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Alternative Refrigerant Technologies

Chlorofluorocarbon Uses in Army Facility Air-Conditioning and Refrigeration

by
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Recent studies have verified that the emission of manmade chlorofluorocarbons (CFCs) into the atmosphere has depleted ozone in the stratospheric layer, and may affect terrestrial ecology. In response to actions intended to reduce or eliminate the production of CFCs, the Department of Defense (DOD) has issued a policy on the use of CFCs and halons.

This study calculated baseline technical information for the Army's air-conditioning and refrigeration (AC&R) equipment inventory based on site studies of three Army installations and information in the 1989 *Red Book*. Such baseline data will help the Army meet CFC regulatory requirements in the context of rapidly developing alternative technologies. The information may also suggest economical guidelines for determining cost-effective approaches to the CFC problems.

Survey results showed that most of the Army's AC&R equipment is relatively new. It may therefore be more economical to retrofit this equipment with non-CFC refrigerants than to replace it with new units that use non-CFC refrigerants. Drop-in refrigerants and retrofitting technology are still in their developmental stages, but should become commercially available within a few years.

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FOREWORD

This research was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA, under project 4A162784AT45, "Energy and Energy Conservation," Work Unit EB-XM2, "Alternative Refrigerant Technologies." The USAEHSC technical monitor was Hank Gignilliat, CEHSC-FU-M.

The work was performed by the Energy and Utility Systems Division (FE), of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USA-CERL principal investigator was Dr. Chang Sohn. Dr. David M. Joncich is Division Chief, CECER-FE, and Dr. Michael J. O'Connor is Laboratory Chief, CECER-FL. Special appreciation is expressed to the Directorate of Engineering and Housing (DEH) staffs at Fort Jackson, the Red River Army Depot, and Fort Campbell, for their help during the site surveys, and also to Hank Gignilliat, USAEHSC, for his assistance throughout the project. The USACERL technical editor was William J. Wolfe, Information Management Office.

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1 INTRODUCTION

Background

Recent studies have verified the depletion of ozone in the stratospheric layer due to the emission of manmade chlorofluorocarbons (CFCs) into the atmosphere (Kurylo 1989). The stratospheric ozone layer blocks most of the ultraviolet (UV) radiation from the sun toward the surface of the earth. Without the shield, the increased UV radiation will have a profound effect on the ecology of terrestrial life, including human beings. For example, the increased UV radiation will likely result in increased skin cancer in humans as well as disturbance of the microorganisms that will ultimately affect the natural food chain. Recognizing the catastrophic consequence of the depletion of the ozone layer, the world bodies have developed plans to reduce/eliminate the production of CFCs. These plans include the Montreal Protocol on substances that deplete the ozone layer, the London Amendment to Montreal Protocol (Salas and Salas 1992), and the U.S. Clean Air Act Amendments signed by the President in November, 1990. In response to these regulations, the Department of Defense (DOD) issued a policy (DOD, 1989), the Army a letter (HQDA, 1990), and the U.S. Army Engineering and Housing Support Center (USAEHSC) a Technical Note (TN 420-54-01, 26 June 1991). As of early 1992, the development of alternative refrigerants and cooling/refrigeration systems in private industry has been rapid; however, the ultimate alternatives are yet to be established. It is essential for the Army to determine baseline data on its air-conditioning and refrigeration equipment to derive the information needed to meet CFC regulatory requirements economically, within the context of rapidly developing alternative technologies. The information will help determine cost-effective approaches to CFC problems, such as the recovery/recycling of CFCs, equipment phase-out schedules, and deployment of alternative cooling/refrigeration systems.

Objective

The objective of this study is to establish baseline technical information on the Army's current use of CFCs for facility air-conditioning and refrigeration (AC&R).

Approach

The 1989 *Red Book** was reviewed to derive an accurate list of the type, capacity, and age of AC&R equipment, as well as the total amount of each type of CFC in the Army. *Red Book* information is lumped into a few broad categories, unsorted by type or age. More detailed information (type, capacity, age, and refrigerant usage of the equipment) was collected from site visits to three typical Army installations, selected in cooperation with Major Commands (MACOMs) and USAEHSC: Fort Jackson, SC (Training and Doctrine Command [TRADOC]), Red River Army Depot, TX (Army Materiel Command [AMC]), and Fort Campbell, KY (Forces Command [FORSCOM]). A procedure to analyze the

* The *Red Book* is the common name for the *Facilities Engineering and Housing Annual Summary of Operations* (U.S. Army Engineering and Housing Support Center [USAEHSC], Fort Belvoir, VA).

information was developed from the installation data itself. This method projects the Army-wide CFC use, based on the overall data from the fiscal year 1989 (FY89) *Red Book*.

