCFC-22 and HFC-410a refrigerants. The total impact on the environment is much less for the large chiller refrigerant HCFC-123 than for HFC-134a. The ozone-depletion potential (ODP) and global warming potential (GWP) factors for each refrigerant are provided in Table 1.2. Ozone depleting substances (ODS) such as CFCs are chemicals that are responsible for thinning the ozone layer. ODS vary in their capacity to destroy ozone molecules. The relative depletion caused by different ODS is represented by the ODP, which is the ratio of calculated ozone change for each mass unit of gas emitted into the atmosphere relative to the reference gas CFC-11 (ODP = 1.0). Global warming is the ongoing global average increase in temperature near the Earth's surface caused by various chemicals. The GWP represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide. Carbon dioxide's GWP is defined as 1.0. All GWP values represent global warming potential over a 100-year time horizon.

Table 1.2. ODP and GWP Values.

Refrigerant	Class	ODP	GWP
HCFC-22	II	0.05	1,700
HCFC-123	II	0.02	93
HFC-134a		0	1,300
HFC-410a		0	1,890

1.5.2. New Refrigerant Transitions.

1.5.2.1. **Long-term Refrigerant Replacements.** Currently, the major HFC refrigerants being used are HFC-134a and HFC-410a. These two refrigerants are long-term solutions and are in full production. There has not been a definite replacement identified for HCFC-123, although R-245fa is a strong possibility. R-245fa is a propane-based refrigerant that is considered non-flammable but slightly toxic. It has a 920 GWP and 0 ODP rating. Currently, the EPA has not approved R-245fa for use in AC/R equipment. When transitioning to new refrigerants the BCE should only install EPA-approved refrigerants and give careful consideration to long-term support requirements and availability.

1.5.2.2. **Management of Refrigerants.** Currently, EPA prohibits intentional venting of all refrigerants, including HFCs and other current alternative refrigerants. However, the leakage rates and documentation for regulatory requirements that apply to Class I and Class II refrigerants currently do not apply to HFCs. Applying these requirements to HFCs and other alternative refrigerants will help ensure better servicing and management of all equipment.

1.5.3. **Establish Base Refrigerant Management Program (BRMP).** The successful management of refrigerants and maintaining mission capability requires the establishment of a formal and permanent BRMP under the direction of the BCE. This pamphlet provides guidance on developing a BRMP.

1.5.4. **Only CE Refrigerants for CE-owned Equipment.**

1.5.4.1. The BCE is responsible for the proper use, storage, record-keeping, and management of refrigerants used in refrigeration and comfort cooling equipment owned by the CE organization. It is up to the BCE to determine if that includes equipment that might be maintained for other customers (e.g., Army and Air Force Exchange Service [AAFES]) on base in shared responsibility agreements. Service contracts to perform refrigerant repairs by outside contractors shall include a requirement in the statement of work (SOW) to report the quantity of refrigerant removed, recovered, recycled, or disposed of, and details on repairs. Contractors are responsible for compliance with Section 608 of the Clean Air Act of 1990 as codified in EPA regulations found in 40 CFR 82, Subpart F, *Recycling and Emissions Reduction*. The same requirements apply to contractor-operated BCE refrigerant management functions.

1.5.4.2. The BCE is not responsible for refrigerants used in motor vehicle air-conditioning (MVAC) or aircraft refrigeration systems.

1.6. Base Refrigerant Management Program (BRMP). The implementation of a successful BRMP consists of focusing on and implementing six major elements. The pamphlet provides specific guidance on implementing the elements of the BRMP in Chapter 2. These elements address and provide specific solutions for (1) certifying technicians and equipment; (2) complying with EPA refrigerant leakage rates legacy data; (3) maintaining equipment to minimize refrigerant leakage; (4) managing refrigerant inventories; (5) planning equipment phase-out; and (6) generating the annual base RMP.

1.6.1. **Certifying Technicians and Equipment.** The EPA requires that any technician servicing the refrigerant section of AC/R equipment must be certified to perform service on the specific refrigerant within the machine. There are four types of certifications allowed by the EPA: Types I, II, III, and Universal. Types I, II, and III are limited in the types of equipment that can be serviced. It is recommended that Air Force refrigeration technicians have a Universal certification that enables them to work on every refrigerant type. In addition, to meet EPA requirements, an EPA-approved testing company must certify recovery equipment used to service refrigerant. The technician and recovery equipment certifications must be kept on file at the base. Submit EPA Form 7610-31, *Refrigerant Recovery or Recycling Device Acquisition Certification Form*, with the initial list of certified equipment. Equipment owners do not have to send in a new form each time they add recycling or recovery equipment to their inventory after the initial list has been submitted.

1.6.2. **Complying with EPA Refrigerant Leakage Rates.** Effective 1 July 1992, Section 608 of the Clean Air Act prohibited intentional venting of ozone-depleting substances into the atmosphere. The EPA is authorized to assess fines of up to $37,500 per day for any violation of these regulations. Leakage rates for Class I and Class II refrigerants in regulated equipment (charge of 50 pounds or more) must not exceed specific levels of leakage. These maximum levels are 15**%** for comfort cooling and 35**%** for commercial and industrial refrigeration applications using the EPA-dictated calculation method to determine the rate. If maximum leakage rates are exceeded, repairs must be made within 30 days. If the leaks cannot be repaired within 30 days, notification must be made to the EPA with a plan to eliminate the issue through either repair or replacement of the equipment. There are very specific time schedules that must be met between identification of the leak and final verification of the leak resolution. The EPA requires that specific records be kept and maintained onsite. The EPA also requires that refrigerant service records be maintained for three to five years, depending on the EPA tier level emission standards. Check with the base environmental office for final determination. The RMS spreadsheet application (and *Refrigerant Management System User's Guide)*, available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website (see paragraph 1.1), is an optional tool for the BCE to monitor equipment leakage rates and document servicing in accordance with EPA requirements. The RMS also provides information needed to develop the base RMP and is described in Chapter 3. Other refrigerant management tracking software is available**,** but bases need to ensure the software meets EPA requirements and complies with MAJCOM CE and base/MAJCOM communications squadron requirements. The EPA is available to answer questions via the Stratospheric Protection Ozone Information Hotline: (800) 296-1996, 0900 to 1630 EST. EPA leak reports required by Section 608 of the Clean Air Act go to the Base Environmental Office, which is responsible for reporting to the EPA.

1.6.2.1. **Legacy Data.**

1.6.2.1.1. As stated above, the RMS has been developed as a tool for the BCE to track performance and maintain records in accordance with EPA requirements. However, legacy data (e.g., leakage rates and equipment inventory) from the current system must be addressed.

1.6.2.1.2. Legacy data is data that already exists and in use in the current system. When migrating to a new system, there are typically two options for the legacy data, depending on the systems involved and the nature and state of the current data: (1) move the data to the new system (after validating and cleaning) and discontinue (or phase out) use of the current system; (2) keep the data in the current system and reference it when needed.

1.6.2.1.3. Data volume and data value are two variables that help determine whether to migrate or keep the data in its current location.

1.6.2.1.4. Since the EPA requires that refrigerant records be maintained for three to five years, depending on EPA tier level, the BRMP will need to address the issue of data in the current system. If the data cannot be migrated from the current system to the new system, then access to the existing service records will need to be maintained. Guidance on data migration and records management is addressed in the *Refrigerant Management System User's Guide*.

1.6.3. **Maintaining Equipment to Minimize Refrigerant Leakage.** Best service practices must be put into place and performed when servicing refrigerant-containing equipment to minimize loss of refrigerant during maintenance. These include a refrigerant leak-detection program, use of low-loss fittings, and use of high-efficiency purge units on low-pressure chillers, evaporator blanket heaters, and removing refrigerants from abandoned or out-of-service equipment. These and other suggestions are explained in Attachment 5, Attachment 6, and Attachment 7.

1.6.4. **Managing Refrigerant Inventories.** It is imperative for the BCE to maintain adequate inventories of each refrigerant type on the installation to ensure the base mission is not compromised. Inventory management is a multi-use tool to know exact quantities at any time, determine future refrigerant needs based on historical usage, identify habitual leaking equipment, monitor refrigerant usage more tightly, and predict when additional supplies are required. Refrigerants should be stored in a secure area with limited accessibility as described in Attachment 4.

1.6.5. **Planning Equipment Replacement.** Scheduling AC/R equipment replacement requires evaluating multiple factors, including equipment operating condition, efficiency, service history, and age. Refrigerant inventory quantities, cost of refrigerant, and availability are also factors. This was a significant factor for Class I equipment for which the refrigerants were no longer available to the Air Force after 1993. Class II refrigerant prices will continue to increase as availability declines due to reduced production. As HCFC-22 equipment is replaced, recovered refrigerant should be added to the inventory and the inventory managed to reduce refrigerant costs and secure adequate supply through the economic life of the remaining refrigerant equipment. Keeping equipment in good repair and minimizing leakage will stretch refrigerant inventories and prolong equipment life.

1.6.6. **Generating the Annual Base Refrigerant Management Plan (RMP).** According to AFI 32-7086, the BCE is required to generate an annual RMP. This plan serves many purposes. It provides the information required by the EPA to be submitted either directly or kept for future review in a single document. It indicates the path forward for the BCE to maintain the facility's mission with respect to the following: future refrigerant needs and from where it will be obtained; equipment replacements that will be required based on condition, efficiency, and/or refrigerant needs; and capital or operating funds that will be required. Guidance on generating the RMP is explained in detail in Chapter 4; a sample RMP is available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website (see paragraph 1.1).

1.6.6.1. **BCE Waiver for Class II Refrigeration Equipment.** AFI 32-7086 requires the BCE to approve an exception for the purchase of equipment that uses Class II refrigerant if the anticipated life of the equipment extends beyond 2020. This applies only to HCFC-123 centrifugal chillers since such chillers will remain in production until 2020 and the refrigerant will be produced until 2030. AFI 32-7086 grants the BCE the authority to approve an exception to the prohibition of purchasing AC/R equipment with Class II refrigerant, but the BCE must have a plan to support the new equipment through its useful economic life. This plan must become part of the base RMP.

1.6.6.2. **BCE Review and Certification of RMP.** The RMP must be updated annually and changes in the plan highlighted. The BCE must annually review, certify, and sign the updated RMP, as required by AFI 32-7086.

1.6.7. **Assignment of Refrigerant Management Duties.** It is recommended that the duties to manage the BRMP be assigned to one individual, as deemed most appropriate by the BCE. The refrigerant manager is responsible for the proper use, storage, record-keeping, and management of refrigerants used in refrigeration, industrial, and comfort cooling equipment owned by the CE organization.

1.7. Summary of Chapters and Attachments. The following is a summary of the organization of the pamphlet chapters and supporting attachments. The chapters explain the process and elements of a properly managed and executed BRMP and the annual report required to document the results. The attachments address technical items and do not necessarily support the daily events in a BRMP.

1.7.1. **Chapter 1, Introduction:** Provides background and sources for BRMP requirements and highlights the elements of a good program.

1.7.2. **Chapter 2, Base Refrigerant Management Program (BRMP) Elements**: Provides the requirements, recommendations, and general guidance for each of the six elements of a good BRMP and insight into the development of the RMP.

1.7.3. **Chapter 3, Refrigerant Management System (RMS):** Describes the individual tools in the RMS. The *Refrigerant Management System User's Guide*, described in this chapter, gives a more detailed summary of the general data input process and the resulting reports generated by the RMS. These reports display information needed by the BCE to ensure that the base complies with EPA requirements and that good practices are followed in the management of base refrigerant inventories and AC/R equipment.

1.7.4. **Chapter 4, Annual Base Refrigerant Management Plan (RMP):** Provides guidance on developing an RMP.

1.7.5. **Attachment 1**, **Glossary of References and Supporting Information:** Includes references, acronyms, abbreviations, and definitions.

1.7.6. **Attachment 2, Update on Refrigerants: Translating the Laws, Regulations, and Policies Into Practice:** Details the policies that affect ODS use, especially regarding refrigerants. It covers the Montréal Protocol, federal taxes, the Clean Air Act Amendments (CAAA), EPA rules and regulations, and Air Force policy.

1.7.7. **Attachment 3, Refrigerant Sensors and Monitoring of Equipment Rooms:** Descriptions, availability, and applications of refrigerant area monitors used in mechanical rooms and refrigerant storage areas.

1.7.8. **Attachment 4, Refrigerant Handling and Storage Recommendations and Requirements:** Safe-handling procedures and storage requirements for facility and container refrigerants.

1.7.9. Attachment 5, **Refrigerant Leak-Detection Methods and Equipment:** Refrigerant leak-detection methods and detection equipment for high-pressure and low-pressure refrigerant use in idle or operating equipment, the advantages and disadvantages of portable units for pinpointing leaks, and common equipment leak locations.

1.7.10. Attachment 6, **Equipment to Reduce Refrigerant Release During Maintenance and Operation of Air-Conditioning and Refrigeration Systems:** Recovery equipment reviews and terms, recycling details, and reclamation details.

1.7.11. Attachment 7, **Refrigerant Leak Mitigation Through Equipment Maintenance and Service Practices:** Major refrigerant leak mitigation through equipment maintenance and service practices.

1.7.12. Attachment 8, **Application of ASHRAE Equipment Room Design Requirements:** Mechanical equipment room design requirements for refrigeration systems covered by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 15-2007, *Standard Safety Code for Mechanical Refrigeration.*

1.7.13. Attachment 9, **Fundamentals of Cooling Load and Energy Analysis:** Calculations for a building's cooling load and energy usage analysis.

1.7.14. Attachment 10, **Chiller Selection Guide:** Guidelines and procedures for selecting water chillers based on efficiency, energy cost and availability, load matching, initial cost, and annual operating cost.

1.7.15. Attachment 11, **Heat Recovery Alternatives for Refrigerant Chillers:** Guidelines to determine if heat-recovery chillers are practical by comparing their life-cycle cost against alternatives.

1.7.16. Attachment 12, **Alternative Refrigerants for Retrofit Applications: Long-Term And Interim Refrigerants:** The Montréal Protocol (1987) was amended in 1992 to halt production of all CFCs by 1996, HCFC R-22 by 2020, and HCFC R-123 by 2030. Manufacturers responded by introducing an assortment of alternative refrigerants. Long-term alternative refrigerants are HFC refrigerants or blends (mixtures) of HFC refrigerants which have 0 ODP and do not face a foreseeable phase-out. However, EPA rules (40 CFR Part 82, Subpart F, Section 82.154) prohibit the venting of any refrigerants.

1.7.17. Attachment 13, **Natural Gas Cooling Technologies:** Commercially available natural gas cooling technologies such as direct-fired absorption systems, gas engine-driven systems, and desiccant dehumidification and cooling systems.

1.7.18. Attachment 14, **Commissioning HVAC Equipment:** Guidelines and procedures to develop the commissioning process for HVAC systems. Requirements for the testing program and procedures are described in detail, in addition to design guidance for setting up the commissioning specification.

Chapter 2

BASE REFRIGERANT MANAGEMENT PROGRAM ELEMENTS

2.1. Certifying Technicians and Recovery Equipment. All technicians working with refrigerants must satisfy EPA training and certification requirements imposed by the Clean Air Act Amendments (CAAA) of 1990 (PL 101-549) to work on AC/R equipment containing Class I or Class II refrigerants. In addition, all refrigerant recovery/recycling equipment must be certified by an EPA-approved organization and the certification copies for all base refrigerant recovery/recycling/reclaiming equipment must be kept onsite at the base.

2.1.1. **Certifying Technicians.** "Technician" refers to any person who performs maintenance, service, or repair, that could be reasonably expected to release refrigerants from appliances, except for MVAC, into the atmosphere. Training and certification sessions may include practicing improved maintenance procedures, finding improvements for current AC/R equipment, and becoming familiar with new equipment. Apprentices are exempt from this requirement provided the apprentice is closely and continually supervised by a certified technician while performing any maintenance, service, repair, or disposal that could reasonably be expected to release refrigerant from appliances into the environment. The supervising certified technician is responsible for ensuring that the apprentice complies with all EPA requirements.

2.1.1.1. **Class I and Class II EPA Requirements.**

2.1.1.1.1. EPA technician certification requirements do not differentiate between Class I and Class II refrigerants. Certification requirements apply equally to these types of refrigerants and are based on the type of appliance that is being serviced in accordance with paragraph 2.1.1.2.

2.1.1.1.2. The EPA is proposing to extend the certification requirements for technicians who work with CFC and HCFC refrigerants to technicians who work with HFCs. Technicians certified to work with CFCs and HCFCs would not have to be retested to work with HFCs, but new technicians entering the field would have to pass a test to work with CFCs, HCFCs, and/or HFCs.

2.1.1.2. Certification Types.

2.1.1.2.1. The EPA has developed four types of certification. All technicians must be certified by an approved technician certification program in accordance with the following classifications and types:

2.1.1.2.1.1. **Type I:** Required for servicing small appliances.

2.1.1.2.1.2. **Type II:** Required for servicing or disposing of high-pressure and very-high-pressure appliances, excluding small appliances and MVAC.

2.1.1.2.1.3. **Type III:** Required for servicing or disposing of low-pressure appliances.

2.1.1.2.1.4. **Universal:** Permits servicing all types of appliances.

2.1.1.2.1.5. Ensure that personally identifiable information (PII), such as Social

Security numbers, date of birth, and age, are not listed for technician certifications.

2.1.1.2.2. Detailed definitions of small, low-pressure, high-pressure, and very-high-pressure appliances can be found in 40 CFR Part 82, Subpart F, Section 82.152.

2.1.1.3. **Documentation Requirements.**

2.1.1.3.1. Technician certification programs must issue individuals a wallet-sized card (or equivalent) to be used as proof of certification upon successful completion of the test. Each card must include, at a minimum, the name of the certifying program, the date the organization became a certifying program, the name of the person certified, the type of certification, a unique number for the certified person, and the following text: "[Name of person] has been certified as a [Type I, Type II, Type III, and/or Universal, as appropriate] technician as required by 40 CFR Part 82 (2008), Subpart F."

2.1.1.3.2. Technicians must keep a copy of their proof of certification at their place of business.

2.1.1.4. Fines.

2.1.1.4.1. Authorized representatives of the certification program administrator may require technicians to demonstrate on the business entity's premises their ability to perform proper procedures for recovering and/or recycling refrigerant. Failure to demonstrate or failure to properly use the equipment may result in revocation of the certificate.

2.1.1.4.2. The EPA performs random inspections and responds to tips. The EPA is authorized to assess fines of up to $37,500 per day for any violation of these regulations.

2.1.1.5. **Air Force Recommendations.** Technician certifications are required to service equipment containing Class I and Class II refrigerants. However, at the present time, the EPA has not extended the same technician certification requirements to HFC or HFC substitutes that do not contain Class I or Class II ODS. Due to the wide variety of refrigeration equipment on Air Force bases, it is recommended that all refrigerant technicians be certified as Universal technicians.

2.1.1.6. **Obtaining Technician Certifications.** There are two ways for training and certification of technicians to be arranged:

2.1.1.6.1. **Air Force CerTest Module.** AFCEC and the Civil Engineering School at Sheppard Air Force Base, Texas, developed a study guide and a CerTest (certification test) module for EPA certification. All Air Force technicians can review the guide and attempt the certification test through the BCE at their home stations. The school has EPA approval to certify technicians and certificates are distributed by Sheppard AFB. Typically, military technician apprentices are trained and tested at Sheppard AFB. The following link lists other training and certification programs: **http://www.epa.gov/Ozone/title6/608/technicians/608certs.html**

2.1.1.6.2. **Local Vendors.** Local vendors who provide refrigeration training and EPA certification may be used based on the vendor's compliance with EPA standards for certifying programs (40 CFR Part 82, Subpart F, Section 82.152).

2.1.1.7. **Technician Recertification.** Currently there are no mandatory requirements for refrigerant technician recertifications. However, the EPA reserves the right to specify the need for technician recertification in the future, if necessary, by placing a notice in the Federal Register.

2.1.2. **Certifying Recovery and Recycling Equipment.** Base personnel who maintain, repair, or dispose of AC/R equipment must use recovery and recycling equipment certified by an EPA-approved testing organization. In addition, owners of recovery and recycling equipment must certify to the EPA that they have acquired certified equipment (according to Section 608 of the Clean Air Act of 1990) and are complying with applicable EPA requirements regarding proper use. The EPA requires that an initial one-time list of the purchased recovery and recycling equipment be submitted to the EPA regional office. Any equipment added after the initial submittal does not have to be reported; however, an updated list of equipment must be kept on file. EPA Form 7610-31, *EPA Refrigerant Recovery or Recycling Device Acquisition Certification Form,* is available at **http://www.epa.gov/ozone/title6/608/recoveryform.pdf**. The addresses for the EPA Regional offices are included at the above website. Reporting should be coordinated through the base environmental office.

2.1.2.1. Class I and Class II EPA Requirements for Recycling and Recovery Equipment.

2.1.2.1.1. All manufacturers and importers of recycling and recovery equipment intended for use on Air Force facilities during the maintenance, service, or repair of appliances containing Class I and Class II refrigerants shall have had such equipment certified by an EPA-approved equipment testing organization to meet the applicable requirements and standards of 40 CFR Part 82 (2008), Subpart F, Section 82.158.

2.1.2.1.2. Manufacturers and importers of recycling and recovery equipment certified by the EPA must place a label on each piece of equipment stating the following: "This equipment has been certified by an approved equipment testing organization to meet EPA's minimum requirements for recycling or recovery equipment intended for use with [appropriate category of appliance]." The label shall also show the date of manufacture and the serial number (if applicable) of the equipment. The label shall be affixed in a readily visible or accessible location, be made of a material expected to last the lifetime of the equipment, present required information in such a manner that it is likely to remain legible for the lifetime of the equipment, and be affixed in such a manner that it cannot be removed from the equipment without damaging the label.

2.1.2.1.3. All persons opening appliances (except for small appliances, MVAC, and MVAC-like appliances) for maintenance, service, or repair, and all persons disposing of appliances (except small appliances, MVAC, and MVAC-like appliances) must have at least one piece of certified, self-contained recovery or recycling equipment available at their place of business.

2.1.2.1.4. Use and maintain all recovery or recycling equipment in accordance with the manufacturer's directions unless such directions conflict with the requirements of the EPA.

2.1.2.1.5. The EPA has proposed standards for HFC recovery equipment that are very similar to the standards for CFC and HCFC equipment. The standards depend upon the saturation pressure of the refrigerant, the size of the appliance in which it is used, and the date of manufacture of the recovery equipment. Manufacturers of recycling and recovery equipment have stated that most recovery and recycling equipment designed for use with multiple CFC or HCFC refrigerants (e.g., 12, 22, 500, and 502) can be adapted for use with HFC refrigerants with similar saturation pressures. Thus, the EPA is proposing to allow technicians to recover HFCs using recovery or recycling equipment designed for use with at least two CFC or HCFC refrigerants of similar saturation pressure. However, recovery or recycling equipment already used for CFC or HCFC equipment should not be used for other alternate refrigerants to avoid mixing different types of refrigerants.

2.1.2.2. **Documentation Requirements.**

2.1.2.2.1. A list of certified refrigerant recovery/recycling/reclaiming equipment that includes manufacturer names, evacuation certification types, the date of certification, and refrigerant type must be available on base. Owners do not have to send in a new certification form to the EPA each time they add new recovery or recycling equipment.

2.1.2.2.2. The design of certified refrigerant recycling or recovery equipment shall not be altered in a way that would affect the equipment's ability to meet the certification standards set forth by the EPA without resubmitting the altered design for certification testing.

2.1.2.3. **Fines.**

2.1.2.3.1. The EPA performs random inspections and responds to tips. The EPA is authorized to assess fines of up to $37,500 per day (all references to days refer to calendar days) for any violation of Section 608 of the Clean Air Act.

2.1.2.3.2. In addition to potential fines, failure to abide by any of the provisions set forth by the EPA may result in revocation or suspension of certification.

2.1.2.4. **Owner Certification.**

2.1.2.4.1. Certification will take the form of a statement signed by the owner of the equipment (or another responsible designee) and shall include the following:

2.1.2.4.1.1. The name and address of the purchaser of the equipment, including the county name;

2.1.2.4.1.2. The name and address of the establishment where each piece of equipment is or will be located;

2.1.2.4.1.3. The number of service trucks (or other vehicles) used to transport technicians and equipment between the establishment and job sites and the field;

2.1.2.4.1.4. The manufacturer's name, the date of manufacture, and, if applicable, the model and serial number of the equipment; and

2.1.2.4.1.5. The certification must include a statement that the equipment will be properly used to service or dispose of appliances and that the information given is true and correct.

2.1.2.4.2. These owner equipment certifications must be sent to the EPA per instructions set forth in 40 CFR Part 82, Subpart F, Section 82.162, *Certification by owners of recovery and recycling equipment,* including mailing addresses, dependent on base location.

2.1.2.5. **Equipment Recertification.** Currently there are no mandatory requirements for refrigerant-recovery equipment recertification by the owner. The EPA does require recovery equipment manufacturers to have their equipment models retested or reinspected at least once every three years by an EPA-approved organization.

2.2. Complying with EPA Refrigerant Leakage Rates. This section provides guidance and information on refrigerant regulation compliance and conservation. This information will assist the BCE to comply with EPA requirements regarding the effective management of Class I and Class II refrigerants. A compliance overview with additional details is available in Attachment 2. Note that there are many exceptions and provisions included within 40 CFR Part 82, Subpart F, Section 82.156, regarding leakage compliance, including leakage identification, extended repair time, and follow-up verification. The following paragraphs are intended to identify the main components of this compliance. It is the responsibility of the BCE to be familiar with all of the detailed provisions as they pertain to their specific equipment.

2.2.1. **Requirements.** The requirements and prohibitions that form compliance with EPA refrigerant leakage rates are provided in 40 CFR Part 82, Subpart F, Section 82.156. The penalties for non-compliance are significant. Venting any refrigerants or substitutes into the environment or improperly evacuating or destroying refrigerants is prohibited.

2.2.1.1. **Applicable Equipment Refrigerant Charges.** EPA regulations regarding refrigerant leakage rates apply to AC/R equipment with a refrigerant charge of 50 pounds or more.

2.2.1.2. **Leakage Rates.**

2.2.1.2.1. According to the EPA, “leakage rate” is the rate at which an appliance loses refrigerant, measured between refrigerant charges. The leakage rate is expressed in terms of the percentage of the appliance’s full charge that would be lost over a 12-month period if the current rate of loss were to continue over that period.

2.2.1.2.2. Allowable EPA leakage rates are based on three main equipment categories: comfort cooling, commercial refrigeration, and industrial refrigeration. Comfort cooling refers to equipment designed for environmental control for occupant comfort. Commercial refrigeration refers to refrigeration appliances used in the retail food and cold storage warehouse sectors. (Retail food includes refrigeration equipment found in supermarkets, convenience stores, restaurants, and other food service establishments.) Industrial process refrigeration refers to complex, customized appliances used in the chemical, pharmaceutical, petrochemical, and manufacturing industries and is directly linked to the industrial process.

2.2.1.2.3. Comfort cooling refrigeration equipment containing 50 pounds or more of refrigerant must have all refrigerant leaks repaired within 30 days if the actual annual leakage rate exceeds 15 percent of the total charge. The annual leakage rate is based on the percentage of the appliance's full charge that would be lost over a 12-month period if the current rate of loss were to continue over that period.

2.2.1.2.4. Commercial and industrial refrigeration equipment containing 50 pounds or more of refrigerant must have refrigerant leaks repaired within 30 days if the actual annual leakage rate exceeds 35 percent of the total charge. The annual leakage rate is based on the percentage of the appliance's full charge that would be lost over a 12-month period if the current rate of loss were to continue over that period.

2.2.1.2.5. The leakage rate can be calculated using one of two methods for each appliance located at an operating facility. These include the "annualized" method (most familiar and most used) and the rolling average method (intended to catch leaks more quickly). The rolling average method has recently been introduced into EPA regulations. The results of the two methods differ only when leakage rates are calculated at periods of less than one year. Although not entirely clear in the EPA regulations, once a method is chosen, that method may be required to be used for the life of all appliances at the facility; therefore, use discretion before switching from the annualized method to the rolling average method. For the purposes of this pamphlet and to maintain continuity in the precedent set in the original BRMP, the annualized method is used in the RMS calculations. A sample calculation follows:

2.2.1.2.5.1. Figure 2.1 shows how to calculate the EPA maximum leakage rate (MLR) and the actual leakage rate (ALR) based on the annualized method. The leakage rate calculations are shown in the RMS reports entitled Refrigerant Service Record Report and Annual Excessive Leakage Rate Report.

Figure 2.1. Sample Leakage Rate Calculation.

An office building is cooled by a 200-ton rotary chiller containing a 400-pound HCFC R-22 refrigerant charge. Ten pounds of HCFC R-22 were added during the last servicing. Because the chiller provides comfort cooling, uses a regulated refrigerant, and contains 50 pounds or more of charge, the 15 percent leakage rate applies. If this were a commercial or industrial refrigerant system, the 35 percent leakage rate would apply.

Service Records

Service Dates		**Refrigerant Added**
Calendar Date	**Julian Date**	
1 October	274	5 lb
4 December	338	10 lb

1. Determine the EPA maximum leakage rate (EPAMLR):

EPAMLR = 400 lb x 15**%**/yr = 60 lb/yr (This is the maximum amount of refrigerant this unit can lose in a 12-month period without violating EPA regulations.)

2. Determine the actual leak rate (ALR):

ALR = lb refrigerant added since last servicing /[(days between servicing)/(365 days/yr)]

$$\text{ALR} = \frac{10 \text{ lb of HCFC R}-22}{(338-274 \text{ days})/(365 \text{ days}/\text{yr})}$$

ALR = 57 lb/yr

Is ALR ≥ EPAMLR?

57 lb/yr is less than 60 lb/yr

Action is **not** necessary. However, the unit used 10 pounds of refrigerant. Good conservation practice requires checking for and repairing any leaks.

2.2.1.2.5.2. If the ALR had been ≥ EPAMLR, it triggers the requirement to repair the leak within 30 days of the leak discovery and to keep records of its timely repair. The repair must be verified within 30 days as required by the EPA. If the appliance cannot be repaired within 30 days, document all repair efforts and have the base environmental office notify the EPA of the inability to comply within the 30-day repair requirement and the reason for not being able to comply in accordance with 40 CFR Part 82, Subpart F, Section 82.166. An extension beyond the 30-day period may be requested from the EPA if the necessary parts are unavailable or if requirements of other applicable federal, state, or local regulations make repair within 30 days impossible.

2.2.1.2.5.3. If the appliance cannot be repaired within 30 days or within 30 days of a failed follow-up verification test, or after making a good-faith effort to repair the leaks, owners can develop a one-year retirement or replacement plan for the leaking appliance. A copy of the retirement or replacement plan needs to be sent by the base environmental office to the EPA within 30 days of discovering the leak. Compliance with the 30-day requirement is based on the date the report was postmarked. Keep a copy of the replacement or retirement plan at the site of the appliance. Further discussion regarding required practices and reporting are included in the following sections.

2.2.1.3. **Service History.** The EPA requires several recordkeeping practices involving the servicing of AC/R equipment containing more than 50 pounds of CFC or HCFC refrigerant. A record must be kept of all CFC or HCFC leaks, even if the EPAMLR is not exceeded. By maintaining these records, technicians can identify equipment with substantial and/or frequent leaks. By discovering these leaks early, refrigerant can be conserved and EPA reporting may be avoided as a result of leaks being fixed before they exceed the EPAMLR. Only leaks exceeding the EPAMLR that are not repaired within 30 days must be reported to the EPA. Refer to the Refrigerant Service Record Report description in paragraph 2.2.2.1.1.

2.2.1.4. **Leakage Identification.** The EPA requires equipment owners or operators to promptly calculate the leakage rate each time refrigerant is added to applicable equipment. The leakage rate should be calculated as soon as possible after refrigerant has been added. If the system is leaking above the EPAMLR, the EPA imposes strict deadlines for compliance (see paragraph 2.2.1.5). This compliance applies to repairing the leaks or retrofitting/retiring the equipment. When EPA notification is required, prompt action will allow more repair time and avoid the potential for time-extension requests.

2.2.1.5. **Leakage Repair.**

2.2.1.5.1. Owners or operators of Class I and Class II refrigeration equipment must repair leaks as indicated in paragraph 2.2.1.2 within 30 days after discovery or within 30 days after the leaks should have been discovered if the owners intentionally shielded themselves from information that would have revealed a leak. Servicing records documenting the date and type of service, leak repair calculations, and quantity of refrigerant added must be kept for a minimum of three years as outlined in paragraph 2.2.1.7.1.

2.2.1.5.2. If the 30-day compliance requirement cannot be met, the leak must be reported to the EPA. The EPA may grant additional time to repair leaks under certain circumstances. These circumstances include, but may not be limited to, the following:

2.2.1.5.2.1. If the refrigeration appliance is located in an area subject to radiological contamination or where shutting down the appliance will directly lead to radiological contamination;

2.2.1.5.2.2. If necessary parts are unavailable or if requirements of other applicable federal, state, or local regulations make a repair within 30 or 120 days impossible;

2.2.1.5.2.3. Instances where an industrial process shutdown is needed to repair leaks from industrial process refrigeration equipment;

2.2.1.5.2.4. Equipment is "mothballed." System mothballing means the intentional shut down of a refrigeration appliance undertaken for an extended period by the owners or operators of that facility, where the refrigerant has been evacuated from the appliance or the affected isolated section of the appliance, at least to atmospheric pressure.

2.2.1.5.3. Equipment repair is unnecessary if a plan to retire or replace the equipment within a year is developed within 30 days after the leak is discovered. This provision also applies to a failed follow-up verification test or after making good-faith efforts to repair the leak(s).

2.2.1.5.4. It is recommended that the BCE and staff become familiar with all provisions included in the EPA regulations regarding equipment repair time allotment and replacement.

2.2.1.6. **Verification Tests.** Verification tests include both initial and follow-up tests and have provisions with regard to leak repairs that require the evacuation of the equipment or portion of the equipment refrigerant charge. Initial verification tests are leak tests conducted as soon as practicable after the repair is completed. Follow-up verification tests are tests that involve checking the repairs within 30 days of the appliance returning to normal operating characteristics and conditions. Initial and follow-up verification can be done in a single service call, provided the unit is operating under normal conditions when the follow-up verification is performed.

2.2.1.7. **Documentation.** The following documentation pertaining to refrigerant leakage compliance is required in accordance with 40 CFR Part 82, Subpart F, Section 82.166:

2.2.1.7.1. Owners/operators of appliances normally containing 50 or more pounds of refrigerant must keep service records for three to five years, depending upon the EPA tier level, documenting the date and type of service and the quantity of added refrigerant. The owner/operator must keep records of refrigerant purchased and added to such appliances in cases where owners added their own refrigerant. Such records should indicate the date(s) when refrigerant was added.

2.2.1.7.2. EPA Initial Report.

2.2.1.7.2.1. An initial report must be submitted to the EPA regarding why more than 30 days are needed to complete repairs. This report must include the following:

2.2.1.7.2.1.1. Identification of the facility;

2.2.1.7.2.1.2. Leakage rate;

2.2.1.7.2.1.3. Method used to determine the leakage rate and full charge;

2.2.1.7.2.1.4. Date a leakage rate above the applicable leakage rate was discovered;

2.2.1.7.2.1.5. Location of leak(s) to the extent determined to date;

2.2.1.7.2.1.6. Any repair work completed thus far and the date that work was completed;

2.2.1.7.2.1.7. The reasons why more than 30 days are needed to complete the work and an estimate of when the work will be completed.

2.2.1.7.2.2. If changes from the original estimate of when work will be completed result in extending the completion date from the date submitted to the EPA, the reasons for these changes must be documented and submitted to the EPA within 30 days of discovering the need for the change.

2.2.1.7.3. **Leak Repair Plans.** Regarding industrial refrigeration equipment, if the BCE intends to establish that the appliance’s leakage rate does not exceed the EPA allowable leakage rate, the BCE must submit a plan to fix leaks for which repairs are planned but not yet completed to achieve a rate below the applicable allowable leakage rate. This plan is submitted only after the BCE has originally notified the EPA that the equipment will be retired due to failed follow-up verification tests.

2.2.1.7.4. EPA Final Report.

2.2.1.7.4.1. Owners or operators must maintain records of the dates, types, and results of all initial and follow-up verification tests. Owners or operators must repair leaks exceeding the EPAMLR, perform an initial verification to confirm the leak is fixed, and submit this information to the EPA within 30 days after discovering the leak. The owners or operators then have 30 days from the date of the repair and initial verification to perform and report the results of a follow-up verification test. Each report must also include the following:

2.2.1.7.4.1.1. Identification of the facility;

2.2.1.7.4.1.2. Leakage rate;

2.2.1.7.4.1.3. Method used to determine the leakage rate and full charge;

2.2.1.7.4.1.4. Date a leakage rate above the applicable leakage rate was discovered;

2.2.1.7.4.1.5. Location of leak(s) to the extent determined to date;

2.2.1.7.4.1.6. Any repair work completed thus far and the date that work was completed.

2.2.1.7.4.2. It is recommended that the BCE and/or staff become familiar with all documentation requirements regarding refrigerant leakage included in the EPA regulations. Records and submitted documentation must be kept for three to five years, depending upon the EPA tier level.

2.2.2. **Tracking Refrigerant Leakage.** Effective tracking of Class I and Class II refrigerant leakage is essential to a successful RMP. The RMS discussed in paragraph 2.2.2.1, and further in Chapter 3, can provide information and reports to assist the BCE to track refrigerant leakage.

2.2.2.1. **Refrigerant Management System (RMS) Reports.** The RMS is a spreadsheet application based on Microsoft® Excel spreadsheets and is customized to provide data the BCE needs to fully implement a BRMP. The following four reports from the RMS can be used to effectively track refrigerant leakage. Each report is described in further detail in the *Refrigerant Management System User's Guide* (see paragraph 1.1).

2.2.2.1.1. **Refrigerant Service Record Report.** This report consists of a complete list of all AC/R equipment using Class I or Class II refrigerants and with reported refrigerant leaks during the past year or longer. The leakage rate is calculated for a 365-day period or the number of days since the last leak was fixed if the repair took place within one year. The list will include the leakage rate and indicate if the leakage rate exceeds the EPA minimum rate that requires EPA notification.

2.2.2.1.2. **Annual Excessive Leakage Rate Status Report.** This report consists of a complete list of all AC/R equipment using Class I or Class II refrigerants and further breaks down the units from the service record report that exhibited leakage above the EPA allowable maximum and what corrective action was taken. The report also includes the outcome of the repair work as well as dates for initial and follow-up verification as required by the EPA.

2.2.2.1.3. **Equipment Inventory Report.** This report includes a complete AC/R equipment inventory of equipment and can be used to list EPA-regulated equipment containing 50 pounds or more of Class I or Class II refrigerant.

2.2.2.1.4. **HFC Equipment Inventory Report.** This report is similar to the Equipment Inventory Report but is sorted to indicate and account for the non-regulated HFC refrigerants as deemed necessary by the BCE.

2.2.2.2. **Optional Air Force Recommendations.** In addition to mandatory EPA compliance regarding refrigerant leakage, and given possible EPA regulations in the future concerning HFC refrigerants, it is recommended to include these types of refrigerants in all service records and leakage calculations.

2.3. Maintaining Equipment to Minimize Refrigerant Leakage. There are several methods and procedures to minimize refrigerant leakage. These consist of required EPA practices, general equipment servicing and repair, leak detection methods, and AC/R equipment modifications. These methods are outlined and described below.

2.3.1. **EPA Service Practice Requirements.**

2.3.1.1. The EPA has outlined several required practices intended to minimize refrigerant leakage. These include, but may not be limited to, the following:

2.3.1.1.1. All persons disposing of appliances, except for small appliances, MVAC, and MVAC-like appliances, must evacuate the refrigerant, including the entire liquid refrigerant, into EPA-approved recovery or recycling equipment as described in paragraph 2.1.2. Refrigerant must be evacuated to the levels indicated in Attachment 6, Table 6.1.

2.3.1.1.2. Technicians must be EPA-certified as indicated in paragraph 2.1.1.

2.3.1.1.3. Persons opening appliances (except for small appliances, MVAC, and MVAC-like appliances) for maintenance, service, or repair must evacuate the refrigerant to the levels set forth in 40 CFR Part 82, Subpart F, section 82.156, before opening the appliance. These levels are indicated in Attachment 6, Table A6.1.

2.3.1.1.4. Use all recovery or recycling equipment in accordance with the manufacturer's directions unless such directions conflict with the requirements of the EPA.

2.3.1.2. These EPA-required practices include many provisions and exceptions based on type of appliance and type of recovery equipment utilized; therefore, see 40 CFR Part 82 for detailed requirements. Those requirements and practices involving refrigerant leakage are covered in paragraph 2.2.

2.3.2. **Equipment Servicing and Repairs.** Detailed requirements and information about performing equipment service and repairs are found in Attachment 6 and Attachment 7.