Scope

This study analyzed the Army's CFC usage in facility air-conditioning and refrigeration only. The study did not include CFCs used as solvents in manufacturing plants or as refrigerants in vehicle air-conditioning systems, nor those CFCs used in foam insulation, or as cleaning agents for electronic components.

Mode of Technology Transfer

It is recommended that the information in this report be used to refine the Department of Defense/Department of the Army (DOD/DA) policy on CFC issues such as CFC equipment phaseout schedules.

2 DATA COLLECTION AND REDUCTION

Fiscal Year 1989 *Red Book* Data

The source of Army-wide information used in this study is the Technical Data Report supplied by the U.S. Army Engineering and Housing Support Center (USAEHSC). The Technical Data Report (TDR) is a facilities engineering document used to provide the previous year's operating costs and workload performance data for all Real Property Maintenance Activities (RPMA) work done at Army installations, activities, and communities. This report is used to help make management and technical evaluations of the adequacy of the facilities engineering operations. The active Army and the U.S. Army Reserves, which include all installations, activities, and communities operating under a lease to or from the Department of the Army are required to report. The flow of this information is illustrated in Figure 1. The Integrated Facilities System (IFS) is a computerized database system used to record all RPMA work done at an installation. An update of this system is in the process of being installed at each Army installation. For those installations without an IFS system, DA Form 2788R, *Technical Data Feeder Report* (Department of the Army [DA], August 1987) is used to record RPMA information. The RPMA information for all Army installations, activities, and communities is compiled in the Headquarters Integrated Facilities System (HQIFS) Technical Data Database. This database serves as the source for compilation of the *Red Book* and various other reports.

The *Red Book* was chosen as the means to access the information contained in the HQIFS system since it is readily available and reports at a level ideally suited for use in this project. The *Red Book* contains information grouped into four major categories:

1. Operation of Utilities (J account)
2. Maintenance and Repair (K account)
3. Minor Construction (L account)
4. Engineering Support (M account).

Entries within each of the four categories are designated by a six-digit Technical Data Activity Code (TDAC). The first digit of each code is a letter identifying the account. The second and third digits designate a group, and the final three digits specify an entry within the group. The two accounts reporting data of value to this project are the J and K accounts.

The J account includes information related to water service, sewage services, electric service, boiler, heat, and purchased steam/hot water, air-conditioning, and cold storage plants, as well as other utilities operation. Of interest to this project are the air-conditioning category and the cold storage category.

The K account reports information related to Maintenance and Repair. Major categories include water systems, sewer systems, electrical systems, boiler and heating plants (air-conditioning included), buildings, maintenance of surfaced areas, bridge maintenance and repair, and miscellaneous. In this account there are 13 categories reporting data related to air-conditioning, cold storage, and refrigeration. For each of these TDACs, the *Red Book* reports the quantity, the quantity units (tons or hp),* total cost, and unit cost.

The FY89 *Red Book* was used as the basis for this study. For that year, the *Red Book* lists 189 installations in the Army. Of these 189, 12 installations report no information at all and 13 do not report

*1 ton = 12,000 Btu/hr; 1 lb = 0.454 kg; 1 hp = 745.7 W.