2.3.3. **Leak Detection.**

2.3.3.1. The BCE should develop a leak detection program that matches individual AC/R equipment with a specific type of leak detection. The BCE should also develop an equipment leak-check schedule based on the equipment type, and leak history, and include it with the equipment's Recurring Work Plan (RWP) requirements. As more leaks occur, equipment checks need to be increased accordingly.

2.3.3.2. Leak-detection procedures vary from soap bubbles to sophisticated sensors. For detailed information, review Attachment 5 and Attachment 7.

2.3.4. **AC/R Equipment Modifications.**

2.3.4.1. Several equipment modifications may prevent excess refrigerant from entering the atmosphere. One example is installing low-loss fittings used to service AC/R equipment.

2.3.4.2. Most low-pressure chillers have or were retrofitted with high-efficiency purge units. The BCE and staff should provide purge units with a safety system that prevents excessive purging created by a malfunction or large leak. These safety systems limit the time a purge unit operates to prevent a control malfunction from allowing a continuous purge.

2.3.4.3. Purge units for chillers or recovery/recycling equipment require regular service. Purge tanks and oil separators must be cleaned, gaskets must be renewed, purge compressors must be overhauled, etc. These functions should be performed according to the purge system manufacturer's product guidelines. More information is available in Attachment 6.

2.3.5. **Venting Prohibitions (All Refrigerants).**

2.3.5.1. Since July 2005, it is an EPA violation to knowingly release any Class I or Class II refrigerant or substitute refrigerant other than carbon dioxide (CO_2), ammonia, or water into the atmosphere. The knowing release of a refrigerant or non-exempt substitute subsequent to its recovery from an appliance is an EPA violation.

2.3.5.2. "De minimis" releases (as outlined within referenced EPA regulations) associated with good-faith attempts to recycle or recover refrigerants or non-exempt substitutes are not subject to this prohibition.

2.3.6. **Refrigerant Management System (RMS).** The Refrigerant Service Record Report from the RMS details the frequency and magnitude of refrigerant leaks and can be used to maintain equipment to minimize refrigerant leaks. This report is described in further detail in the *Refrigerant Management System User's Guide*.

2.4. Managing Refrigerant Inventories. This element includes effectively managing Class I and Class II refrigerants used in AC/R equipment to ensure adequate supplies are available to support Air Force mission requirements. Given that Class I refrigerants can no longer be purchased on the open market or be provided by the Defense Logistics Agency (DLA) for AC/R equipment, the BCE must rely on inventories already on hand or made available through transfers with other bases. The effective management of Class I refrigerants must also include supplies contained in equipment to be decommissioned. Existing equipment containing Class I refrigerants must be managed to the end of their service lives or until Class I refrigerant inventories are below critical levels. Once all Class I equipment has been decommissioned or retired, the Class I refrigerants must be transferred to the DLA (see paragraph 2.4.4.5). Given reductions of Class II refrigerant production levels and their eventual elimination by the year 2030, diminishing supplies of Class II refrigerants will require close management of refrigerant inventories to ensure adequate supplies of refrigerant are available to meet Air Force mission requirements. Additionally, managing refrigerant inventories will help contain costs associated with the service and maintenance of equipment containing Class I and Class II refrigerants.

2.4.1. **By Refrigerant Type.** Inventory management must be accomplished on a per-refrigerant basis. A refrigerant transaction log must be maintained for each refrigerant so the refrigerant's actual consumption rate can be used to predict how much refrigerant should be stored for maintenance purposes.

2.4.2. **Determining Adequate Inventory Levels.**

2.4.2.1. The determination of adequate inventory levels must be made by the BCE based on certain criteria such as mission capability, refrigerant cost and availability, and AC/R equipment phase-out. One approach may be to take the average of the consumption in the past year, along with the refrigerant charge of the largest piece of equipment, minus any refrigerant recovered, to determine the minimum inventory level for each refrigerant type. The RMS Refrigerant Transaction Report (see paragraph 2.4.6.3) may be used to predict historical leakage (i.e., consumption) for each refrigerant type.

2.4.2.2. In determining the minimum inventory level, an additional safety factor that should be considered is the amount of charge associated with the largest critical AC/R equipment unit.

2.4.3. **Management Inventory Controls.**

2.4.3.1. Management inventory controls refer to those measures and practices, both administrative and physical, which may be used to ensure accurate refrigerant inventory levels. They may include, but are not limited to, the following:

2.4.3.1.1. Use of a refrigerant transaction log (see paragraph 2.4.6.1);

2.4.3.1.2. Limited access to refrigerant storage areas;

2.4.3.1.3. Check-in and check-out procedures (i.e., weigh-in procedures) for refrigerant containers, including potential same-day check-in/check-out;

2.4.3.1.4. Ongoing training for technicians and other affected personnel;

2.4.3.1.5. Written labeling policy for refrigerant cylinders.

2.4.3.2. Because of the importance of tracking refrigerant use and disposition, the BCE should publish and enforce a refrigerant and storage policy, to include designation of individual positions responsible for inventory management and record-keeping.

2.4.4. **Refrigerant Transactions.** Multiple refrigerant transactions may be used to effectively manage refrigerant inventories. The RMS may be used to track and document these transactions. Data input for refrigerant transactions is discussed in the *Refrigerant Management System User's Guide*. The data input is compiled in two reports developed to support the BCE in managing the base's refrigerant inventories. The Refrigerant Transaction Report tracks the daily withdrawals from inventory which is used to service AC/R equipment and calculates the actual consumption for each refrigerant type. The Refrigerant Inventory Report can be compiled for each refrigerant stored on base. This report tracks all transactions into and out of the inventory of each refrigerant and calculates the current volume of each refrigerant available in storage. These two reports are described in more detail in the *Refrigerant Management System User's Guide.* The types of refrigerant transactions are briefly described in the paragraphs below.

2.4.4.1. **Daily On-Base Transactions.** These transactions include those required in the day-to-day service and maintenance of AC/R equipment. All classes and types of refrigerants should be recorded. These are the only transactions tracked by the Refrigerant Transaction Report.

2.4.4.2. **Purchases.**

2.4.4.2.1. Air Force CE units are not allowed to purchase commercial Class I ODS; however, refrigerant may be obtained, if available, through inter-base transfers.

2.4.4.2.2. There are currently no restrictions to purchasing Class II refrigerants; however, ownership of both Class I and Class II refrigerants must remain within the Department of Defense (DOD).

2.4.4.2.3. The BCE may approve a variance to purchase AC/R equipment that uses HCFCs (e.g., R-123) but a BRMP is required to ensure adequate refrigerant inventories are available to service the equipment for its expected life. Requirements are described in AFI 32-7086, Chapter 4, paragraph 4.8.

2.4.4.2.4. Refrigerant purchased or transferred must be recorded as a transaction in the Refrigerant Inventory Report (see paragraph 2.4.6.1).

2.4.4.3. **Recover/Recycle/Reclaim.**

2.4.4.3.1. Recovery, recycling, and reuse of Class I and Class II refrigerants will be accomplished to the maximum extent practicable to ensure responsible use and prevent losses to the atmosphere.

2.4.4.3.2. Anyone who disposes of AC/R equipment must recover the remaining refrigerant and/or verify that the refrigerant is evacuated properly as detailed in Attachment 6, Table A6.1.

2.4.4.3.3. Refrigerant may be returned to the appliance from which it is recovered or to another appliance owned by the Air Force without being recycled or reclaimed.

2.4.4.4. **Transfers.**

2.4.4.4.1. The transfer of excess Class I ODS outside the Air Force, except to the DLA ODS Defense Reserve Stockpile, is prohibited (see paragraph 2.4.4.5).

2.4.4.4.2. AC/R equipment containing Class I refrigerants must rely on internal refrigerant inventories, without access to the DLA Class I ODS Defense Reserve stockpile. These internal inventories may result from decommissioned equipment and, in some rare cases, inter-base transfers.

2.4.4.4.3. Class I or Class II refrigerant ownership cannot be sold or transferred outside of DOD. Transfers of excess refrigerant to other bases are encouraged and should be arranged through the MAJCOM. Excess Class I ODS refrigerant must be turned into the DLA Refrigerant Bank.

2.4.4.5. **DLA Turn-ins.**

2.4.4.5.1. If the BCE identifies excess Class I refrigerants that cannot be reused on the base or reallocated within the MAJCOM, these supplies should be returned to the DLA Class I ODS Defense Reserve stockpile. This includes Class I refrigerants that cannot be reused on the base or reallocated within the MAJCOM. An example of this may be the retirement or disposal of the last item of equipment containing that refrigerant.

2.4.4.5.2. If a refrigerant is identified to be turned over to the DLA, note this transaction in the Refrigerant Transaction Report described in paragraph 2.4.6.3.

2.4.4.5.3. For further information on DLA turn-in procedures, see *Department of Defense Ozone Depleting Substances Turn-in Procedures.*

2.4.4.6. **Disposal.**

2.4.4.6.1. All refrigerants should be recovered/recycled by removing the refrigerant using EPA-certified recovery equipment and storing it in an approved container. Any refrigerant contaminated by other refrigerants and that cannot be reclaimed must be disposed of as hazardous waste. For this reason, it is imperative that refrigerants are not mixed during recovery.

2.4.4.6.2. If a refrigerant is determined to require disposal, this transaction should be duly noted in the Refrigerant Transaction Report described in paragraph 2.4.6.3. Refrigerant evacuation must be accomplished per EPA guidelines summarized in Attachment 2.

2.4.5. **Secure Storage Areas.** Refrigerant is valuable and supplies are limited. The base should have one or more secure storage areas to store, issue, and receive refrigerants. The storage location(s) should be convenient and secure. For information on storage room construction standards, see Attachment 4.

2.4.5.1. **Limited Accessibility.** Secure storage areas should include limited accessibility by only those individuals responsible for distributing and tracking refrigerant. For this reason, such storage areas should not include mechanical equipment rooms.

2.4.5.2. **Protection of Personnel.** Refrigerant storage areas must comply with ASHRAE 15-2007 (see Attachment 8). This standard includes details on such items as refrigerant storage facility ventilation and exhaust requirements, and refrigerant monitoring and alarms.

2.4.6. **Refrigerant Management System (RMS).** The following three reports from the RMS can be used to effectively manage base refrigerant inventories. Each report is described in further detail in the *Refrigerant Management System User's Guide.*

2.4.6.1. **Refrigerant Inventory Report.** This report shows all refrigerant transactions (both additions and withdrawals) and can be used for tracking refrigerant inventory levels for each refrigerant to ensure the required minimum levels are maintained.

2.4.6.2. **Decommissioned Equipment List.** This report shows decommissioned equipment and the amount and type of recovered refrigerant.

2.4.6.3. **Refrigerant Transaction Report.** This report provides historical usage by showing the amount of refrigerant consumed from inventory (e.g., refrigerant used for servicing equipment). It is used to estimate future needs and inventory levels.

2.5. Planning Equipment Phase-out and Funding Requirements. The RMS can be used by the BCE to plan for the strategic and cost-effective replacement of both Class I and Class II refrigerant-containing equipment. Planning the phase-out of Class I and Class II refrigerant equipment will assist in meeting Air Force objectives regarding the elimination of ODS. Additionally, this process can be used to establish equipment replacement budgets.

2.5.1. **Recommendations.** The recommendations noted below refer predominantly to equipment containing a charge of 50 pounds or greater but can also be applied to smaller equipment. Recommended replacement decision criteria may include equipment age, equipment condition, refrigerant type and availability, equipment service, equipment cost, energy efficiency, and operational status. Replacement should not be decided by equipment age alone. Equipment average or median service life is shown in ASHRAE Handbook, *HVAC Applications*, Chapter 37, Table 4, "Comparison of Service Life Estimates."

2.5.1.1. **Class I Refrigerants.**

2.5.1.1.1. AC/R equipment containing Class I refrigerants have not been manufactured since 1996. The number of such units in use within the Air Force continues to dwindle and the replacement of such equipment should take into consideration refrigerant inventory, the condition of the equipment, equipment efficiency, and runtime. For example, if the equipment is in good condition, serves as emergency back-up, and/or there is an ample supply of refrigerant available, it may be best to maintain the equipment in service; replace other equipment that is less efficient, in poor condition, and/or prone to refrigerant leaks.

2.5.1.1.2. Consider the following when evaluating Class I refrigerant equipment for replacement:

2.5.1.1.2.1. **Equipment Age.** Has the equipment exceeded the ASHRAE median service life? This includes 15 years for unitary equipment, 20 years for reciprocating and rotary chillers, and 23 years for centrifugal chillers. See ASHRAE Handbook, *HVAC Applications*, Chapter 37, Table 4, "Comparison of Service Life Estimates."

2.5.1.1.2.2. **Equipment Condition.** Refer to past equipment service records and maintenance costs. What would be the maintenance cost savings associated with equipment replacement? What is its leakage rate and is it in EPA compliance?

2.5.1.1.2.3. **Refrigerant Availability.** Does current inventory exceed all remaining units' full charge? If not, what percentage of the equipment's full charge is available and what is the likely or historical leakage rate? Given the limited availability of Class I refrigerants, refrigerant availability may be a primary decision criterion regarding Class I refrigerant equipment replacement. For instance, if there is one remaining piece of equipment on base containing Class I refrigerant and there is little to no inventory of that refrigerant, equipment replacement would be a likely recommendation (pending other decision criteria).

2.5.1.1.2.4. **Equipment Service.** Does the equipment service a mission-critical function? What are the consequences if this equipment fails?

2.5.1.1.2.5. **Equipment Cost.** The greater the replacement cost, the greater the planning horizon is needed to obtain funding, procure design services, and schedule outages.

2.5.1.1.2.6. **Energy Efficiency.** Compare the potential energy savings by evaluating the current equipment energy cost to a similar new high-efficiency unit.

2.5.1.1.2.7. **Operational Status.** Does the equipment serve as primary or back-up? If primary, does the equipment have a functional backup? The replacement priority may be lower if the equipment serves as a backup and is a tight, low-leakage unit.

2.5.1.2. Class II Chillers.

2.5.1.2.1. It is anticipated that through good service practices, inventory control, and conservation, the supply of Class II refrigerants will meet the servicing needs of existing equipment through their expected service lives. A replacement plan based upon the remaining useful life of the equipment should be developed for planning purposes. Select replacement equipment based upon a life-cycle cost analysis.

2.5.1.2.2. A key consideration with Class II refrigerant equipment involves those using HCFC-123. Equipment designed to use HCFC-123 can be manufactured until 2020 and the refrigerant will be produced until 2030. HCFC-123 has a low GWP, a very low ODP, and is typically more efficient than other AC/R equipment using any other refrigerant. This makes chillers containing HCFC-123 still a viable alternative as discussed in paragraphs 1.6.6.1 and 2.4.4.2.

2.5.1.3. **Class II Unitary.**

2.5.1.3.1. Unitary equipment consists predominantly of packaged-type, self-contained equipment using the direct expansion of a refrigerant for cooling supply airflow. Equipment types such as packaged rooftop units and split-system air-conditioners are included in this category. The ASHRAE average service life is 15 years.

2.5.1.3.2. The predominant refrigerant utilized in this type of equipment is HCFC-22. Much of this equipment contains refrigerant charges of less than 50 pounds. Therefore, before the decision is made to replace HCFC-22 equipment, potential HCFC-22 recovery from equipment containing smaller refrigerant charges must be considered. Recommendations similar to those indicated for Class I AC/R equipment apply to Class II refrigerant equipment as well as taking into account the refrigerant phase-out schedule for Class II refrigerants and the fact that Class II refrigerants are still available for purchase. These conditions lower the significance of decision criteria involving equipment age and condition.

2.5.2. **Refrigerant Management System (RMS).** The RMS tool can be used to help plan the phase-out of Class I refrigerant equipment and to program future replacement requirements for Class II refrigerant equipment. Each report included below is described in the *Refrigerant Management System User's Guide* (see paragraph 1.1). The information provided by these reports can be combined to develop a programmed phase-out list for both Class I and Class II AC/R equipment.

2.5.2.1. **Equipment Inventory Report.** This report includes a complete AC/R equipment inventory that can compile either regulated equipment or all refrigerant-containing equipment. This RMS-generated list can be sorted by equipment age and refrigerant type. By sorting equipment by age, the BCE can determine AC/R equipment with the longest service lives and develop priorities for an equipment replacement plan.

2.5.2.2. **Refrigerant Service Record Report.** This report can be used to evaluate the condition of the equipment by noting the frequency of refrigerant services as well as the required refrigerant quantity. The more frequent the service, the more likely the equipment condition is deteriorating.

2.5.2.3. **Excessive Leakage Rate Status Report.** This report includes a complete list of all AC/R equipment with a Class I or Class II refrigerant charge of 50 pounds or greater and with reported refrigerant leaks during the past year or earlier. This report can be used to evaluate the condition of the equipment. Such items as multiple leakage events and extent or magnitude of leaks should be noted.

2.6. Generating the Annual Base RMP. The final element of the BRMP is developing and updating the annual base RMP. The annual base RMP provides a phase-out schedule for Class I equipment and anticipated Class II equipment in the near future. It also provides one concise document showing compliance with Air Force and EPA requirements. The RMP also summarizes inventory levels and provides a projection of refrigerant inventory levels into the future. The RMP does not include motor vehicle or aircraft refrigerants.

2.6.1. **BCE Waiver for Class II Refrigerants.** Installing new equipment using Class II refrigerants requires the BCE to issue a waiver. All such waivers should be included in the RMP. Note that the purchase and application of HCFC-123 chillers is allowed. HCFC-123 equipment production will continue until 2020. The refrigerant is expected to remain readily available for years after its production ceases in 2030.

2.6.2. **BCE Review and Certification. A**ccording to AFI 32-7086, the BCE is required to review and certify the annual base RMP. This pamphlet provides guidance to help the BCE certify the RMP.

Chapter 3

REFRIGERANT MANAGEMENT SYSTEM (RMS)

3.1. RMS Working Tool. The daily working tool for the base RMP is the RMS, available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website (see paragraph 1.1). This system can be used to manage refrigerants in place of the current private-sector compliance software. If the RMS is utilized, make sure provisions are made to retain access to past service records for three to five years, depending upon the EPA tier level, before discontinuing use of the existing compliance software. Use of the RMS is not mandatory but it is provided as a tool to facilitate tracking equipment leakage rates, meeting documentation requirements, and developing the base RMP.

3.2. RMS Spreadsheet Application Description. The RMS is a spreadsheet application based on Microsoft® Excel and is customized to provide the data the BCE needs to fully implement a BRMP. It supports the daily refrigerant management requirements, daily and annual recordkeeping, and provides management tools for planning future actions required to maintain a mission-capable base refrigerant system. The RMS tracks refrigerant service records and notifies the user of an EPA excessive leakage event which requires timely resolution. The system will continue to monitor the event until it is resolved and verified according to EPA requirements.

3.3. RMS User's Guide. The *Refrigerant Management System User's Guide* contains descriptions of the individual tools in the RMS and other valuable information, including details on adding data, and system navigation. The *Refrigerant Management System User's Guide* focuses on the general data-input process and RMS-generated reports that provide information to ensure the base is in compliance with EPA requirements for managing base refrigerant inventories and AC/R equipment. Chapter 4 of this pamphlet provides guidance for applying this information to develop a fact-based, realistic RMP. A sample RMP, complete with sample RMS-generated reports, is available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website (see paragraph 1.1).

Chapter 4

ANNUAL BASE REFRIGERANT MANAGEMENT PLAN (RMP)

4.1. Introduction.

4.1.1. An RMP must be produced annually and reviewed by the MAJCOM refrigerant program manager for each installation to meet the requirements of AFI 32-7086. This RMP should include the records required by the EPA. This will enable one document to serve as a single source for all required recordkeeping in print. Some of this information will be stored in the RMS and can be accessed at any time.

4.1.2. This chapter provides guidance on the development of an RMP. A sample RMP is available on the AFCEC Heating, Ventilation and Air Conditioning (HVAC) Systems Air Force Portal website (see paragraph 1.1) in an editable Microsoft Word® version.

4.2. Requirements. The RMP is an Air Force requirement per AFI 32-7086. The EPA requires certain items to be retained and/or submitted to the EPA. The following items are expected to be included in the RMP:

4.2.1. Records maintained for three to five years, depending upon the EPA tier level;

4.2.2. Timely notification of leakage events;

4.2.3. Timely notification of fix verification;

4.2.4. Copies of certifications.

4.3. RMP Development Guidance. This chapter provides guidance for developing a useful and practical RMP.

4.3.1. **RMP Suggested Table of Contents.**

4.3.1.1. A suggested table of contents for the RMP is listed in Figure 4.1. This is the organizational format which will be followed as each section is discussed through this chapter.

Figure 4.1. RMP Suggested Table of Contents.

1.0	Executive Summary
2.0	General Information
3.0	Certifying Technicians & Recovery Equipment
4.0	Complying with EPA Refrigerant Leakage Rates
5.0	Maintaining Equipment to Minimize Refrigerant Leakage
6.0	Managing Refrigerant Inventories
7.0	Planning Equipment Replacements
8.0	Approval of Annual Base Refrigerant Management Plan (RMP)
Appendix A1	Refrigerant Technician Certifications
Appendix A2	Refrigerant Recovery/Recycle Machine Certifications
Appendix B1	EPA Required Refrigerant Service Records
Appendix B2	Excessive Leakage Notifications to EPA
Appendix B3	Decommissioned Equipment Report

Appendix B4	Excessive Leakage Rate Annual Report
Appendix C	Equipment Inventories (By Refrigerant) and Refrigerant Service Records
Appendixes C1–C8	Equipment Inventories, Refrigerant Service Records, Consumption and Storage Records by Refrigerant Type
Appendix D	HCFC-123 Equipment Purchase Waiver

4.3.1.2. The order indicated in Figure 4.1 allows sections or divisions within a section to be removed and copied or given to the EPA in the event of an inspection. The numbered sections of the RMP describe the refrigerant management activities underway at the base and summarize the status of meeting the base's EPA requirements. The appendices contain the actual documents and reports required to meet EPA requirements and the RMS reports that help the BCE manage AC/R equipment and refrigerant inventories.

4.3.2. **Executive Summary.** Include an executive summary, no more than a page in length. It should highlight equipment or refrigerant concerns, risks, and/or inventory level projected for the upcoming year in terms of regulatory issues, mission impacts, and funding requirements. The BCE might want to include, and thus document, significant accomplishments from the just-completed year. The sample RMP (see paragraph 1.1) has examples of items that might be included under each of the above headings.

4.3.3. **General Information.** This section serves as a place for the "boilerplate" items that might be specific to a particular base or MAJCOM. These items are part of the total BRMP and are essentially constant. These might include requirements of the EPA or AFI 32-7086 to serve as a reminder. List the persons designated as BRMP points of contact (POC) in this section. The sample RMP includes only what is recommended as the minimum amount of information to be included in this section. Ensure that PII, such as Social Security numbers, date of birth, and age, are not listed for any personnel.

4.3.4. **Certifying Technicians & Recovery Equipment.** This section provides documentation that all staff servicing AC/R equipment have refrigeration technician certifications from EPA-approved testing agencies. The list and documentation for the manufacturer-certified recovery equipment should also be referenced in this section. It would be appropriate in this section to indicate items to be addressed or actions to be taken in the upcoming year. Examples might include the following: "Staff retirements caused the need for [x] more certified refrigerant technicians"; "Intent to purchase additional recovery equipment to eliminate servicing 'funnel.'"

4.3.5. **Complying with EPA Refrigerant Leakage Rates.**

4.3.5.1. This section of the RMP summarizes EPA-required documentation relating to refrigerant leakage provided in Appendices B1 to B4. This documentation applies only to regulated equipment that contains 50 pounds or greater of CFC or HCFC refrigerant.

4.3.5.2. Each base is required to maintain service records for three to five years, depending upon the EPA tier level, noting when refrigerant was added to regulated equipment. This information includes the RMS Refrigerant Service Record Report, described in paragraph 4.3.11.3.

4.3.5.3. The EPA has established an MLR for regulated equipment. The EPA must be notified and leaks fixed within 30 days unless delays are approved. Paragraph 4.3.11.4 describes the notification documentation.

4.3.5.4. To resolve a refrigerant leak in regulated AC/R equipment if a leak cannot be fixed, a plan can be submitted to replace or retire the equipment within one year. This solution is documented in the required EPA leakage notification and by the RMS in the Decommissioned Equipment Report described in paragraph 4.3.11.5.

4.3.5.5. Documentation of the refrigerant leakage mitigation steps is provided in detail in the Excessive Leakage Rate Annual Report described in paragraph 4.3.11.6.

4.3.6. **Maintaining Equipment to Minimize Refrigerant Leakage.** This section of the RMP may be used to describe the specific methods used by the base to reduce refrigerant leaks. This could include preventative maintenance leak-checking, the purchase of more accurate detection devices, or tracking refrigerant leaks in unregulated equipment as well as the required tracking of leaks in regulated equipment.

4.3.7. **Managing Refrigerant Inventories.**

4.3.7.1. Appendix C of the sample RMP contains equipment inventories for all AC/R equipment and refrigerant service records for that equipment. The reports are: Equipment Inventory Report (All Equipment) and Refrigerant Service Records Report (All Equipment).

4.3.7.2. Appendices C1 through C(x) provide the inventory status of each refrigerant used on base for refrigerant 1 through refrigerant x. Each of the eight refrigerants listed in Appendices C1 through C8 contains four RMS reports. The reports are: Equipment Inventory Report; Refrigerant Service Record Report; Refrigerant Transactions Report; and Refrigerant Inventory Report. By compiling these reports individually, the inventory status for each refrigerant can be compiled and used to predict future refrigerant needs. Examples of these reports are found in Appendices C1 through C8 of the sample RMP. This inventory analysis is described in detail in paragraph 4.3.12.1.

4.3.8. **Planning Equipment Replacements.** There is no reason at this time to phase out any CFC or HCFC AC/R equipment before the end of its useful economic life unless the base is unable to provide the refrigerant needed for servicing. (Excessive servicing and leakage may indicate the equipment is at the end of its useful economic life.) This section is intended to identify equipment that should be replaced based on information discussed in Appendix C of the RMP. For example, the base may have equipment containing several CFC refrigerants such as R-11, R-12, R-113, and R-500. The base cannot purchase CFCs and the DLA will not transfer refrigerant to the bases to service AC/R equipment. Other than the unlikely possibility of a transfer from another base, the refrigerant presently stored and any refrigerant that becomes available through recovery from decommissioned AC/R equipment are the only sources of refrigerant. Recycling HCFC refrigerant from decommissioned AC/R equipment is a cost-effective way to increase refrigerant inventories. Although most CFC AC/R equipment has already been replaced, considerable HCFC equipment is still in place. Therefore, maintaining inventories of HCFC refrigerants as prices go up will be an important consideration in planning equipment replacement.

4.3.9. **Approval of Annual Base Refrigerant Management Plan (RMP).** The BCE annually reviews and certifies the RMP.

4.3.10. **Appendix A.** Appendices A1, A2, and B1 through B4 should include only those items required by the EPA and thus can be pulled out in their entirety and forwarded to the EPA without editing, should the need arise. Appendix A will include (Appendix A1) Refrigerant Technician Certifications and (Appendix A2) Refrigerant Recovery/Recycle Machine Certifications.

4.3.11. **Appendix B.** This section provides the documentation required by the EPA for regulated equipment at the installation, leakages that occurred, the chronology of what, when, and how leaks were fixed, and the status of these leakage events. The RMS is instrumental in providing the documentation for this requirement. Most of this section will refer to the documentation in Appendix B.

4.3.11.1. Equipment leakage events should be described in this section in appropriate detail. Events still awaiting disposition might be specifically listed.

4.3.11.2. The remaining items pertinent to this section are indicated in the sample RMP and refer to documents that will be placed in the supporting appendices listed below.

4.3.11.3. **Appendix B1.**

4.3.11.3.1. This appendix provides the following reports to meet the EPA requirement to maintain refrigerant service records for CFCs and HCFCs for three to five years, depending upon the EPA tier level: Refrigerant Service Record Report and Equipment Inventory Report.

4.3.11.3.2. This EPA requirement can be met by keeping service invoices to document the service work and filing them in folders for retrieval in the event of an EPA inspection. The RMS provides not only this minimum requirement but enables the analysis needed to manage the base inventory of regulated AC/R equipment and refrigerants. By inputting these service records into the RMS, the Refrigerant Service Record Report can provide service records for any period or refrigerant type. This report, if sorted by building and unit number (or refrigerant type), enables the BCE to identify equipment which may have been troublesome during the past year (or earlier). The Refrigerant Service Record Report is sorted so that multiple leak occurrences for the same units will appear in adjacent rows in the report and the total leakage from the same unit is summed to illustrate the impact of multiple leaks from one unit. The BCE can then take additional corrective action to fix the unit or replace it even if the percentage leak does not exceed the EPA MLR.

4.3.11.3.3. For additional information, the Equipment Inventory Report is provided that documents the entire base's regulated equipment data, including equipment age, which can help the BCE make repair or replacement decisions for problematic AC/R equipment.

4.3.11.4. **Appendix B2.** Appendix B2 contains copies of refrigerant leak notification letters. Placed within this appendix are the correspondence records and the past correspondence with the EPA concerning refrigerant leakage events that exceeded the allowable maximum rates. This would include initial notifications, plans for resolution, and resolution verification. For events that require simple on-the-spot fixes, these notifications would likely all be reported in a single document. For events that require major fixes or equipment replacements, an extension may be requested with a plan for resolution included. This plan is attached to the notification letter and located in Appendix B2. These reports must be retained for three to five years, depending upon the EPA tier level. All the items below must be submitted to the EPA within 30 days. They can be multiple letters or one letter for all. The notifications are: Non-Compliance Report Letter; Plan for Resolution Letter; Resolution Achieved Letter; Extension Request Letter; and Equipment Replacement Plan.

4.3.11.5. **Appendix B3.** If the second leak follow-up verification fails, the equipment must be retired. Open the Decommission Equipment option from the RMS Main Menu. Enter the equipment data, including the unit name, building, and quantity of refrigerant recovered. The Decommission Equipment option takes the unit out of inventory and removes it from noncompliance tracking. The recovered refrigerant is added to the storage inventory for the appropriate refrigerant. The Decommissioned Equipment Report documents this process and is located in Appendix B3 of the sample RMP.

4.3.11.6. **Appendix B4.** Appendix B4 includes the Excessive Leakage Rate Annual Report. The Excessive Leakage Rate Status Report is discussed in detail in the *Refrigerant Management System User's Guide*. This report displays the status of all regulated AC/R equipment which has an unresolved refrigerant leak in excess of the EPA maximum allowable leakage rate. When leaks are resolved through repair, replacement, or retirement, the unit is no longer displayed on the Excessive Leakage Rate Status Report. These resolved leaks remain on the Excessive Leakage Rate Annual Report, which maintains records indefinitely and may be provided to the EPA if requested. The Excessive Leakage Rate Annual Report maintains historical data but also displays issues that were open at the time the report was generated, so only the Excessive Leakage Rate Annual Report is included in Appendix B4. This report should be retained for three to five years, depending upon the EPA tier level.

4.3.12. **Appendix C.** Appendix C contains reports which assist the BCE to evaluate and manage refrigerant inventories and associated AC/R equipment. The base may have equipment containing several CFC refrigerants, such as R-11, R-12, R-113, and R-500. The base cannot purchase CFCs and the DLA will not transfer refrigerant to bases to service AC/R equipment. Other than the unlikely possibility of a transfer from another base, the refrigerant presently stored and any refrigerant that becomes available through recovery from decommissioning AC/R equipment are the only sources of CFC refrigerant. Therefore, the decommissioning of AC/R equipment is the only dependable option to increase CFC inventory. The reports recommended to be included in Appendix C can guide the BCE in making these refrigerant-related decisions.

4.3.12.1. **RMS Inventory Status Reports.** To review the inventory status of the refrigerants used on base, four RMS reports should be compiled separately for each refrigerant type. The four RMS reports include: Equipment Inventory Report; Refrigerant Service Record Report; Refrigerant Transactions Report; and Refrigerant Inventory Report. These reports can be found as examples in Appendices C1 through C8 of the sample RMP. Appendices C1 through C8 contain the reports for R-11, R-12, R-113, R-500, R-123, R-22, R-134a, and R-410a, respectively. (**Note:** The refrigerants included in the sample RMP are examples, but the actual number of refrigerants for each base will be input during the setup phase for the RMS, as described in the *Refrigerant Management System User's Guide*.) The Equipment Inventory Report is printed separately for each refrigerant and shows refrigerant use by equipment. A Refrigerant Service Record Report is also provided for each refrigerant. This report highlights equipment that requires charging due to excessive leaks and may have to be decommissioned to save refrigerant. The Refrigerant Transactions Report records daily refrigerant withdrawals from the storage center used to charge AC/R equipment. Tracing the withdrawals allows refrigerant use to be accounted for in smaller equipment and regulated equipment (50 pounds or more of CFC or HCFC). This report separately tabulates the total refrigerant consumption for each refrigerant. The fourth report, the Refrigerant Inventory Report, tracks each positive or negative transaction for each refrigerant, such as withdrawals, purchases, transfers in or out, and recovered or destroyed refrigerants. A running total of the amount available for each refrigerant is calculated and displayed. Adding this running inventory total to the anticipated recovery and dividing by the consumption rate compiled on the Refrigerant Transaction Report yields the number of years the refrigerant may be available to service AC/R equipment at current consumption rates. Transfers are possible between bases but very unlikely. Since bases cannot buy CFC and transfers are unlikely, current refrigerant inventory can service existing equipment as follows: [(Inventory + recovery – destroyed) / annual consumption] = years remaining of inventory

4.3.12.2. **Minimum Required Inventory.**

4.3.12.2.1. This value can be subjective and is calculated to establish a value that provides confidence for the BCE and staff. The determination of this value should include, at a minimum:

4.3.12.2.1.1. Supplying the largest AC/R equipment single refrigerant charge in the inventory;

4.3.12.2.1.2. The historical annual consumption rate;

4.3.12.2.1.3. Evaluation of the number of machines in the inventory, their charges, and the criticality of the building or process they serve.

4.3.12.2.2. Calculating the years a refrigerant will be available is not very relevant because a large chiller could have a catastrophic failure and lose its entire charge. However, the number of years of availability for each refrigerant can be observed over time and the results recorded and compared monthly to see trends in refrigerant consumption and inventory transactions.

4.3.12.3. **Class II Refrigerants.**

4.3.12.3.1. Class II refrigerants are typically subdivided into two groups due to the different phase-out dates for the production of the refrigerants. The first group consists of HCFC-22, which will be phased out by 2020. The second group consists of HCFC-123, which will not be supplied in AC/R equipment after 2020 and will not be produced after 2030. Concerns about these Class II refrigerants include the following:

4.3.12.3.1.1. Current existing inventory;

4.3.12.3.1.2. Open-market purchases (even after production has ceased in 2020);

4.3.12.3.1.3. Refrigerant charges still in operational equipment;

4.3.12.3.1.4. Possible transfer from other bases in the MAJCOM.

4.3.12.3.2. While HCFCs are still available for purchase, their availability is not as important as it is for CFCs, but the same four RMS reports are still compiled for each refrigerant.

4.3.12.4. **Equipment Retirement.**

4.3.12.4.1. As discussed in Chapter 1, there is no reason to retire any AC/R equipment because of the type of refrigerant. Using the four RMS reports (described in paragraph 4.3.12.1) that are compiled for each of the refrigerants on base, the BCE staff can quickly identify refrigerant shortages, such as the example in Appendix C3 of the sample RMP. That example shows three R-113 chillers with very low availability. It is necessary to retire one R-113 chiller to obtain recovered refrigerant to keep the remaining two operating. The Refrigerant Service Record Report in Appendix C5 of the sample RMP shows two R-123 chillers requiring service calls for refrigerant. A review of the report shows that more than 350 pounds of refrigerant were lost, indicating improvements are required in the servicing of this equipment.

4.3.12.4.2. The goal of the sample RMP is to provide information and guidance to the BCE to develop the annual RMP. The sample RMP contains examples of reports and provides an outline of information required to be submitted to the EPA either directly or for future review in a single document. The RMS is used to support daily refrigerant management requirements and provides a management tool to generate the reports and input for the annual RMP to ensure continued mission support.

4.3.13. **Appendix D.** This appendix contains copies of equipment purchase waivers.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

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Prescribed Forms

None

Adopted Forms

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AF Form 847, *Recommendation for Change of Publication*

Abbreviations and Acronyms

%—percent

>—greater than

≥—greater than or equal to

<—less than

≤—less than or equal to

°C—degrees Celsius

°F—degrees Fahrenheit

AAFES—Army and Air Force Exchange Service

AC/R—air-conditioning and refrigeration

ACGIH—American Conference of Government and Industrial Hygienists

AEL—allowable/acceptable exposure limit

AFB—Air Force base

AFCEC—Air Force Civil Engineer Center

AFCEC/CO—Air Force Civil Engineer Center, Operations Directorate

AFI—Air Force instruction

AFPAM—Air Force pamphlet

AHRI—Air-Conditioning, Heating, and Refrigeration Institute (formerly ARI)

AIHA—American Industrial Hygienists Alliance

ALR—actual leakage rate

ANG—Air National Guard

ANSI—American National Standards Institute

API—American Petroleum Institute

APLV—application part-load value

ARI—Air-Conditioning and Refrigeration Institute or American Refrigeration Institute (now AHRI)

ASHRAE—American Society of Heating, Refrigerating and Air-Conditioning Engineers

BAS—building automation system

BCE—base civil engineer

BRMP—Base Refrigerant Management Program

Btu/hr—British thermal unit per hour

Btu—British thermal unit

CAAA—Clean Air Act amendments

CAA—Clean Air Act

CE—civil engineering

CerTest—U.S. Air Force-administered certification test

CFC—chlorofluorocarbon

cfm—cubic feet per minute

CFR—Code of Federal Regulations

CGA—Compressed Gas Association

CLTD—cooling load temperature difference

CO_2—carbon dioxide

COP—coefficient of performance

CR—consumption rate

CRR—critical refrigerant reserve

cSt—centistoke

DDRV—Defense Distribution Depot, Richmond, Virginia

DLA—Defense Logistics Agency

DLAI—Defense Logistics Agency Instruction

DOD—Department of Defense

DOE—Department of Energy

DOT—Department of Transportation

DSCR—Defense Supply Center Richmond (Defense Logistics Agency)

DX—direct expansion

EEL—emergency exposure limit

E.O.—Executive Order

EPA—Environmental Protection Agency

EPAMLR—EPA maximum leakage rate

EST—Eastern Standard Time

ft2—square foot

gal/min—gallon per minute

GAX—generator/absorber heat exchange

GED—gas engine-driven

g/m3—gallon per cubic meter

gpm—gallon per minute

GWP—global warming potential

HCFC—hydrochlorofluorocarbon

HFC—hydrofluorocarbon

Hg—mercury

HVAC—heating, ventilating, and air-conditioning

HW—hot water

IDLH—immediately dangerous to life and health

IPLV—integrated part-load value

IR—infrared

IR-PAS—infrared-photo acoustic spectroscopy

kg—kilogram

KOH—potassium hydroxide

kW/ton—kilowatt per ton

kWh—kilowatt-hour

kW—kilowatt

lb—pound

lb/hr/ton—pound per hour per ton

lb/yr—pound per year

LCC—life-cycle cost

MAJCOM—major command

mA—milliamperes

Mbh—1,000 Btu per hour

Mbh/ton—1,000 Btu per hour per ton

mg—milligram

MLR—maximum leakage rate

MRR—marginal refrigerant reserve

MSDS—Material Safety Data Sheet

MVAC—motor vehicle air-conditioning

NIOSH—National Institute for Occupational Safety and Health

NIST—National Institute of Standards and Technology

NPT—National Pipe Thread

O&M—operations and management/maintenance

OBRA—Omnibus Budget Reconciliation Act

ODC—ozone-depleting chemicals

ODP—ozone-depletion potential

ODS—ozone-depleting substances

ODSP—Ozone-Depleting Substance Program

OEM—original equipment manufacturer

OSHA—Occupational Safety and Health Administration

PII—personally identifiable information

PL—Public Law

POC—point of contact

POE—polyol ester

ppm—parts per million

psig—pound per square inch gauge

psi—pound per square inch

PVC—polyvinylchloride

RCL—refrigerant concentration limit

RMP—Refrigerant Management Plan

RMS—Refrigerant Management System

RWP—Recurring Work Plan

SNAP—Significant New Alternatives Policy

SOW—statement of work

steam/hr/ton—steam per hour per ton

STEL—short-term exposure limit

TAN—total acid number

TLV—threshold limit value

TLV—TWA—threshold limit values – time-weighted average

TWA—time-weighted average

UFC—Unified Facilities Criteria

UFGS—Unified Facilities Guide Specification

UL—Underwriters' Laboratory

UNEP—United Nations Environment Programme

UN—United Nations

USAF/A7C—The Air Force Civil Engineer

UV—ultraviolet

vDC—volts of direct current

W—watt

wt—weight

yr—year

Terms

Appliance—Any device that contains a Class I or Class II chlorofluorocarbon (CFC) as a refrigerant and is used for household or commercial purposes (e.g., air conditioner, refrigerator, chiller, freezer).

Application Part-Load Value (APLV)—A single kW/ton value which modifies the integrated part-load value (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.

Btu—British thermal unit. 1. A unit of heat. 2. The heat required to raise the temperature of 1 pound of water, at its maximum density, 1 °F. 3. The heat to be removed in cooling 1 pound of water 1 °F.

Central Chilled Water Plant—Multiple chilled water systems served from a single piping network.

Challenging Alternative—A proposed optimization of the defending alternative to find a more energy-efficient alternative with a lower life-cycle cost (LCC).

Chilled Water System—(see also Chiller System) One or more chillers that serve a single piping network.

Chiller System—A chiller system uses refrigerant flowing through a coil to cool chilled water. The chilled water is pumped through a piping loop to air handlers where the chilled water flows into an air handler coil to cool the air flowing over the coil that goes to the space.

Cluster—Individual chilled water systems within close proximity to 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.

Consumption Rate (CR)—The annual rate at which a refrigerant is lost to leaks and emissions, typically expressed in pounds per year (lb/yr).

Cooling Load Temperature Difference (CLTD)—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 solar heat transfer through walls, roofs, and glass using an equivalent temperature difference.

Critical Refrigerant Reserve (CRR)—The single largest charge (in pounds) for each refrigerant used at an AFB.

Days—All references to days refer to calendar days.

Defending Alternative—Lowest LCC chiller alternative from the previous analysis.

Demand Charge—Charge assessed by a utility for the largest amount of power used during a specified period of time.

Disposal—1. The process leading to appliance disassembly where the appliance components are reused. 2. The disassembly of any appliance for discharge, deposit, dumping, or placing of its discarded component parts into or on any land or water. 3. The discharge, deposit, dumping, or placing of any discarded appliance into any land or water.

Emergency Exposure Limit (EEL)—The concentration of a hazardous material from which escape is feasible without any irreversible effects on health in an emergency situation where recurrence is expected to be rare during an individual's lifetime.

Enhanced Retrofit—The enhanced retrofit involves re-engineering the chiller to be compatible with the properties of a 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 impellers, and a revised refrigerant expansion orifice system.

EPA Maximum Leakage Rate (EPAMLR)—The maximum percentage of the total charge a machine can lose based on a 12-month period without exceeding EPA leakage limitations. Exceeding the maximum leakage rate (MLR) 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.

High-Pressure Appliance—Uses refrigerant with a boiling point between -50 °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.

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.

Integrated Part—Load Value (IPLV)—A single kW/ton value that describes part-load chiller efficiency 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 Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 550/590-2011 by the equation IPLV = 0.05 (100% kW/ton) + 0.3 (75% kW/ton) + 0.4 (50% kW/Ton) + 0.25 (25% kW/ton).

Life—Cycle Cost (LCC)—The total cost associated with the purchase, installation, operating, and maintenance of a system or equipment over its expected life.

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, AC/R 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—Appliance that uses 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 removing the compressor, evaporator, or auxiliary heat exchanger coil.

Marginal Refrigerant Reserve (MRR)—The sum of the appropriate EPAMLRs (15**%** or 35**%**) for each machine, plus the critical refrigerant reserve (CRR) for each refrigerant.

Off-peak—A time period when utility energy costs are reduced to below-normal demand rates.

On-peak—A time period when energy costs are raised by a utility due to above-normal demand.

Opening an Appliance—Any service, maintenance, or repair of an appliance that could be reasonably expected to release refrigerant to the atmosphere unless the refrigerant was previously recovered from the appliance.

Partition—Any wall, ceiling, or floor assembly that is not exposed to outside ambient conditions.

Primary Chilled Water Pump—A pump that distributes chilled water between the chiller plant and the secondary chilled water pumps serving the load.

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, thus causing the refrigerant to flow by pressure differential. A separate line between the system liquid port and the receiving vessel is connected for the refrigerant transfer.

Reclaim—Reprocessing of refrigerant to new product specifications. The purity of the final product must be chemically verified to meet Air-Conditioning, Heating, and Refrigeration Institute (AHRI) 700 standards.

Recover—Removal of refrigerant from a system. Testing the refrigerant’s condition is not necessary.

Recycle—To clean refrigerant for re-use without chemical purity verification.

Refrigerant Management Plan (RMP)—A schedule with the associated costs required to eliminate CFC refrigerants in AC/R equipment at an Air Force base. 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.

Refrigerant Manager—An individual selected to manage the BRMP and is responsible for developing the RMP.

Retirement—The ability to recover refrigerant from a machine by retrofit or replacement.

Retrofit—The conversion of equipment containing a CFC refrigerant to use a more environmentally friendly refrigerant.

Schedule—Equipment retirement schedule. A pre-determined plan developed to establish the specific dates and order in which AC/R equipment retirements should be conducted to maintain sufficient refrigerant inventories and maintain annual funding requirements as level as possible.

Secondary Chilled Water Pump—Pump which serves the users at the end of the distribution loop. The pump is sized to overcome only the piping losses in the secondary piping loop going to the end-users.

Self-Contained Recovery Equipment—Equipment that has its own means of drawing refrigerant out of an appliance.

Small Appliance—Air-conditioners, refrigeration equipment, or freezers that are fully manufactured, charged, and hermetically sealed in a factory with a charge of 5 pounds or less.

System-Dependent Recovery Equipment—Relies on the appliance compressor or the refrigerant pressure in the appliance to extract the appliance's refrigerant.

Technician—Any person who maintains, services, or repairs AC/R equipment that could reasonably be expected to release CFCs or HCFCs to the atmosphere.

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).

Very-High-Pressure Appliance—AC/R equipment that contains refrigerant with a boiling point below -50 °C (-58 °F) at atmospheric pressure.

Attachment 2

UPDATE ON REFRIGERANTS: TRANSLATING THE LAWS, REGULATIONS, AND POLICIES INTO PRACTICE

A2.1. The Montréal Protocol. Since 1974, atmospheric scientists worldwide have substantiated and refined the hypothesis confirming the long-term, negative consequences of CFC use. In response to scientists' concerns, representatives of 35 nations met in 1987 at the United Nations Environment Programme (UNEP) in Montréal and established an international protocol for restricting CFC and halon production. Representatives from 93 nations met in London in 1990 to revise the Montréal Protocol because of new information regarding ozone destruction. This meeting accelerated the CFC phase-out. UNEP's November 1992 meeting in Copenhagen accelerated the phase-out schedules. The Montréal Protocol representatives generally meet every year to assess the status of ODS reduction efforts and consider new recommendations. The 2007 meeting increased the pace of the R-22 phase-out. The 2008 meeting urged the use of natural refrigerants such as carbon dioxide (CO_2).

A2.1.1. **Phase-Out Schedules.** By 2015, HCFC refrigerants were to be reduced by 65 percent from their baseline. However, based on a 2007 meeting of the Montréal Protocol representatives, HCFCs were further reduced by 75 percent from their baseline by 2010. By 2020, the production of all new refrigerants will cease. In addition, manufacturing new equipment using HCFC refrigerants was banned beyond January 2010. The exception is HCFC-123. Equipment designed to use HCFC-123 can be produced until January 2020. The refrigerant itself will be produced until 2030. This special consideration is based on HCFC-123's low ODP (0.02), low GWP (93), and short atmospheric lifetime (less than two years).

A2.1.2. **Applicable CFCs.** The CFC refrigerants used by the Air Force for AC/R units that are affected by the Montréal Protocol include CFC-11, CFC-12, CFC-113, CFC-500, CFC-501, CFC-502, and CFC-503.

A2.1.3. **Applicable HCFCs.** The most widely used HCFC refrigerants affected by the Montréal Protocol are HCFC-22 and HCFC-123.

A2.2. Taxes.

A2.2.1. **Federal Excise Tax.** The Omnibus Budget Reconciliation Act (OBRA) of 1989 (PL 101-239) imposed an excise tax on certain ozone-depleting chemicals (ODC) and products made with or using those chemicals. The tax, increased in late 1992, penalized ODC consumers and brought the prices of these chemicals closer to their new alternatives. The tax affects only new refrigerant and is calculated by multiplying each chemical's ODP by the base tax rate. The base tax per pound began at $1.37 in 1991 and increased to $7.15 by 1999. Base tax rates for 2009 were $11.65 per pound and increased to $12.10 in 2010. This excise tax will have negligible effects on Air Force AC/R operations.

A2.2.2. **Floor Stocks Tax.** ODCs are subject to a tax on floor stocks that are held for sale or use in further manufacture on the date the tax is imposed. This tax does not apply to Air Force operations. An ODC held by a government agency 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.

A2.3. Clean Air Act Amendments. Table A2.1 shows the current phase-out schedule for HCFCs, including the change at the Montréal Protocol meeting in 2007.

Table A2.1. Current Phase-Out Schedule for HCFCs.

Montréal Protocol		**United States**	
Year to be implemented	Percent reduction in consumption and production using the cap as a baseline	Year to be Implemented	Implementation of HCFCs phase-out to Clean Air Act regulations
2004	35.0%	2003	No production and no importing of HCFC-141b
2010	75.0%	2010	No production and no importing of HCFCs R-22 or R-142b except for use in equipment made before 1 January 2010
2015	90.0%	2015	No production and no importing of any HCFCs except for use as refrigerants and equipment manufactured before 1 January 2010
2020	99.5%	2020	No production and no importing of HCFC-142b and HCFC-22
2030	100.0%	2030	No production and no importing any HCFCs

A2.4. EPA Regulations.

A2.4.1. **Overview.** A refrigerant recycling requirement overview of CAAA, Section 608, follows. It includes the final regulations published in the 14 May 1993 Federal Register, 40 CFR Part 82 (2008). The prohibition against venting became effective 1 July 2008. These requirements directly impact base CE daily activities. For additional information, call the EPA Stratospheric Ozone Information Hotline at (800) 296-1996 from 0900 to 1630 EST**,** Monday through Friday, or visit their web site: **http://www.epa.gov/ozone**/. The following regulation summarizes these procedures:

A2.4.1.1. Require service practices that maximize ODS recovering or recycling during servicing and disposal of AC/R equipment.

A2.4.1.2. Establish certification requirements for recycling and recovery equipment, technicians, and reclaimers.

A2.4.1.3. Confine Class I and Class II ODS refrigerant sales to certified technicians.

A2.4.1.4. Require that substantial leaks in AC/R equipment with a refrigerant charge of 50 pounds or greater be repaired.

A2.4.1.5. Establish safe disposal requirements for small appliances such as home refrigerators and room air-conditioners which typically enter the waste stream with an intact charge.

A2.4.2. **Prohibition on Venting.** Effective 13 June 2005, no person maintaining, servicing, repairing, or disposing of appliances may knowingly vent or otherwise release into the environment any appliance's refrigerant or its substitute. The exceptions include nitrogen, water, ammonia, hydrocarbons, and chlorine. Some industrial uses are not affected. This applies to HFC refrigerants, including, but not limited to, R-134a and R-410a.

A2.4.3. **Service Practice Requirements.** The EPA established requirements that must be met when servicing AC/R equipment.

A2.4.3.1. Technicians are required to evacuate AC/R equipment to established vacuum levels. If the technician's recovery or recycling equipment was manufactured before 15 November 1993, the AC/R equipment must be evacuated to the levels indicated in the first column of Table A6.1. The recovery or recycling equipment must have been certified by an EPA-approved equipment testing organization (see 40 CFR Part 82 [2008], Subpart F, 156 to 158). Technicians repairing small appliances, such as household refrigerators, household freezers, and water coolers, are required to recover 80 to 90 percent of the system refrigerant, depending on the system's compressor status.

A2.4.3.2. The EPA has established limited exceptions to its evacuation requirements for minor repairs and repairs of leaky equipment not followed by an equipment evacuation into the environment. If evacuation to the level described in Table A6.1 is not attainable, or would significantly contaminate the recovered refrigerant, persons opening the appliance must isolate the leaking components from the non-leaking components whenever possible; evacuate non-leaking components to the levels shown in Table A6.1; and evacuate leaking components to a level that will not significantly contaminate the refrigerant (≤ 0 pound per square inch gauge [psig]).

A2.4.3.2.1. If evacuation of the equipment to the environment will not be performed when repairs are complete, and if the repair is not major, then the appliance must be evacuated to at least 0 psig before it is opened if it is a high-pressure or very-high-pressure appliance, or be pressurized to 0 psig before it is opened if it is a low-pressure appliance. Methods that require subsequent purging (e.g., nitrogen) cannot be used.

A2.4.3.2.2. Major repairs include the removal of a compressor(s), condenser, evaporator, or auxiliary heat exchanger coil.

A2.4.3.3. The EPA permits the return of recovered and/or recycled refrigerant to the same system or other systems owned by the same person without restriction. If refrigerant changes ownership, the refrigerant must be reclaimed. (It must be cleaned according to purity standards of AHRI 700-2006, *Specification for Fluorocarbon Refrigerants*, and chemically analyzed to confirm it meets that standard.)

A2.4.4. **Equipment Certification.** The EPA has created a certification program for recovery/recycle equipment. Under the program, the EPA requires that equipment manufactured on or after 15 November 1993 undergo tests administered by an EPA-approved testing organization to verify it meets the EPA's requirements. Recycling and recovery equipment intended for use with AC/R equipment other than small appliances must be tested according to AHRI 740-2006, *Refrigerant Recovery/Recycling Equipment*. Recovery equipment designed for small appliances must also be tested to comply with AHRI 740-2006.

The EPA requires recovery efficiency standards that vary based on the AC/R equipment size and type being serviced. For recovery and recycling equipment designed for AC/R equipment other than small appliances, the standards are identical to those shown in the second column of Table A6.1. Recovery equipment intended for small appliances must recover 90 percent of the refrigerant in a small appliance while the appliance's compressor is operating or 80 percent if the compressor is not operating.

A2.4.5. **Grandfathering Equipment.** Equipment manufactured before 15 November 1993, including homemade equipment, will be grandfathered if it meets the standards in the first column of Table A6.1. Third-party testing is not required for equipment manufactured before 15 November 1993 (see paragraph A2.4.4).

A2.4.6. **Refrigerant Leaks.** Owners of equipment with charges of 50 pounds or more must repair leaks that exceed the annual maximum leakage rate of 15**%** for comfort cooling and 35**%** for commercial and industrial refrigeration applications within 30 days. If the owner is unable to repair the equipment, a retirement plan must be developed within 30 days and implemented within 12 months. A copy of the plan must be present with the equipment. Upon completion of the repair, a follow-up verification must occur within 30 days. Owners must maintain records of the refrigerant quantity added to their equipment during servicing and maintenance procedures. To help meet this requirement, AFCEC developed the Refrigerant Management System (RMS). The RMS is explained in the *Refrigerant Management System User's Guide*.

A2.4.7. **Mandatory Technician Certification.** The CAAA of 1990, Title VI, Section 608, imposes requirements for training and certifying technicians involved in maintaining and servicing refrigeration systems with CFC or HCFC refrigerants. Technicians servicing MVAC must also be certified to work with R-134a. The best practice for the Air Force is to train and certify all technicians working with any refrigerants.

A2.4.7.1. The EPA has four types of certification:

A2.4.7.1.1. Type I: Required for servicing small appliances.

A2.4.7.1.2. Type II: Required for servicing or disposing of high-pressure or very high-pressure appliances, except small appliances and MVAC.

A2.4.7.1.3. Type III: Required for servicing or disposing of low-pressure appliances.

A2.4.7.1.4. Universal: Approved for servicing all equipment types.

A2.4.7.2. Technicians, as defined in 40 CFR 82, Subpart F, 82.15, who service or repair small appliances must have Type I certification.

A2.4.7.3. Technicians must pass an EPA-approved test administered by an EPA-approved certifying organization. Technicians must be certified to be able to maintain, service, and repair AC/R equipment. Apprentice technicians working in an approved program under the direction of a certified technician do not require certification.

A2.4.8. **Refrigerant Sales Restrictions.** Any CFC or HCFC refrigerant sold in any size container will be restricted to technicians certified by an EPA-approved program.

A2.4.9. **Certification by Owners of Recycling and Recovery Equipment.** The EPA requires that persons who service or dispose of AC/R equipment must certify to the EPA that they have purchased and use recovery or recycling equipment certified to meet EPA requirements and that they are complying with the applicable requirements of EPA Section 608, *Refrigerant Recycling Rule* (40 CFR Part 82, Subpart F). The initial certification form, EPA Form 7610-31, *Refrigerant Recovery or Recycling Device Acquisition Certification Form*, must be signed by the equipment's owner or another responsible officer and sent to the appropriate EPA regional office. Equipment owners do not have to send in a new form each time they add recycling or recovery equipment to their inventory after the initial list has been submitted. Although recycling and recovery equipment owners are required to list the number of trucks based at their shops, they do not need a piece of recycling or recovery equipment for every truck.

A2.4.10. **Safe Disposal Requirements.** Under the EPA's rule, equipment that is typically dismantled onsite before disposal (e.g., retail food refrigeration, cold storage warehouse refrigeration, chillers, or industrial process refrigeration) must have its refrigerant recovered according to the EPA's servicing requirements. However, equipment that typically enters the waste stream with the charge intact (e.g., household refrigerators, freezers, or room air-conditioners) is subject to special safe disposal requirements. Under these requirements, the final person in the disposal chain (e.g., scrap metal recycler or landfill owner) must ensure the refrigerant is recovered before final disposal of the equipment. If the final person in the disposal chain accepts appliances that no longer hold a refrigerant charge, that person is responsible for obtaining a signed statement from whom the appliance is being accepted. The signed statement must include the name and address of the person who recovered the refrigerant and the date the refrigerant was recovered, or a copy of a contract stating that the refrigerant will be removed before delivery. The signed statement or contract must be available onsite for inspection. The EPA does not mandate a sticker as a form of verification that the refrigerant has been removed prior to disposal of the appliance, but such stickers do not relieve the final disposer of their responsibility to recover any remaining refrigerant in the appliance. Technician certification is not required for individuals removing refrigerant from appliances prior to disposal; however, the equipment used to recover refrigerant from appliances prior to final disposal must meet the same performance standards as EPA-certified refrigerant recovery equipment used prior to servicing. Per EPA Section 608 of the Clean Air Act of 1990, disposable cylinders should be emptied (recover the refrigerant until the pressure is reduced to a vacuum). The container's valve should be closed and the container itself marked as empty; the container is now ready for disposal. It is recommended, but not required, by EPA Section 608 that the cylinder valve be opened afterwards to allow air to enter. The cylinder valve is then broken off while the valve remains open and the cylinder is punctured. This will prevent cylinder misuse by untrained individuals. Once the cylinder has been rendered useless as a container, it can be disposed of as scrap metal. For details on disposal rules, refer to Department of Transportation (DOT) Specification 39, 49 CFR 178.65, *Specification 39 Non-reusable (non-refillable) cylinders*, and Defense Logistics Agency Instruction (DLAI) 4145.25, *Storage and Handling of Liquefied and Gaseous Compressed Gasses and Their Full and Empty Cylinders*.

A2.4.11. **Major Recordkeeping Requirements.** The EPA recordkeeping requirements discussed in paragraphs A2.4.11.1 and A2.4.11.2 can be met by using the RMS spreadsheet.

A2.4.11.1. Technicians servicing appliances containing 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.

A2.4.11.2. Owners of appliances that contain 50 or more pounds of refrigerant must keep service records documenting the date and type of service and the quantity of refrigerant added.

A2.4.12. **Hazardous Waste Disposal.** The EPA has requirements for safely disposing of refrigerants.

A2.4.12.1. If refrigerants are recycled or reclaimed, they are not considered hazardous under federal law. In addition, used oils contaminated with CFCs or HCFCs are not hazardous as long as they are not combined with other waste.

A2.4.12.1.1. CFC-contaminated oils are subject to CFC recycling or reclamation.

A2.4.12.1.2. HCFC-contaminated oils are subject to HCFC recycling or reclamation.

A2.4.12.1.3. Contaminated oils are not to be mixed with used oils from other sources.

A2.4.12.2. Used oils containing CFCs after the CFC reclamation procedure are, however, subject to specification limits for used oil fuels if they are not burned.

A2.4.13. **Enforcement.** The EPA is continually performing random inspections, responding to tips, and pursuing violators. Under the CAAA, the EPA is authorized to assess fines of up to $37,500 per day for any violations.

A2.5. Air Force Requirements. Air Force requirements are in AFI 32-7086. That instruction comprises the major policy and procedural guidance used to develop the BRMP.

A2.5.1. **Refrigerant Management Required.** By order of the Secretary of the Air Force, the implementation by Air Force CE of AFI 32-7086 is mandatory. AFI 32-7086, Chapter 4, “Air Force Ozone Depleting Substance (ODS) Program (ODSP),” discusses managing ODS. The RMP establishes a base-level BRMP that guides BCEs to achieve the objectives of AFI 32-7086.

A2.5.2. **Air Force Goal.** The Air Force will provide its bases with AC/R equipment to support the elimination of Class I ODS and the management of Class II ODS base inventories in accordance with applicable codes and environmental regulations. The remaining capabilities of existing Class II equipment will be fully exhausted. This goal will be met by reaching the objectives of AFI 32-7086.

A2.5.3. **AFI 32-7086 Objectives.** The key objectives in AFI 32-7086, Chapter 4, paragraphs 4.1 and 4.2, include managing ODS inventories to eliminate Class I ODS and managing Class II ODS before it is necessary to maintain a central Class II stockpile. This will reduce the cost and risk of ODS maintenance and ensure compliance with federal laws, regulations, and international agreements. The BRMP, as discussed in Chapter 1 of this pamphlet, was developed to meet the requirements of AFI 32-7086.

Attachment 3

REFRIGERANT SENSORS AND MONITORING OF EQUIPMENT ROOMS

A3.1. Introduction. All new mechanical equipment rooms must be designed to comply with ASHRAE 15-2007. All current mechanical rooms must comply with this standard whenever new mechanical equipment is installed or current mechanical equipment is retrofitted. ASHRAE 15-2007 includes requirements for installing permanent refrigerant leak detectors. This attachment provides an overview of these requirements and an introduction to refrigerant leak-detection equipment.

A3.2. Refrigerant Sensor Terminology. The following section describes these refrigerant sensor and detection terminology comparison criteria: sensitivity, detection limits, and selectivity. These are applicable to portable pinpoint detectors and permanently mounted area monitors.

A3.2.1. Sensitivity.

A3.2.1.1. The device sensitivity is the amount of input needed to change an output signal. For refrigerant sensors, the refrigerant vapor concentration being measured is displayed on a panel meter, a voltage output, or other display. Highly sensitive refrigerant sensors require little material to generate a large change in output signal. Low-sensitivity sensors need large amounts of material to change the output signal. The sensitivity is affected by the detection method and the material under consideration.

A3.2.1.2. 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 the reduction in chlorine content, very easily ionized and detected, from CFC- to HCFC- to HFC-class compounds. Sensitivity differences of 100x to 1000x have been reported when comparing CFC-12 to HFC-134a with some ionization-based sensors. Another example of this varying sensitivity is an infrared (IR) -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. Refrigerant blends such as HCFC-410a and HCFC-406 are covered in Table A3.1 for sensor comparisons.

A3.2.2. **Detection Limit.** Sensitivity values are well defined but refrigerant sensor sensitivity values do not exist. The most common measure of sensor performance is the detection limit. It is the minimum amount of material a unit can sense that returns a signal at least two times stronger than the background noise level. A sensitive device does not necessarily have a low-detection limit, but that is usually the case. Area-monitoring application detection limits are measured in parts per million (ppm). Area monitors have detection limits as low as 1 ppm but are typically 3 ppm to 4 ppm for most compounds. A highly sensitive detector may be able to accurately record vapor concentration levels ranging from 1 ppm to 2 ppm, while a low-sensitivity detector may record the same vapor using increments of 20 ppm or higher. A refrigerant sensor must match the intended application. For example, an ionization detector that boasts a 2-ppm CFC-12 detection limit will not work as well when detecting HFC-134a. Conversely, an ionization detector designed specifically for HFC-134a may be too sensitive to monitor CFC-12.

A3.2.3. Selectivity.

A3.2.3.1. Selectivity is the ability to detect only one refrigerant of interest without interference from other compounds. Area monitoring selectivity requirements vary with specific installations. This is an important issue because monitors must work continuously and they become exposed to refrigerants with potentially more interference in a wider concentration range over a long period of time.

A3.2.3.2. Area monitors require selectivity if other refrigerants present have vastly different threshold limit values (TLV). ASHRAE 15-2007 requires that an alarm activate the mechanical ventilation system with a value not exceeding the threshold limit values – time-weighted average (TLV-TWA). A TLV is the maximum chemical vapor air concentration that workers can be chronically exposed to (defined as an eight-hour work day and a 40-hour work week) without suffering adverse health effects during their career. TWA is the time-weighted average for the TLV. Workers can be exposed to concentrations greater than the TLV, but the average exposure during a day will not exceed the average exposure level. These values were created by the American Conference of Government and Industrial Hygienists (ACGIH). A monitor's selectivity feature allows the alarm to actuate for a specific chemical and identify it. This helps maintenance technicians to determine the exposure to workers.

A3.3. Electronic Area Monitor Detection Equipment. Electronic area monitor detection equipment belongs in one of the following categories according to selectivity criteria: (1) nonselective; (2) halogen-selective; (3) compound-specific.

A3.3.1. **Nonselective Sensors.** These equipment sensors can detect any emission or vapor present, regardless of its chemical composition. Detectors in this category are based on electrical ionization, thermal conductivity, ultrasonic, or metal-oxide semiconductors. These detectors are simple to use, very rugged, and typically inexpensive. Nonselective sensors excel at pinpointing leaks.

A3.3.2. **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 chemicals. These sensors reduce the number of false alarms generated by non-refrigerant compounds such as paint or gas fumes. These durable detectors are easy to use and have a higher sensitivity than nonselective detectors (detection limits are typically < 5 ppm). The detector's partial specificity makes calibration easy.

A3.3.3. **Compound-Specific Sensors.** Compound-specific sensors are complex and expensive. They can detect a single variety without suffering interference from other compounds. Compound-specific sensors are IR-based. Newer types are based on infrared-photo acoustic spectroscopy (IR-PAS). These have detection limits around 1 ppm, depending upon the compound detected. Technological improvements have reduced prices, but expect to pay between $3,500 to $4,000 for a compound-specific detector.

A3.3.4. **Comparing Sensors.** These three types of sensors are compared in Table A3.1.

Table A3.1. 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 varieties Most cannot be calibrated	Not compound-specific Detector lifetime/stability	Complexity/ maintenance Stability questionable High price
Refrigerants detected:	All CFCs, HCFCs, HFCs, blends (e.g., 410a, 406, 407C) Not recommended due to cross-sensitivity and poor detection limits	All CFCs, HCFCs, HFC-134a, blends (e.g., 410a, 406, 407C)	All CFCs, HCFCs, HFC-134a, blends (e.g., 410a, 406, 407C)
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

A3.4. Refrigerant Sensors. ASHRAE 15-2007 requires that every refrigerating machinery room contain a refrigerant detector that activates an alarm and mechanical ventilation for a refrigerant vapor level no greater than the TLV-TWA. The detector can reduce a workforce’s chemical exposure and may help save enough refrigerant to pay for itself by preventing partial or entire charge losses.

A3.5. Continuous Duty Area Monitors. Area monitors check the refrigerant vapor level continuously in an equipment room or other locations where exposure is possible. Monitoring happens for several reasons: to protect personnel health and safety, conserve refrigerant, and protect valuable refrigeration equipment.

A3.5.1. **Monitor Characteristics.** If a monitor continuously samples air inside an equipment room, it should have several capabilities that short-term or leak-checking monitors do not require. These include low 0-drift or an auto-zeroing capability and outputs for triggering external alarms that alert appropriate base personnel. Continuous monitors should be refrigerant-specific to prevent nuisance alarms generated by untargeted compounds. Monitors with poor selectivity will react to compounds other than refrigerants, including cleaning agents or paints.

A3.5.2. **Monitor Requirements.** ASHRAE 15-2007 requires a monitor to activate an alarm and start mechanical ventilation when limits are exceeded. Alerting personnel that a refrigerant level has exceeded TLV-TWA is a basic monitor function. Long-term monitoring devices should remain stable inside the temperature, voltage, humidity, and barometric pressure ranges they will encounter. One output should notify base emergency personnel if a major refrigerant release occurs. They should require minimal maintenance.

A3.5.3. **Calibration Stability.** Calibration stability is very important for long-term monitoring. Stability is provided by electronics that read the sensor output. In general, the electronics should be able to correctly interpret sensor output under all equipment room conditions, such as those involving temperature and humidity changes. Recalibrate an area monitor after a repair involving a sensor, bridge board, or a main control board replacement. Replacing any of these components can significantly affect unit calibration. There are many situations where multiple refrigerants are monitored. R-123 does not have ACGIH TLV, but it has a 50-ppm TLV listed on a Material Safety Data Sheet (MSDS) provided by the American Industrial Hygienists Alliance (AIHA). TLVs for most refrigerants are much higher. For instance, R-134a has 1000-ppm TLV. Several sensor types are used in refrigerant-detection devices, but they can generally detect a wide range of refrigerants. Monitor sensitivity is tuned best for detecting a specific refrigerant. Even after tuning, a monitor will be sensitive to other common refrigerants. Manufacturers often publish cross-sensitivity charts that show how the monitor will react to various chemicals, including other refrigerants, if it is tuned to a specific refrigerant. If you know which refrigerants will be inside the equipment room, it is possible to choose a monitor calibration that will generate alarms at or below those refrigerants' TLV-TWA. If a proper calibration setting cannot be found, multiple detectors are needed. For example, Trane's monitor set detects R-123. It would also detect R-134a at a level that would generate alarms for both refrigerants below their respective TLV-TWA.

A3.5.3.1. **Sensitivity.**

A3.5.3.1.1. Although most area monitors will detect all halogen-based refrigerants, their sensitivity varies with the specific refrigerant type. Commonly used refrigerants can be divided into four groups based on their sensitivity levels:

A3.5.3.1.1.1. Highest sensitivity: R-11, -22, -123

A3.5.3.1.1.2. Moderate sensitivity: R-502

A3.5.3.1.1.3. Low sensitivity: R-12, -500, -114

A3.5.3.1.1.4. Lowest sensitivity: R-134a

A3.5.3.1.2. 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 when calibrating.

A3.5.3.2. **Refrigerant Detection Sensors.** Typically, sensors last approximately two to five years from the installation date before a new sensor is required. As refrigerant detection takes place, the sensor loses some of its ability to detect refrigerant again. Sensor life is mostly determined by how much refrigerant it senses over time. Choose a sensor with a built-in calibration leak (a pre-programmed leak for a large selection of gases [refrigerants]), built into the leak detector to quickly verify the unit's calibration status. Recalibrate when necessary. To ensure accuracy, the calibrated leak contains unique electronics that correct for leak rate changes created by temperature fluctuations.

It also monitors the calibrated leak's history and provides prompt alerts when replacements are needed.

A3.5.4. **Characteristics.** Monitors should also have a way to set the 0 reference point. Monitors used on a long-term basis should have either a very small 0-drift (ppm) between inspections or an auto-zero feature.

A3.6. Monitor Alarm Outputs. Monitors must provide a relay to activate an alarm signal if the TLV-TWA limit is reached. It should be used to trigger an audible and visible alarm, alert other building areas about the condition, and activate the ventilation system to purge the room. The monitor should perform equipment room alarm signaling and activate mechanical ventilation systems. Remote alarm indicators can be connected through a building automation system (BAS). Some monitors provide relay outputs triggered by various refrigerant concentration levels. These can be used to alert others about the possibility of exposure. ASHRAE 15-2007 states, "The alarm shall annunciate a visual and audio alarm inside the refrigerating machinery room and outside each entrance to the refrigerating machinery room. The alarms required in this section shall be of the manual reset type with the reset located inside the refrigerating machinery room. Alarms set at other levels (such as IDLH) and automatic reset is permitted in addition to those required by this section. The meaning of each alarm should be clearly marked by signage near the annunciators."

A3.6.1. **Self-Monitoring.** Many monitors are capable of detecting failures that occur as they operate. They have an output signal, such as a relay, to report sensor failures. Failures can include low airflow through the monitor, circuit failure, and a saturated or absent sensor signal. Power loss can be detected if the monitor's alarm contacts are normally powered open. This output should send an alarm condition to the building's operator who can check the monitor and restore its operation. After receiving a signal, the operator should bring a portable monitoring device to the equipment room to check the permanent monitor. The operator should determine the refrigerant level in the mechanical equipment room before entering.

A3.6.2. **Serial Signal.** Some monitors provide 0 to 10 volts of direct current (vDC), 4 to 20 milliamperes (mA), or serial signal proportional to the refrigerant level sensed by the monitor. This signal can provide a remote indication of the equipment room's refrigerant level. If connected to a building automation system, a signal can alert operating personnel about a leak, begin a ventilation purge of the room, generate an electronic log of the equipment room's refrigerant level, and notify a hazardous response team.

A3.6.3. **Advantages.** Monitoring equipment room refrigerant concentrations with a BAS may eventually become common practice for all refrigerants. This level of control not only monitors the refrigerant level and sets off necessary alarms; it automatically alerts the service order desk responsible for repairing the equipment. This inexpensively replaces a trained expert who would quickly respond to a problem by constantly monitoring equipment room operations.

A3.6.3.1. Refrigerant concentration in the equipment room can be logged electronically and documented. This provides documentation that refrigerant concentrations are maintained below the acceptable levels. Any level below 100 ppm of the refrigerant concentration limit (RCL) is acceptable. Personnel also feel comfortable that they are working in a safe environment.

A3.6.3.2. A refrigerant vapor monitor is used for early refrigerant leak detection and may prevent significant refrigerant losses. Monitoring the purge unit with a BAS provides valuable information that can lead to early leak detection.

A3.6.3.3. Chillers that use CFC-11 or HCFC-123 operate at a pressure less than atmospheric pressure; therefore, air and water vapor leak into the chiller rather than refrigerant leaking out. An intermittently running purge unit removes these non-condensable gases that leak in. The purge unit pumps the non-condensable gases back to the atmosphere but a small amount of refrigerant escapes. Purge unit runtimes can be automatically logged and plotted in graph form to reveal trends. In addition, an alarm message can be triggered if the purge rate exceeds a preset limit. In general, purge unit runtimes exceeding one hour per week are signs of excessive leakage. This value depends on the purge unit’s capacity and the chiller’s internal volume; therefore, it is only a guideline. Consult the chiller manufacturer to determine the actual maximum purge unit runtimes allowed for each chiller that is indicative of good operating condition.

A3.7. Sensor Locations.

A3.7.1. Refrigerant sensors paired with area monitors must be properly located. Some refrigerant leak detectors are capable of monitoring multiple locations and may use multiple sensors in a single unit. Other leak detectors are single-zone units capable of monitoring only one location. Some of the key factors to determine sensor locations are leak locations, airflow patterns, and where occupants are likely to inhale refrigerants. With occupant safety in mind, the recommended sensor height is 18 inches (457 millimeters) above the floor. The sensor should remain below the 5-foot (1.5-meter) common breathing zone height. When undisturbed by air currents, leaking refrigerants descend to the floor and spread out. Refrigerants are three to five times heavier than air and seek the lowest areas. Once these areas are saturated, the space begins filling up from the bottom as if it were being filled with water.

A3.7.2. **Locating Sensors.** ASHRAE 15-2007 states, “Locate the sensor where refrigerant is likely to concentrate." This is the only direction offered by ASHRAE 15-2007 when positioning a refrigerant monitor sensor. This recommendation is intentionally vague because of the wide variety of equipment room configurations. Follow instructions provided by the monitor manufacturer when positioning a sensor.

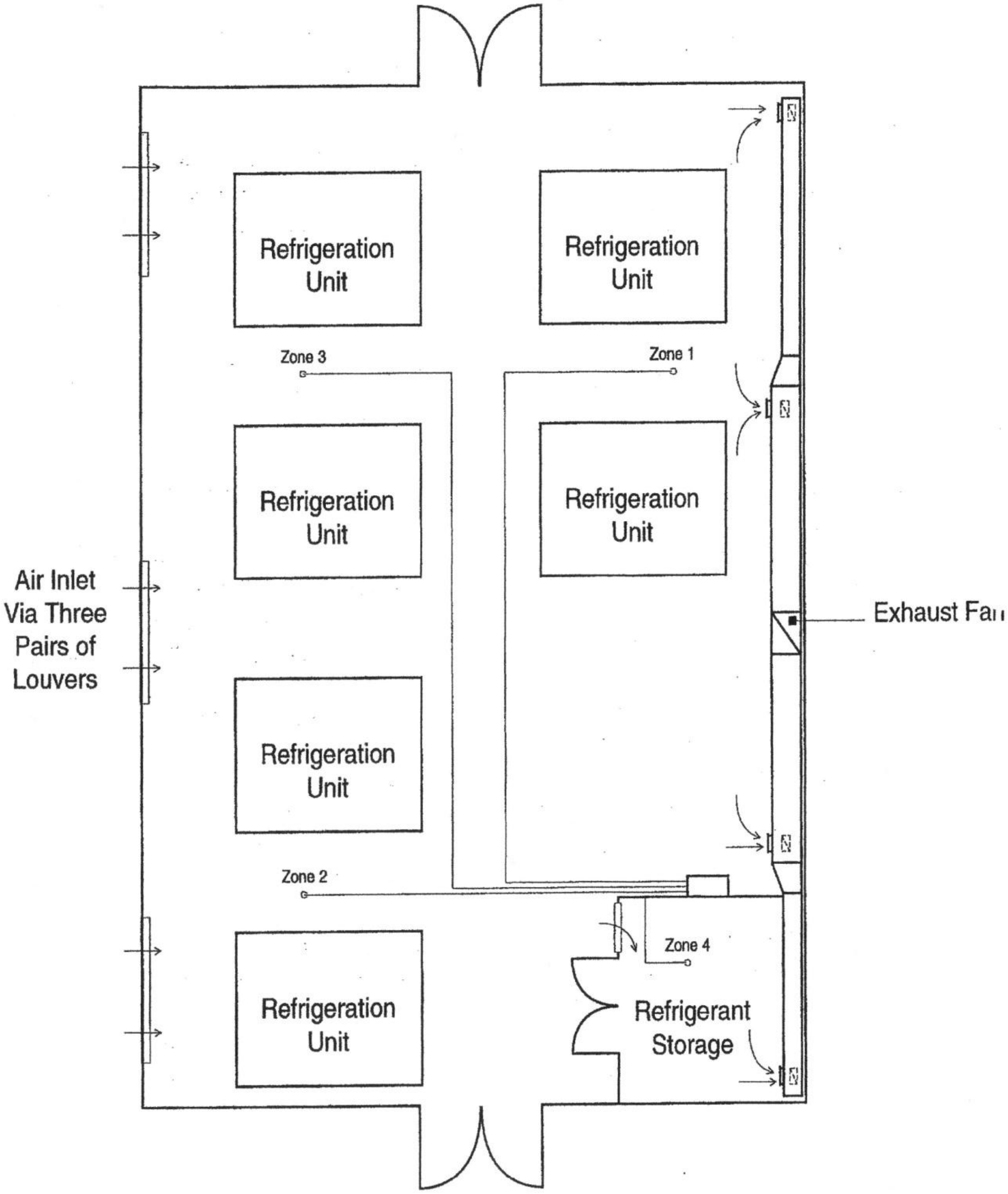
A3.7.2.1. Because the sensor measures airborne refrigerant concentration levels, each zone inlet tube should be mounted where leaks are most likely to occur. Place the inlet as close as possible to an area with potential leaks on the downstream side of the room’s airflow pattern. Place the inlet close to the floor since refrigerants are typically heavier than air. Position the control unit so the farthest pickup point will not exceed the manufacturer's recommendations for zone inlet tube length.

A3.7.2.2. Moisture can damage refrigerant sensors. Protect pickup points from water entering the system.

A3.7.2.3. Figure A3.1 shows the general location of pickup points where sensors should be located in accordance with ASHRAE 15-2007.

A3.8. Additional References. Additional references are provided as suggested sources where more in-depth information can be found: *Modern Refrigeration and Air Conditioning* (Althouse, Turnquist); DuPont #ARTD27, *Leak Detection for Alternative Refrigerants*.

Figure A3.1. Sensor Pickup Points.