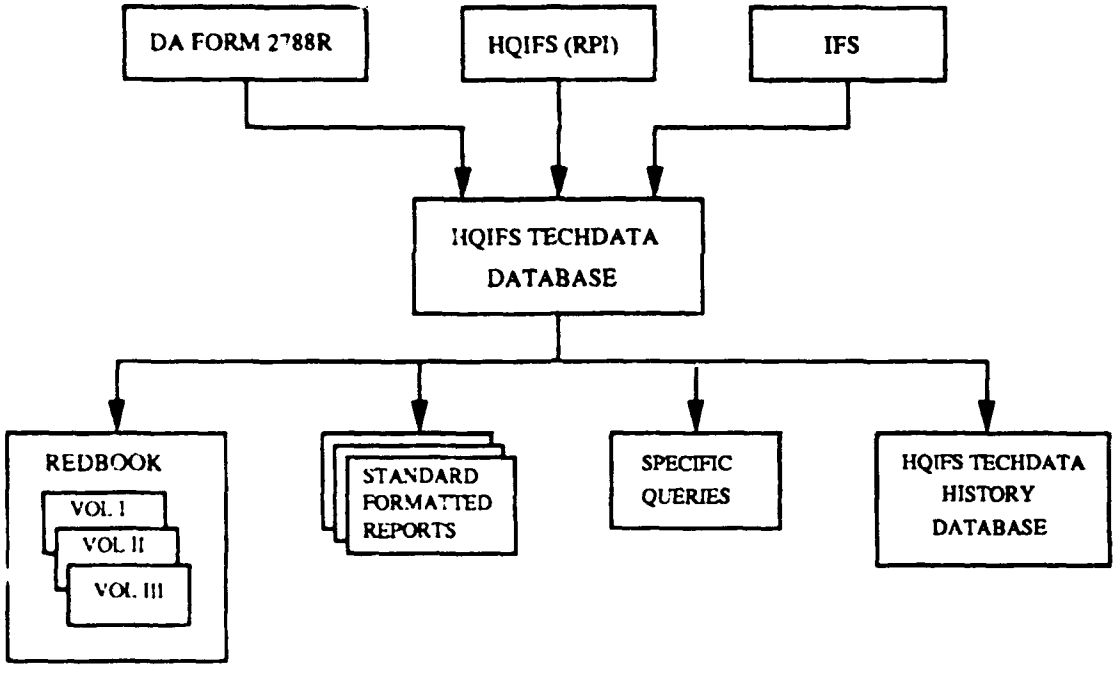

Figure 1. Real Property Maintenance Activities Information Tree.

any air-conditioning-related data. Thus there are 164 installations for which air-conditioning and refrigeration (AC&R) data has been obtained.

A complete listing of the AC&R data reported in the FY89 *Red Book* is given in Table 1. Quantities have been listed by MACOM for conciseness and to aid in identifying the size of the equipment inventory maintained by each MACOM. This information is also presented in Figures 2 and 3. Figure 2 shows a comparison of the quantities of each type of air-conditioning equipment in use as reported by the *Red Book*. Notice that large air-conditioning units (greater than 100 tons capacity) and small air-conditioning units (less than 5 tons) make up the majority of the equipment inventory. This conclusion is supported by the findings of the site studies conducted as part of this project. Figure 3 shows the use of refrigeration equipment in the Army as reported in the *Red Book*. Based on the findings of the Site Studies, the total quantity reported is reasonable, but the relative amounts of each size is subject to some question.

Selection of Test Sites

Detailed information for an individual piece of AC&R equipment, such as the age of the unit and the type of refrigerant used, is available only through field inspection of the installed unit. Since a field study for the 164 installations is not a practical approach, three typical Army installations were selected for the field study. Each of the three MACOMs (FORSCOM, TRADOC, and AMC) recommended a representative installation (one each from each MACOM) for the field study. A survey team, comprised of personnel from EHSC, USACERL, and a USACERL-hired contractor, visited Fort Jackson (TRADOC)

Table 1

FY89 Redbook Air-Conditioning and Refrigeration Totals

	Air-Conditioning* (tons)										Refrigeration (hp)		
Major Command	**J51000**	**J52000**	**K15111**	**K15112**	**K15113**	**K15114**	**K15115**	**K15130**	**K15120**	**K15140**	**K15220**	**K15211**	**K15212**
Corps of Engrs	1,533		1,968										
Health Serv Cmd	36,297	890	19,512	277	472				7,273		890	2,863	1,232
Mil Dist of Wa	24,100	448	19,560	1,503	1,182				1,088	21	446	904	211
Mil Traf Mgt Cmd	2,357	1,125	1,340	243	105				630	43	825	759	
Forces Cmd	240,666	20,922	111,385	25,667	20,355	9,490	829	1,431	64,915	82	7,055	17,583	7,501
Army Europe	12,221	6,021	19,236	68	3,184				3,418		4,189	16,760	1,807
Southern Cmd	24,801	1,050	5,740	3,508	1,382	1,443	429		11,600		1,050	40	100
Western Cmd	403	860	15,816						2,762		1,550	1,827	
Army Mtrl Cmd	93,839	2,844	124,799						19,155		2,257	15,660	
U.S. Milit Acad									660		593	693	
U.S. Army Japan	7,656	149	6,397						3,685			761	
Eighth U.S. Army	27,003	4,188	22,997						2,595		1,616	4,466	
Intel & Sec Cmd	594	68	2,442	541	60				600		41	137	63
Trng & Doc Cmd	268,071	3,870	143,783	35,825	53,686	1,647	2,181	2,834	81,512	8,323	4,492	22,638	5,069
Info Sys Cmd	7,743		3,650	2,095	2,236				887		25		2
Totals	**747,284**	**42,435**	**498,625**	**69,727**	**82,662**	**12,580**	**3,439**	**4,265**	**200,780**	**8,469**	**25,029**	**85,091**	**15,985**

*Refer to Table 2 (p 15) for descriptions of air-conditioning and refrigeration units.

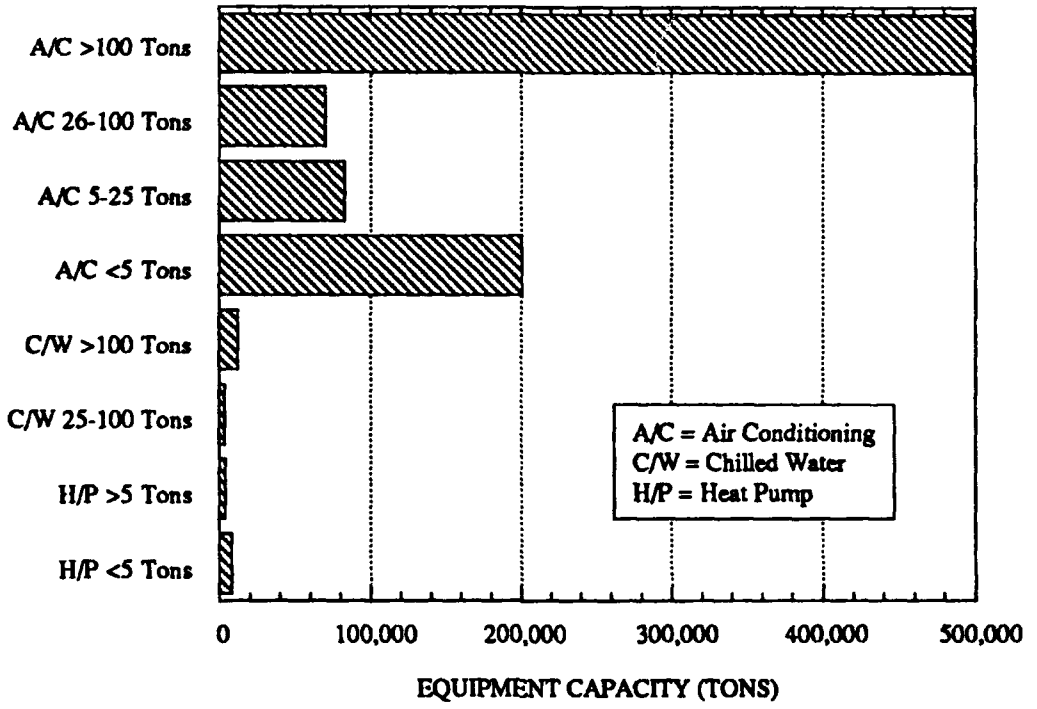

Figure 2. FY89 *Red Book* Air-Conditioning Equipment.

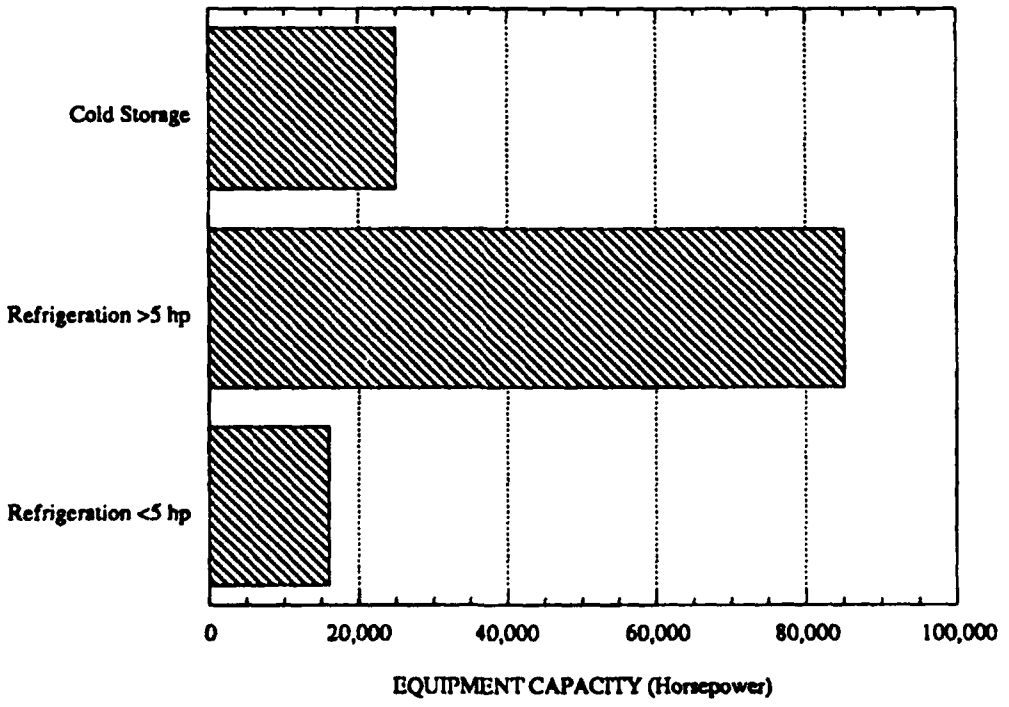

Figure 3. FY89 *Red Book* Refrigeration Equipment.

in the week of 15 July 1991, Red River Army Depot (AMC) in the week of 26 August 1991, and Fort Campbell (FORSCOM) in the week of 19 September 1991.

Fort Jackson Site Study

Preliminaries

Fort Jackson is a TRADOC installation located near Columbia, SC. Its primary function is training. The large number of personnel staffed and trained at the installation require a large support system such as dining halls, barracks, training centers, schools, hospital, and family housing units.