Attachment 4

REFRIGERANT HANDLING AND STORAGE RECOMMENDATIONS AND REQUIREMENTS

A4.1. Introduction. Refrigerants, whether regulated or non-regulated, should be stored in a controlled environment. For safety, it is important to limit access to refrigerants; some refrigerants are very toxic, flammable, or stored in high-pressure containers. With the upcoming HCFC production ban in 2030, the limited availability and increasing expense for HCFC and the prohibition to purchase CFC makes refrigerant inventory control very important. Whenever possible, store refrigerants at a single location for better control and management. This simplifies refrigerant inventory management and guarantees that essential recordkeeping practices are followed. If refrigerant is stored within an enclosed space, the area monitor and emergency ventilation system cost savings are significant, particularly if one site is used; otherwise, all storage sites will require these systems.

A4.2. Refrigerant Storage Requirements: Enclosed Space. Buildings or areas within buildings, designed or used specifically as enclosed refrigerant storage facilities, shall comply with ASHRAE 15-2007 (see Attachment 8 of this pamphlet). ASHRAE 15-2007 guidelines include, but are not limited to, refrigerant storage facility ventilation and exhaust requirements, refrigerant monitors, and alarms. ASHRAE 15-2007 limits the amount of refrigerant stored in containers without relief valves and piping to not more than 330 pounds (150 kilograms [kg]) of refrigerant. Store all refrigerants in approved containers and store additional refrigerants in an enclosed room that meets ASHRAE 15-2007 requirements.

A4.3. Refrigerant Storage Recommendations: Open Space. Currently, there are no regulations governing refrigerant storage in non-enclosed refrigerant storage areas other than following safe refrigerant-handling practices. Storage areas must have limited access. See Attachment 8 for guidelines on natural ventilation. The following practices are recommended:

A4.3.1. All storage areas should be roofed for protection from weather extremes and be large enough to shield the refrigerant containers from direct sunlight. At a minimum, enclose the area with a chain-link fence for security.

A4.3.2. An open enclosure should be a stand-alone entity.

A4.3.3. If an enclosure is located adjacent to a building with which it shares a common wall with the remaining sides open, do not install a door in the common wall within the enclosure confines.

A4.4. Other Recommendations. Technicians or anyone with the potential to be working with or around refrigerants should complete a training program that meets the minimum guidelines in 29 CFR 1910.120, *Hazardous waste operations and emergency response* (Occupational Safety and Health [OSHA] 1910.120), including training on the flammability and toxicity of refrigerants commonly used on base and safe work practices and handling of refrigerants, especially when working in an enclosed space. Emergency procedures in the event of accidents, spills, and exposure involving refrigerants should be provided during training.

A4.5. Refrigerant Health and Safety Issues. There are many health and safety issues associated with both the new, alternative non-CFC refrigerants and HCFC refrigerants. The following section addresses several of these issues.

A4.5.1. **Physical Properties of Refrigerants.** Table A4.1 provides an overview of the refrigerants used in AC/R applications, including the type and designation number, chemical formula, boiling point, TLV, 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. Table A4.2, from ASHRAE 15-2007, provides the weight per unit volume of various refrigerants to determine the volume of mechanical ventilation required and where to set an oxygen sensor for chemicals that do not have a TLV/TWA. Table A4.2, item c (alternatives), indicates the oxygen level settings. Table A4.2 also shows the amount of refrigerant in a given space that, when exceeded, requires a machinery room**.** Ventilation for the machinery room is addressed in ASHRAE 15-2007, Section 8.11.5.

A4.5.1.1. Refrigerants which are CFC, HCFC, and HFC compounds have been identified in the “Refrigerant” column of Table A4.1 and Table A4.2 by replacing the "R" designation with the appropriate compound designation. In Table A4.1, the boiling point is the temperature at which the refrigerant will boil off as a gas at atmospheric pressure.

A4.5.1.2. The various refrigerant concentration levels at which an individual can be safely exposed are usually time-dependent. In Table A4.1, these levels are indicated by the TLV, STEL, and IDLH columns, and are expressed in ppm.

A4.5.1.2.1. The compound TLVs are established by the ACGIH. TLVs are the maximum chemical vapor concentration in the air to which workers can be exposed daily (eight-hour work days and a 40-hour work week during a working lifetime) without adverse effects. Several years can elapse before the TLVs for a new chemical are established.

A4.5.1.2.2. The compound allowable/acceptable exposure limit (AEL) is determined by the manufacturer of a chemical or substance. It is listed in the MSDS for the substance for guidance on personnel exposure. This value is typically used until ACGIH can establish TLVs. Often the AEL and TLV are equal and used interchangeably.

A4.5.1.2.3. The STEL is defined by ACGIH as a 15-minute 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 be at least 60 minutes between successive exposures at the STEL. STEL represents the concentration to which workers can be exposed continuously for a short period 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 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.

A4.5.1.2.4. 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 dropping below 19.5 percent. 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.

A4.5.2. **Refrigerant Exposure.** Refrigerants handled in accordance with the manufacturer's recommended exposure limits pose no acute or chronic inhalation toxicity hazard. However, certain precautions should be taken, as shown in Tables A4.1 and A4.2.

Table A4.1. Physical Properties of Refrigerants.

Refrigerant	**Name**	**Chemical Formula**	**Boiling Point °C/°F**	**TLV (ppm)****	**STEL (ppm)**	**IDLH (ppm)**
Group A1	This grouping signifies least toxic and least flammable					
CFC-11	Trichlorofluoromethane	CCl_3F	23.9/75	1,000	--	10,000
CFC-12	Dichlorodifluoromethane	CCl_2F_2	-30/-22	1,000	--	50,000
CFC-13	Chlorotrifluoromethane	$CClF_3$	-82/-115	--	--	50,000
R-13B1	Bromotrifluoromethane	$CBrF_3$	-57.8/-72	1,000	--	--
R-14	Tetrafluoromethane (carbon tetrafluoride)	CF_4	-128/-198	--	--	--
HCFC-22	Chlorodifluoromethane	$CHClF_2$	-40.6/-41	1,000	1,250	--
CFC-113	Trichlorotrifluoroethane	CCl_2FCClF_2	47.8/118	1,000	1,250	4,500
CFC-114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	3.3/38	1,000	--	50,000
CFC-115	Chloropentafluoroethane	$CClF_2CF_3$	-38.9/-38	1,000	--	--
HFC-134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3	-26/-15.2	--	--	--
R-C318	Octafluorocyclobutane	C_4F_8	-6/21.2	--	--	--
CFC-400	R-12 and R-114	$CCl_2F_2/C_2Cl_2F_4$	Boiling point changes with pressure	1,000	--	50,000
HCFC-401a	R-22/R-152a/R-124 (53%/13%/34% by wt)	$CHClF_2/CH_3CHF_2/$ $CHClFCF_3$	-32.8/-27	--	--	--
HCFC-401b	R-22/R-152a/R-124 (61%/11%/28% by wt)	$CHClF_2/CH_3CHF_2/$ $CHClFCF_3$	-35/-30.5	--	--	--
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	--	--	--
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	--	--	--
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	--	--	--
CFC-500	R-12/152a (73.8%/26.2% by wt)	CCl_2F_2/CH_3CHF_3	-33.3/-28	1,000	--	--
CFC-502	R-22/115 (48.8%/51.2% by wt)	$CHClF_2/CClF_2CF_3$	-45/-49.7	1,000	--	--
CFC-503	R-23/13 (40.1%/59.9% by wt)	$CHF_3/CClF_3$	-88/-126	--	--	--

Refrigerant	**Name**	**Chemical Formula**	**Boiling Point °C/°F**	**TLV (ppm)****	**STEL (ppm)**	**IDLH (ppm)**
HFC-507	R-125/R-143a (50%/50% by wt)	CHF_2CF_3/CH_3CF_3	-46.7/-52	--	--	--
R-718	Water	H_2O	100/212	--	--	--
R-744	Carbon Dioxide	CO_2	-78/-109	5,000	30,000	50,000
Group A2	This grouping signifies least toxic but more flammable					
CFC-142b	1-Chloro-1,1,-Difluoroethane	CH_3CClF_2	-10/14	--	--	--
HFC-152a	1,1-Difluoroethane	CH_3CHF_2	-25/-13	--	--	--
Group A3	This group signifies least toxic but most flammable					
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)	$CH(CH_3)_3$	-11.7/11	--	--	--
R-1150	Ethene (Ethylene)	C_2H_4	-104/-155	--	--	--
R-1270	Propene (Propylene)	C_3H_6	-47.8/-54	--	--	--
Group B1	This grouping signifies more toxicity but least flammable					
HCFC-123	2,2-Dichloro-1,1,1-Tri-fluoroethane	$CHCl_2CF_3$	27.6/81.7	--	--	--
R-764	Sulfur Dioxide	SO_2	-10/14	2	5	100
Group B2	This grouping signifies most toxic but more flammable					
R40	Chloromethane (Methyl chloride)	CH_3Cl	-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
mple asphyxiant						
Vorkplace environmental exposure limit as defined by ACGIH						

Table A4.2. Refrigerant[a] and Amounts[b,c].

Refrigerant	**Chemical Name**	**Chemical Formula**	**Quantity of Refrigerant per Occupied Space**		
			lb per 1000 ft^3 [a,d]	**ppm by volume**	**g/m^3 [a,d]**
Group A1	This grouping signifies least toxic and least flammable				
R-11	Trichlorofluoromethane	CCl_3F	1.6	4,000	25
R-12	Dichlorodifluoromethane	CCl_2F_2	12	40,000	200
R-13	Chlorotrifluoromethane	$CClF_3$	18	67,000	290
R-13B1	Bromotrifluoromethane	$CBrF_3$	22	57,000	350
R-14	Tetrafluoromethane (Carbon tetrafluoride)	CF_4	15	67,000	240
R-22	Chlorodifluoromethane	$CHClF_2$	9.4	42,000	150

Refrigerant	Chemical Name	Chemical Formula	Quantity of Refrigerant per Occupied Space		
			lb per 1000 ft^3 [a,d]	**ppm by volume**	**g/m^3 [a,d]**
R-113	Trichlorotrifluoroethane	CCl_2FCClF_2	1.9	4,000	31
R-114	Dichlorotetrafluoroethane	$CClF_2CClF_2$	9.4	21,000	150
R-115	Chloropentafluoroethane	$CClF_2CF_3$	27	67,000	430
R-134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3	16	60,000	250
R-C318	Octafluorocyclobutane	C_4F_8	35	67,000	550
R-400	R-12 and R-114	$CCl_2F_2/C_2Cl_2F_4$	e	e	e
R-401a	Chlorodifluoromethane/ Difluoroethane/ Tetrafluoroethane	HCFC-22/HFC-152a/HCFC-124	6.6	27,000	110
R-407c	Pentafluoroethane/ Tetrafluoroethane/ Difluoromethane	HFC-125/HFC-134a/HFC-32	17	76,000	270
R-417a	Tetrafluoroethane/ Pentafluoroethane/Butane		3.5	13,000	56
R-410a	Pentafluoroethane/ Difluoromethane	HFC-125 HFC-32	25	130,000	390
R-500	R-12/152a (73.8/26.2)	CCl_2F_2/CH_3CHF_2	12	47,000	200
R-502	R-22/115 (48.8/51.2)	$CHClF_2/CClF_2CF_3$	19	65,000	300
R-503	R-23/13 (40.1/59.9)	$CHF_3/CClF_3$	15	67,000	240
R-718	Water	H_2O	f	f	f
R-744	Carbon dioxide	CO_2	5.7	50,000	91
Group A2	This grouping signifies least toxic but more flammable				
R-142b	1-Chloro-1,1,-Difluoroethane	CH_3CClF_2	3.7	14,000	60
R-152a	1,1-Difluoroethane	CH_3CHF_2	1.2	7,000	20
Group A3	This group signifies least toxic but most flammable				
R-170	Ethane	C_2H_6	0.50	6,400	8.0
R-290	Propane	C_3H_8	0.50	4,400	8.0
R-600	Butane	C_4H_{10}	0.51	3,400	8.2
R-600a	2-Methyl propane (Isobutane)	$CH(CH_3)_3$	0.51	3,400	8.2
R-1150	Ethene (Ethylene)	C_2H_4	0.38	5,200	6.0
R-1270	Propene (Propylene)	C_3H_6	0.37	3,400	5.9
Group B1	This grouping signifies more toxicity but least flammable				
R-123	2,2-Dichloro-1,1,1-Trifluoroethane	$CHCl_2CF_3$	0.40	1,000	6.3
R-764	Sulfur dioxide	SO_2	0.016	100	0.26
Group B2	This grouping signifies most toxic but more flammable				
R-40	Chloromethane (Methyl chloride)	CH_3Cl	1.3	10,000	21
R-611	Methyl formate	$HCOOCH_3$	0.78	5,000	12
R-717	Ammonia	NH_3	0.022	500	0.35

Alternative

a The refrigerant data and safety classifications shown are from Table 1, ASHRAE 34-2010, *Designation and Classification of Refrigerants.*

b To be used only in conjunction with Section 7, ASHRAE 34-2010.

Refrigerant	Chemical Name	Chemical Formula	Quantity of Refrigerant per Occupied Space		
			lb per 1000 ft^3 [a,d]	ppm by volume	g/m^3 [a,d]

c The basis of the table quantities is a single event where a complete discharge of any refrigerant system into the occupied space occurs. The quantity of refrigerant is the most restrictive of a minimum oxygen concentration of 19.5% or as follows: Group A1: 80% of the cardiac sensitization level for R-11, R-12, R-13B1, R-22, R-113, R-114, R-134a, R-500, and R-502. 100% of the IDLH (21) for R-744. Others are limited by levels where oxygen deprivation begins to occur. Groups A2, A3: Approximately 20% of LFL. Group B1: 100% of IDLH for R-764 and 100% of the measure consistent with the IDLH for R-123. Groups B2, B3: 100% of IDLH or 20% of LFL, whichever is lower.

d To correct for height, H (ft), above sea level, multiply these values by (1 – 2.42 × 10 – 5 • H). To correct for height, h (m), above sea level, multiply these values by (1 – 7.94 × 10 – 5 • h).

e The quantity of each component shall comply with the limits set in Table 1, ASHRAE 34-2010, for the pure compound, and the total volume % of all components shall be calculated per Appendix A, ASHRAE 34-2010 (not to exceed 67,000 ppm by volume for any refrigerant blend).

f The quantity is unlimited when R-718 (water) is used as the refrigerant.

A4.5.2.1. At room temperature, 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 vapor 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.

A4.5.2.2. 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 attention from an emergency medical response team must be provided if exposure to high concentrations of refrigerants occurs. Do not use 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.

A4.5.2.3. 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. If a large release of vapor occurs, an alarm should sound and purge ventilation should be activated. Notify the emergency response team immediately.

A4.5.2.4. 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 remove refrigerant vapors. Check that air-monitoring equipment has been installed to detect leaks. Ensure the area is clear of vapors before beginning work.

A4.5.2.5. 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.

A4.5.3. **Flammability Precautions.**

A4.5.3.1. Typical AC/R refrigerants are nonflammable and non-explosive. 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.

A4.5.3.2. When storing A2, B2, A3, and B3 refrigerants, the room must meet requirements of the National Fire Protection Association (NFPA) 70, National Electrical Code (NEC), Class I, Division I. Per ASHRAE 15-2007, the total of all Groups A2, B2, A3, and B3 refrigerants other than R-717 (ammonia), shall not exceed 1100 pounds (500 kilograms [kg]) without approval by the authority having jurisdiction.

A4.6. Disposable and Reusable Refrigerant Cylinders. Refrigerants are contained in 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. Specific guidance on the storage and handling of refrigerant cylinders is found in DLAI 4145.25, *Storage and Handling of Liquefied and Gaseous Compressed Gasses and their Full and Empty Cylinders*.

A4.6.1. **Identifying Containers.**

A4.6.1.1. Both disposable and reusable cylinders are painted (or otherwise marked) in a color code system. This code was voluntarily established by refrigerant manufacturers to identify their products. Common refrigerant colors and identification are set out in Figure A4.1.

Figure A4.1. Color Code System.

R-11	orange
R-12	white
R-12/114	light gray
R-13	light blue
R-13b1	pinkish-red
R-22	light green
R-23	light blue-gray
R-113	dark purple
R-114	navy blue
R-123	light blue-gray
R-124	dot green
R-134a	light blue (sky)
R-401a	pinkish-red
R-401b	yellow-brown
R-402a	light brown
R-402b	green-brown
R-403b	light gray
R-404a	orange
R-407c	brown
R-408a	medium purple
R-409a	medium brown
R-410a	rose
R-414b	medium blue
R-416a	yellow-green
R-417a	green
R-500	yellow
R-502	light purple
R-503	blue-green
R-507	aqua blue
R-508b	dark blue
R-717	silver
NH3	silver

A4.6.1.2. 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 that any cylinder be repainted with a different color and used with another refrigerant. Refer to Air-Conditioning, Heating and Refrigerating Institute (AHRI) Guideline N, *2008 Guideline for Assignment of Refrigerant Container Colors*.

A4.6.2. **Container Pressure.** All refrigerant cylinders come equipped with either a pressure-relief valve or relief plug designed to prevent the cylinder from being over-pressurized, either while filling the cylinder with refrigerant or during 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 frangible (rupture) disc style or spring-loaded relief integrated into the valve stem of the cylinder. Never adjust or tamper with the pressure-relief valves.

A4.6.3. Refrigerant Cylinders.

A4.6.3.1. Reusable cylinders meet 49 CFR 178.35, Subpart C, *General Requirements for Specification Cylinders*, and DOT Specification 4BA-300, 49 CFR 178.51, Subpart C, *Specification 4BA welded or brazed steel cylinders*, with a water capacity of 122.7 pounds (55.6 kg). Low-boiling-point, high-vapor-pressure refrigerants such as R-13 and R-503 are supplied in cylinders with DOT Specification 3AA-1800, 49 CFR 178.37, *Specification 3AA and 3AAX seamless steel cylinders*, and DOT Specification 3AA-2015, 49 CFR 178.37, Subpart C, *Specification 3AA and 3AAX seamless steel cylinders*, 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 the gas or liquid phase by selecting the gas or liquid valve. The large, reusable cylinders bear a stamp on the shoulder that 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).

A4.6.3.2. **Disposable Refrigerant Cylinders.** DOT Specification 39, 49 CFR 178.65, requires disposable refrigerant cylinders to be rated for a service pressure of 260 pounds per square inch (psi). Under laboratory tests, one cylinder per thousand 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 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 will 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 per 49 CFR 178.65.) When the cylinder is empty, ensure all pressure is released to 0 psi. The cylinders should be rendered useless for any purpose by breaking off the valve or puncturing the cylinder. After the cylinder has been rendered incapable of containing any compressed gas under pressure, it shall be disposed of as scrap metal.

A4.7. 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 (non-flammable gases), is pertinent to 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-410a, R-407a, R-407c, R-408a, R-409a, R-423a, R-437a, R-417a, R-422a, R-438a, R-500, R-502, and R-507 shipped in cylinders and ton tanks. They require marking and labeling. R-11, R-113, R-114, and R-123 are not DOT-regulated hazardous materials; therefore, DOT labeling and marking requirements do not apply.

A4.7.1. **Labeling.** Each cylinder shall display a DOT diamond (square-on-point) "Nonflammable Gas" label. The 4-inch by 4-inch (102-millimeter by 102-millimeter) green diamond-shaped label may be printed on a tag and securely attached to the cylinder's valve protection cap before shipment. Ton tanks require two DOT nonflammable gas labels, one on each end.

A4.7.2. **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. Markings must be stamped plainly and permanently in any of the following locations on the cylinder:

A4.7.2.1. On shoulders and top heads when they are not less than 0.087 inch (2.2 millimeters) thick.

A4.7.2.2. On a metal plate attached to the top of the cylinder or permanent part thereof; sufficient space must be left on the plate to provide for stamping at least six retest dates; the plate must be at least 0.0625 inch (1.6 millimeters) thick and must be attached by welding or brazing. The brazing rod will melt at a temperature of 593 °C (1100 °F). Welding or brazing must be along all edges of the plate.

A4.7.2.3. On the neck, valve boss, valve protection sleeve, or similar part attached to the top of the cylinder.

A4.7.2.4. On the foot ring permanently attached to the cylinder, provided the water capacity does not exceed 25 pounds (11.3 kg).

A4.7.3. **Precautionary Labels.** Each container shall display a precautionary label prepared in accordance with American National Standards Institute (ANSI) Z400.1/Z129.1-2010, *Hazardous Workplace Chemicals - Hazard Evaluation and Safety Data Sheet and Precautionary Labeling Preparation*, and Compressed Gas Association (CGA) C-7, *Guide to the Preparation of Precautional Labeling and Marking of Compressed Gas Containers*. This label will include:

A4.7.3.1. Product identity;

A4.7.3.2. Antidotes;

A4.7.3.3. Signal word;

A4.7.3.4. Notes to physicians;

A4.7.3.5. Statement of hazards;

A4.7.3.6. Instructions in case of contact or exposure;

A4.7.3.7. Precautionary measures;

A4.7.3.8. Instructions in case of fire, spill, or leak; and

A4.7.3.9. Instructions for container handling and storage.

A4.7.4. **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, and products containing or made with either substance.

A4.8. Transporting Refrigerants. The shipper of recovered refrigerant is responsible for determining if there is any state or local regulations restricting transportation, such as classifying recovered refrigerant and oil mixtures as hazardous waste. The EPA does not classify these materials as hazardous waste.

A4.8.1. **Shipping Papers.** Shipping papers are required whenever refrigerant is transported using public roadways, railroads, and airways. This includes transferring 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 following information (**Note:** For material not regulated by DOT as a hazardous material, the words "Not Regulated by DOT" are recommended, but not required.):

A4.8.1.1. The quantity and type of container used (for example, "2-RETURNABLE CYLINDERS");

A4.8.1.2. The total gross weight of recovered refrigerants;

A4.8.1.3. The shipping name (for example, “Chlorodifluoromethane Mixture”);

A4.8.1.4. The DOT hazard class (for example, "NONFLAMMABLE GAS"); and

A4.8.1.5. The UN identification number (for example, "UN1018").

A4.8.2. **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 (102-millimeter) tag, reading "NONFLAMMABLE GAS," 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 (453 kg) (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 placards. For materials being transported in ton tanks, the placards must also include the appropriate UN four-digit identification number. Affixing the placards to the truck is the responsibility of the motor carrier.

A4.8.3. **DLA ODS Reserve.** All CFC ownership is retained by the government and all excess CFCs are shipped to the DLA (Defense Logistics Agency). The DLA is responsible for managing the DOD ODS Reserve for weapons system support. The material manager of the Reserve is DLA’s Defense Supply Center Richmond (DSCR) and operational support and storage are provided by the co-located Defense Distribution Depot, Richmond, Virginia (DDRV). Contact phone numbers for the ODS Reserve Program Management Office are DSN 695-5203, -5202, -5004 and -3064, or COMM (804) 279-5202, -5203, -5004 and -3064. The email address to contact the ODS Reserve is **dscr.odsreserve@dla.mil.** Additional information about the ODS Reserve can be found at the following website: **http://www.aviation.dla.mil/userweb/aviationengineering/OZONE**/. Also see *Department of Defense Ozone Depleting Substances Turn-in Procedures*.

A4.9. Additional References. An additional reference is provided as a suggested source where more in-depth information can be found: DuPont Booklet No. P-HP, *SUVA® HP Refrigerants - Properties, Uses, Storage, and Handling*.

Attachment 5

REFRIGERANT LEAK DETECTION METHODS AND EQUIPMENT

A5.1. Introduction. The EPA created regulations (40 CFR Part 82 [1993]) in response to the CAAA. There is greater emphasis on reducing refrigerant leak losses. This attachment provides an overview of methods and technologies currently available to help service technicians locate refrigerant leak sources.

A5.2. Background. A large amount of refrigerant used to be lost during normal chiller operation. Fortunately, losses of this kind have been reduced significantly. Presently, high-efficiency purge units on low-pressure chillers lose as little as 0.05 pound (0.02 kg) of refrigerant per pound of air. Older chillers and older purge units experienced losses as high as 7 pounds (3.1 kg) of refrigerant per pound of air. Refrigerant leakage occurs in high-pressure chillers and DX systems. Normally, these losses occur because of mechanical failures in piping systems, pressure vessels, and gasket materials. Refrigeration equipment manufacturers believe that approximately 40 percent of emissions occur during normal operation and from common wear and tear. Leaks are usually found in tubing, flanges, O-rings, and other connections. Gasket and O-ring improvements and better manufacturing techniques have significantly reduced leaks in AC/R equipment. An ongoing program for detecting leaks is the best solution for managing refrigerant losses during normal operations. The program requires equipment knowledge, awareness of available methods, and knowledge of the advantages the equipment and the methods offer.

A5.3. Leak Test Methods: High-Pressure Refrigerants. There are several methods available for leak-testing equipment containing high-pressure refrigerants. These methods depend on the refrigerant charge and the equipment's operational status. The following paragraphs describe these methods.

A5.3.1. **Operating Equipment with Refrigerant Charge.** A positive-pressure refrigerant has sufficient pressure within all components of the system to make most external leaks detectable using leak detectors. Use caution whenever leak-testing equipment is operating; moving and rotating parts present hazards.

A5.3.2. **Idle Equipment with Refrigerant Charge.** A positive-pressure refrigerant can be found using leak detectors if the mechanical room or air pressures are under normal ambient conditions. There is only one method to check for evaporator or condenser tube leaks that use water to transfer heat. The equipment must be isolated from the water piping with the tubes drained and tube sheet access plate removed. Use an eddy current analysis or leak detector (electronic or ultrasonic) to locate leaks.

A5.3.3. Equipment without Refrigerant Charge.

A5.3.3.1. There are situations in which leak-testing needs to take place after all refrigerant is lost. Do not pressurize the system with refrigerant to see if the leaks were repaired. There are also situations where using system refrigerant may be inadequate to detect leaks. The refrigerant charge may have to be evacuated from the entire system or a single component. When leak-testing a system or component where refrigerant has been removed, refer to the guidelines below.

A5.3.3.1.1. Do not use a refrigerant as a tracer gas. If this cannot be avoided, use only HCFC-22 refrigerant; never use another refrigerant. Use only a small quantity of the tracer gas in combination with nitrogen to pressurize the system and inspect for leaks. Never use air or oxygen to pressurize the tracer gas, per EPA Section 608 of the CAA.

A5.3.3.1.2. Use compressed dry nitrogen to pressurize the system. **WARNING: Never use compressed air, oxygen, or a flammable gas to pressurize the system! This could cause an explosion.** Always use a regulator when adding nitrogen to a system. Small amounts of R-22 mixed with nitrogen can be used as tracer gas and then vented. Add nitrogen slowly for better mixing with the tracer gas and prevent sweeping the tracer gas away from the access port. To ensure that the rating of the relief valve is not exceeded, a maximum test pressure of 200 psig is recommended.

A5.3.3.1.3. Whenever possible, isolate and pressure-test only that part of the system that requires testing.

A5.3.3.2. After a system is pressurized with nitrogen, allow it to stand for 12 to 24 hours, if possible, to allow the tracer gas to disperse uniformly throughout the system. Once fully dispersed, use any of the methods described in paragraph A5.7 to identify leaks.

A5.4. Leak Test Methods: Low-Pressure Refrigerants. Leak-testing equipment containing low-pressure refrigerants is more difficult than high-pressure refrigerants. The methods available are discussed in the following paragraphs.

A5.4.1. **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; be aware of moving and rotating parts. Evaporator and condenser tube leaks typically include water leaking into the refrigerant rather than the reverse. This happens because refrigerant pressure is lower compared to chilled and condenser water system pressures.

A5.4.2. **Offline Equipment Testing.** A thorough leak check can be performed on a low-pressure refrigerant system only if the system is not operating. Base maintenance personnel should schedule a maintenance shut-down period of at least 48 hours before a leak test. The test should be timed to negate the test's impact on the facility. A leak check is not a simple process even when the equipment is offline. The refrigerant pressure 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 (117 °F), respectively.

A5.4.2.1. The refrigerant pressure must be increased above atmospheric pressure to detect leaks. Equipment containing refrigerant can no longer be pressurized using a non-condensable 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 create a corresponding pressure increase. Increasing the temperature of CFC-11 to 38 °C (100 °F) will produce system pressure of 9 psig.

A5.4.2.2. There are two pressure equalization system types used to increase refrigerant temperature to achieve the desired pressure: the blanket heater (see paragraph A6.6.1) and the water heater system (see paragraph A6.6.2).

A5.4.2.3. Use caution when heating the refrigerant charge. The pressure cannot exceed the pressure relief valve and/or rupture disk setting, which is normally set at 15 psig. This will allow refrigerant to escape to the atmosphere. Stop adding heat when 8 to 10 psig is reached.

A5.4.2.4. Leak-check all gaskets, fittings, and penetrations using the leak detection equipment or substances described in paragraph A5.7.

A5.4.3. **Idle/Standby Equipment.** A low-pressure system will usually be in a vacuum at typical room or ambient temperature when it is not operating. Any leaks will be due to air and water vapor entering the chiller instead of refrigerant. An integral pressure equalization system, as described in paragraphs A5.4.2.2.1 and A5.4.2.2.2, can be used for refrigeration equipment that operates intermittently, especially if the equipment remains on standby. Use these two methods for either pressure equalization or leak testing. It will control the pressure automatically; its internal pressure is always equal to atmospheric pressure when the chiller is idle. This reduces or eliminates refrigerant loss. Another option involves removing the chiller's refrigerant charge when chillers are idle for long periods. The refrigerant will be stored in a leak-tight tank capable of withstanding a pressure range from 29.8 inches of mercury vacuum to 15 psig. While idle, the chiller should be charged with dry nitrogen to a pressure of 1 to 2 psig to prevent moisture accumulation inside the chiller vessels.

A5.4.4. **Equipment Without Refrigerant Charge.** Two steps are involved in leak-testing a low-pressure chiller without its charge. The first step involves pressurizing the system to pinpoint leaks. Once completed, a vacuum is applied to ensure the equipment does not leak under its normal negative-pressure operating conditions. Follow these two steps:

A5.4.4.1. **Step 1.** Pressurize the chiller to 10 to 13 psig with dry nitrogen and use a soap-and-water solution to check all joints. Leaks will appear when the soap solution bubbles.

A5.4.4.2. **Step 2.** Evacuate the chiller, using a vacuum pump capable of achieving 1000 microns of mercury absolute. Once that level is reached, allow the chiller to stand idle for 12 hours. Some pressure rise from microscopic, unpreventable leaks is acceptable. The Trane Company suggests that if the pressure does not rise above 2500 microns, the unit's condition is acceptable and may be charged with refrigerant. If the vacuum rises above 2500 microns, the unit's condition is unacceptable and further leak-testing is required. Repeat Step 1 and the pull the vacuum again.

A5.4.5. **Spectrographic Oil Analysis.** Routine spectrographic oil analyses will detect moisture inside the refrigerant circuit. Moisture indicates a leak has occurred. This technique will not indicate where the leak is or its severity. Refer to Attachment 7 for detailed information on spectrographic oil analysis. Recommended moisture ceiling values for oil samples are included in Attachment 7.

A5.5. Potential Refrigerant Leak Areas.

A5.5.1. During inspections, leak-check the leak-prone system areas for integrity. These areas include all area penetrations where refrigerant is used and all non-welded connections. Inspect the following areas:

A5.5.1.1. Motor terminals;

A5.5.1.2. Sight glasses;

A5.5.1.3. Shaft seals;

A5.5.1.4. Schrader cores;

A5.5.1.5. Service, solenoid, and relief valves;

A5.5.1.6. Flare fittings;

A5.5.1.7. Gasket joints;

A5.5.1.8. Filter dryers.

A5.5.2. Oil stains on positive-pressure equipment or components indicate leak paths.

A5.6. Leak Detection Equipment Terminology. The following section describes refrigerant sensor and detection terminology comparison criteria: sensitivity, detection limits, and selectivity. These are applicable to portable pinpoint detectors and permanently mounted area monitors.

A5.6.1. Sensitivity.

A5.6.1.1. The device sensitivity is the amount of input needed to change an output signal. For refrigerant sensors, the refrigerant vapor concentration being measured is displayed on a panel meter, a voltage output, or other display. Highly sensitive refrigerant sensors require little material to generate a large change in output signal. Low-sensitivity sensors need large amounts of material to change the output signal. The sensitivity is affected by the detection method and the material under consideration.

A5.6.1.2. An ionization sensor that is highly sensitive to CFC-12 may have little sensitivity for HCFC-123 and even less for HFC-134a. Sensor comparisons for HCFC blends like 410a and 406 can be found in Table A5.1. Reductions in easily ionized and detected chlorine content created from CFC to HCFC to HFC class compounds account for changes in sensor sensitivity. Sensitivity differences ranging from 100x to 1000x were found after comparing CFC-12 to HFC-134a using ionization-based sensors. Infrared-based sensors have roughly the same sensitivity to CFC-12, HCFC-123, and HFC-134a.

A5.6.2. **Detection Limit.** Sensitivity values are well defined but refrigerant sensor sensitivity values do not exist. The most common measure of sensor performance is the detection limit. Detection limit is the minimum amount of material a unit can sense that returns a signal at least two times stronger than the background noise level. A sensitive device does not necessarily have a low-detection limit, but that is usually the case. Area monitoring application detection limits are measured in ppm. Area monitors have detection limits as low as 1 ppm but are typically 3 to 4 ppm for most compounds. A highly sensitive detector may be able to accurately record vapor concentration levels ranging from 1 ppm to 2 ppm while a low-sensitivity detector may record the same vapor using 20 ppm or higher increments. A refrigerant sensor must match the intended application. For example, an ionization detector that boasts a 2-ppm CFC-12 detection limit will not work as well when detecting HFC-134a. Conversely, an ionization detector designed specifically for HFC-134a may be too sensitive to monitor CFC-12.

A5.6.3. Selectivity.

A5.6.3.1. Selectivity is the ability to detect only one refrigerant of interest without interference from other compounds. Area monitoring selectivity requirements vary with specific installations. This is an important issue because monitors must work continuously and they become exposed to refrigerants with potentially more interference in a wider concentration range over a long period.

A5.6.3.2. Area monitors require selectivity if other refrigerants present have vastly different TLV. ASHRAE Standard 15-2007 requires that an alarm activate the mechanical ventilation system when a value not exceeding the TLV-TWA is reached. A TLV is the maximum chemical vapor air concentration workers can chronically be exposed to (defined as an 8-hour work day making up a 40-hour work week) without suffering adverse health effects during their career. TWA is the time-weighted average for the TLV. Workers can be exposed to concentrations greater than the TLV, but the average exposure during a day will not exceed the average exposure level. These values were created by the ACGIH. A monitor's selectivity feature allows the alarm to activate for a specific chemical and identify it. This helps maintenance technicians determine worker exposure.

A5.7. Leak Detection Sensors and Fluorescent Dyes. There are several methods available to pinpoint refrigerant leaks, ranging from simple fluorescent dyes to more complex electronic detectors. Electronic detection sensors belong in one of three categories using selectivity criteria: (1) nonselective; (2) halogen-selective; and (3) compound-specific.

A5.7.1. **Nonselective Sensors.** These equipment sensors can detect any emission or vapor present, regardless of its chemical composition. Detectors in this category are based on electrical ionization, thermal conductivity, ultrasonic, or metal-oxide semiconductors. These detectors are simple to use, very rugged, and typically inexpensive. Nonselective sensors excel at pinpointing leaks.

A5.7.2. **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 chemicals. These sensors reduce the number of false alarms generated by non-refrigerant compounds such as paint or gas fumes. These very durable detectors are easy to use and have a higher sensitivity than nonselective detectors (detection limits are typically < 5 ppm). The detector's partial specificity makes calibration easy.

A5.7.3. **Compound-Specific Sensors.** Compound-specific sensors are complex and expensive. They can detect a single compound variety without suffering interference from other compounds. Compound-specific sensors are IR-based. Newer types use IR-PAS technology. They have detection limits around 1 ppm, depending upon the compound detected. Although compound-specific sensors are more expensive, technological improvements have reduced prices, but expect to pay between $3,500 to $4,000 for a compound-specific detector.

A5.7.4. **Fluorescent Dyes.** Fluorescent dyes are used in refrigeration systems to detect leaks that are invisible under ordinary lighting but visible under ultraviolet (UV) light. Fluorescent dyes are available for all refrigerants in use today. The dyes are placed in 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 recommendations 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 visible bright green or yellow. Fluorescent dyes work very well because large areas can be rapidly checked by a single individual.

A5.7.5. **Comparing Sensors and Fluorescent Dyes.** Table A5.1 provides considerations when comparing sensors and fluorescent dyes for selecting leak detection options.

Table A5.1. Comparison of Refrigerant Sensors and Fluorescent Dyes.

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
Disadvantages	Poor detection limits Cross-sensitive to other varieties 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

A5.8. Additional References. Additional references are provided as suggested sources where more in-depth information can be found: *Modern Refrigeration and Air Conditioning* (Althouse, Turnquist); DuPont #ARTD27, *Leak Detection for Alternative Refrigerants.*

Attachment 6

EQUIPMENT TO REDUCE REFRIGERANT RELEASE DURING MAINTENANCE AND OPERATION OF AIR-CONDITIONING AND REFRIGERATION SYSTEMS

A6.1. Introduction. The EPA requires AC/R equipment owners and maintenance technicians to engage in practices that reduce refrigerant loss. This attachment discusses equipment that can be added to or used to service AC/R equipment to meet these requirements, explains EPA equipment performance requirements, and addresses EPA requirements for reusing refrigerant removed from AC/R equipment.

A6.2. Recovery and Recycling Equipment. Recovery equipment must meet certain evacuation standards to reduce refrigerant losses when a service call requires opening the refrigeration system. The EPA is grandfathering equipment manufactured or imported before 15 November 1993, as long as it meets the evacuation requirements listed in Table A6.1. 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. The EPA is requiring performance verification for vapor recovery and non-condensable purge devices on recycling machines. All certified recycling and recovery equipment must have a manufacturer's or importer's label that indicates it was certified and who certified it (see Attachment 2).

Table A6.1. Required Levels of Evacuation for Appliances Except for Small Appliances, MVACS, and MVAC-Like Appliances.

Type of Appliance	**Inches of Hg Vacuum (relative to standard atmospheric pressure of 29.9 inches Hg)**	
	Using recovery or recycling equipment manufactured or imported before November 15, 1993	**Using recovery or recycling equipment manufactured or imported on or after November 15, 1993**
Very high-pressure appliance	0	0
High-pressure appliance, or isolated component of such appliance normally containing 200 pounds of refrigerant	0	0
High-pressure appliance, or isolated component of such appliance normally containing 200 pounds or more of refrigerant	4	10
Medium-pressure appliance or isolated component of such appliance normally containing less than 200 pounds of refrigerant	4	10
Medium-pressure appliance, or isolated component of such appliance normally containing 200 pounds or more of refrigerant	4	15

Type of Appliance	**Inches of Hg Vacuum (relative to standard atmospheric pressure of 29.9 inches Hg)**	
	Using recovery or recycling equipment manufactured or imported before November 15, 1993	**Using recovery or recycling equipment manufactured or imported on or after November 15, 1993**
Low-pressure appliance	25	25 mm Hg absolute

A6.2.1. **Evaluation Criteria.** Many manufacturers offer a variety of recovery equipment. When selecting equipment, consider the following:

A6.2.1.1. Safety. Look for high-pressure, low-pressure, and high-temperature sensors for system safety shutdowns or lockouts.

A6.2.1.2. Underwriters Laboratory (UL) approval.

A6.2.1.3. Job function versatility.

A6.2.1.4. Cylinder or tank capacity of the container that holds the refrigerant during servicing.

A6.2.1.5. The recovery rate (one hour maximum).

A6.2.1.6. Filter replacement prices.

A6.2.1.7. Tanks: proprietary or non-proprietary.

A6.2.1.8. Fitting designed for low-loss.

A6.3. Recovery, Recycling, and Reclaiming Definitions. Removing refrigerant from a refrigeration system is known as recovery. When equipment operation shows signs of contamination or refrigerant deficiency, refrigerant can be recovered and recycled on base. If severe contamination occurs 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 so contaminated that distillation is ineffective, it must be disposed of at an authorized treatment facility.

A6.3.1. **Recovery.** Recovery involves removing refrigerant, regardless of its condition, from a refrigeration system either actively or passively. It is later stored in an external container. Recovery is mandatory if the system is opened to the atmosphere. If an equipment component that requires service is isolated, only the isolated equipment section needs to be evacuated. Internal refrigerant storage should become the standard.

A6.3.2. **Recycling.** Recycling reduces refrigerant contaminants by separating it from the oil with single and multiple passes through devices such as replaceable filter core driers. These devices reduce moisture, acidity, and particulate matter. Recycling can be useful for drying refrigerants that contain moisture instead of water or for removing particulate matter.

A6.3.3. **Reclamation.** Reclamation purifies, tests, and certifies used refrigerant to new product specifications using distillation or other methods. Refrigerant chemical analysis is required to assure that appropriate product specifications are met. Refrigerant reclamation from a system undergoing repairs is not required in most cases. Reclamation is required if, for example, free water stands in the system due to a tube failure or because a motor burned out. Recovered refrigerants from the equipment must be reclaimed if ownership is transferred. Bases are not considered owners in this context. The Air Force is considered a single owner so reclamation is not necessary given inter-base transfers. If reclamation is required (e.g., to salvage phased-out CFC), it must be accomplished by a vendor under contract with the Air Force.