Much of Fort Jackson's air-conditioning is supplied by three large central energy plants. These plants include equipment for the production of chilled water and high temperature steam. The air-conditioning units in these plants are all large CFC-11 centrifugal chillers except for one lithium bromide absorption unit. In addition, several remote buildings and complexes are served by high capacity chillers. The remaining air-conditioning is supplied primarily by small units, as is typical of small buildings of WWII vintage originally constructed without central air-conditioning. Each of the 1270 family housing units on post also has an air-conditioning unit.

Refrigeration is supplied by a variety of equipment. Large loads such as the cold storage buildings and commissary are served by custom designed, reciprocating compressor-based systems. Mid-sized refrigeration loads are served by off-the-shelf compressor/condenser packages. The remaining refrigeration is supplied by household refrigerators and freezers as well as a number of specialty refrigerators and freezers used in the dining halls.

Data Collection and Reduction

The Fort Jackson study was complemented by a study already done at Fort Jackson (PM&A 1991), which included an inventory of air-conditioning and refrigeration equipment at Fort Jackson and presented a schedule for replacing CFC refrigerants in use. The USACERL study supplemented the information already gathered in the previous study by concentrating on buildings and areas not previously covered.

Data was obtained during the USACERL study by physically examining the equipment and recording the information found on the equipment nameplate. Often, information could also be obtained from persons familiar with the equipment. Specifically, the survey sought four pieces of information for each equipment unit:

1. Capacity of the unit (in tons or hp)
2. Type of refrigerant being used
3. Size of the refrigerant charge
4. Age of the unit.

This information was generally not available on the equipment nameplates. However, the model number was almost always readable so the desired information could be found in company catalogs or through company representatives. This method proved very successful for air-conditioning units of any size. For small refrigeration units, such as those found in dining facilities, information was sparse. For a number of units, an estimate had to be made of the missing information.

To aid in analysis, data obtained during the site study and that contained in the CFC Reduction Study were entered into a spreadsheet. This allowed for the manipulation of the data with relative ease.

Comparison to Red Book Data

Table 2 compares the equipment inventory found by the USACERL site survey and that reported in the FY89 *Red Book*. The J account AC category shows very little agreement with the site study. However, the Cold Storage category agrees well. The comparison in category K15100 (K15100 is equal to the sum of K15111, K15112, K15113, K15114, K15115, and K15130) is good, although the breakdown of this quantity does not compare as well. This is the first indication of a trend seen in the data from the other site surveys as well: the overall quantities reported in the *Red Book* compare well with the site study, but the breakdown of these quantities does not always agree. Note that all of the large units at Fort Jackson have been reported in the air-conditioning category even though they all produce chilled water. However, this distinction is of little consequence since equipment in these two categories (K15111 and K15114) would be identical. A blurring of the categories also occurs with refrigeration. The amount found by the USACERL study in category K15300 (K15300 is equal to the sum of K15211 and K15212) matches reasonably well with the quantity reported in the *Red Book* as K15211. The difference in the K15300 code between the Technical Data and the site survey is likely to be an underestimation in the site survey of the number of smaller refrigerators in locations other than family housing. This data was very difficult to determine in the survey because of the many scattered locations of such systems and the necessity for room-by-room inspections, which were impractical in this study. The potential for a large number of small refrigeration systems is supported by the experience during the Red River Army Depot survey. In this survey (p 17), computer printouts of preventative maintenance data showed that about 200 small household-type refrigerators exist at Red River in buildings other than family housing. A similar number of such units at Fort Jackson would easily account for the discrepancy in the K15300 TDAC. Overall, agreement between the *Red Book* and the site survey is quite good, especially since 2 years separate the FY89 *Red Book* data and the USACERL study.

Results

The results of the Fort Jackson site survey are summarized in Figure 4 and Tables 2 through 4. Figure 4 shows the quantity of each type of refrigerant in use at Fort Jackson. Several important observations can be made from the data contained in Table 2:

1. Chillers of greater than 100 tons capacity use primarily CFC-11.
2. Air-conditioning units of less than 100 tons used HCFC-22 almost exclusively.
3. Cold storage and refrigeration systems use primarily CFC-12 and R-502.

Table 3 shows the type of refrigerants being used by the equipment within each Technical Data Activity Code (TDAC). This clearly shows the types of refrigerant being used by the various sizes and types of equipment. Table 4 shows a breakdown of the number of units by age. For each group it is clear that much of the equipment is quite new. Fort Jackson is in the process of updating all of its family housing air-conditioning equipment, so those units more than 15 years old will soon be replaced. Note that this table is based on only that portion of the total units at Fort Jackson where age information was available.

Table 2

Comparison of *Red Book* and Site Study Data (Fort Jackson)

TDAC	Description	Units	Study	Redbook
J51000	AC plant (plt) (all tonnage)	Ton cap	15,274	7650
J52000	Cold storage plt (incl. ice manuf.)	Hp cap	575	525
K15100	Air-cond and chill water plts	Ton cap	12,216	12,031
K15111	Air-cond plts (>100 tons)	Ton cap		12,031
K15112	Air-cond plts (26-100 tons)	Ton cap	742	
515113	Air-cond plts (5-25 tons)	Ton cap	1,065	
K15114	Chilled water plts (>100 tons)	Ton cap	10,353	
K15115	Chilled water plts (25-100 tons)	Ton cap	51	
K15130	Heat pump (>5 tons)	Ton cap	5	
K15120	Air-cond plts (<5 tons)	Ton cap	3,058	3,001
K15140	Heat pump (<5 tons)	Ton cap	350	
K15220	Cold storage plt (incl ice mfg)	Hp cap	575	525
K15300	Refrigeration	Hp cap	875	1,054
K15211	Refrigeration (>5 hp)	Hp cap	258	1,054
K15212	Refrigeration (<5 hp)	Hp cap	617	

Table 3

Distribution of Refrigerant Usage by TDAC (Fort Jackson)

TDAC	Description	CFC-11	CFC-12	HCFC-22	CFC-113	R-502
K15111	Air-cond plts (>100 tons)					
K15112	Air-cond plts (26-100 tons)			1,170		
K15113	Air-cond plts (5-25 tons)			2,028		
K15114	Chilled water plts (>100 tons)	20,050	1,095	620	220	
K15115	Chilled water plts (25-100 tons)			60		
K15130	Heat pump (>5 tons)			11		
K15120	Air-cond plts (<5 tons)			7,300		
K15140	Heat pump (<5 tons)			1,221		
K15220	Cold storage plt (incl ice mfg)		6,970			
K15211	Refrigeration (>5 hp)		2,161			1,599
K15212	Refrigeration (<5 hp)		1,007	191		362
Totals	**(lb of refrigerant)**	**20,050**	**11,233**	**12,601**	**220**	**1,961**

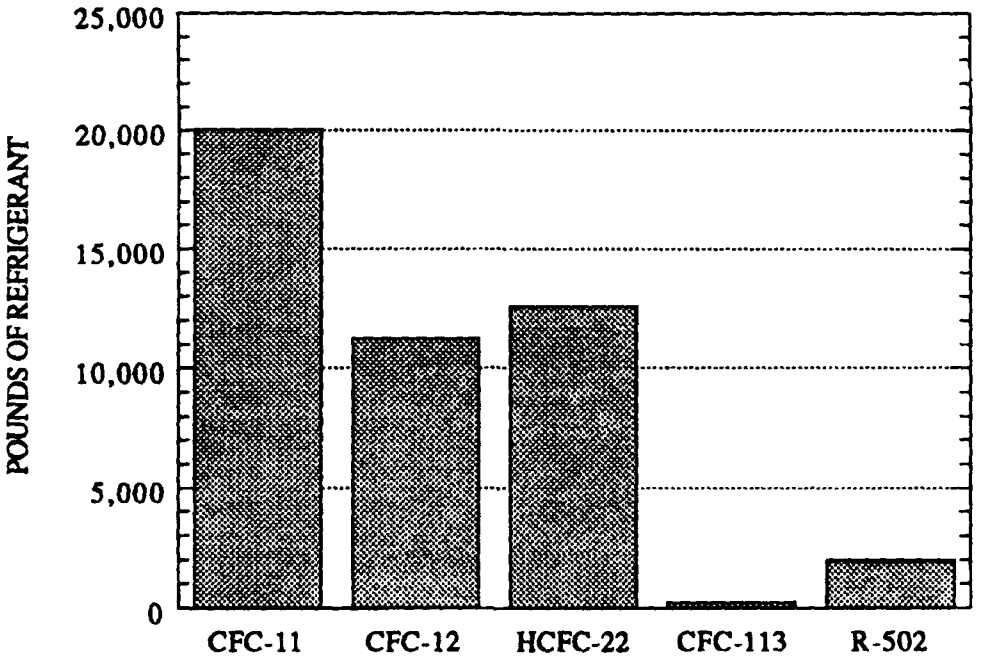

Figure 4. Refrigerant Usage at Fort Jackson.

Table 4

Age Distribution of AC&R Equipment (Fort Jackson)

Age	A/C >100 Tons	A/C <100 Tons	Family Housing	Refrigeration
0-5 yr	8	217	853	167
6-10 yr	1	34	279	97
11-15 yr	0	3	0	21
15+ yr	2	6	138	7

Red River Army Depot Site Study

Preliminaries

Red River Army Depot (RRAD) is located near Texarkana, TX and is part of the Army Materiel Command (AMC). Activities at RRAD include the production, maintenance, and storage of various types of ammunition, missiles, and vehicles. The installation is highly industrialized and has many large factory-type buildings. Except for office and administrative areas, most of the floor area in these buildings is not air-conditioned. For this reason, the majority of air-conditioning systems are packaged or split units located along the perimeter or on the roof of the large industrial buildings. There are no central chilled water plants at RRAD and there are only a few air-conditioning systems with capacities greater than 100 tons. All of the equipment at RRAD, including chillers, have air-cooled condensers.