A6.4. Low-Loss Fittings. In 40 CFR Part 82, the EPA defines a low-loss fitting as any device meant to establish a connection between hoses, AC/R equipment, and recovery/recycling machines. They are designed to close automatically or manually after being disconnected to reduce refrigerant loss from hoses, AC/R equipment, and recovery/recycling machines. The EPA requires that recovery or recycling machines manufactured or imported after 15 November 1993 have low-loss fittings. Low-loss fittings should be added to refrigeration equipment connection points and service equipment hoses.

A6.5. High-Efficiency Purge Units. Purge units are used with low-pressure chillers and refrigerant recovery equipment to remove non-condensable material that entered the system. All low-pressure chillers (R-11 or R-123) should have high-efficiency purges either by retrofit or when they are purchased. All new low-pressure chillers include a high-efficiency purge as standard equipment. Traditional purge unit designs could expel large amounts of refrigerant. High-efficiency purge units allow non-condensable material to be vented while leaking very little refrigerant. There are two high-efficiency levels: (1) discharges of approximately 0.7 to 1 pound of refrigerant per pound of non-condensable material and (2) an ultra-high-efficiency discharge of 0.0005 pound of refrigerant per pound of non-condensable material. Most low-pressure chillers are equipped with ultra-high-efficiency purge units. Given information about runtime and the refrigerant amount lost per unit of non-condensable matter during purges, maintenance technicians can determine the amount of runtime that would result in refrigerant losses that exceed EPA limits. Choose a purge unit with a safety system to prevent excessive purging resulting from malfunctions or large leaks. These safety systems limit the time that a purge unit operates so a control malfunction will not cause a complete refrigerant purge.

A6.5.1. **Low-Pressure Chiller Purge Units.** The EPA has not established any requirements for chiller purge units. However, the Air Force replaces older purge units with new, high-efficiency purge units equipped with runtime meters.

A6.5.2. **Recycling Equipment Purge Units.** The EPA’s maximum purge-loss limit for recycling equipment purge units is 3 percent of the total refrigerant being recycled.

A6.5.3. **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. Servicing should be performed according to 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 whenever a new high-efficiency unit is introduced.

A6.6. 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 discharge refrigerants and non-condensable materials more often. Installing a pressurization system can solve this problem. There are two types of systems: blanket heater and water heater/pump. Both operate on the principle of increasing system pressure through heat added to the refrigerant.

A6.6.1. **Blanket Heater.** The most common pressurization system is an electric-resistant blanket heater installed between the evaporator’s outer shell and its insulation jacket. Because it is mounted on the underside of the shell, it is commonly known as a 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 level. The blanket heater can also be used to raise the system pressure above atmospheric pressure to allow leak testing. Typically, temperature or pressure sensors monitor the condenser conditions and control the blanket heater. To prevent system over-pressurization and refrigerant loss, temperature and pressure sensors should be checked before energizing the blanket heater.

A6.6.2. **Water Heater/Pump.** The second system type uses a small electric water heater and circulating pump package. It heats and circulates water through the evaporator tubes to raise the refrigerant temperature. This raises the system pressure. Before beginning the heating process, isolate the evaporator from the distribution piping system. The heat added to the water is typically controlled by monitoring the water temperature once it has left the evaporator. To prevent system over-pressurization and any resulting refrigerant loss, the temperature sensor should be checked before starting the water heater/pump system.

A6.7. Re-use of Recovered Refrigerants. The EPA allows refrigerant remaining onsite to be returned to the AC/R equipment or transferred between equipment owned by the Air Force with or without being recycled or reclaimed.

A6.8. Additional References. Additional references are provided as suggested sources where more in-depth information can be found: AHRI 740-2006, *Refrigerant Recovery/Recycling Equipment*; 40 CFR Part 82, Subpart F, *Recycling and Emissions Reduction*.

Attachment 7

REFRIGERANT LEAK MITIGATION THROUGH EQUIPMENT MAINTENANCE AND SERVICE PRACTICES

A7.1. Background. Refrigeration service and maintenance practices commonly used in the past resulted in the routine release of significant amounts of refrigerant to the atmosphere. In response, the EPA issued new regulations in response to CAAA, Title 6, which are designed to minimize the refrigerant loss. These laws and regulations have serious implications for AC/R owners, operators, and maintenance personnel. Given these implications, persons servicing AC/R equipment must adhere to 40 CFR 82.156, *Required practices*, to minimize refrigerant losses.

A7.1.1. **Technician Training.** Training chiller operators and maintenance and service personnel is the first line of defense against refrigerant loss. Service and maintenance personnel should be familiar with refrigerant emission-reduction procedures, safety equipment uses, and techniques for proper refrigerant handling.

A7.1.2. Technician Certification.

A7.1.2.1. Any person who performs maintenance, service, or repair to AC/R equipment must be a certified technician unless they are serving as an apprentice in an approved program under the supervision of a certified technician.

A7.1.2.2. The EPA requires all individuals who maintain, install, service, or repair AC/R equipment to be certified. It has created four technician certification categories based on the ability to handle and service refrigerants and any applicable equipment. Three categories are for specific equipment types and the fourth is a universal category. Technicians must be certified by an EPA-approved organization. For more information, see Chapter 2 and Attachment 2.

A7.2. Minimizing Maintenance and Service Emissions. A lot of refrigerant has been lost due to inefficient methods for maintaining and servicing equipment. Routine operating logs (which are required by the EPA for equipment containing 50 pounds or more of refrigerant charge) should be kept so that the operator or technician knows how much refrigerant and oil are used. At a minimum, any equipment requiring daily attention should have maintenance logs of basic operating parameters completed during shift intervals. Use the RMS to collect and organize maintenance and operating data for all refrigeration systems. The RMS Refrigerant Service Report can assist base maintenance personnel to identify adverse trends and predict future refrigerant needs.

A7.2.1. Service Practices.

A7.2.1.1. Current service practices revolve around containing refrigerant within the system. Service practices that keep refrigerants isolated from the environment to the greatest extent possible are now required. In addition, certain service practices are prohibited by the EPA, including the following:

A7.2.1.1.1. Knowingly venting refrigerants during the maintaining, servicing, repairing, or disposing of AC/R equipment. This is extended to HFCs included by the EPA.

A7.2.1.1.2. Opening refrigerant drums to the atmosphere.

A7.2.1.1.3. Using refrigerants as cleaning solvents.

A7.2.1.1.4. Leak-testing with nitrogen when the system contains a refrigerant charge.

A7.2.1.1.5. Running systems in under-charged or over-charged modes.

A7.2.1.1.6. Changing oil filters at intervals more frequently than required by manufacturers' recommendations or as indicated by spectrographic oil analyses.

A7.2.1.2. The EPA requires low-pressure systems undergoing minor servicing, such as oil changes, to be pressurized to atmospheric pressure to minimize air intrusion and the need to purge it later. Methods that do not require system purging (e.g., heat) must be used.

A7.2.1.3. Purge runtime should be monitored. Many manufacturers suggest that purge systems operating in excess of one hour of runtime per week indicate excessive loss.

A7.2.1.4. For proper operation, purge systems require regular maintenance and service: purge tanks and oil separators must be cleaned; gasket material must be renewed; purge compressors must be overhauled. These tasks must be performed with little or no refrigerant loss by installing permanent access and isolation valves that guarantee minimal losses. Such valves should be installed the next time the machine is serviced. When servicing the purge unit, the liquid and vapor refrigerant must be evacuated before opening the unit to the atmosphere.

A7.2.1.5. Specified high-efficiency purge units should be installed on older chillers. The purge units should be standard equipment on new replacement chillers. Some high-efficiency purge units 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 Attachment 6, paragraph A6.5, for more information on purge units and maximum purge-loss limits.

A7.2.1.6. Oil should not be changed arbitrarily; instead, oil samples should be checked for contamination on a regular, scheduled basis. The result may indicate the need for an oil and filter change. These tasks must be completed with minimal refrigerant loss. An oil sample port and isolation valves should be installed around the filter when the unit is first serviced.

A7.2.1.7. Isolate equipment subcomponents for service and repair by installing isolation valves. Replace missing system connections and refrigerant cylinder caps. Check the seal’s condition. Personnel using Schrader core replacement can replace a leaking Schrader core without opening the system or isolating the refrigerant charge.

A7.2.1.8. The refrigeration gauge sets should be rebuilt, if necessary, with new seals, valve seats, and packing to reduce refrigerant losses. Additional features that reduce refrigerant loss include:

A7.2.1.8.1. Quick-connect hose fittings.

A7.2.1.8.2. Four-valve manifolds to reduce hose and manifold refrigerant purging amounts.

A7.2.1.8.3. Quality, high-strength hoses to prevent ruptures.

A7.2.1.8.4. Separate refrigeration gauge sets for each refrigerant that will prevent cross-contamination.

A7.2.1.9. Equipment service requiring refrigerant charge removal can be completed with either an active pump-out or a passive pump-down method.

A7.2.1.9.1. The pump-out method is used for system refrigerant removal. It involves using a self-contained recovery unit that is often referred to as a recovery/recycling machine. These machines are capable of both liquid and vapor removal. Remove as much of the refrigerant in its liquid form as possible. This equipment removes liquid at a much higher rate than vapor. The vapor charge must be removed using the recovery/recycle unit. The system or isolated section must be evacuated to the level shown in Table A6.1. A higher ambient temperature decreases recovery time because of increased system internal vapor pressures.

A7.2.1.9.2. The pump-down process uses the refrigeration system's compressor to remove the refrigerant from a component and move it to an integral receiver or another system component where it is stored during maintenance. The isolated section must be evacuated to the level shown in Table A6.1.

A7.2.1.10. All preventative maintenance work plans should be modified to include leak-checks of leak-prone system areas. The following items should be checked regularly:

A7.2.1.10.1. Flanges and gaskets.

A7.2.1.10.2. Connections with screwed piping.

A7.2.1.10.3. Compressor seals.

A7.2.1.10.4. O-rings.

A7.2.1.10.5. Valves and cylinders.

A7.2.1.10.6. Valves with missing caps.

A7.2.1.10.7. Purge systems.

A7.2.1.10.8. Receivers.

A7.2.1.10.9. Flare fittings.

A7.2.1.10.10. Schrader cores.

A7.2.1.10.11. Sight glasses.

A7.2.1.11. Before opening a system, certified technicians should clearly understand the type of service work required. Previous service records obtained from the RMS or operating logs can provide equipment background. This information can be used to develop a work plan that ensures refrigerant losses are minimal and identifies areas to check for possible leaks.

A7.3. Spectrographic Oil Analysis. Laboratory analysis of chiller oil is a method of analyzing the mechanical condition of equipment and pinpoints locations when tear-down and visual inspections are required. A spectrographic oil analysis is inexpensive and typically has a quick turn-around time. Each analysis costs approximately $150. An analysis should be performed for comfort cooling applications twice a year or for every 2,000 to 2,500 hours of operation. Before obtaining an oil sample for analysis, a chiller must operate for at least one hour; otherwise, any metals in the oil will not have enough time to be re-entrained from the machine bottom and will go undetected during analysis. With complete and accurate laboratory oil analysis testing recommendation actions will become more reliable.

A7.3.1. **Particulate Evaluation.** The oil filter is an important source of information. Technicians can spot debris trapped on the filter material, remove it, and send it to the spectrographic oil analysis laboratory to identify the sediments and further evaluate the system's condition. This evaluation can be just as important as testing the liquid oil sample. When laboratory analysis of chiller oil is required, select a qualified laboratory that can perform a full range of tests.

A7.3.2. Analysis Readings.

A7.3.2.1. Chiller oil laboratory analyses should include the following information:

A7.3.2.1.1. Water suspension.

A7.3.2.1.2. Acid level.

A7.3.2.1.3. Metal content by source.

A7.3.2.1.4. Viscosity.

A7.3.2.1.5. Total acid number (TAN).

A7.3.2.1.6. Dielectric strength.

A7.3.2.1.7. Color.

A7.3.2.1.8. Interfacial tension.

A7.3.2.1.9. Equipment condition assessment.

A7.3.2.2. The amount of water suspended in a lubricant is measured in ppm. Sample chiller oil water content should not exceed 40 ppm in reciprocating systems or 50 ppm in centrifugal and rotary screw systems.

A7.3.2.3. The viscosity, reported in centistoke (cSt) at 40 °C (104 °F)**,** measures a fluid's internal resistance to flow at a given temperature in relation to time. Changes in viscosity can indicate dilution, oxidation, improper servicing, or lubricant break-down. Viscosity increases are normally a result of lubricant oxidation and degradation or contamination with higher-grade oil. Viscosity decreases are almost always a result of contamination, either with fuel (in the case of engine oils) or product (in the case of industrial oils). The viscosity index is a calculated number that indicates the rate of viscosity change as the lubricant is heated. The less the viscosity change, the higher the viscosity index number. The lubricant's viscosity is determined at two different temperatures, usually 40 °C (104 °F) and 100 °C (212 °F), and using an American Petroleum Institute (API) formula, the viscosity index is calculated. Viscosity indexes of 95 to 105 are normal for most industrial mineral oils.

A7.3.2.4. The TAN indicates how much of a lubricant's acidic product is present. Generally, increase in TAN greater than that of a new product indicates oil oxidation or acidic product contamination. Total acid should not exceed 0.150 milligram (mg) KOH (potassium hydroxide) per gram.

A7.3.2.5. Dielectric strength measures a fluid's insulating ability. A low value can indicate water or other conducting compounds.

A7.3.2.6. A fluid's color can indicate contaminants and system operating conditions.

A7.3.2.7. The interfacial tension analysis indicates whether compounds with a strong affinity for water are present.

A7.3.3. **Analysis of Metal Content.**

A7.3.3.1. Chiller oil spectrographic analysis shows the oil's metal content and should indicate the possible source of the metal. Elements typically discovered during analyses and available sources are listed in Table A7.1.

Table A7.1. Elements and Sources.

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

A7.3.3.2. Oil analysis results should be included in the maintenance history. In many cases, rapid changes in values may indicate more problems than the value's magnitude at any given point in time. In fact, the real strength of spectrographic analysis is the ability to spot excessive wear rates indicated by rapidly increasing concentrations of the elements listed in Table A7.1 relative to the number of operating hours between samples. To properly spot these trends, the analytical laboratory performing the tests must have historical test data.

A7.3.4. **Disposing of Contaminated Oil.**

A7.3.4.1. Federal, state, and local regulations must be observed when disposing of contaminated oil. Per 40 CFR Part 261, Subpart A, Section 261.3, *Definition of hazardous waste*, used refrigerant oils are not classified as hazardous waste if the following conditions are met:

A7.3.4.1.1. The used refrigeration oils are not mixed with other hazardous waste.

A7.3.4.1.2. The used refrigeration oils will be recycled or reclaimed for future use.

A7.3.4.1.3. The used refrigeration oils are not mixed with used oils from other sources.

A7.3.4.1.4. The 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 CFR Part 261, Subpart A, Section 261.24, *Toxicity characteristic*.

A7.3.4.2. Those who dispose of contaminated refrigerant oil must determine whether the material should be classified as hazardous waste per paragraph A7.3.4.1. Local and state codes may be even more stringent than federal regulations; therefore, the base environmental office should be consulted before disposing of any potentially hazardous waste.

A7.3.4.3. When oil analysis indicates that the refrigerant oil should be replaced, avoid an atmospheric release of the refrigerant which may be present in the oil solution. This can be achieved by pumping the oil into a sealed and 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 be returned to the refrigeration system or placed in proper storage containers. Under no circumstances should refrigerant oil be pumped into a vented container. This will allow an uncontrolled loss of refrigerant into the atmosphere.

A7.4. Chiller Tube Testing.

A7.4.1. **Chiller Tube Testing Program.** A vital element of a successful preventive maintenance program that minimizes emissions is a regularly scheduled chiller tube-testing program. It ensures tube integrity and efficiency and can provide early warnings.

A7.4.2. **Eddy Current Tube-Testing.** Eddy current tube testing 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. It can prevent unscheduled chiller downtime, lost production, lost cooling, major chiller damage, and refrigerant charge contamination. Refrigerant contaminated with water in-leakage requires reclamation. To protect the refrigerant charge, a chiller requires eddy current tube-testing at least once every three years. This analysis, when 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.

A7.5. Additional EPA Requirements. The EPA requires equipment service and refrigerant usage records to be maintained for three to five years, depending upon the EPA tier level. This applies to all comfort cooling and refrigeration equipment with an operating charge of 50 pounds or more.

A7.5.1. **Refrigerant Management System (RMS).** The RMS will provide equipment refrigerant usage and servicing history as required by the EPA. The RMS will also track refrigerant inventory and consumption as required by the BRMP. Information about using the RMS can be found in the *Refrigerant Management System User's Guide*.

A7.5.2. **Repairing Leaks.** Commercial and industrial process refrigeration equipment with 50 pounds or more of refrigerant (for example, cold storage plants) must have all leaks repaired within 30 days if the equipment is leaking at a rate that exceeds 35 percent of the total charge during a 12-month period. Other equipment, including comfort cooling and all other appliances containing 50 or more pounds of refrigerant, must have all leaks repaired within 30 days if the unit leaks at a rate exceeding 15 percent of the total charge, prorated over a 12-month period. Equipment does not require repair if, within 30 days after leak identification (as described above), a plan is developed for retiring the equipment within one year. A copy of the plan must be available at the equipment site and submitted to the EPA. Leaking equipment repaired under this plan must have an initial and follow-up verification test at the conclusion of any repair efforts. Some state or local regulations, codes, and ordinances may impose more stringent requirements than EPA regulations. Before engaging in major leak repairs, evaluate the condition and age of the equipment to determine whether it is more cost-effective than replacing the equipment. Include in the evaluation the potential increase in energy savings from installing new equipment. 40 CFR Part 82, Subpart F, Section 82.152, and 40 CFR Part 82, Subpart F, Section 82.156, call for verification tests within 30 days of normal operation to confirm that the leak has been fixed.

A7.6. Additional References. An additional reference is provided as a suggested source on leak detection where more in-depth information can be found: DuPont #ARTD-27 (H-31753-2), *Leak Detection for Alternative Refrigerants.*

Attachment 8

APPLICATION OF ASHRAE EQUIPMENT ROOM DESIGN REQUIREMENTS

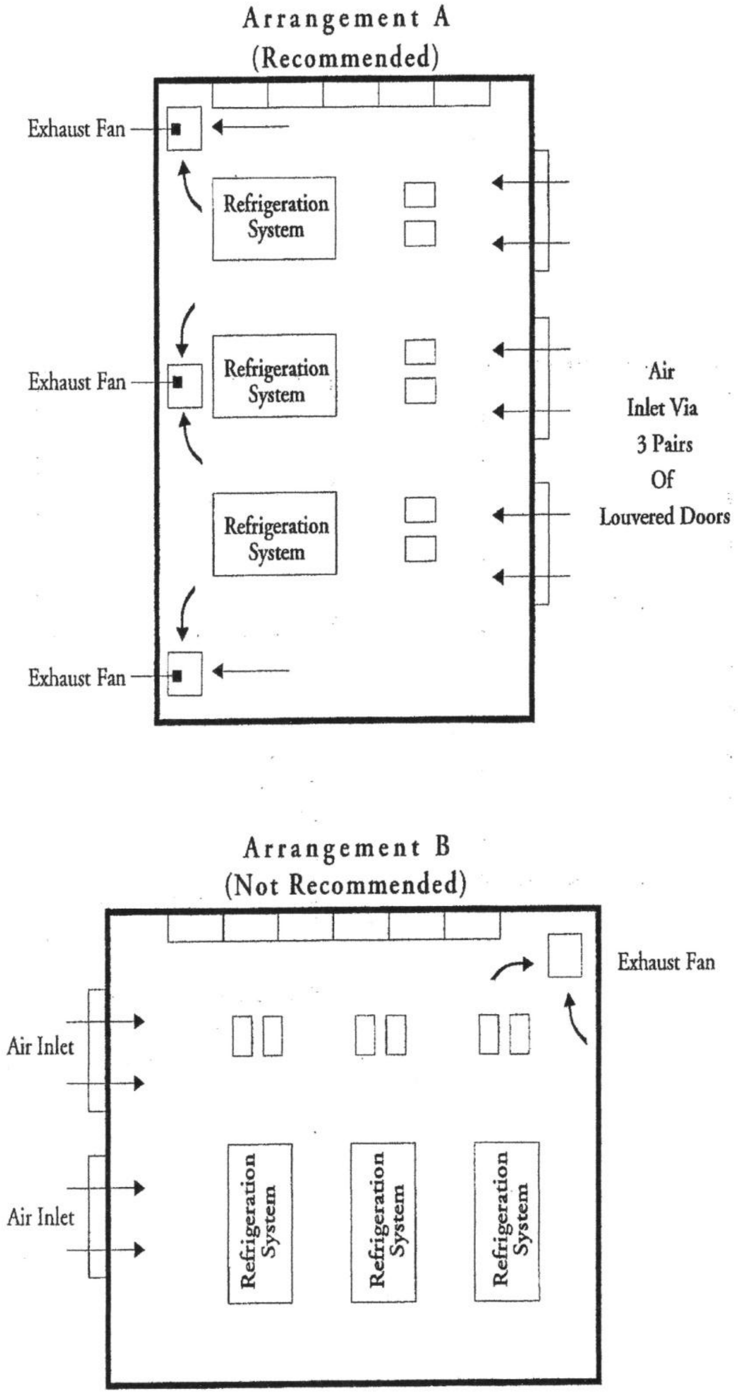
A8.1. Introduction. All new mechanical rooms must be designed to meet ASHRAE 15-2007 requirements. ASHRAE 15-2007 requires upgrading current mechanical rooms to comply with its standards after current equipment is either retrofitted or replaced. ASHRAE 15-2007 defines a set of minimum requirements to keep personnel safe while working inside equipment rooms. This standard describes the requirements that help preserve the operability and maintainability of the equipment stored in these rooms. The Refrigerant Quantity Rules referenced in earlier versions of ASHRAE Standard 15 have been superseded by Sections 7 and 8 of ASHRAE 15-2007. Most equipment rooms located in Air Force facilities will fall under the ASHRAE 15-2007 requirement because of the quantity and type of refrigerants found there. This standard applies to all low-probability and high-probability systems for all occupancy classifications using either a Group A1 or B1 refrigerant. A low-probability system is any system in which the basic design or location of the components prevents leaking refrigerant from a failed connection, seal, or component from entering the occupied space. Typical low-probability systems are indirect closed systems, double-indirect systems, and indirect open-spray systems. A high-probability system is any system in which the basic design or the location of components guarantees that leaking refrigerant from seals or components will enter the occupied space. Typical high-probability systems are direct systems or indirect open spray systems where the refrigerant can produce pressure greater than the secondary coolant (see Table A4.1). Other mechanical equipment room operational requirements, such as safety equipment and the placement of leak-detection devices, are discussed in greater detail in Attachment 3.

A8.2. Refrigeration System Placement.

A8.2.1. Chiller placement inside mechanical equipment rooms depends on various factors that include service work access, proximity to other equipment inside the mechanical equipment room, and airflow ventilation through the mechanical equipment room. Consider all clearances to be minimum requirements for normal operation, maintenance, service, and repair. ASHRAE 15-2007 calls for a clear head room of 7.25 feet (2.2 meters) below equipment situated over passageways. This requirement is designed to prevent piping and equipment from being installed in a location that will present a physical hazard to people or equipment moving through the aisles. While these clearances are guiding factors for positioning the chillers in the mechanical equipment room, to avoid stagnant areas attention must be paid to airflow patterns resulting from the interaction between the ventilation system and equipment inside the room.

A8.2.2. Chillers should be positioned between the ventilation inlet and outlet. Areas with stagnant air should be avoided. Figure A8.1 shows both good and bad configurations for multiple-chiller mechanical equipment rooms. Arrangement A shows optimally placed equipment. Arrangement B shows equipment creating stagnant areas between the chillers.

Figure A8.1. Multiple Chiller Equipment Room Layouts.

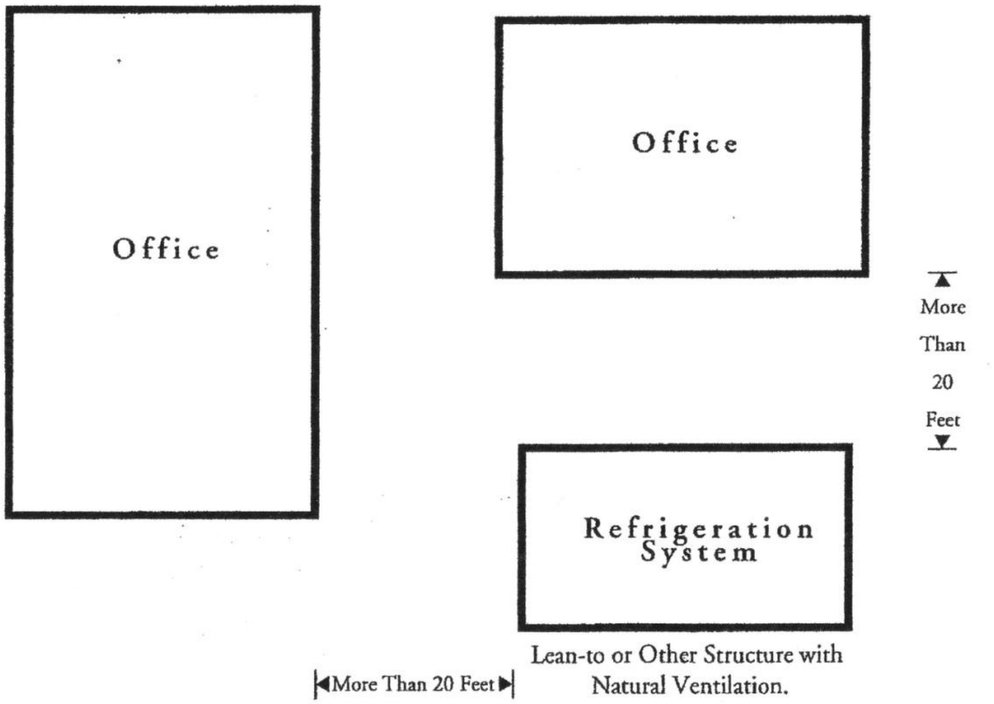


A8.3. Ventilation Volume Requirements. Mechanical equipment room volume requirements are covered in ASHRAE 15-2007. This standard splits ventilation air requirements into natural and mechanical ventilation, based on equipment location.

A8.3.1. Natural Ventilation.

A8.3.1.1. ASHRAE 15-2007 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 or mechanical ventilation shall be provided." Natural ventilation requirements are provided by the formula in ASHRAE 15-2007, Section 8.11.5c. Figure A8.2 shows an example of a remote mechanical equipment room.

Figure A8.2. Remote Mechanical Equipment Room.



A8.3.1.2. ASHRAE 15-2007 states that the free-aperture cross-section for ventilating machinery rooms should amount to at least $F = G^{0.5}$, where F = the free opening area in square feet, and G = the weight of refrigerant in pounds in the largest system, any part of which is located in the machinery room. The opening or openings are located with respect to the refrigerant density. For example, if the refrigerant being used is heavier than air (the specific gravity of the refrigerant is greater than 1) the opening(s) should be located flush or nearly level with the floor. If the refrigerant is lighter than air, the opening(s) should be located close to the mechanical room ceiling for maximum ventilation effect. For example, consider a chiller with an 800-pound charge. The free opening area in square feet (ft^2) would be calculated this way: $F = 800^{0.5} = 28\ ft^2$. Thus, a 5-foot by 6-foot opening would slightly exceed this square-footage requirement.

A8.3.2. Mechanical Ventilation.

A8.3.2.1. The ventilation system must be operable to not exceed either an 8 °C (18 °F) temperature rise from outside air maximum temperature or 50 °C (122 °F). Regarding mechanical ventilation, ASHRAE 15-2007 states that the minimum mechanical ventilation required to exhaust potential refrigerant accumulation from leaks or system ruptures must be sufficient to remove refrigerant from the machinery room using the following airflow (purge ventilation rate): $Q = 100 \times G^{0.5}$, where Q = the airflow in cubic feet per minute (cfm) in purge mode, and G = the refrigerant weight in pounds in the largest system, any part of which is located in the machinery room. Using an 800-pound charge, the airflow in cfm would be calculated as follows: $Q = 100 \times 800^{0.5} = 2800$ cfm. Q represents the minimum airflow the ventilation system must provide to remove refrigerant vapors from the mechanical room. According to ASHRAE 15-2007, it is unnecessary to continuously run the ventilation at this volume if the following conditions are met:

A8.3.2.1.1. Ventilation is provided when occupied of at least 0.5 cfm per square foot of machinery room area or 20 cfm per person.

A8.3.2.1.2. Operable, if necessary for operator comfort, at a volume required to maintain a maximum temperature rise of 8 °C (18 °F) based on all heat-producing machinery in the room.

A8.3.2.1.3. Ventilation must be designed to remove sensible heat loads generated by the equipment in the room. This flow rate should be designed to maintain room temperature no greater than 8 °C (18 °F) above the outdoor ambient temperature. Most electrical devices (e.g., motors and switchgears) 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 it may impose the higher ventilation flow rate requirement than those required for ventilating refrigerant gases following dilution.

A8.3.2.2. There are two distinct ventilation rates defined for the mechanical equipment room:

A8.3.2.2.1. Normal ventilation at a rate of 0.5 cfm per square foot or more if the room generates excessive heat. It is required any time the mechanical equipment room is occupied.

A8.3.2.2.2. The purge ventilation rate, based on the weight of refrigerant in the refrigeration system ($Q = 100 \times G^{0.5}$).

A8.3.2.3. If the mechanical equipment room is occupied, the ventilation system must be operated to produce the normal ventilation rate of 0.5 cfm per square foot or more. This can be achieved by running the fan continuously, starting it automatically with a motion detector, or by providing a fan switch near the mechanical equipment room entrance(s). If a switch is provided, a posted sign or other prompt should display the ventilation requirement for occupancy. To assure purge ventilation system operation, interlock the ventilation system with the room’s lighting.

A8.3.2.4. The purge ventilation rate is required whenever a refrigerant build-up occurs inside the mechanical equipment room. This is indicated by the refrigerant vapor (or oxygen) monitor. Ventilation at purge volume must be initiated by the monitor's alarm contacts. A switch for manual control should be outside the mechanical equipment room’s main entrance.

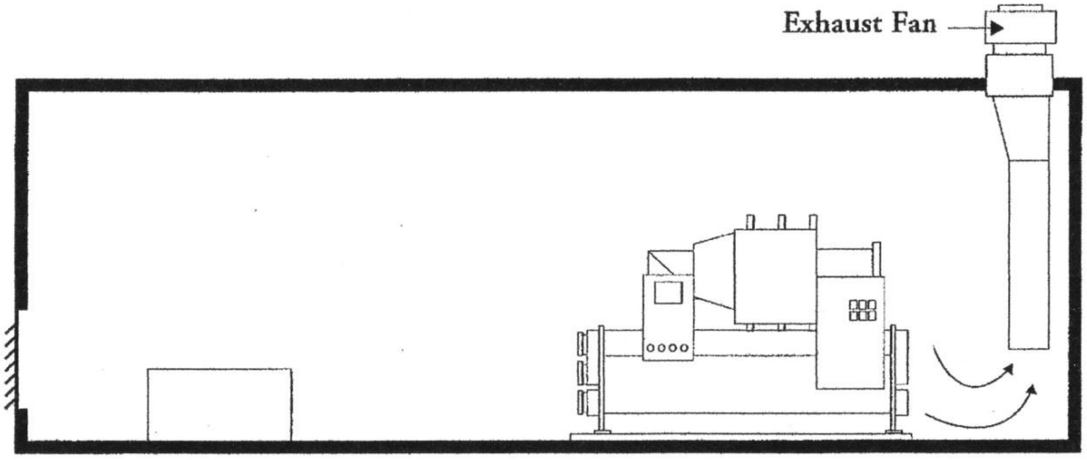
A8.3.2.5. A single ventilation system can serve both purge ventilation and normal ventilation requirements. If the required normal ventilation flow rate is higher than the required purge ventilation flow rate, no additional purge requirement is needed since the ventilation system will operate constantly when the room is occupied. If the purge ventilation flow rate is higher than the normal ventilation flow rate, the flow rate can be increased from the normal ventilation flow rate to approach the purge ventilation flow rate when the mechanical room is occupied with two-speed fan motors, variable-speed fan motors, or additional exhaust fans. This higher flow rate can be achieved with motion detectors or by interlocking the fans with the local lighting circuits.

A8.4. Location of Vents. The ventilation system's inlet and discharge must be properly positioned for efficient mechanical equipment room ventilation. ASHRAE 15-2007 addresses this requirement as follows: Provision shall be made for inlet air to replace that being exhausted. Openings for inlet air shall be positioned to avoid recirculation. Air supply and exhaust ducts to the machinery room shall serve no other area. Discharge of the air shall be to the outdoors in such a manner as not to cause a nuisance or danger.

A8.4.1. **Separate Ventilation System.** Equipment room ventilation must be separate from ventilation systems devoted to other building areas. The equipment room fans and ductwork should not ventilate other areas. The ventilation system discharge cannot feed other fresh air intakes. Because some fans may not run continuously, it is important to keep the fan discharge from being blocked while the fan is off. Make-up or outside air must be properly conditioned to prevent damage caused by large, rapid temperature swings or freezing temperatures.

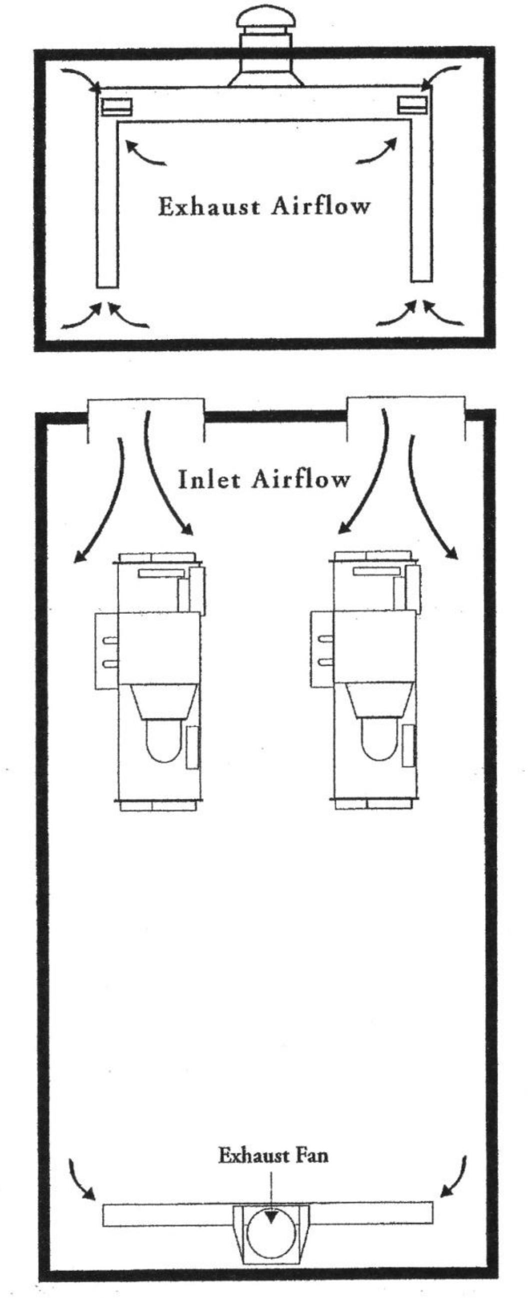
A8.4.2. **Exhaust Fan Provides Purging.** The exhaust fans must purge refrigerant from the equipment room. To remove heavier-than-air refrigerants, the exhaust fan inlet should be located near the equipment and the floor whenever possible. Refrigerants released into an equipment room drop to the floor and fill the room from the bottom up unless it is disturbed by air turbulence. The equipment room occupants are safest when the exhaust fan intake is below the normal breathing zone as shown in Figure A8.3. It is important for the ventilation to create an air sweep across all of the refrigeration equipment.

Figure A8.3. Suggested Exhaust Fan Location.



A8.4.2.1. When exhaust fans are used to keep the equipment room cool or remove smoke from accidental fires, they are typically installed in the ceiling because heat and smoke both rise. However, if the ventilation system exhausts refrigerants and/or combustion products and removes heat from the mechanical equipment room, inlets should be present at the floor and ceiling levels. This can be achieved by using either separate fans or a ducted fan with inlets at the floor and ceiling levels, as shown in Figure A8.4.

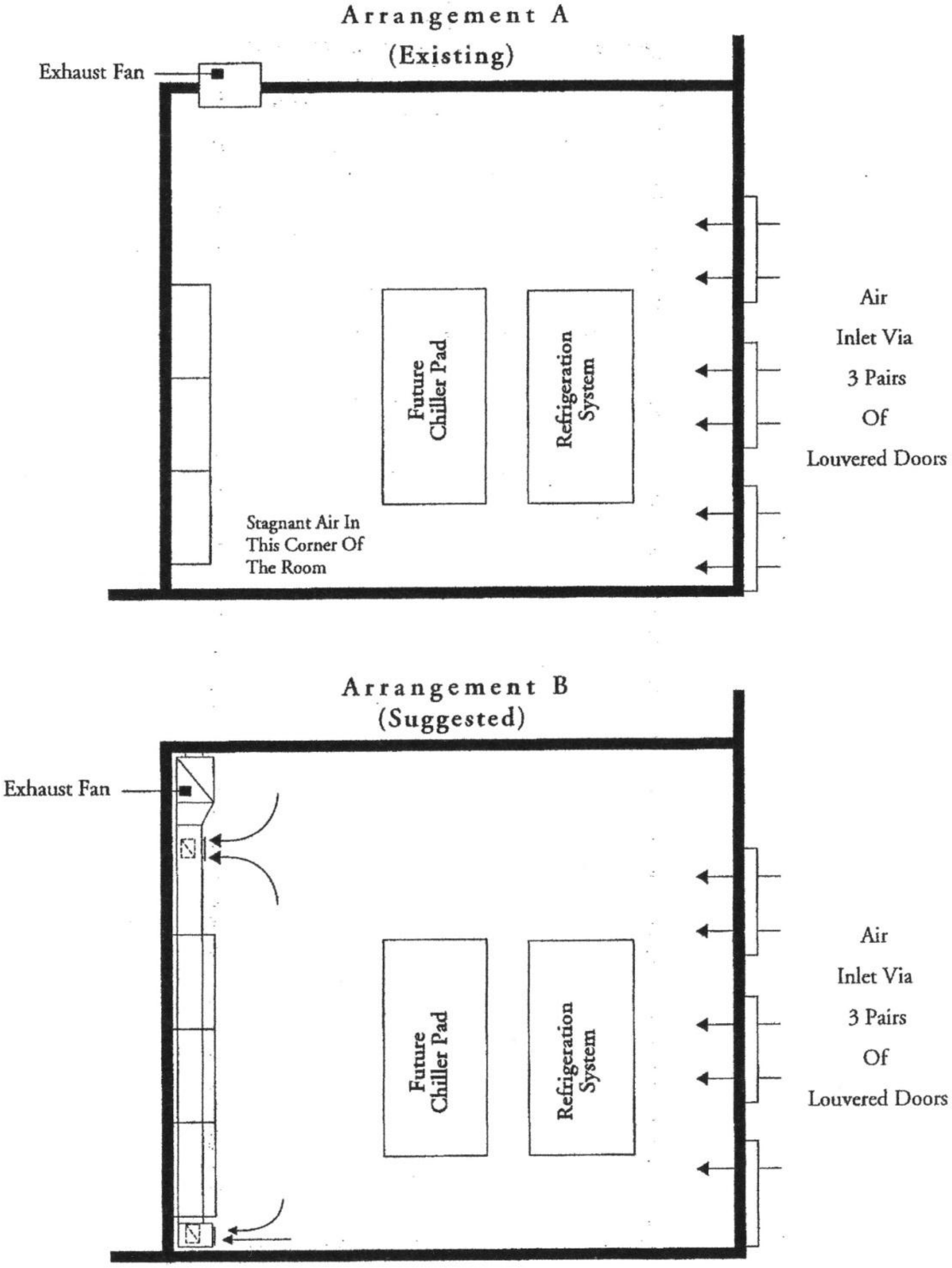
Figure A8.4. Dual Duct Exhaust.



A8.4.2.2. The total ventilation volume required during refrigerant purging could be provided by the ceiling-level and floor-level fans. The most effective refrigerant purge includes a floor-level fan 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 after a refrigerant alarm condition occurs. The fan inlet should be near a potential leak source and away from the fresh air intake. This arrangement will produce a sweeping action that draws fresh air across the leaking refrigerant toward the exhaust fan.