The majority of personnel at RRAD are civilians living off post. There are only 22 family housing units at RRAD.

The Red River Army Depot site study was conducted during 25-29 August 1991. Due to the small size of the installation, much of the air-conditioning and refrigeration was examined. In addition, a printout of a portion of RRAD's programmed maintenance documentation was obtained. This printout listed all air-conditioning and refrigeration on post, with the exception of family housing.

Data Collection and Reduction

Data collection followed the same process as at Fort Jackson. AC&R equipment was physically examined and the model number, manufacturer, capacity, refrigerant, refrigerant charge, and age were recorded. If the age of the unit was not recorded on the nameplate, it was estimated. Because of the large number of units at RRAD in the 5 to 25 ton capacity range, the examination of each of these units was not possible. The maintenance printout was relied upon for those units not actually examined.

The data collected was again entered into a spreadsheet for further analysis. Unknown quantities were filled in using the same method as used for the Fort Jackson data.

Comparison to Red Book Data

Table 5 shows the data obtained from the USACERL site study and that reported in the *Red Book*. Notice the *Red Book* did not report a quantity for either of the J account categories. With regard to air-conditioning in the K account, the site study found that Red River uses predominantly small to mid-sized air-conditioners. Only a few air-conditioning units of capacity greater than 100 tons are used on post. The difference in TDAC K15120 has been checked in detail using data from the site survey and the maintenance printout, and the figure determined by this study is believed to be correct. The discrepancy in the refrigeration categories is likely due to incorrect placement in the *Red Book* since installation personnel were specifically queried on this issue. When the value reported by the *Red Book* in K15111 is compared to that found by the site survey in K15212, the agreement is good. Note that the overall agreement for air-conditioning and refrigeration (Categories K15100 and K15300) is quite good. Differences between the *Red Book* data and the site survey data are similar to those observed at Fort Jackson, namely:

1. For overall categories, the *Red Book* and site survey are in general agreement.
2. Discrepancies in the breakdown of equipment capacities are significant.

Table 5

Comparison of *Red Book* and Site Study Data (Red River AD)

TDAC	Description	Units	Study	Redbook
J51000	AC plt (all tonnage)	Ton cap	3,744	
J52000	Cold storage plt (incl. ice manuf.)	Hp cap		
K15100	Air-cond and chill water plts	Ton cap	3,067	
K15111	Air-cond plt (>100 tons)	Ton cap		2,825
K15112	Air-cond plt (26-100 tons)	Ton cap	420	
K15113	Air-cond plt (5-25 tons)	Ton cap	1,527	
K15114	Chilled water plt (>100 tons)	Ton cap	360	
K15115	Chilled water plt (25-100 tons)	Ton cap	760	
K15130	Heat pump (>5 tons)	Ton cap		
K15120	Air-cond plt (<5 tons)	Ton cap	677	862
K15140	Heat pump (<5 tons)	Ton cap		
K15220	Cold storage plt (incl ice mfg)	Hp cap		
K15300	Refrigeration	Hp cap	181	194
K15211	Refrigeration (>5 hp)	Hp cap		194
K15212	Refrigeration (<5 hp)	Hp cap	181	

Results

The results of the Red River Army Depot site survey are summarized in Figure 5 and Tables 6 and 7. Figure 5 shows the quantity of each type of refrigerant in use at Red River. Table 6 shows the type of refrigerants used by the equipment within each Technical Data Activity Code. As at Fort Jackson, air-conditioning equipment of capacity less than 100 tons uses HCFC-22 almost exclusively. Table 7 shows the number of units in each age category. This table accounts for much of the equipment at RRAD. Note that, for all of the equipment categories, most of the equipment is less than 10 years old.

Fort Campbell Site Study

Preliminaries

Fort Campbell is a FORSCOM installation located on the Kentucky-Tennessee border, near Clarksville, TN. It is a large installation with a variety of building types ranging from rehabilitated WWII barracks to "New-Modular" type barracks.

There is a wide range of air-conditioning and refrigeration equipment types at Fort Campbell. One large central chilled water plant provides 3600 tons of cooling from three centrifugal chillers, which use R-500. The hospital has two large centrifugal chillers using R-11, and one large absorption chiller. The installation also has many 1970s-vintage absorption chillers, which provide 4800 tons of cooling capacity.