A8.4.2.3. Figure A8.5 is a sketch of a mechanical equipment room in a building corner. In Arrangement A, ventilation is provided via six louvered service doors along one wall (the fresh air inlet) and an exhaust fan mounted 4 feet (1.2 meters) above the floor in an adjacent wall. Continuous ventilation is provided at the refrigerant purge volume. While this arrangement provides adequate air movement across the chiller, it also creates a stagnant area in one corner. Ducting the exhaust fan inlet across the opposite wall, as depicted by Arrangement B, would provide better airflow across the entire room.

Figure A8.5. Modifying an Existing Ventilation System.



A8.5. Mechanical Equipment Room Doors, Passageways and Access. ASHRAE 15-2007 requires that, with the exception of access doors and panels in the air ducts and air-handling units conforming to ASHRAE 15-2007, Section 8.11.7, 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. Doors communicating with the building shall be approved, self-closing, tight-fitting fire doors. Access to the refrigerant machinery room shall be restricted to authorized personnel. Doors shall be clearly marked or permanent signs shall be posted at each entrance to indicate this restriction. The louvered doors shown in Figure A8.5 are used to provide the required service clearance for the chillers and a direct exit leading outdoors. Machinery room access is specifically restricted by ASHRAE 15-2007 to authorized personnel only.

A8.6. Open Flame Devices.

A8.6.1. **Machinery Room Combustion Air and Refrigerants.**

A8.6.1.1. ASHRAE 15-2007 states that no open flames that use combustion air from the machinery room shall be installed where any refrigerant is used. Combustion equipment shall not be installed in the same machinery room with refrigerant-containing equipment except under one of the following conditions:

A8.6.1.1.1. Combustion air is ducted from outside the machinery room and sealed in such a manner as to prevent any refrigerant leakage from entering the combustion chamber; or

A8.6.1.1.2. A refrigerant detector, conforming to ASHRAE 15-2007, Section 8.11.2.1, is employed to automatically shut down the combustion process in the event of refrigerant leakage.

A8.6.1.2. Exceptions are available for machinery rooms that use only carbon dioxide or ammonia for refrigerant and internal combustion engines are the prime mover for compressors. There shall be no flame-producing device or continuously operating hot surface over 426 °C (800 °F) permanently installed in the room. Erecting a partition wall to isolate the flame-producing device from the refrigerant-containing device is no longer an option.

A8.6.2. **Machinery Room and Storage Room Special Requirements.**

A8.6.2.1. The total of all groups A2, B2, A3 and B3 refrigerants, other than R-717 ammonia, shall not exceed 1100 pounds (500 kg) without approval by the authority having jurisdiction.

A8.6.2.2. Walls, floor, and ceiling shall be tight and of noncombustible construction. Walls, floor, and ceiling separating the refrigerant machinery room from other occupied spaces shall be of at least one-hour fire-resistive construction.

A8.6.2.3. The refrigerant machinery room shall have a door that opens directly to the outside or through vestibules equipped with self-closing, tight-fitting doors.

A8.6.2.4. Exterior opening, if present, shall not be under any fire escape or any open stairway.

A8.6.2.5. All pipes piercing the interior walls, ceiling, or floor of such rooms shall be tightly sealed to the walls, ceiling, or floor through which they pass.

A8.6.2.6. If refrigerant groups A2, A3, B2, and B3 are used, the machinery room shall conform to Class I, Division II of the NEC. If refrigerant groups A1 and B1 are used, the machinery room is not required to meet Class I, Division II, of the NEC.

A8.7. Pressure-Relief Piping.

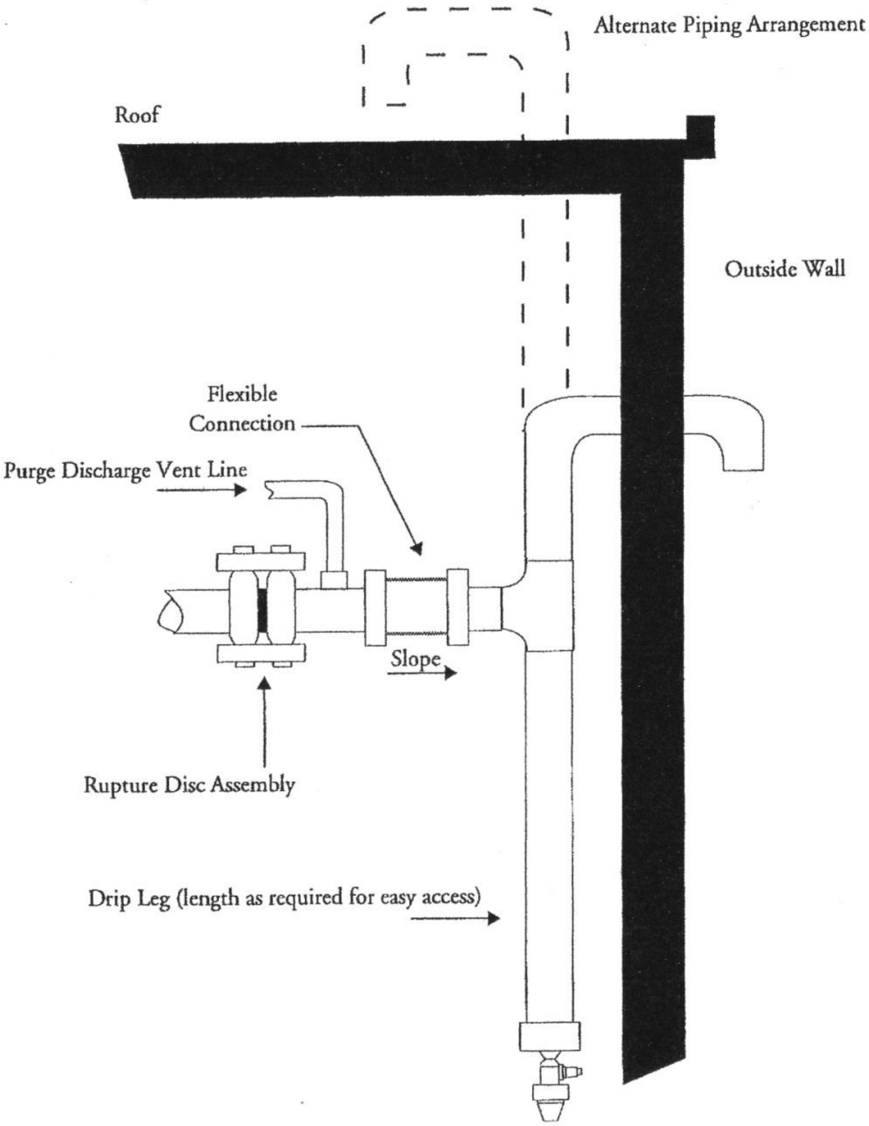
A8.7.1. ASHRAE 15-2007 states that refrigeration systems shall be protected by a pressure-relief device or other approved means to safely relieve pressure due to fire or other abnormal conditions. ASHRAE 15-2007 also includes very specific descriptions for determining when pressure-relief devices are necessary and how to size them. The original equipment manufacturer provides such devices on packaged systems and on major system components built-up in the field. However, ASHRAE 15-2007 should be reviewed in all cases to ensure compliance with that standard.

A8.7.2. **Piping Rupture Devices.** After the equipment is installed, each rupture device must be piped to a safe location according to the following ASHRAE 15-2007 guidelines: Pressure-relief devices and fusible plugs on any system containing a group A3 or B3 refrigerant; and on any system containing more than 6.6 pounds of a group A2, B1, or B2 refrigerant; and on any system containing more than 110 pounds of a group A1 refrigerant shall discharge to the atmosphere at a location not less than 15 feet (4.5 meters) above the adjoining ground level and not less than 20 feet (6 meters) from any window, ventilation opening, or exit in a building. The discharge shall be terminated in a manner that will prevent the discharge refrigerant from being sprayed directly on personnel in the vicinity and for material or debris from entering the discharge piping. Discharge piping connected to the discharge side of the fusible load or rupture member should have provisions to prevent plugging the pipe in the event the fusible plugs or rupture member functions. If a pressure relief valve is used in series with a rupture disc, the rupture disc should be a non-shattering type. A metallic non-fragmenting rupture disc is normally specified in this situation. A list of refrigerants in groups A1, A2, A3, B1, B2, and B3 can be found in Attachment 4, Table A4.1.

A8.7.2.1. It is critical that the materials used in the pipe and joints of the relief device piping are compatible with the vented refrigerant. Acceptable materials like steel or copper pipe are commonly used. Polyvinylchloride (PVC) piping is not recommended. Many adhesives and flexible connection devices that isolate vibration are untested for refrigerant compatibility with these types of piping constructions. A flexible stainless-steel pump connector or its equivalent is recommended.

A8.7.2.2. Vent pipes should be equipped with a drip leg capable of holding up to 1 gallon (3.8 liters) of liquid. Use a standard 0.25 inch FL by 0.25 inch NPT capped refrigerant service valve to remove the liquid. Accumulated liquid should be removed from the drip leg as part of a regular maintenance schedule once every six months. When draining the vent, use recommended refrigerant oil-handling procedures. Refrigerant oil may be discharged from the purge unit’s exhaust. This oil may, over time, accumulate inside the drip leg. A correctly piped vent pipe is shown in Figure A8.6. **Note:** 1 gallon = 231 cubic inches. The following equation should be used to find the amount of L, the pipe length in inches, required for the drip leg: $L = 294/d^2$, where d = pipe’s inside diameter in inches.

Figure A8.6. Suggested Refrigerant Vent Piping.



A8.8. Purge Discharge.

A8.8.1. Purge units that remove non-condensable gas from the refrigeration system should have their discharge lines piped in accordance with relief piping requirements (see paragraph A8.7). 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 be free of liquid traps and sloped away from the purge unit to prevent liquid from collecting near it. Additionally, do not allow liquid to 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 A8.6. Consult the purge equipment manufacturer about properly sizing the purge discharge line.

A8.8.2. **Minimize Loss.** Low purge-related refrigerant loss minimizes atmospheric refrigerant discharge and reduces refrigerant replacement costs. To minimize purge-related refrigerant loss:

A8.8.2.1. Choose a purge unit with a low refrigerant-to-non-condensable-gas discharge ratio that can operate while the chiller is off. The EPA has not defined high-efficiency with respect to purge units. However, several commercially available units are now capable of achieving 0.0005 pound of refrigerant discharged per pound of air purged. See Attachment 6 for more details about purge systems.

A8.8.2.2. Routinely check for and repair refrigeration system leaks. Routine logs of purge operations and chiller runtimes provide excellent information about system integrity.

A8.9. Occupied Space Contamination. There shall be no airflow to or from an occupied space through a machinery room unless the air is ducted and sealed to prevent any refrigerant leakage from entering the airstream. Access doors and panels in ductwork and air-handling units shall have gaskets and be tightly fitted.

A8.10. Additional Reference. An additional reference is provided as a suggested source where more in-depth information can be found: Trane APP-APM001-EN, *Refrigerating Systems and Machinery Rooms – Application Considerations for Compliance with ASHRAE Standard 15*.

Attachment 9

FUNDAMENTALS OF COOLING LOAD AND ENERGY ANALYSIS

A9.1. Introduction. Energy conservation measures and building function changes made since the design of the current cooling system may have changed the maximum required cooling load the air-conditioning equipment must meet. Future conservation measures may create more changes. These changes must be kept in mind when selecting air-conditioning equipment for replacement. Equipment size should be analyzed to correctly meet present and future demands. Load and energy analyses are needed for buildings that have undergone a significant change since the chiller's installation. If the building function has not changed but the chiller was never fully loaded or remained overloaded for a substantial time, analysis is needed to accurately size an affordable 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.

A9.1.1. **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 the following: 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.

A9.1.2. **Cooling Load Calculation.** To determine the maximum cooling capacity required from the chiller, a building peak cooling load calculation must be performed. This analysis can be completed by following the guidelines in the latest edition of the ASHRAE Handbook, *Fundamentals*. Cooling load and energy analysis calculations range from the simple to the complex.

A9.1.3. **Energy Analysis.**

A9.1.3.1. 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 define annual energy usage are:

A9.1.3.1.1. **Space Load:** The energy required to maintain thermal comfort in the space.

A9.1.3.1.2. **Equipment Load:** The energy required by the equipment that distributes the heating or cooling medium to the conditioned space (e.g., air handling units, pumps, fans).

A9.1.3.1.3. **Plant Load:** The energy required by the central plant equipment that converts fuel or electricity to cooling effects (e.g., chillers and cooling towers).

A9.1.3.2. Many computer programs are available to model energy and financial impacts. Some of the most common are Trane's Trace, Carrier's HAP, and eQUEST. eQUEST was developed by DOE and is free to use and download online at **http://www.energydesignresources.com/resources/software-tools/equest.aspx**. Other DOE-sponsored energy analysis tools are found at **http://apps1.eere.energy.gov/buildings/tools_directory/doe_sponsored.cfm**.

A9.1.3.3. 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 a 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.

A9.1.4. **Procedure.** The following information is required when using manual calculation or an energy/economic analysis program. The following sections outline the basic steps to determine the design load and annual cooling load profile for a given building. This analysis determines:

A9.1.4.1. The required capacity of the chiller(s).

A9.1.4.2. The total annual energy usage.

A9.1.4.3. The number of hours at part-load conditions, defined as 100 percent (peak), 75 percent, 50 percent, and 25 percent of peak load.

A9.2. Conduct Building Survey. Before conducting the survey, obtain the building's construction drawings. While performing the physical survey, talk with the building occupants and the 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.

A9.2.1. **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. Use Unified Facilities Criteria (UFC) 3-400-02, *Design: Engineering Weather Data,* for outdoor design conditions.

A9.2.2. **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 conduct a spot-check to verify the information.

A9.2.3. **Occupancy.** Record the number of people who occupy each space and their activity level. Determine the schedule of occupants since this can impact the cooling load.

A9.2.4. **Lighting.** Record the number of fixtures, type, watts per 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-lamp, 32-watt (W) T-8 lamp fixture with ballasts draws approximately 110W of power.

A9.2.5. **Other Internal Heat Sources.** These sources include, but are not limited to, computers, monitors, photocopying machines, coffee makers, refrigerators, vending machines, and cooking equipment. Record the number of heat sources found, the type, and the amount of heat entering the space. Consider both latent heat and heat that can be sensed. 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.

A9.2.6. **Ventilation.** Measure and record the rate of 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 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*, and any local requirements.

A9.2.7. **Infiltration.** It is practically impossible to record infiltration rates; however, they can be estimated by surveying for in-leakage and building pressure differences. An engineer who understands ASHRAE methods for estimating infiltration can accurately survey a building.

A9.2.8. **System Operational Characteristics.** Determine if:

A9.2.8.1. The chiller(s) are shut down during the winter months and the length of the shutdown period;

A9.2.8.2. The air handling systems use air-side economizers;

A9.2.8.3. The air handling systems use night set-back or shutdown;

A9.2.8.4. The chiller(s) are integrated with an operation schedule for duty-cycling.

A9.3. Conduct Cooling Load Calculation. The method used to determine the cooling load is detailed in the latest edition of the ASHRAE Handbook, *Fundamentals.* 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. A computer program should be used for large buildings.

A9.3.1. Computer Software.

A9.3.1.1. 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 analysis provide 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 for an entire year or another representative time period. Building cooling loads are accumulated over an annual period.

A9.3.1.2. Any computer programs used to conduct cooling load calculations should use the latest ASHRAE methods. Check with your base communications squadron for approved cooling load software to install on Air Force computer systems.

A9.3.2. **Simplified Cooling Load Calculation.** The building maximum cooling load calculation is presented in a simplified manner in Figure A9.1. (Details of each equation are published in the latest edition of the ASHRAE Handbook, *Fundamentals*.)

A9.3.3. **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 with maximum load conditions. For most systems, the peak load occurs on a hot, humid, sunny day with full internal occupancy and equipment usage.

A9.3.3.1. 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, measuring chiller loading will define the maximum building cooling load. Measure and record:

A9.3.3.1.1. The chiller voltage across all phases;

A9.3.3.1.2. The chiller amperage readings of all phases;

A9.3.3.1.3. The outdoor conditions at the time of readings (dry-bulb and wet-bulb temperatures, cloudiness, date, and time of day);

A9.3.3.1.4. The chilled water entering-and-leaving conditions and the flow, if available.

A9.3.3.2. This information can be compared to the chiller's rated capacity to determine maximum cooling load. For example, if the chiller is 95 percent loaded (electrically), 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 = Flow (gal/min) x (TENTERING – TLEAVING) x 500. If desired, additional data may be gathered for part-load weather conditions to estimate the cooling load profile.

Figure A9.1. Cooling Load Calculation.

1) The overall building cooling load (Q) can be expressed as:
Q = QSPACE + QRA + QSA
Where:
QSPACE = heat gain to the conditioned space

QRA = heat gain to the return air side of airflow

QSA = heat gain to the supply side of airflow

Each element of this equation may have both sensible and latent heat gain components.
2) QSPACE can be further defined as:
QSPACE = QW&R + QGLASS + QPAR + QINT
Where:

QW&R = heat gain through walls and roofs, both conduction and solar effects

QGLASS = heat gain through glass, both conduction and solar effects

QPAR = heat gain through partitions

QINT = heat gain internal to the space

The elements of this equation, with the exception of QINT, will have sensible heat components only. If the space under consideration has several zones (separately controlled areas), then QSPACE will be a summation of all zone space loads.
Furthermore, QINT can be expressed as:
QINT = QPEOPLE + QLIGHTS + QEQUIP + QINFIL
Where:

QPEOPLE = heat gain from people within the space

QLIGHTS = heat gain from lighting within the space

QEQUIP = heat gain from equipment within the space

QINFIL = heat gain from infiltration

Each element of this equation, with the exception of QLIGHTS, may have both sensible and latent heat gain components.

3) Heat gain to the return side of airflow can be expressed as:

QRA = QPLENUM + QRAFAN + QVENT

Where:

QPLENUM = heat gain to any return plenums or ductwork

QRAFAN = heat gain from any return air fans and motors

QVENT = 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 regarding indoor air quality, refer to ASHRAE 62.1-2007.)

4) Heat gain to the supply side of air flow may be expressed as:

QSA = QPLENUM + QSAFAN

Where:

QPLENUM = heat gain to any supply plenums or ductwork

QSAFAN = 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), QSA and QRA do not apply.

Attachment 10

CHILLER SELECTION GUIDE

A10.1. Introduction. This attachment is a guide for engineers who select and optimize water chillers. Chiller selection is the most important component when optimizing chilled-water systems. All options must be examined and a selection made based on the lowest life-cycle cost (LCC). Because of site-specific conditions—no waste-heat source or low-cost electricity relative to natural gas—some alternatives can be eliminated immediately. Figure A10.1 illustrates a broad summary of the chiller selection process. Table A10.1 provides a summary of various chiller types, including typical costs, sizes, and efficiencies.

Figure A10.1. Chiller Selection Flowchart.

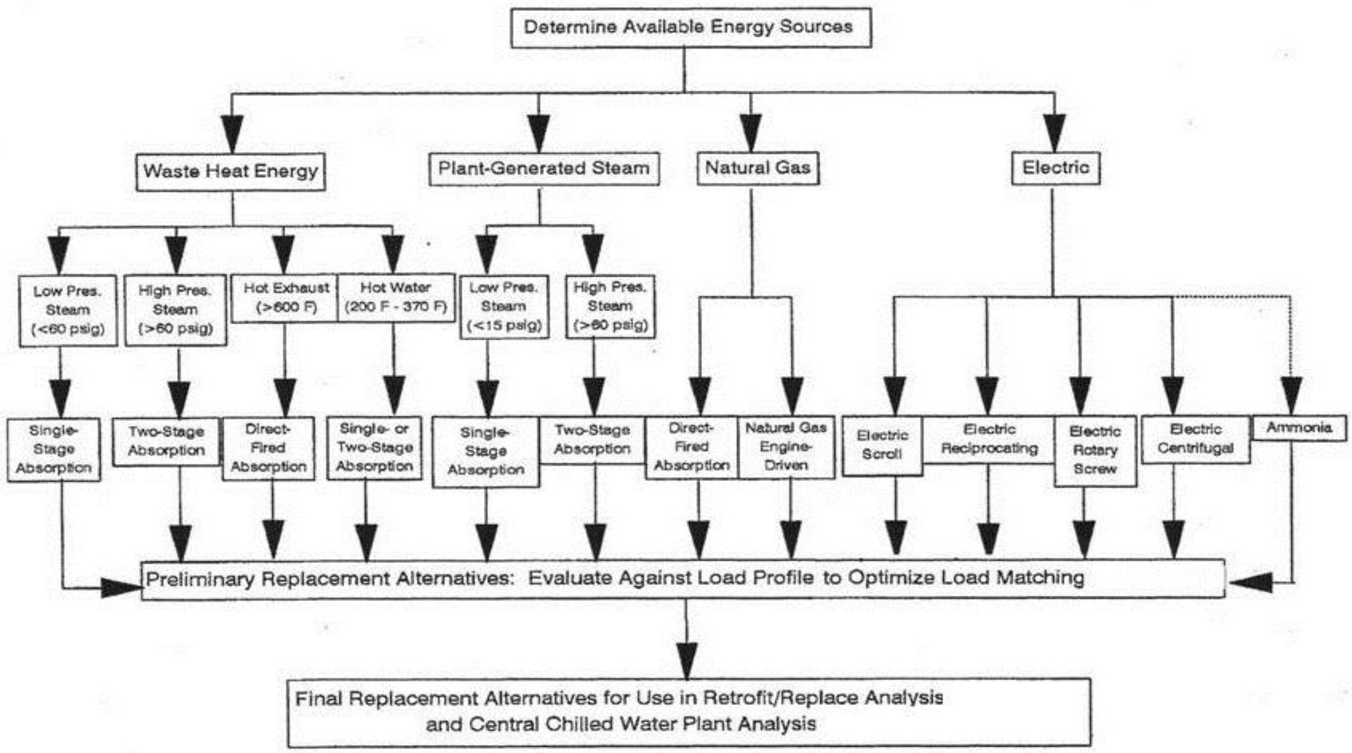


Table A10.1. Chiller Selection Guide.

Equipment Type	Available Tonnage Range	Equipment Cost (Chiller Only) $/Ton	Full Load Efficiency	Coefficient of Performance (COP)
Single-stage steam absorption	100–1800	350–650	15–20 lb/hr/ton	0.85–0.63
Two-stage steam absorption	100–1800	475–700	5–10 lb/hr/ton	0.95–1.05
Direct-fired absorption	100–1100	600–880	10–15 Mbh/ton(1)	1.2–0.80
Electric scroll	20–60	350–450	0.85–2.0 kW/ton	4.0–1.8

Electric reciprocating(3)	N/A	N/A	N/A	N/A
Electric rotary screw(2)	60–400	300–600	0.75–0.85 kW/ton	4.7–4.1
Electric centrifugal	350–1500	260–330	0.45–0.80 kW/ton	6.4–4.4
Natural gas engine-driven	100–500	750–1200+	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				

A10.1.1. **Applicability.** The selection process discussed in this attachment applies to chilled water systems with single or multiple chiller installations. Chiller types under consideration should include steam, hot water, and direct-fired absorption chillers; scroll, reciprocating, rotary screw, and centrifugal electric chillers; ammonia chillers; and natural gas engine-driven (GED) chillers.

A10.1.2. **Selection Procedure.** The guidelines for selecting the most effective chiller(s) contain two parts:

A10.1.2.1. Part one describes various types of chillers, including their advantages and disadvantages, and suggests when each chiller type should be considered. The chiller information in this attachment is general. More detailed information should be sought from chiller manufacturers.

A10.1.2.2. Part two describes a general selection procedure.

A10.1.2.3. Chiller efficiency is expressed by the ratio of energy input divided by cooling capacity. Refrigeration capacity is expressed as kilowatts per ton (kW/ton) or pounds of steam per hour per ton (steam/hr/ton).

A10.1.2.4. Chillers are heat pumps that transfer heat from one source to another. The energy required to "pump" the heat is usually less than the available cooling capacity. Because this concept is somewhat different from the traditional definition of efficiency, the term coefficient of performance (COP) is often used to express 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 1.

A10.1.2.5. Chiller efficiency and performance cannot 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 less than a full load.

A10.2. Chiller Descriptions and Performance Characteristics. The following paragraphs describe the commonly available chiller types and their applications. Of the chiller types discussed below, absorption chillers are rarely used unless there is an available significant source of waste heat nearby.

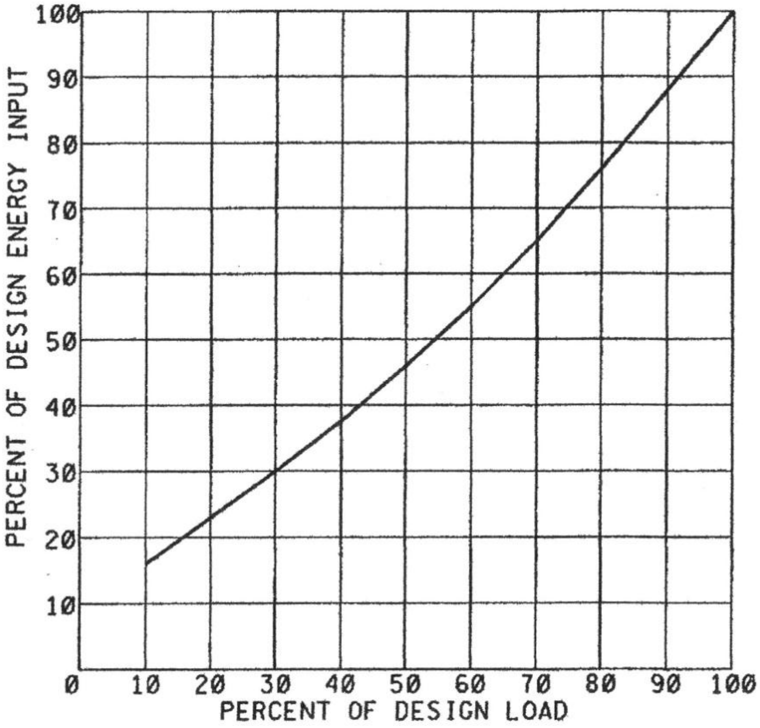
A10.2.1. **Single-Stage Steam or Hot Water Absorption Chiller (Water-Lithium Bromide Solution).** Consider single-stage steam or hot water absorption chillers only when there is enough excess steam or hot water available. Steam inlet pressures at the chiller cannot exceed 12 to 14 psig with maximum temperatures of 171 °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).

A10.2.1.1. A single-stage steam or hot water absorption chiller uses heat energy to boil a dilute solution of lithium bromide and water. The resulting refrigerant vapor 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 into the concentrator.

A10.2.1.2. Single-stage absorption chillers are approximately 20 percent more expensive than a comparable electric centrifugal chiller. However, if excess waste heat energy is available, energy cost savings may be gained. Waste heat energy should be available year-round to obtain the maximum cost benefit.

A10.2.1.3. Single-stage absorption chillers cost between $260 to $650 per ton of refrigeration capacity. Their efficiencies range from 15 to 20 pounds per hour per ton (lb/hr/ton) with COPs ranging from 0.85 to 0.63. Figure A10.2 shows that a single-stage absorption machine can operate as low as 10 percent of its maximum capacity. The chiller is most efficient at 50 to 80 percent of maximum capacity.

Figure A10.2. Single-Stage Steam Absorption Chiller Part-Load Performance.



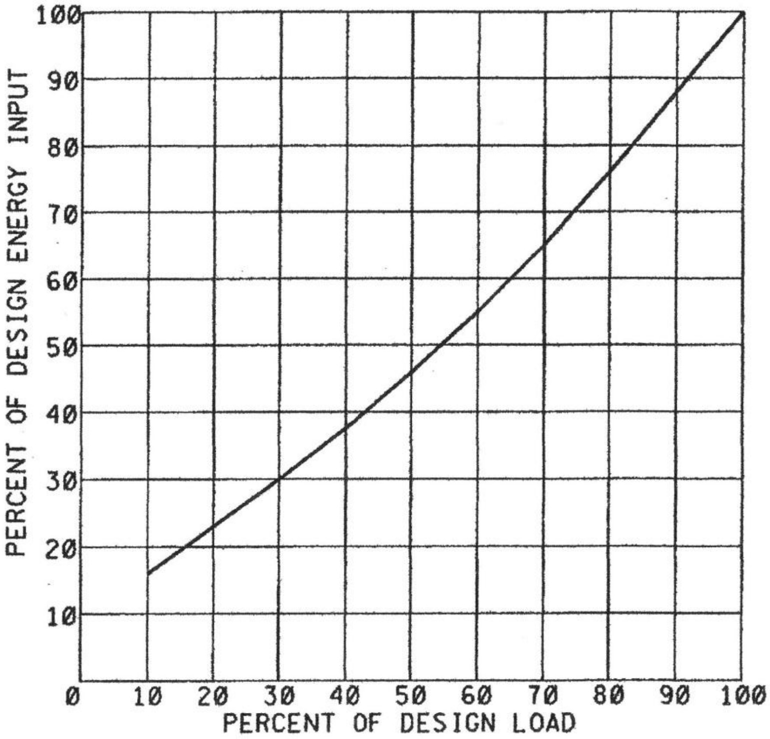
A10.2.2. **Two-Stage Steam or Hot Water Absorption Chillers (Water-Lithium Bromide Solution).** Two-stage steam or hot water absorption chillers are similar to single-stage models, except that a two-stage machine uses higher steam pressures or hot water temperatures in two concentrator stages. For these machines, steam pressures between 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.

A10.2.2.1. Two-stage absorption chillers cost between $460 to $600 per ton. They require cost-effective waste heat energy and are approximately two to two-and-one-half times as expensive as a comparable electric centrifugal chiller.

A10.2.2.2. Full-load efficiencies range from 5 to 10 lb/hr/ton, with COPs ranging from 2.7 to 1.3. Figure A10.3 shows that a two-stage absorption machine can operate with 10 percent of its maximum capacity. The chiller is most efficient at 60 to 80 percent of its maximum capacity.

Figure A10.3. Two-Stage Steam Absorption Chiller Part-Load Performance.



A10.2.3. **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 burn 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.

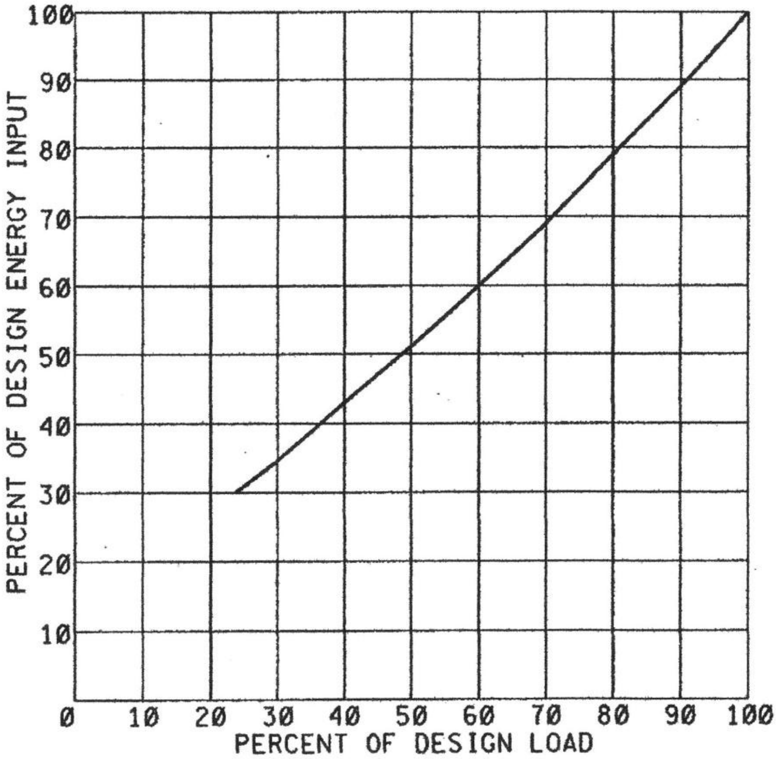
A10.2.3.1. In general, direct-fired absorption chillers have the same configuration and processes as two-stage steam or hot water absorption chillers except for the input energy source. A unique feature of most direct-fired absorption chillers is that they can also provide heat. Most manufacturers refer to direct-fired absorption chillers as a chiller-heater.

A10.2.3.2. The heater portion of the direct-fired chiller operates when the first-stage generator energy source heats the diluted lithium bromide solution. This drives off refrigerant vapor and leaves a concentrated solution. The hot refrigerant vapor's heat is transferred to the building's hot water system via an auxiliary heat exchanger or through the unit's internal heat exchanger. The condensed refrigerant liquid returns to the first-stage generator and completes the cycle.

A10.2.3.3. A direct-fired absorption chiller is approximately two-and-one-half times more expensive than a comparable-capacity electric centrifugal chiller, but it remains competitive with two-stage steam or hot water absorption chillers.

A10.2.3.4. Direct-fired absorption chillers range in price from $530 to $860 per ton of refrigeration capacity. Their full-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 A10.4 shows that a direct-fired machine can operate at as low as 25 percent of its maximum capacity. The chiller is most efficient between 70 to 90 percent of its maximum capacity.

Figure A10.4. Direct-Fired Absorption Chiller Part-Load Performance.



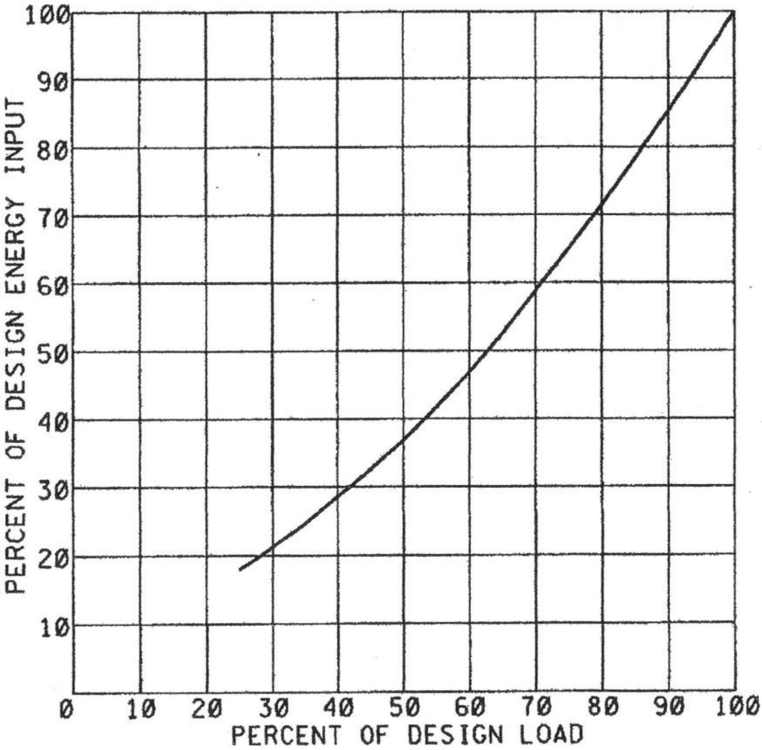
A10.2.4. **Electric Scroll Chiller.** The electric scroll chiller is the smallest of the electrical chillers. It is available in both water-cooled and air-cooled configurations. Sizes range from 20 to 80 tons of refrigeration capacity. Due to their small size, scroll chillers should not be considered for central plant applications. Good applications for scroll chillers include areas that have special temperature and humidity requirements that packaged DX equipment cannot meet.

A10.2.4.1. Its general operating characteristics are similar to a reciprocating chiller. The main difference is that the scroll chiller uses a rotary-type compressor. The compressor operates by rotating a spiral-shaped scroll that compresses the vapor as it is forced through the scroll.

A10.2.4.2. Scroll chillers can be manifolded together to provide multiple staging and load-matching capabilities. Manifolded scroll chillers can be 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 capacity.

A10.2.4.3. 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 A10.5 shows that an electric scroll machine can operate at 25 percent of its maximum capacity. The chiller is most efficient at 25 to 50 percent of its maximum capacity.

Figure A10.5. Electric Scroll Chiller Part-Load Performance.

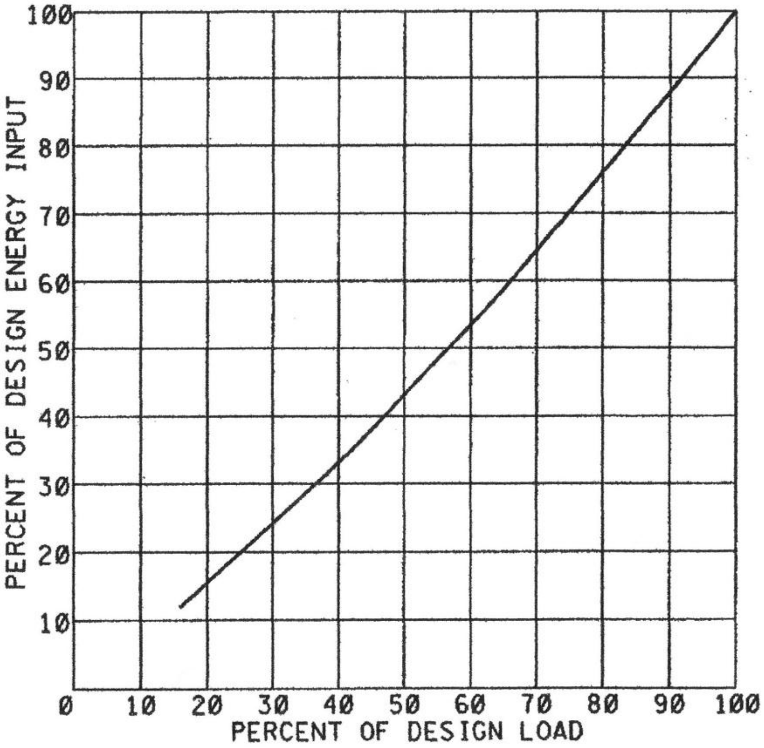


A10.2.5. Electric Reciprocating Chiller.

A10.2.5.1. The reciprocating chiller has the lowest first cost and the lowest efficiency of the chillers considered in this pamphlet. Initial cost is between $340 to $470 per ton, with full-load efficiencies from 0.90 to 1.10 kW/ton. Reciprocating chillers are available only with HFC-134a, HCFC-410A, or ammonia refrigerants. Reciprocating chillers are available in either air-cooled or water-cooled configurations.

A10.2.5.2. 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 condenser water pump. An air-cooled system requires more space than a water-cooled system due to the larger condenser surface areas and clearances needed for circulation air. Figure A10.6 shows an electric reciprocating machine operating at 15 percent of its maximum capacity. The chiller is most efficient between 30 to 50 percent of its maximum capacity.

Figure A10.6. Electric Reciprocating Chiller Part-Load Performance.

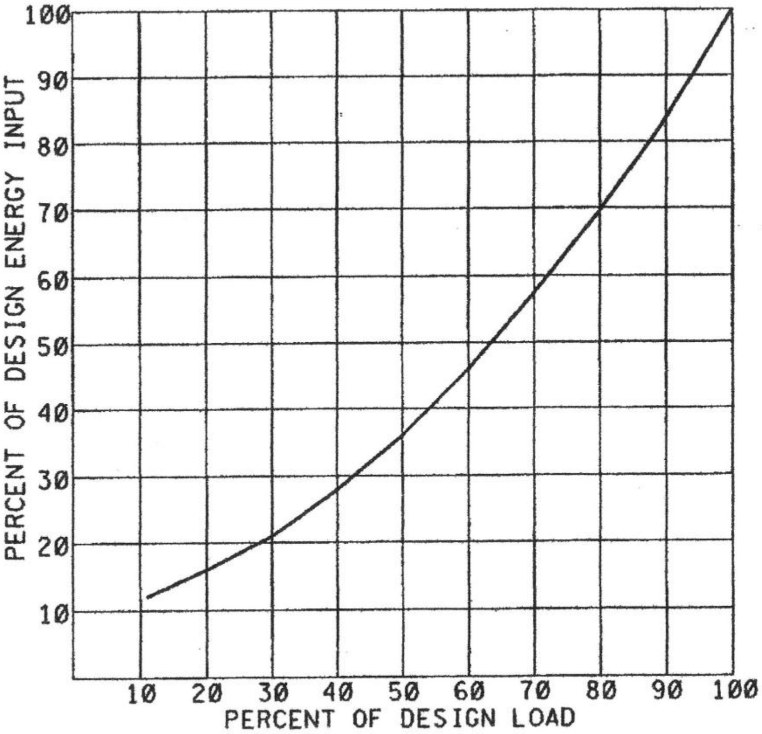


A10.2.6. **Electric Rotary Screw Chiller.** The rotary screw chiller is similar to the scroll chiller; neither type uses piston compressors. The rotary screw chiller uses two rotors for the compression cycle. A male rotor is driven by the motor that compresses refrigerant gas between a female rotor.

A10.2.6.1. Rotary screw chillers offer higher efficiencies than reciprocating chillers of equal capacity. They are more expensive than reciprocating chillers. Screw chillers are available only with HFC-134a or ammonia refrigerants.

A10.2.6.2. Screw chillers are available in either air-cooled or water-cooled configurations. The air-cooled machines range in capacity from 70 to 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-sized machines, the part-load efficiency of a screw chiller is better than the part-load efficiency of a reciprocating chiller. When load-matching cannot be achieved 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 A10.7 shows that an electric screw machine can operate at 10 percent of its maximum capacity. The chiller is most efficient between 35 to 55 percent of maximum capacity.

Figure A10.7. Electric Rotary Screw Chiller Part-Load Performance.

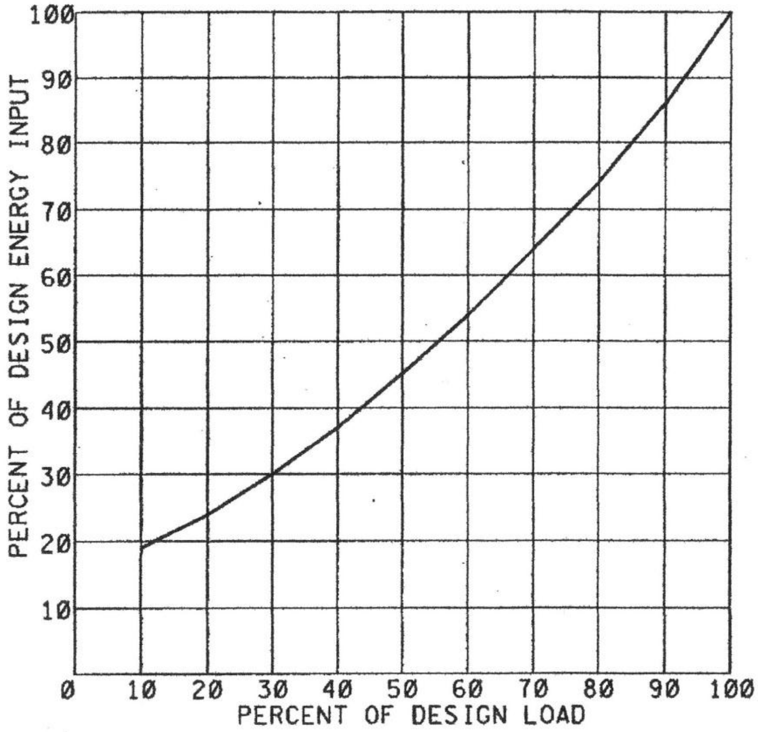


A10.2.7. Electric Centrifugal Chiller.

A10.2.7.1. Electric centrifugal chillers use hermetically sealed or open-drive compressor/motor assemblies. They come with one-stage, two-stage, or three-stage compression cycles. Refrigerant vapor is accelerated through the impeller, increasing both 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; this chills the water. Finally, the low-pressure refrigerant vapor returns to the compressor.

A10.2.7.2. Electric centrifugal chillers have the highest full-load efficiency of the electric chillers discussed in this pamphlet. The average full-load efficiency is approximately 0.45 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 $260 to $330 per ton. Centrifugal chillers can operate with many environmentally friendly refrigerants, such as HCFC-123 and HFC-134a. Electric centrifugal chillers range in size from approximately 100 to 1500 tons. Only water-cooled configurations are available. Figure A10.8 shows that an electric centrifugal machine can operate at 10 percent of its maximum capacity. The chiller is most efficient at 55 to 85 percent of its maximum capacity. An emerging technology is the Turbocor® chiller with frictionless magnetic bearings. It is currently offered by McQuay and is available in the 110- to 175-ton range. It uses HFC-134a for refrigerant. The Turbocor has an integrated part-load efficiency of 0.4 kW per ton.

Figure A10.8. Electric Centrifugal Chiller Part-Load Performance.



A10.2.8. **Natural Gas Engine Chiller.** Natural gas engine-driven chillers use a natural gas-fired engine rather than an electric motor. Engine-driven chillers are currently only available with screw compressors but may soon be available with reciprocating compressors. These chillers are water-cooled and range in size from 100 to 500 tons. The refrigerant used is HFC-134a. The efficiency is approximately 9 cubic feet/hour of natural gas per ton of cooling capacity. Natural gas engine-driven chillers can be used to control peak electrical demand during high summer electrical use periods. Engine-driven chillers are more expensive than motor-driven chillers of comparable capacity and require more maintenance.

A10.3. Chiller Selection Procedure. This section outlines a step-by-step procedure for selecting chiller(s).

A10.3.1. **Cooling Load Profile.** It is essential that the cooling load profile be determined (see Attachment 9, paragraph A9.1.3.3). The site should be surveyed for available utilities.

A10.3.1.1. **Step 1.** Determine available input energy sources. There are four potential input energy sources that should be evaluated:

A10.3.1.1.1. Waste heat energy:

A10.3.1.1.1.1. Low-pressure steam (< 60 psig).

A10.3.1.1.1.2. High-pressure steam (≥ 60 psig.

A10.3.1.1.1.3. Hot water (93 °C [200 °F] to 188 °C [370 °F]).

A10.3.1.1.1.4. Hot gas (> 316 °C [600 °F]).

A10.3.1.1.2. Plant-generated steam:

A10.3.1.1.2.1. Low-pressure steam (12 to 15 psig).

A10.3.1.1.2.2. High-pressure steam (60 to 115 psig).

A10.3.1.1.3. Natural gas.

A10.3.1.1.4. Electric.

A10.3.1.1.5. Survey the site and find all available energy sources, including natural gas, steam, and electric from adjoining sites. The cost of extending utility services from distant sites may be too great.

A10.3.1.2. **Step 2.** Because some energy sources may be unavailable, some chillers can be eliminated after analyzing their costs based on the utility rate structure. Examples:

A10.3.1.2.1. If natural gas is unavailable, natural gas direct-fired absorption and natural gas engine-driven chillers should not be considered.

A10.3.1.2.2. If waste heat energy in the form of steam, hot gas, or hot water is unavailable, additional chiller types, such as single- and two-stage absorption chillers can be eliminated.

A10.3.1.3. **Step 3.** Consider all possible alternatives and compare each chiller's capabilities with load-matching needs, space requirements, and special humidity and temperature requirements. This process will eliminate certain chillers. See the following examples below.

A10.3.1.3.1. **Example**: If the load profile shows a peak load requiring 1000 tons, the use of scroll or reciprocating chillers would not be affordable. Using this criterion in Figure A10.1, a single refined chiller system selection cannot be determined but a set of possible alternatives will be available.

A10.3.1.3.2. **Example**: The chiller must 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.

A10.3.1.3.3. A proper chiller selection matches the performance of single or multiple chillers to the required load profile. Load matching requires profile scrutiny and attention to detail to achieve optimum chiller load performance.

A10.3.1.3.3.1. **Example**: If the load profile reflects a 1000-ton peak load, but a constant base load of 250 tons exists, multiple chillers should be considered. In this example, 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.

A10.3.1.3.4. When selecting and matching chillers to load profiles, consider part-load performance, peak-load performance, initial cost, space requirements, utility rate structures, and the availability of alternative energy input sources.

A10.3.1.3.4.1. **Example**: If natural gas is available and the electric utility rate structure is such that high electrical rates and demand charges are imposed, natural gas becomes attractive. However, 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.

A10.4. Recommendations for Further Study. To further optimize chiller selection, there are several areas to consider. Some gas and electric utilities offer rebates and purchase incentives for selecting a chiller and chiller plant accessories with high-efficiency performance.

A10.4.1. **Gas Utility Rebates.** Some gas utility companies provide rebates and incentives for converting from electric-driven chillers to natural gas engine-driven chillers.

A10.4.2. **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. Using this waste heat can significantly reduce LCC.

A10.5. Additional Reference. An additional reference is provided as a suggested source where more in-depth information can be found: AHRI Standard 550/590-2011, *Performance Rating of Water Chilling Packages Using the Vapor Compression Cycle*.

Attachment 11

HEAT RECOVERY ALTERNATIVES FOR REFRIGERANT CHILLERS

A11.1. Introduction. The purpose of this attachment is to optimize water chiller selection by considering heat recovery to convert waste heat into useful energy. This analysis should be performed by an engineer familiar with the building's mechanical systems and should include a cost-benefit analysis.

A11.1.1. **Applicability.**

A11.1.1.1. This evaluation procedure is applicable to chiller installations where heat-recovery chillers may be financially feasible. Before heat recovery can be considered a viable alternative, the following questions must first be answered: Is there heat to recover? Can the recovered heat be used? 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. An in-depth analysis of the heating and cooling load profiles of the building, as well as the equipment used, may be necessary. Recovered heat from chillers can provide the following:

A11.1.1.1.1. Reheat for process air-conditioning systems.

A11.1.1.1.2. Reheat for comfort air-conditioning systems.

A11.1.1.1.3. Perimeter zone heating for comfort air-conditioning systems.

A11.1.1.1.4. Outdoor air preheating.

A11.1.1.1.5. Domestic hot water (HW) for systems in dormitories, dining halls, kitchens, shower rooms, and locker rooms.

A11.1.1.1.6. Preheat for boiler make-up water systems.

A11.1.1.1.7. Provide heat for any HW process or comfort load.

A11.1.1.2. 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.

A11.1.2. **Advantages/Disadvantages.** A potential advantage of heat recovery is the reduced energy cost gained 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.

A11.1.2.1. 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 added cost of a heat-recovery chiller is a second condenser shell that must be dedicated to the heat-recovery loop.

A11.1.2.2. Heat-recovery systems may not eliminate the need for an auxiliary heat source. This will depend on the required HW temperature. Because of 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 to convert to a new refrigerant, retrofitting to add heat recovery is not often cost-effective.

A11.2. Analysis. This section helps determine whether a heat-recovery system should be incorporated into a potential chilled-water system. Each chilled-water system using heat-recovery chillers that has a lower LCC than the current or proposed cooling-only chilled-water system should be considered for implementation.

A11.2.1. **Obtain Data.** Determine the total cooling load on the chilled-water system being considered for heat recovery. More information and building evaluations 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 be a candidate for thermal energy storage.

A11.2.2. **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 that will use heat recovery. The analysis should include engineering and construction cost estimates and additional costs for HW pumps, piping, equipment room modifications, energy usage controls, and projected annual maintenance costs for the proposed heat-recovery system.

A11.2.3. **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 to perform the LCC analysis.

A11.2.3.1. **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 that will support the heat-recovery distribution system. Consider items like heat exchangers, pumps, and HW storage tanks.

A11.2.3.2. **Annual Energy Cost.** Determine the annual energy costs by calculating the requirements for cooling and recovered heat. See paragraph A11.3 for an evaluation example on calculating the annual energy cost for replacing chillers.

A11.2.3.3. **Heat-Reclaim Energy Savings.** Determine the heat-reclaim energy savings ($BOILER-ENERGY). The savings from usable reclaimed energy will depend largely on the hourly cooling load profile compatibility and the hourly heating load profile as discussed in Attachment 9. Typically, the cooling load profile estimates are based on groups of hours representing 25, 50, 75, and 100 percent of part-load conditions. The annual heating load profile must be estimated similarly. The evaluator will need to group the annual hourly heating demand into estimated groups of hours matching those included in chiller operations. Once the bins of operation have been determined, contact the chiller manufacturer and request the part-load heat reclaim performance of each chiller under evaluation. Request the part-load performances that match the cooling-only chiller. Once the amount of reclaimed usable heat has been determined, annual energy savings can be calculated.

A11.2.3.4. Calculate the present value ($PV) of the LCC. The LCC's $PV is an equivalent cost, calculated to compare mutually exclusive alternatives.

A11.2.3.5. 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 be considered for implementation.

A11.3. Evaluation Example. The following assumptions, figures, and Table A11.2 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.

A11.3.1. **Assumptions.** The following assumptions have been made to develop a representative example of heat recovery chiller engineering and LCC analyses.

A11.3.1.1. Average energy cost for this example is $0.07/kWh.

A11.3.1.2. The replaced chiller is part of an existing central plant, but it is the only chiller in the plant being considered for replacement. Total central plant peak cooling load is 1,000 tons with a constant year-round base cooling load of 400 tons. The central plant previously had two 500-ton chillers based on the LCC analysis. The heat will be recovered nine hours per day and five days per 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 produce a base cooling load of 400 tons. A nominal 500-ton heat-recovery chiller will be selected based on the given system parameters.

A11.3.1.3. The annual process heating load is 5,300 Mbh (Mbh = 1,000 Btu/hour). This load is present nine hours a day and five days a week (2,340 hours/year). This load will be supplied by the reclaimed heat from the heat-recovery chiller.

A11.3.1.4. An electric HW boiler is the existing heat source for the process load. The boiler provides the required 5,300 Mbh load nine hours a day, five days a week. The boiler's electrical demand is 1,550 kW.

A11.3.1.5. The heat-recovery water loop and the process-heating water loop will be independent circuits. Heat will be transferred between them through a plate-and-frame type heat exchanger.

A11.3.1.6. The present value ($PV) for the cooling-only replacement chiller is $1,510,000.

A11.3.1.7. Estimate the initial cost of the heat-recovery system. See Table A11.1.

Table A11.1. Heat-Recovery System Cost Estimate.

Description	Cost Estimate	Source
500-ton heat-recovery chiller	$180,000	Manufacturer
Pump	$1,400	Manufacturer
Heat exchanger	$4,200	Manufacturer
Controls	$12,000	Manufacturer
Piping and specialties	$8,000	Cost estimate guide
Labor	$65,000	Cost estimate guide

Total Initial Cost: $270,600

A11.3.2. **Heat-Recovery Chiller Annual Energy Cost ($ENERGY).** The first step in the evaluation is to calculate the annual energy cost ($ENERGYHeat Recovery) for the proposed heat-recovery chiller. This calculation is shown in Figure A11.1.

Figure A11.1. Calculate $ENERGY.

$ENERGYHeat Recovery = Σ{(EFFxx%)(HRSxx%)(LOADxx%)} × ($/kWh)

Where:

$ENERGYHeat Recovery = estimated annual energy cost for heat-recovery chiller operation ($/year)
EFFxx% = chiller efficiency at xx% of maximum capacity (kW/ton)
HRSxx% = hours of chiller operation at xx% of maximum capacity (hours/year)
LOADxx% = cooling load at xx% of maximum capacity (tons)
$/kWh = average cost of electricity from the utilities data sheets ($/kWh)

The chiller in this example is operating at a constant base load of 400 tons year-round, with xx% = 80%.

$ENERGYHeat Recovery = {(0.645)(6,420)(400) + (0.750)(2,340)(400)} × (0.07)
$ENERGYHeat Recovery = $165,000/year

A11.3.3. **Boiler Annual Energy Costs.** Calculate the energy costs to provide the required process heat output with the existing electric HW boiler ($BOILER-ENERGY). This calculation shows money saved by producing the required heat from the heat-recovery chiller instead of the electric boiler. Figure A11.2 illustrates this calculation.

Figure A11.2. Calculate $BOILER-ENERGY.

$BOILER-ENERGY = Σ(INPUTxx%)(HRSxx%)($/kWh)

Where:

$BOILER-ENERGY = annual energy cost to operate boiler ($/year)
INPUTxx% = electrical input at xx% of maximum capacity (kW)
HRSxx% = 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)(0.07)
$BOILER-ENERGY = $253,800/year

A11.3.4. **Chiller and Boiler $PV.** Calculate the LCC for the cooling-only replacement chiller and HW boiler and compare it to the calculated heat recovery option, as shown in Figure A11.3.

Figure A11.3. Calculate Chiller and Boiler $PV.

$PVReplacement = $BOILER-ENERGY(P/A,i%,N) + $PVChiller
= (253,800)(13.36) + 1,510,000
= 3,390,800 + 1,510,000
$PVReplacement = $4,900,800

Table A11.2. 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.

Note: This table 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.

A11.3.5. **Present Value ($PV) Formula.** A present value formula review is presented before it is applied to the heat-recovery chiller LCC. This analysis assumes a 20-year study period and an expected 20-year equipment lifespan. The useful equipment lifespan is assumed to be the same across the study's length ($REMAIN is zero). No capital equipment is replaced during the study period ($REPLACE is zero). Heat-recovery system maintenance is approximately $2,000 more per year compared to chiller/boiler combinations. A portion 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 A11.4.

Figure A11.4. Present Value ($PV) Formula.

$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 (%)[1]

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 standard engineering economics
2. NISTR 85-3273-26, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis*

A11.3.6. **Calculate Present Value of LCC for Heat-Recovery Chiller ($PV).** Calculate the present value of the heat-recovery chiller's life-cycle costs ($PV). This calculation is shown in Figure A11.5.

Figure A11.5. Calculate $PV.

$PV = $INITIAL + ($ENERGY + $MAINT)(P/A,i%,N) - ($REMAIN)(P/F,i%,N)
For the heat-recovery chiller system
$PVHeat Recovery = $270,600 + ($120,280 + $2,000)(P/A,4.2%,20)
= $270,600 + $122,280(13.36)
= $270,600 + $1,633,700
$PVHeat Recovery = $1,904,300

A11.3.7. **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.

Figure A11.6. LCC Comparative Analysis Results.

$PVReplacement = $4,042,400
$PVHeat Recovery = $1,932,400
Select the heat-recovery chiller.

Attachment 12

ALTERNATIVE REFRIGERANTS FOR RETROFIT APPLICATIONS: LONG-TERM AND INTERIM REFRIGERANTS

A12.1. Introduction. The Montréal Protocol (1987) was amended in 1992 to halt production of all CFCs by 1996, HCFC-22 by 2020, and HCFC-123 by 2030. Manufacturers responded by introducing an assortment of alternative refrigerants. Some confusion resulted from manufacturers marketing the same alternatives by one trade name before receiving an ASHRAE "R" designation and then by a different trade name after the designation was granted. Alternatives may have similar properties but careful consideration is required to make the proper selection. Consider four issues before choosing an alternative refrigerant: (1) the long-term or interim nature; (2) lubrication; (3) chemical stability of refrigerant blends; and (4) equipment operation and maintenance. These factors are explained in the following sections.

A12.1.1. **Long-Term Versus Interim Alternative Refrigerants.** Some refrigerants are scheduled for phase-out before others. Equipment using interim refrigerants was scheduled to be manufactured until 2010. Interim refrigerant production will continue until 2020. Equipment using R-123 will be produced until 2020. R-123 will be produced until 2030. At this time, production phase-out of R-123 is not an issue. An increasing number of refrigerant alternatives means market acceptance will be dictated largely by availability rather than phase-out dates.

A12.1.1.1. Long-term alternative refrigerants are HFC refrigerants or blends (mixtures) of HFC refrigerants which have 0 ozone-depleting potential (ODP) and do not face a foreseeable phase-out. However, EPA rules for venting CFC and HCFC refrigerants also apply to HFCs; no one can knowingly release an HFC. Sometimes a long-term alternative refrigerant can be installed with a simple oil change. However, most HFC alternatives require a polyol ester (POE) lubricant and a system 95 percent free of mineral oil. Choosing a long-term alternative relieves concern about refrigerant supplies after HCFCs are phased out. This is not an issue for equipment expected to last less than 25 to 30 years—HCFC refrigerants will still be produced during this time. The 2009 meeting of the United Nations Climate Change Conference in Copenhagen focused on the issue of global warming but conference members were not able to reach a global agreement that would have limited the future availability of refrigerants with higher global warming potential (GWP).

A12.1.1.2. Interim refrigerant alternatives are refrigerant blends with one or more HCFC refrigerants. HCFCs and any refrigerant blends with HCFCs are scheduled for phase-out between 2020 and 2030. Therefore, any equipment retrofitted for HCFCs or HCFC blends may have to be retrofitted again or replaced during the HCFC phase-out. Interim refrigerants make retrofitting CFC equipment financially feasible. It is also possible to use them to retrofit equipment ill-suited for long-term alternative refrigerants. Many interim alternatives can be installed during maintenance by removing the CFC refrigerant and adding the alternative. However, most interim alternatives require a mineral oil/alkylbenzene lubricant mixture; lubricant adjustments may be necessary.

A12.1.2. **Mineral Oil or Polyol Ester (POE) Lubricants?** Lubricants play a major role in the selection of a long-term or interim alternative refrigerant. Typically, long-term alternatives require a POE lubricant and interim alternatives require an alkylbenzene/mineral oil mixture. Equipment using mineral oils should not be retrofitted to a POE lubricant unless absolutely necessary

A12.1.2.1. Long-term alternatives require POE lubricants because they are not miscible in mineral oil. Therefore, a system must be free of mineral oil before a long-term alternative is used. Expensive POE is used to flush the system of mineral oil with the current refrigerant still in place. At least three flushings are required. Since POEs cost $50 or more per gallon, flushing a system requiring large quantities of lubricant can become quite expensive. The lubricant used to flush the system must be properly disposed of. Lubricant disposal must be coordinated with the environmental flight. POEs work like a cleaning agent: they can free up and suspend wear particles, metal fragments, etc., and carry them through the system. This can damage the compressor(s) or obstruct system parts. For this reason, systems using mineral oil lubricants which had mechanical difficulties or are over four years old should not be converted to POE lubricants. It is virtually impossible to flush all the mineral oil from a hermetic compressor. For this reason, hermetic compressors cannot be converted to long-term refrigerants.

A12.1.2.2. Most interim alternatives require an alkylbenzene/mineral oil lubricant mixture. Using an alternative refrigerant compatible with a lubricant mixture of mineral oil/alkylbenzene is simpler and less expensive than converting to a POE. The mixing ratio of alkylbenzene to mineral oil varies from 50/50 to 80/20 depending on the application, refrigerant type, etc. Different mixing ratios are recommended by different refrigerant and compressor manufacturers. Always consult the compressor manufacturer for the proper lubrication requirements.

A12.1.3. Refrigerant Blends.

A12.1.3.1. Azeotropic refrigerant blends are mixtures of two or more refrigerants that behave as a pure fluid. In short, during evaporation or condensation, the liquid and vapor components of the blend do not change composition; this happens only at a given temperature and pressure. With other temperatures and pressures, deviation from this behavior is virtually undetectable. Like a pure fluid, azeotropic refrigerant blends can be charged in their liquid or vapor state. If the evaporator or condenser leaks, it can simply be topped off with new refrigerant following the leak repair. Azeotropic blends like R-500 and R-502 have been available for years.

A12.1.3.2. Zeotropic refrigerant blends are mixtures of two or more refrigerants that have different vapor pressures and boiling points. During a phase change, the vapor and liquid states will have different compositions and exhibit different properties. This is known as fractionation. When using a zeotropic blend, the equipment must be charged only with liquid. If a large leak occurs with vapor and liquid refrigerant present, the components of the refrigerant blend will leak in different proportions because of fractionation. The result will be a refrigerant blend that has different operating characteristics than the original blend. This will cause a shift in the refrigerant's temperature-pressure curve, making accurate recharging difficult and affecting system efficiency. Consequently, after a large refrigerant leak or an accumulation of many minor leaks, the total charge may have to be removed and disposed of as required by EPA regulations. After the old refrigerant is evacuated, the system has to be completely recharged. Zeotropic blends display a characteristic known as "temperature glide" or "glide." Glide classifies how much the zeotropic blend's behavior is different from an azeotropic blend. Glide temperatures range from below -17 °C (1 °F) to above -11 °C (12 °F). Higher glide numbers mean worse fractionation.

A12.1.3.2.1. The liquid and vapor components of a zeotropic blend have different compositions and properties during evaporation and condensation. In a pure vapor form with no liquid present or in a pure liquid form with no vapor present, the zeotropic blend is completely mixed and its properties are uniform throughout the mixture. However, in phase change areas of a system where both vapor and liquid are present, the vapor and liquid will have different compositions. Consider a zeotropic blend with only two components: one will have a higher boiling point. When a liquid-to-vapor phase change begins, the component with the lowest boiling point begins to evaporate. The temperature at which this component reaches its boiling point and forms a vapor is called the bubble point. Bubble point is defined as the temperature at which bubbles first appear in the refrigerant. The vapor is rich and grows richer in the low-boiling-point (higher vapor pressure) component. This enrichment or difference in composition is fractionation. At the same time, the liquid is becoming rich with the higher-boiling-point (lower vapor pressure) component. The higher-boiling-point component eventually begins to evaporate. The point at which the last drop of the higher-boiling-point component evaporates is the dew point. It is also the temperature at which the first drop of liquid appears during condensation. Condensation takes place in the reverse order.

A12.1.3.2.2. In the evaporator and the condenser, two phases of refrigerant exist: a liquid phase and a gas phase. Since each component of the refrigerant goes from the liquid phase to the vapor phase at different times due to each component's different boiling point, phase composition is constantly changing. The evaporation and condensation temperatures of each refrigerant component are not constant. As the phase composition changes from constant pressure, the evaporation and condensation temperatures of each refrigerant component actually fluctuate. These temperatures may increase or decrease as each refrigerant component changes in each phase. This change in temperature during constant pressure phase change is called temperature glide. Simply put, temperature glide is the difference between the dew point and bubble point temperatures. It varies with the refrigerant component percentage composition and pressure. The amount of glide a mixture exhibits is a measure of deviation from being an azeotrope. Unfortunately, glide is defined differently by different organizations and companies. For example, ICI Americas, Inc. (ICI) uses the term "boiling range" instead of temperature glide. Glide or system glide is defined by ICI as the difference between the inlet and outlet temperatures in a DX evaporator or condenser. When looking for glide in product literature, be certain you know how the term is defined.

A12.1.3.3. The alternative refrigerants discussed in this attachment are either azeotropic or zeotropic blends. Azeotropic refrigerant blends are the easiest to maintain and use. When selecting an alternative refrigerant, choose an azeotrope over a zeotrope, if possible. Since most CFC alternatives are zeotropes and alternative azeotropes require POE lubricants, it is likely that most retrofits will be completed with a zeotrope. A technically significant factor about zeotropes is glide. Since most of the alternative refrigerants are relatively new, opinions differ about their glide severity. DuPont states: “After a series of large leaks followed by topping off, a system could show a few percent loss in capacity.” In Elf Atochem’s opinion, systems using a low glide temperature of -17 °C (1 °F) that do not lose over 50 percent of their charge during a leak can be topped off. Copeland states they have not witnessed a leaking system that required a total charge removal followed by a system recharge. The systems they dealt with were topped off after leaking. ICI’s opinion is that topping off a system which has leaked is acceptable and presents no real problems. Their experience shows that after topping off a system a couple of times, the composition of the refrigerant does change, but it reaches a point of consistency that is unaffected by future top-offs. AlliedSignal’s opinion is that if a system suffers a leak and loses over 10 percent of its charge, the remaining refrigerant should be removed and the system totally recharged. They believe that if a system suffers one or two leaks of less than 10 percent, the system can be topped off, but following a third leak the system should be completely recharged. To reduce the effects of glide, an alternative with a low glide temperature should be selected. Although most of these manufacturers do not believe glide poses a problem, technicians should be aware of possible refrigerant temperature changes. Systems can be topped off after a leak occurs. Still, there are no concrete procedures for dealing with temperature glide and zeotropic refrigerant leaks. Glide will be solved only with time and experience.

A12.1.3.4. Charging a system using a zeotropic refrigerant is different than doing so with a pure fluid. A system that uses a zeotropic refrigerant must be charged/topped off with liquid refrigerant. If the entire cylinder is used during charging, the vapor may be charged after the liquid has been charged. Based on the refrigerant type being replaced, the alternative refrigerant will have a larger or smaller charge requirement. Consult the refrigerant’s manufacturer for information about proper charge capacities for alternative refrigerants. Most refrigerant manufacturers recommend that measuring operating conditions—e.g., discharge and suction pressures, suction line temperature, compressor amps, superheat—is the best way to charge a system. Sight glass charging can be completed for most systems. If the sight glass is located too close to the condenser exit or if there is a little sub-cooling before the sight glass, bubbles may be present in the sight glass even after the system is properly charged. To determine the appropriate suction pressure for an alternative refrigerant, the suction pressure for the refrigerant being replaced must be known. Using a pressure/temperature chart, determine the evaporator temperature for the current refrigerant. Adjust the evaporator temperature as instructed by the manufacturer to get the new evaporator temperature for the alternative refrigerant. Using a pressure/temperature chart for the alternative refrigerant, the suction pressure can now be found. Consult the refrigerant’s manufacturer for proper charging and topping-off procedures.

A12.1.4. **Operation/Maintenance Issues.** Operation and maintenance of equipment using a large number of different refrigerants can be problematic. As the number of base refrigerants increase, the complications tend to increase. Proper refrigerant handling can be an issue. A large number of refrigerants require diverse handling and storage needs. All refrigerants must be properly inventoried and tracked. It becomes difficult to keep track of what is entering storage, what is being issued to technicians, and what refrigerants the technicians are returning. Refrigerants with different purities have to be tracked, including good, contaminated, or reclaimable refrigerant. A large number of containers are needed. Containers require more storage space. Properly marking and separating these containers by refrigerant type and purity can become difficult and time-consuming. There must be an MSDS maintained for each refrigerant. All machinery using refrigerants must be properly marked so that the wrong refrigerant is not introduced into the wrong system. Proper color-coding of refrigerant cylinders according to AHRI Guideline N is helpful to ensure proper separation of stored refrigerants and to avoid mixing.

A12.2. Alternative Refrigerants That Replaced CFCs. Refrigerant R-11 was replaced by HCFC-123 (R-123). A pure fluid, R-123 is an interim HCFC (Class II) alternative; therefore, new long-term refrigerant alternatives must be developed. At this time, no suitable alternative refrigerant has been developed. It was used in retrofits and is currently used in new, low-pressure chillers. AFI 32-7086 requires Class II refrigerants to be part of the RMP. The Air Force will not centrally stockpile CFC and purchasing equipment using Class I refrigerants is prohibited. The BCE can approve exceptions to this prohibition. The BCE is allowed to purchase equipment with Class II refrigerant as long as the refrigerant is included on the EPA list of Significant New Alternatives Policy (SNAP) -approved refrigerants (see paragraph A12.3.1.1.). The BCE must document how the equipment will be supported following the phase-out, update the RMP initially, and update the support plan annually. Trane is currently the only manufacturer that still offers chillers using R-123. Most manufacturers use HFC-134a (R-134a) primarily for their large, centrifugal chillers. Chillers that use R-123 are generally more efficient. R-123 has a 93 GWP compared to R-134a’s 1300 GWP**,** but R-123 has a 0.02 ODP compared to R-134a’s 0 ODP. There are very few R-123 refrigerant leaks because R-123 chillers operate at below-atmospheric pressure. If leaks do occur during normal operation, air leaks in rather than R-123 refrigerant leaking out. Because of the low leakage rate of its chillers, the year of its phase-out (2030), and because stockpiles of recycled/recovered/reclaimed R-123 can be used after 2030, R-123 supplies should be readily available throughout the useful life of centrifugal chillers. R-11, the predecessor to R-123, was phased out in 1996, and low-cost supplies of that refrigerant are still readily available. Trane has requested that R-123 be excluded from the required 2030 phase-out because of its high-efficiency, very low GWP, very low ODP, and low toxicity. There are apparently no exceptions for R-123 being considered. The BCE should consider these issues before allowing R-123 use in new equipment purchases for the base. R-123 should remain on the SNAP-approved refrigerant list for new equipment until 2020. Equipment purchased up to 2020 should have R-123 supplies available for service.

A12.3. Alternative Refrigerants for HCFCs.

A12.3.1. Alternate Refrigerant Evaluation and Approval.

A12.3.1.1. The EPA SNAP program was developed to meet the requirements of Section 612 of the CAA. The SNAP program describes the procedure for submitting safe alternative refrigerants that replace Class I and Class II refrigerants. The current approved SNAP list is available at **http://www.epa.gov/ozone/snap**.

A12.3.1.2. These refrigerants were evaluated for their toxicity, flammability, efficiency, GWP, stable blends, and many other properties. The manufacture of CFC refrigerants has been phased-out since 1996. The current focus of the Montréal Protocol and the EPA is the phase-out of Class II (HCFC) refrigerants, which include HCFC-22 (R-22) and R-123. R-22 has a 0.055 ODP and a 1700 GWP. R-123 has a 0.02 ODP of and a 93 GWP.

A12.3.1.3. Each year, the list of approved and unapproved chemicals is published in the Congressional Federal Register. The list of approved chemicals from the Congressional Federal Register, updated in 2008, was used to develop a comprehensive list of approved refrigerants, the applications they are approved for, and their various chemical properties. Some of the proposed substitutes have been available before SNAP began. Some refrigerant replacements are intended for only new equipment. For instance, R-410a is used as a substitute for R-22 but is used only in newly manufactured equipment because its condensing pressure is much higher than that required by R-22. HFC-410a (R-410a) has a 0 ODP and a 1725 GWP.

A12.3.1.4. When evaluating alternative refrigerants for a particular application, the GWP is considered along with the refrigerant's performance properties. GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale that compares the gas in question to a carbon dioxide mass with 1 GWP. GWP is calculated over a specific time interval (usually 100 years) and the time interval must be revealed when a GWP is quoted; otherwise, the value is meaningless.

A12.3.1.5. GWP should be considered for a direct case or indirect case. A direct case involves venting refrigerant directly into the atmosphere. The refrigerant works like a blanket to hold in heat. Indirect GWP involves the refrigerant manufacturing process or the energy required to operate the equipment the refrigerant serves. For every additional kWh used by equipment, greenhouse gas emissions are generated by electric utility power plants. This is the indirect effect of global-warming refrigerants. Even small changes in chiller energy use have an environmental impact. The use of refrigerants that minimize both ODP and GWP address global environmental concerns. HCFC R-123 and HFC R-134a are the primary refrigerants used in chillers. R-134a has 0 ODP and a 1300 GWP. R-123 has a 0.02 ODP and a 93 GWP. Chillers using R-123 are generally more efficient than those using R-134. The indirect GWP of a chiller using R-134a may be higher than a chiller using R-123.

A12.3.1.6. Due to the Kyoto Protocol and the 2009 United Nations Climate Change Conference in Copenhagen, GWP is getting a lot of attention. The global regulation of greenhouses gas emissions failed after delegates were unable to reach an agreement. Based on the earlier Kyoto Protocol, Europe is trying to rapidly reduce greenhouse emissions. R-134a has replaced CFC R-12 in many applications, including chillers and automotive air-conditioning. Although R-134a performs adequately, it is being phased out for automotive air-conditioning in Europe by 2013 because of its 1300 GWP. The leading refrigerant to replace it is R-744 or CO_2. HFO-1234yf is Honeywell's latest offering to meet the American auto industry's need for a cost-effective, commercially viable, and environmentally friendly R-134a refrigerant replacement. Although HFO-1234yf is flammable, the benefits of HFO-1234yf are lower lifetime greenhouse gas emissions; dramatically shorter atmospheric lifetime; compatibility with current automotive air-conditioning systems; superior cooling efficiency; ease of adoption; and safety for mobile applications.

A12.3.1.7. As HFCs come under continued pressure from environmental regulations, it is expected that the HFOs will replace the HFCs in heating, ventilation, and air-conditioning (HVAC) applications. Manufacturers are testing and evaluating these options today.

A12.3.1.8. Another key refrigerant property that must be considered is safety. The safety code for refrigerants is ASHRAE 15-2007, *Standard Safety Code for Mechanical Refrigeration*. Each refrigerant is categorized A1, A2, A3 or B1, B2, B3. As the A-scale increases from A1 to A3, refrigerant flammability increases. As the B-scale increases from B1 to B3, the refrigerant toxicity increases. An A1 refrigerant is not flammable under test conditions and B1 is only slightly toxic. B3 is highly toxic and highly flammable. As discussed in paragraph A12.1.3, the blend properties also influence refrigerant selection.

A12.3.2. **Alternatives to R-22.** R-401A, made by both AlliedSignal and DuPont, is a retrofit alternative for R-12 in medium-temperature refrigeration applications. It is a zeotropic blend. Since R-401A is a blend of refrigerants involving HCFC, it is considered an interim replacement. It will be phased out with R-22 in 2020. Using R-401A in systems where the evaporator temperatures are -23 °C (-10 °F) and above should produce capacities and efficiencies similar to R-12. R-401A is suitable for walk-in coolers, food and dairy display cases, beverage dispensers, beverage vending machines, and home refrigerators. Refrigerant alternatives have differing compressor lubrication requirements, depending on the manufacturer. Always consult the compressor manufacturer for proper lubrication requirements since the manufacturer provides the warranty. Seek out original equipment manufacturer (OEM) assistance when attempting retrofits. Precautions must be taken to assure material and refrigerant compatibility. DuPont's SUVA® HP refrigerants are not recommended for flooded evaporators. Consult the OEM before choosing a refrigerant replacement or determining material compatibility.

A12.3.2.1. **R-407C.**

A12.3.2.1.1. HFC-407c (R-407c) is a zeotropic blend refrigerant that closely matches the properties of R-22. R-407c is a blend of R-32, R-125, and R-134a. This refrigerant can be used in several air-conditioning applications, including new residential and commercial DX air-conditioning equipment, or as a drop-in replacement for R-22. R-407C is not good for equipment using flooded evaporators such as chillers because of its zeotropic properties. The glide is -10.3 °C (13.3 °F).

A12.3.2.1.2. R-407c requires an approved POE lubricant where it replaces R-22. This replacement affects refrigerant performance.

A12.3.2.1.3. Temperature glide is a concern when using R-407C. It can become a serious issue if a leak develops. Performance diminishes because different components have different rates of boiling and condensation. If a leak occurs, the refrigerant ratio may be changed. Due to this factor, refrigerant cannot simply be added—the system has to be completely evacuated and recharged with the proper component ratio. Service duties will require more training and caution because of the refrigerant's nature. R-407C has a 1600 GWP, slightly lower than R-22 with a GWP of 1730. Its operating pressures are similar to R-22.

A12.3.2.2. **R-417a.**

A12.3.2.2.1. NU-22 (R-417a) is another possible drop-in replacement for R-22. There are several different applications where this refrigerant can replace R-22. This drop-in refrigerant has several qualities like R-22. R-417a is able to replace it without any unit modification or oil change. R-417a can be used with mineral and alkyl benzene oils and new POE lubricants. This makes transitioning between the two refrigerants easy. It is an effective zeotropic 3-component. R-417a works well in higher temperature applications.

A12.3.2.2.2. This refrigerant has 0 ODP and can be used as a drop-in replacement or in new equipment. There have been tests performed by other refrigerant manufacturers on R-417a and it has been compared to R-22. The test results reported a decrease in compressor oil levels. Another reported finding was a 27 percent lower cooling capacity than R-22. A 15 percent lower COP was also reported between R-417a and R-22. The 1938 GWP for R-417a is higher than R-22 at 1700 GWP. It has a temperature glide of 10, and an A1 ASHRAE safety classification.

A12.3.2.3. **R-410a.** HFC-410a (R-410a) is a substitute for R-22 but it is used only in newly manufactured equipment because the condensing pressure is much higher than that required by R-22. R-410a has a 0 ODP and a 1725 GWP, which is slightly higher than R-22. R-410a is one of the easier refrigerants to work with because it is a near-azeotropic blend with a glide less than 1. It works like a single chemical. R-410A is not suitable as a drop-in for R-22 because of differences in the high-pressure operating point. R-410a operates at over 400 psi while R-22 operates at about 260 psi. R-410a is the most widely used replacement for R-22 in new equipment by all the major manufacturers of AC/R equipment, including Trane, Carrier, McQuay, and York.

A12.3.3. **R-123 Substitute and Other Alternative Refrigerants.**

A12.3.3.1. Refrigerant manufacturers and manufacturer groups are working continuously to develop safe, efficient, stable and environmentally friendly refrigerants. R-123 is, by most of these measures, a very good refrigerant. R-123 was the replacement for CFC R-11. R-123 has a 93 GWP and a 0.02 ODP. Because R-123 has a very slight ODP and is a HCFC, it is being phased out by 2030. No completely suitable replacement has been developed that operates as efficiently and safely as this refrigerant or at such a low GWP.

A12.3.3.2. R-245fa closely matches R-123's capabilities. R-245fa is a propane-based refrigerant but has a B1 ASHRAE safety classification. It is non-flammable and slightly toxic. R-245fa operates at below-atmospheric pressure inside the evaporator but operates at a higher pressure than R-123 inside the condenser. This may require modifications to current equipment. It has a 920 GWP. R-245fa is not currently being offered by refrigeration equipment manufacturers.

A12.3.4. **Alternative Refrigerant Issues.**

A12.3.4.1. Other refrigerants used in the air-conditioning industry are less efficient and have a much higher GWP: R-134a has a 1300 GWP, R-410a has a 1725 GWP, and R-407c has a 1600 GWP. These three refrigerants represent most of the alternative refrigerants in use by Trane, Carrier, McQuay, York, and Lennox. Trane is the only manufacturer still using R-123 in their chillers. Because of R-123, Trane chillers have the highest efficiency in the industry. R-123 evaporates at a pressure below atmospheric pressure so the chillers' design must be changed if the substitute refrigerant operates at a positive pressure. There has been some discussion in the past of giving HCFC R-123 an exemption in the HCFC phase-out in light of its very low ODP and GWP, but there is no progress evident at this time.

A12.3.4.2. As mentioned above, R-744 is considered a likely replacement for R-134a in European automobile air-conditioning systems. In the United States, R-152a is being considered for automotive air-conditioning systems. Both refrigerants cause concern. At over 1000 psi, R-744 has over five times the operating pressure of R-134a. R-152a is being considered for automotive air-conditioning in the United States and is considered flammable, with an A2 ASHRAE safety classification and a GWP of 140. R-123 is slightly toxic, with a B1 ASHRAE rating. R-744 has an A1 ASHRAE safety classification. R-152a has an A2 ASHRAE refrigerant classification, which indicates slight flammability.

A12.3.4.3. Some hydrocarbons have similar characteristics as refrigerants. Three hydrocarbon blends have been created to serve in the same capacity as common refrigerants. These are HC-12a, HC-22a, and HC-502a. However, these are not considered acceptable refrigerants because of their high flammability.

A12.4. Best Alternative Refrigerants.

A12.4.1. **Considerations on Alternative Refrigerants.** This attachment recommends alternative refrigerants based on literature from refrigerant and compressor manufacturers. The pursuit of an ideal refrigerant alternative for HCFCs constantly produces new data on existing alternatives and future alternatives. Therefore, always consult the OEM for approved recommendations that will not void warranties.

A12.4.2. **Use POE Sparingly.** It is recommended that unless a system is already using a POE lubricant, an alternative that requires such a lubricant should not be the first choice for retrofit. In other words, any system using mineral oil should not be retrofitted to use a POE unless absolutely necessary. It can be quite expensive and troublesome to retrofit a system to a refrigerant that requires a POE lubricant. Using an alternative that requires mineral oil or a mineral oil/alkylbenzene mixture is less expensive, simpler, and just as efficient with the proper refrigerant. The three alternative refrigerants listed for R-12 do not require a POE lubricant and should be the first choice in refrigeration equipment retrofits. R-401b is the best choice when retrofitting R-500 refrigeration equipment. If an R-502 system is currently using a POE lubricant, R-507 should be the first consideration for an alternative refrigerant. However, if the system is not using a POE, R-408a is suggested as the first choice for retrofit.

A12.5. Handling Alternative Refrigerants. Most alternative refrigerants are stored like CFC and HCFC refrigerants. Storage areas must meet ASHRAE 15-2007 requirements. They should be stored away from heat sources in an area where the temperatures are below 51 °C (125 °F). Under certain conditions, some refrigerants are flammable or pose other hazards. Alternative refrigerants mixed with the HCFC refrigerants they replace create no real danger but system performance is probably adversely affected. The combined refrigerants cannot be separated and must be incinerated after use. Exposure levels, hazards for humans, toxicity, etc., vary for each refrigerant. Always refer to the MSDS for proper handling and storage procedures for all refrigerants.

A12.5.1. **Mixing Refrigerants.** Refrigerants should not be mixed. Each refrigerant should be segregated into at least three categories: good refrigerant, refrigerant awaiting reclamation, and contaminated refrigerants requiring destruction. The fewer refrigerants maintained on a base, the simpler the storage and inventory requirements and the fewer the number of MSDS on file. In addition, limiting the number of refrigerants reduces the possibility of contaminating refrigerants through accidental mixing.

A12.5.2. **Refrigerant Tracking, Marking, and Storage.** All bases should minimize the number of refrigerants. As detailed in paragraph A12.1.4, the more refrigerants on base, the more difficult it is to maintain the refrigerants. All refrigerants must be properly marked by refrigerant type and purity level. MSDS must be maintained for all refrigerants. Tracking refrigerant movement in and out of storage can be difficult and time-consuming. Lots of refrigerant requires large storage facilities. By reducing the number of base refrigerants, the refrigerant manager simplifies the already difficult tasks of controlling and maintaining air-conditioning and refrigeration operations.

A12.6. Conclusions. The information in this attachment is based on refrigerant and compressor manufacturers' data and their case studies. Retrofits should be performed using OEM guidance. Precautions must be taken to assure material and refrigerant compatibility. The OEM will know if certain equipment materials are incompatible with alternative refrigerants and be able to supply retrofit guidelines. Although the refrigerant manufacturers also have retrofit guidelines, always consult the OEM before retrofitting refrigerants. Measures should be taken to track refrigerant usage, minimize refrigerant leaks, and maintain the equipment to operate at its peak efficiency.

Attachment 13

NATURAL GAS COOLING TECHNOLOGIES

A13.1. Introduction.

A13.1.1. New, more efficient and reliable gas cooling products made by U.S. manufacturers illustrates how natural gas cooling technology and equipment has improved tremendously in the past few years. This is one of the reasons that interest in gas cooling has been renewed. Interest in natural gas cooling has also been prompted by desires to reduce energy costs and avoid electric peak-demand charges, financial incentives such as rebates, and creative financing from the gas industry. Gas cooling equipment with high efficiencies and microprocessor controls are available for commercial facilities such as hotels, office buildings, supermarkets, and industrial facilities. Equipment suitable for residential applications also exists.

A13.1.2. Basic Types of Gas Cooling Systems.

A13.1.2.1. The three basic types of gas cooling systems are absorption systems, gas engine-driven (GED) systems, and desiccant systems. Absorption systems and desiccant systems can be matched with cogeneration systems that provide the heat needed to operate the cooling systems. The heat source that powers these systems can be in the form of steam, hot water, or high-temperature gases.

A13.1.2.2. In many cases, the heat source may be a byproduct of another operation, as in the case of a cogeneration system whose primary purpose is the generation of electricity, but from which a “waste” heat source in the form of low-pressure steam is available to power the absorption refrigeration cycle or to regenerate a desiccant. An absorption cooling system is one that uses condensation and evaporation of two liquids—an absorbent and a coolant—to produce cooling. The process uses heat instead of mechanical means to operate. Absorption systems may be direct-fired or indirect-fired. There are two basic types of absorption systems: chillers and chiller/heaters. There are also two types of chiller systems: single-stage/single-effect (referred to as single-stage by this attachment) and double-stage/double-effect (referred to as double-stage by this attachment). GED systems use the same refrigeration cycle as electric systems. The difference is simply the replacement of the electric motor in a conventional vapor compression refrigeration system with a natural gas-fueled internal combustion engine as the prime mover for the compressor(s). Desiccant cooling systems directly control humidity by absorbing water vapor from an airstream. This allows for separation of the latent cooling load from the sensible cooling load. Simply put, desiccants are used to dry the air before it is cooled.

A13.2. Absorption Chiller Systems. Both single- and double-stage chillers are used in various operations. Double-stage chillers are the more efficient of the two. Single-stage absorption chillers provide a lower initial cost.

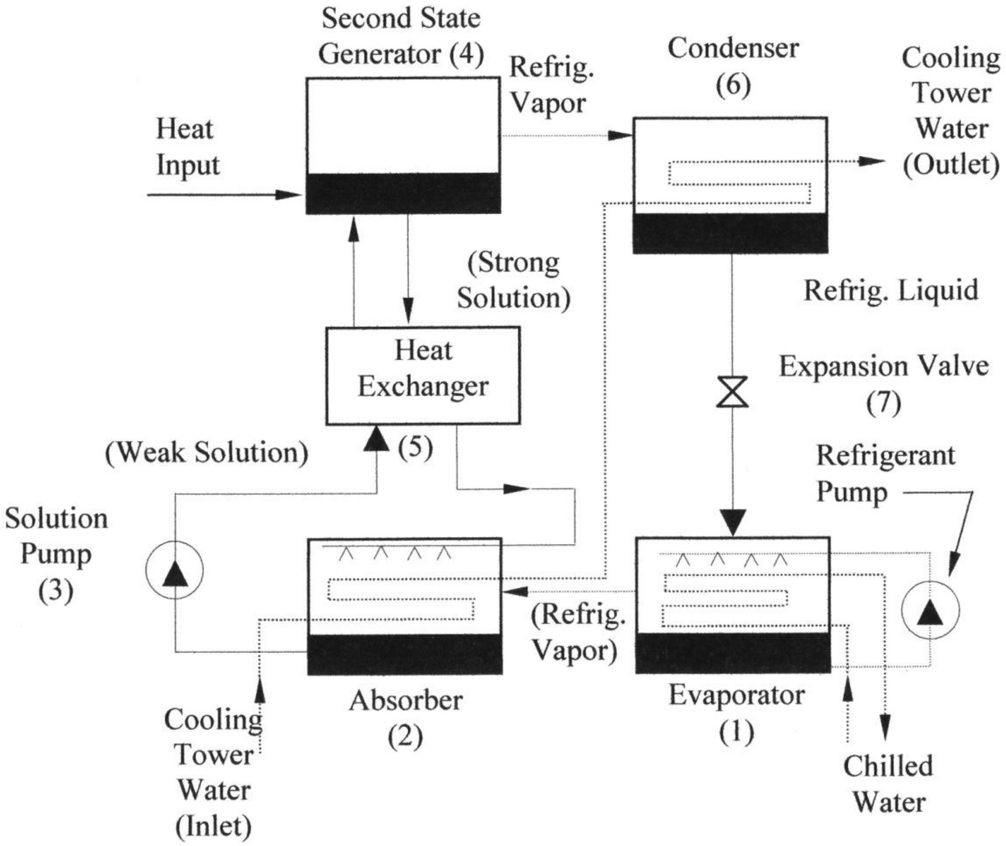
A13.2.1. **General Advantages.** Gas absorption systems help to avoid electrical peak-demand charges by reducing electrical consumption. There are few moving parts with an absorption system, allowing for quiet, vibration-free, low-maintenance operation. This makes absorption systems ideal for applications where quiet operation is a necessity, such as hospitals, libraries, churches, schools, and office buildings. Absorption chiller systems are classified by single-, double-, or triple-stage effects, which indicate the number of generators in a given system. The greater the number of stages, the higher the overall efficiency. Double–effect absorption chillers typically have a higher first cost but significantly lower energy cost than single-effect chillers. Absorption systems range in size from 3 to 1,700 tons. These systems may be either chiller systems or chiller/heater systems that provide heat as well as cooling. Advantages of absorption systems over electrical systems include low operating costs; no fluorocarbon-based (CFC, HFC, or HCFC) refrigerants; safe, quiet operation due to few moving parts and low-pressure operation; reduced space requirements because absorption systems can also provide heat, eliminating the need for boilers; and reliability and low maintenance.

A13.2.2. **General Disadvantages.** The biggest disadvantage with any gas cooling equipment is the first cost. This first cost is substantially higher than that of electric systems. Currently, the initial cost per ton of a double-stage, direct-fired absorption machine is approximately one-and-one-half to two times the cost of an electrically driven centrifugal machine.

A13.2.3. **Technological Advances.** The development of a triple-stage (triple-effect) absorption chiller system and the generator/absorber heat exchange (GAX) system are the latest technological advances in the area of absorption refrigeration. The triple-stage absorption chiller works like the double-stage. A third stage has been added to increase efficiency and performance. A COP of 1.5 is expected. When they become commercially available, triple-stage absorption systems should provide a 40 to 50 percent increase in performance over today’s systems. It is also projected that triple-stage systems can be produced at only a 25 percent cost increase over double-stage systems. The GAX system is being developed as a low-cost, highly efficient (COP = 0.8) system for use in residential applications. Presently no triple-effect absorption chillers are offered, but with the increased efficiency from the double-effect systems it is approaching the efficiency capabilities of the triple-effect. When Trane and York did triple-effect testing in the 1990s, COPs were in the range of 1.52 to 1.58. The double-effect presently offered has a COP of 1.35 for steam and 1.2 for direct-fired. GAX heat pumps, which boost efficiency by recovering heat when ammonia is absorbed into water, are now available for small commercial applications and large residential homes.

A13.2.4. **Single-Stage Absorption Systems.** Absorption chillers, like electric chillers, use a condensation-evaporation cycle to provide cooling. However, absorption chillers usually use water as the refrigerant and an absorbing material which can be a liquid or salt. Figure A13.1 shows the main components of a single-stage absorption cycle. The single-stage absorption process is described below.

Figure A13.1. Main Components of Single-Stage Absorption Cycle.



A13.2.4.1. The evaporator (1) operates identically to an evaporator in a standard refrigeration cycle. Liquid refrigerant enters the evaporator and absorbs the heat picked up from the building by the chilling medium.

A13.2.4.2. Concentrated absorbent or working fluid is in the absorber (2). At this point, it has a strong affinity for the refrigerant, causing it to readily absorb the refrigerant vapor from the evaporator. As the working fluid absorbs the refrigerant vapor, a vacuum is created. In turn, this low-pressure situation allows the refrigerant to evaporate at low temperatures. This causes the liquid refrigerant to vaporize and migrate into the absorber (2).

A13.2.4.3. The absorbent's affinity for the refrigerant diminishes as it absorbs more and more refrigerant. This solution, referred to as the weak solution due to its weak affinity for the refrigerant, is pumped (3) through the liquid-to-liquid heat exchanger (5) to the generator (4). Heat is added to the generator, causing the refrigerant to evaporate. This refrigerant vapor moves on to the condenser (6), but the newly concentrated solution (strong solution) returns to the absorber.

A13.2.4.4. Heat is recovered from the strong solution by a liquid-to-liquid heat exchanger (5). This heat is used to preheat the weak solution before it enters the generator.

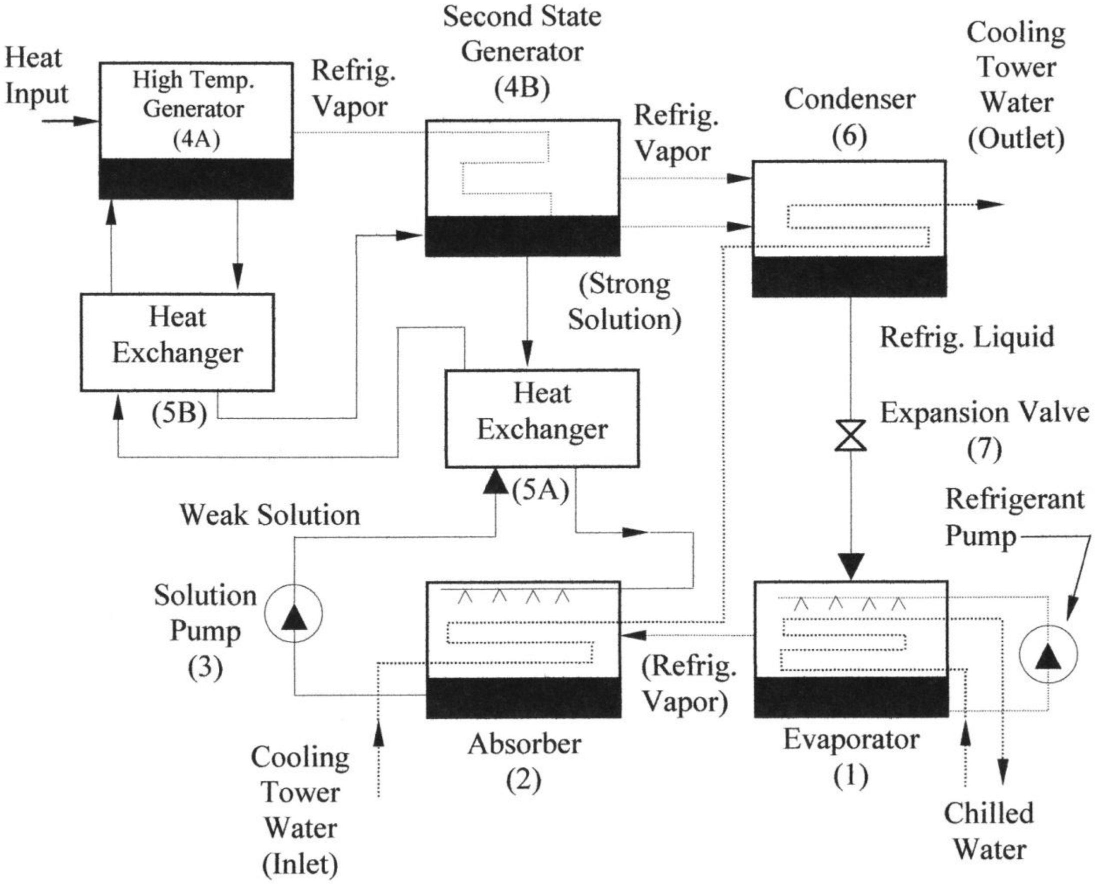
A13.2.4.5. The condenser cools and condenses the hot refrigerant vapor from the generator. This liquid refrigerant passes through the expansion valve (7) back into the evaporator.

A13.2.5. **Double-Stage Absorption Systems.** The double-stage (double-effect) cycle is the system preferred by most chiller users today. It uses two generators to more efficiently harness energy from the heat source. Figure A13.2 shows the more efficient double-stage cycle. The main differences between the double-stage and the single-stage systems are:

A13.2.5.1. The low-temperature generator (4B) uses the high-temperature generator (4A) as its heat source. The low-temperature generator is used to produce additional refrigerant vapor. A double-stage system generates around 30 to 40 percent more refrigerant vapor than a single-stage system.

A13.2.5.2. One additional liquid-to-liquid heat exchanger is used with the double-stage system; this is the high-temperature heat exchanger (5B). This additional device improves the efficiency of the system heating the weak solution with heat recovered from the strong solution leaving the high-temperature generator.

Figure A13.2. Main Components of Double-Stage/Double-Effect Absorption Chiller.



A13.2.6. **Driving Force for Absorption Systems.** Absorption chillers can use virtually any source of heat as a driving force, as long as the heat provided is of sufficient temperature. For a single-stage system using water and lithium bromide, the heat source should provide heat at a minimum of 93 °C (200 °F) for optimum performance. Low-pressure steam, around 15 psig, is a common driving force for single-stage absorption systems. Heat sources generating temperatures as low as 72 °C (162 °F) can and have been used to drive single-stage systems. However, capacity and efficiency drop as the temperature of the driving force drops. Double-stage absorption systems require heat sources to provide temperatures of approximately 149 °C (300 °F). This means that double-stage systems are either direct-fired by natural gas or oil or use high-pressure steam of 120 psig and above as a driving source. Steam at pressures as low as 45 psig have been used to drive double-stage systems at reduced capacity.

A13.2.7. **Applications.** In the private sector, direct-fired absorption systems are most commonly applied where high peak electrical rates concurrent with low natural gas rates create a favorable economic climate for their operation. Additionally, the unique ability of these machines to be configured to simultaneously provide chilled water and hot water is often an advantage where the equipment room space is limited and the cost of expanding an equipment room is prohibitive. Indirect-fired single- and double-stage absorption systems are particularly well-suited to applications where a waste energy source in the form of hot water or steam from an industrial process or cogeneration plant is available. Steam-powered absorption systems are often used in hospitals where steam boilers must be fired year-round to support typical hospital operations. In these circumstances, the steam consumption of the absorption system helps provide a base load to the existing boiler, thus making boiler operation more efficient during the summer months.

A13.3. Gas Engine-Driven (GED) Systems. GED systems are vapor compression refrigeration systems that use a natural gas-fueled internal combustion engine instead of an electric motor as the prime mover for the compressor. The engines used to power these systems can be automotive derivatives, industrial diesel engine derivatives, or stationary industrial engines specifically designed to operate with natural gas as a fuel source. Even rotary (Wankel) engines have been adapted to serve as prime movers for GED systems. Centrifugal, rotary screw, and reciprocating compressors can be used in GED systems. GED systems can be chillers, packaged rooftop DX systems, and even residential packaged heat pump systems.

A13.3.1. **General Advantages.** GED systems have been in use for several decades. In the past, they were not economically feasible for general use due to the combination of high first cost and high fuel costs. The deregulation of the gas industry in the 1980s caused the cost of natural gas to drop considerably for the commercial and industrial consumer. GED systems are now becoming economically viable alternatives to conventional electrically driven systems in many locations. GED systems can also be used for peak shaving in circumstances where utility rate structures impose severe time-of-use penalties to discourage electrical consumption during peak electrical demand periods.

A13.3.1.1. Using a GED system allows for recovery of most of the engine’s waste heat. This heat can be used to generate domestic hot water or low-pressure process steam. Hot water at 121 °C (250 °F) and 30 psig or steam at 112 °C (235 °F) and 8 psig can be produced when using a forced engine jacket cooling system. Steam at 121 °C (250 °F) and 15 psig can be produced by ebullient cooling of the engine. Up to 75 percent of the exhaust gas heat can also be recovered. The hot water or steam produced can be used for domestic purposes or industrial purposes. This recovered energy can also be used to operate a single-stage absorption chiller system or as the regeneration energy source for desiccant cooling systems.

A13.3.1.2. GED systems offer higher efficiencies than current absorption systems. Depending upon equipment size, thermal COPs range from 1.3 to as high as 1.9. If an effective use for the recoverable waste energy produced by the engine is available, the effective COP of these systems can be increased even further.

A13.3.1.3. GED systems offer very efficient part-load performance. These systems have variable speed capabilities. Cooling capacity can be controlled by varying the engine speed. A low operating cost and a high degree of flexibility can be achieved by combining engine speed variation with conventional capacity-reduction techniques such as inlet guide vane operation in centrifugal systems and cylinder unloading in reciprocating systems. Variations of 30 to 50 percent of the rated engine speed are possible. However, to avoid problems with lubrication and fuel economy, engine speed should not be reduced below the operating range recommended by the engine manufacturer.

A13.3.2. **General Disadvantages.** The biggest disadvantage of using GED systems is the first cost. Currently, the initial cost per ton of a GED chiller is approximately one-and-one-half to two times the cost of an electrically driven centrifugal machine. In fact, the cost per ton of these machines is very similar to the cost per ton of direct-fired absorption machines. GED machines do, however, offer higher efficiencies than direct-fired absorption machines, particularly when engine jacket and exhaust heat recovery can be used. The maintenance cost for these machines is higher than either absorption or conventional electrically driven chillers. Currently, the additional maintenance cost for the internal combustion engines that drive these machines is approximately $0.01/ton-hour of cooling load when compared to similar electrically driven machines. This maintenance cost should cover scheduled periodic maintenance (oil and filter changes at 750 run-hour intervals), minor engine overhauls at 12,000 to 15,000 run-hour intervals, and major engine overhauls or engine replacements (with automotive-derivative engines) at 25,000 to 30,000 run-hour intervals. Actual maintenance intervals will vary from unit to unit. Manufacturers should be consulted for up-to-date costs. In contrast, electrically driven machines can be expected to operate for upwards of 100,000 hours without a motor failure with only periodic lubrication and annual checks of the motor winding insulation.

A13.3.3. **Technological Advances.** Current advances in GED systems are in the engine area. The engines have better automated controls. The maintenance requirements have been minimized by installing high-performance spark plugs, plug wires, distributor cap, and rotor buttons. Supplemental oil systems extend the oil change interval. Continued advancements will be in the areas of reducing emissions, increasing engine performance, and reducing first cost.

A13.3.4. **Gas Engine-Driven (GED) Chillers.** Methods of operation for chillers range from combustion and steam turbines to automotive-derivative engines. Automotive-derivative engines are commonly used to power GED chillers and they work well for both large and small systems. Industrial engines manufactured by companies such as Caterpillar and Waukesha are also being used with large systems. The major maintenance distinction between automotive-derivative engines and industrial engines is that the automotive engines are typically replaced at 15,000 to 20,000 hours rather than being overhauled as in the case of industrial engines. GED systems are currently being produced with capacities between 30 and 2100 tons with COPs of up to 1.9. Periodic maintenance of these systems can be simple.

Many building operators choose to send only one representative to a manufacturer's training program. This representative then returns to conduct an in-house training program for other technicians. Maintenance contracts, where an outside contractor maintains the system, are also popular with users of GED systems. Oil-change procedures are being simplified. A standard oil change may take less than an hour. If a remote oil system (such as a 55-gallon drum type) is being used, oil changes can sometimes be accomplished in 15 minutes. With the continuing advancement in GED systems, maintenance is simpler.

A13.3.5. **Gas Engine-Driven (GED) Direct Expansion (DX) Equipment.** GED packaged rooftop systems are the same as electric packaged rooftop systems except they use small, reciprocating natural gas engines as a driving force. Also, small four-cycle engines have been adapted to provide efficient operation for residential systems. It is common to see small engines driving DX systems. The York Triathlon is a perfect example of a residential packaged DX system using a small engine as a driving force. It uses a one-cylinder, four-stroke engine. Rotary engines of the Wankel configuration are also being used to drive DX systems. Small GED natural gas systems have not proven to be as economically viable as originally thought in the 1990s.

A13.3.6. **Applications.** Larger GED systems have been successfully tested and applied in a wide range of cooling applications where the comparative fuel cost between electricity and natural gas is sufficient to offset the difference in first cost and maintenance cost. In areas where electric utility rates and demand charges are high, the natural gas engine-driven chillers may be an excellent choice, depending on the economics. Since GED chillers operate in essentially the same manner as conventional electrically driven chillers, they are often integrated into existing chilled water plants. Their operation can be staged to provide cooling only at times when peak electrical demand and consumption charges are in effect. The ability to rapidly start one of these machines and bring its capacity online makes GED machines particularly well-suited for this type of mission. In situations where a beneficial use for the waste heat rejected from these machines is present, GED operation as a baseline cooling source may become an attractive proposition. GED chillers have been successfully used in schools, hospitals, apartment buildings, office buildings, ice rinks, nursing homes, hotels, retailers, and industrial facilities.

A13.3.7. **Additional GED Applications.** A common situation found on many bases is a complex of dormitories that can potentially be served by a district cooling system. In addition to cooling, dormitories are also large consumers of domestic hot water. In many cases, dining halls are also concurrently located next to dormitory complexes, providing yet another significant user of domestic hot water. Using a GED chiller to supply the chilled water for a district cooling system for a hypothetical dormitory complex, the waste heat rejected from the engine jacket and the engine exhaust can be recovered and used as the energy source to heat this domestic hot water. Since domestic hot water consumption is not uniform throughout the day, the recovered waste heat energy can be stored in the form of heated domestic water in an insulated storage tank located adjacent to the chilled water plant. This heated domestic water can then be piped to individual dormitories and the dining hall. If the potentially recoverable waste heat is fully utilized, the effective thermal COP for this type of operation may be as high as 2.25.

A13.4. Desiccant Cooling Systems. Desiccants are ideal for applications that require low humidity such as hotels, offices, and medical facilities. Desiccant dehumidification systems have been in use for a number of years. In the past, their use was limited to industrial applications where extremely low humidity levels were required to support process needs. In these systems, desiccants are used to remove water vapor from an airstream by absorption rather than by cooling the airstream to condense the moisture. The desiccant material becomes saturated with moisture and must be "regenerated" by heating to force the moisture to be released. This regeneration process can occur by alternatively passing the airstream through one of two or more desiccant-filled containers while the other desiccant-filled container(s) are being regenerated. Another approach, more commonly used in comfort cooling/dehumidification applications, uses a porous desiccant-impregnated wheel placed perpendicular to the airstream. Approximately 30 percent of the wheel surface area is exposed to the airstream while the remaining surface area is subjected to a heated airstream, thus regenerating this portion of the desiccant. The saturated side of the desiccant wheel, which is in the main air supply stream, rotates to the regenerative side. Here, hot air—heated either by direct-fired natural gas or an indirect source, such as a gas-fired heater or boiler—can be used to regenerate or dry the desiccant. Hot water or steam generated from the engine of a GED chiller system may also be used for desiccant regeneration. Two examples of solid desiccants are lithium salt and silica gel. The desiccant which dries the air becomes saturated with water. The other type of desiccant is a liquid. The liquid is sprayed through the airstream to remove moisture from the air. Desiccants do not cool the air; the air actually heats up when moisture is removed. However, by removing the moisture, the latent cooling is converted into sensible cooling.

A13.4.1. **Advantages to Desiccant Cooling.** There are many benefits in using a desiccant system. First, desiccants, unlike standard dehumidification systems, do not freeze. They are also available in standard factory-assembled configurations of up to 60,000 cfm of airflow. Sizes larger than this can be constructed onsite. Desiccants also come in packaged assemblies with downstream cooling coils that allow these systems to provide dehumidification and cooling in one packaged unit. Some systems use mechanical cooling while others use evaporative cooling. Other benefits of using desiccants include the following:

A13.4.1.1. With the moisture removed from the air, condensation is virtually eliminated on the system's cooling coils. Drip pans are relatively dry. Also, the moisture in the ductwork is dramatically reduced; therefore, mildew, fungus, and bacterial growth are practically eliminated.

A13.4.1.2. Since the processed air is dry, the humidity in the cooled space is lower. This allows the temperature in the space to be raised while comfort is maintained. Since less cooling is required, cooling set points can be raised, lowering operating cost. Additionally, since space humidity levels are kept lower, mold and mildew growth can be reduced significantly in humid environments. In the hotel and motel industry, this reduction in mold and mildew growth has allowed the replacement interval for carpets, bedding, and furnishings to be greatly extended, thus reducing this significant cost to operate these facilities while improving the comfort and satisfaction of the occupants.

A13.4.1.3. Up to half of the energy used by a cooling system can go toward latent cooling. Since the moisture in the air has been removed and the cooling system is not responsible for the latent cooling, the load on the cooling system is greatly reduced. This allows for downsizing cooling systems in new operations.

A13.4.1.4. Desiccants also allow for the addition of extra load to an existing cooling system. When the load increases on a cooling system, a desiccant, by removing the latent cooling load, could prevent the cooling system capacity from being insufficient and having to replace the system.

A13.4.2. **Disadvantages to Desiccant Cooling.** Disadvantages with desiccants vary with the type of desiccant and the type of system being used. Packed-tower systems allow high and low spikes in humidity to occur during changing of the desiccant chambers. The rotating beds require large amounts of regenerative energy due to the massive amounts of desiccant being used. The desiccant breaks down and settles in the bottom of the beds, causing uneven airflow. Also, due to the settling of the desiccant, the beds must be topped off, thus increasing maintenance costs. These systems are also quite heavy. The new-generation desiccant wheels are relatively trouble-free but do require regular maintenance of seals and drive belts. Some maintenance is required to maintain the desiccant wheels. Sometimes these wheels can become obstructed and may need back-flushing to clear the obstruction. To minimize these problems, filters should be installed upstream of both the supply and regeneration side of the wheel to prevent dirt accumulation. Due to the corrosive nature of some processes, the seals of a desiccant wheel may need replacing at regular intervals. The replacement period is a function of the type of desiccant used, the airflow velocity, and the degree of saturation of the desiccant. The system manufacturer should be consulted for guidance on predicted service intervals on a case-by-case basis.

A13.4.3. **Technological Advances.** New and improved desiccants have been developed. New desiccants have allowed for reducing the system size by up to 50 percent. Also, new desiccants such as Engelhard titanium silicate (ETS) can remove up to 100 percent more water than older desiccants. Desiccant systems are constantly being improved so their size can be decreased. These new desiccants are less corrosive and more stable than their predecessors.

A13.4.4. **Applications.** Desiccant cooling systems have found great acceptance in two private sector applications. In humid climates, the hotel and motel industry has experienced problems with the growth of mold and mildew on carpets, furnishings, and bedding materials. In the past, the common practice to prevent this deterioration was to operate the HVAC systems at reduced temperatures to mechanically remove this moisture. This resulted in unreasonably high energy costs to operate the HVAC systems and oversized mechanical equipment. In some cases this situation was made worse by overcooling, which resulted in condensation forming on exterior walls. With the use of desiccant systems to control humidity levels, space temperatures can be raised several degrees, saving cooling energy and eliminating the need to oversize mechanical systems while simultaneously providing a more comfortable environment for guests. The deterioration of carpets and furnishings is also dramatically reduced, providing additional cost savings. The associated lower humidity levels reduce mold and mildew growth and metal corrosion. These same benefits are directly applicable to military housing units. A second application for desiccant systems has been found in the retail grocery business. High humidity levels in grocery stores result in condensation and ice buildup on frozen food items in open display cabinets, increased latent cooling loads on the refrigeration systems for these display fixtures, and condensation on the glass doors of closed frozen and refrigerated food display cases. The doors of closed display cases are usually equipped with heaters to prevent this condensation buildup from occurring as it inhibits product visibility and may eventually freeze the doors shut. After the installation of desiccant systems, the condensation is practically eliminated, usually to the extent that the continued operation of the door heaters is no longer necessary. Space temperature can be raised several degrees, saving cooling energy. Additionally, the latent cooling load on the display case refrigeration systems is nearly eliminated, again reducing energy consumption. At the same time, the appearance of the products is enhanced and the customers are provided a more comfortable environment. Most military bases have a commissary and other outlets for the sale of frozen foods that will benefit in the same fashion from this technology. In both of the aforementioned scenarios, profit motivation drove the use of this technology. Unlike absorption and GED technology, some of the cost savings realized from the application of desiccant technology are derived from sources not traditionally included in an analysis of the cost impact of a cooling system on overall facility operation costs. Credit should be taken for the cost reductions associated with the extended service life of bedding materials, carpets, and furnishings in military housing units. Additionally, the reduction in mold and mildew growth in ductwork may produce some maintenance cost savings resulting from extended filter life and eliminate the need to periodically clean interior ductwork surfaces in high-mold-growth areas. These factors should be considered in an economic analysis of this technology along with energy cost savings and savings resulting from a reduction in required cooling capacity.

A13.5. Operation and Maintenance of Gas Cooling Equipment. Due to advances in gas cooling technology, operating and maintaining gas cooling equipment can be as simple as maintaining an electric cooling system. Due to advances in automated controls, the ability to remotely monitor equipment, and increased system reliability, gas cooling technology is becoming an important part of the cooling industry. Absorption systems are simple to maintain and have few moving parts, making them more reliable today than in the past. By using high-performance parts and remote oil systems, maintenance intervals have been increased. Desiccant systems are smaller and more efficient. As with any other equipment, operating and maintaining gas cooling equipment has its advantages and disadvantages.

A13.5.1. **Advantages of Gas Cooling Equipment.** One of the most obvious advantages of gas cooling systems is that they use little electricity, which allowed avoiding electrical peak-demand rates. For example, if a chilled-water system is composed of several electrical chillers that incur large peak demand charges, replacing one or more chillers with a GED chiller may reduce the electrical demand, thus avoiding peak demand charges. However, the cost feasibility of chiller replacement and gas options must be determined. If electric rates are high and gas rates low, it is sometimes more cost-effective to replace an electric cooling system with a gas cooling system. The replacement cost can sometimes be recovered in as little as two to three years due to savings in energy cost. Also, many gas companies offer rebates to customers who choose to cool with natural gas, helping to offset first cost. Gas equipment is also very dependable. Absorption chillers have few moving parts and therefore seldom need maintenance. With so few moving parts, there is little vibration that can damage or weaken other systems. The engines used in GED equipment have been proven to be reliable and durable. With preventive maintenance such as proper oil changes, these systems seldom incur downtimes. Gas engines can be overhauled to extend the life of the system. Desiccant systems are also very reliable; they need little maintenance. Overall, gas cooling equipment is simple to operate, can be low-maintenance when operated properly, and can provide substantial energy savings when properly applied.

A13.5.2. **Disadvantages of Gas Cooling Equipment.** The sole disadvantage of gas cooling equipment is the first cost. Initial investments can be several times more than that of electrical equipment. A primary energy source is converted to produce cooling onsite; this requires specialized equipment. With an electric system, the primary energy is converted at a central location. The electric system is a simple converter of secondary energy (electricity) into cooling and is not as complex as a natural gas system. The first cost of gas equipment is usually offset by energy savings. Based on utility rates, it can be much less expensive to operate than electrical equipment.

A13.6. Choosing between Natural Gas and Electric Systems. The choice between natural gas or electric cooling systems is usually an economic decision. A computer program should be used to model buildings, cooling loads, and cooling systems for several different scenarios. The program should be able to generate energy usage based on the models. Cooling systems can be modeled using all-electric equipment, systems using all-gas equipment, and systems using a combination of the two. Modeling cooling systems does not have to be limited to the three situations mentioned, but should include them. Gas suppliers will commonly provide incentive programs to offset a portion of the first cost of the natural gas cooling systems. Using the energy usage and total costs determined by a computer model, along with annual maintenance cost and first cost, a life-cycle cost can be performed for each scenario. The economic analysis can then be used to select the best option. Other factors must also be considered when trying to decide between electric and gas cooling, such as the overall dependability of the systems or the criticality of the facilities being served by a system. For example, is the facility part of a critical operation that must always be cooled and therefore cannot suffer a power outage? This may be a situation where a dual-fuel system is needed, regardless of the cost. Air quality situations are another case where system operating conditions can take precedence over economic factors. For example, if a specific facility needs low-humidity air to support production operations, then a desiccant system may be the best system to provide the required space conditions. Additionally, economic factors that are not a part of the usual set of parameters typically analyzed when evaluating competing cooling technologies should be considered when developing an overall economic comparison of gas cooling technologies versus conventional systems. For example, the ability of a desiccant system to provide year-round low humidity levels may result in a significant reduction in cost for replacing bedding, carpeting, and furnishings in a housing complex. The inclusion of this factor has largely contributed to the acceptance of this technology in the hotel and motel industry, where these costs constitute a significant portion of the operating cost of these facilities. All of these factors and more must be considered when choosing between gas and electric cooling options.

A13.7. Operations and Maintenance Training Sources. Many of the technologies described in this attachment are unfamiliar to facilities design and maintenance personnel. This lack of familiarity should not prevent an organization from installing systems that employ new technologies, such as gas cooling. For example, in the case of GED systems, the refrigerant side of these systems is essentially identical to conventional electrically driven systems. Only the maintenance and operation of the natural gas-fueled engines are different from existing conventional systems. The engines can be maintained either in-house by power production personnel or this service can be contracted through outside vendors. Additionally, the local manufacturer’s representative for engine-driven, absorption, and desiccant systems can provide assistance to maintain these systems either by providing contracted maintenance and/or technician-level training or by assisting in the development of an in-house maintenance training program. The Gas Research Institute and the American Gas Cooling Center are also available to provide assistance in developing maintenance and operations training programs.

A13.8. Natural Gas Summary. Natural gas cooling technologies will continue to find acceptance within the broad spectrum of available cooling technologies. The initial costs of this equipment will drop as these technologies become more widely accepted and production rates for the equipment increase. The manufacturers of mechanical cooling equipment have made a significant commitment to research and development to advance and create new applications for natural gas cooling technology. Many institutions and government agencies, including DOE, the Gas Research Institute, the American Gas Cooling Center, major refrigeration equipment manufacturers, and gas utilities are working together to promote acceptance of these technologies. All potential users of this technology should continually evaluate the usefulness and economic viability of this growing family of technologies that is becoming more cost-effective.

Attachment 14

COMMISSIONING HVAC EQUIPMENT

A14.1. Commissioning HVAC Equipment. The successful operation of any cooling system requires that all components of the system fulfill design requirements. To ensure proper operation, a process known as “commissioning” should be undertaken prior to accepting the system. Commissioning should not be confused with the usual component-level startup testing ordinarily performed by the installing contractor. Rather, commissioning is an organized process that begins during the design phase of a project and describes, executes, and documents a series of tests designed to ensure that all components in a system are properly installed so the system completely fulfills design requirements. This testing program will be designed to ensure that all components are properly installed and are operated throughout their complete performance range, that all system alarms and safety systems are fully operational, and that all components in the system are properly assembled to allow the individual components to function together as a system. Unfortunately, too many systems have been installed that, although capable of operating at a minimally acceptable level of performance, have never achieved the efficiency or capacity of operation sought by the system designer and the facility operator. The commissioning process should uncover problems (obstructed flow paths, improper component installation, improper control set point adjustment, and improper refrigerant charges) that can affect system performance, while still allowing the system to marginally operate.

A14.1.1. During the design of a mechanical system, care should be exercised to ensure that all critical operating parameters can be evaluated during the commissioning process. The design should include provisions to accurately measure flow rates, temperatures, pressures, electrical currents, and other parameters. The designer should establish testing procedures that describe the modifications necessary to isolate individual components or control loops so that each function can be tested independently. Additionally, the designer should strive to ensure that ductwork and piping systems are configured in a manner to allow flow rates to be accurately measured. The installation of inexpensive pressure/temperature taps, or “Pete’s Plugs,” can be specified throughout piping systems to allow these parameters to be verified at locations where the cost of permanent instruments are not justified but where verification of these parameters could be useful during the commissioning process and aid system maintenance.

A14.1.2. Although the commissioning process should begin during the design phase of a project, the commissioning/testing process occurs during the construction phase. Unified Facilities Guide Specification (UFGS) 23 08 00.00 10, *Commissioning of HVAC Systems*, can be used as a basis for developing a commissioning specification for inclusion in the construction specification package. UFGS 23 08 00.00 10 describes who should participate in the commissioning process, the scope of the testing, the responsibilities of the commissioning team members, and provides a draft format for documenting the required testing. Selecting the actual tests to be run, their sequence, and where the sensors should be located is dependent on the individual installation.