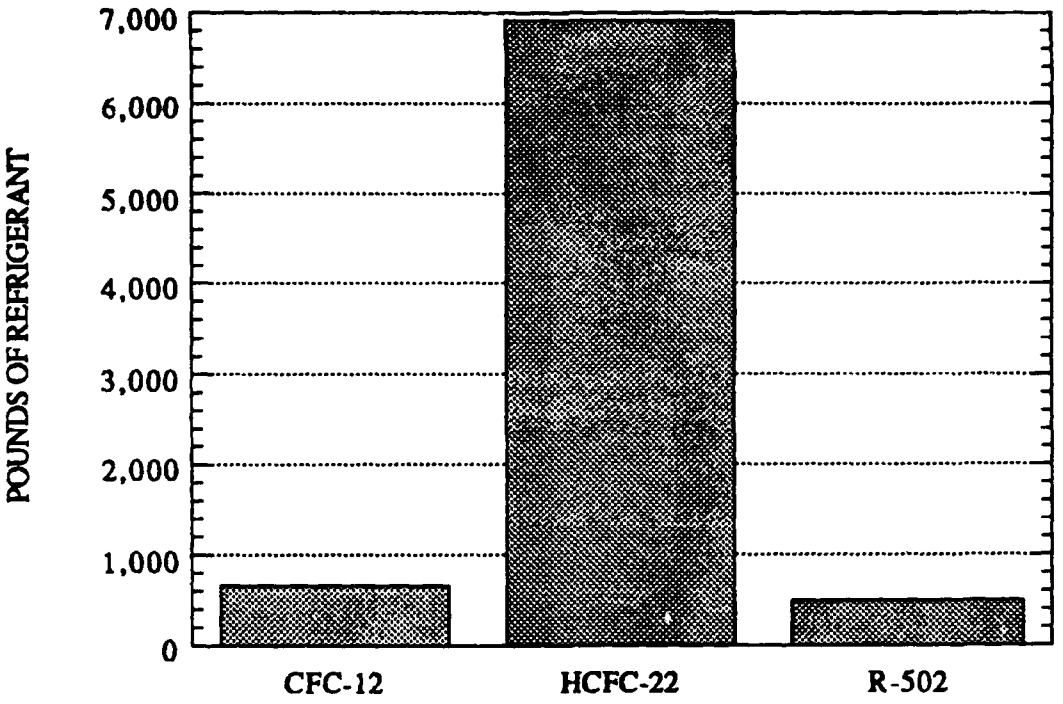

Figure 5. Refrigerant Usage at Red River Army Depot.

Table 6

Distribution of Refrigerant Usage by TDAC (Red River AD)

TDAC	Description	CFC-12	HCFC-22	R-502
K15111	Air-cond plts (>100 tons)			
K15112	Air-cond plts (26-100 tons)		851	99
K15113	Air-cond plts (5-25 tons)		2,946	
K15114	Chilled water plts (>100 tons)		462	
K15115	Chilled water plts (25-100 tons)		1,580	
K15130	Heat pump (>5 tons)			
K15120	Air-cond plts (<5 tons)		1,074	
K15140	Heat pump (<5 tons)			
K15220	Cold storage plt (incl ice mfg)			
K15211	Refrigeration (>5 hp)			
K15212	Refrigeration (<5 hp)	665		394
Totals	**(lb of refrigerant)**	**665**	**6,913**	**493**

Table 7

Age Distribution of AC&R Equipment (Red River AD)

Age	A/C >100 Tons	A/C <100 Tons	Family Housing	Refrigeration
0-5 yr	0	116	0	49
6-10 yr	3	184	22	94
11-15 yr	0	85	0	79
15+ yr	0	50	0	28

There are also many packaged chillers and split units in the 5 to 100 ton range, all using HCFC-22. A significant number of air-conditioning units of less than 5 tons capacity are also in use because of the large number of family housing units. Fort Campbell is somewhat unique in that a part of its family housing receives heating and cooling from a central plant.

Data Collection and Reduction

Data collection was conducted similarly to that at Fort Jackson and RRAD. Due to the large size of the installation, an unpublished study performed by an Austin Peay University student was especially helpful (personal communication with Len May of the Fort Campbell, KY DEH). This study was a comprehensive inventory of air-conditioning and refrigeration equipment at Fort Campbell and included much of the equipment on post. However, the Austin Peay study did not include window air-conditioning units and in some cases incorrectly identified refrigerant types used, for instance, by the ice makers and the absorption chillers. The Austin Peay inventory did not include equipment located at such facilities as the hospital, commissary, flight simulators, cold storage facilities, and family housing. This allowed the USACERL site survey to concentrate on these areas to produce a comprehensive listing of AC&R equipment at Fort Campbell.

Data on family housing was provided by personnel at Fort Campbell. The data included installed tonnage, equipment manufacturer and model number, as well as date of installation. This enabled an accurate estimation of refrigerant use for that portion of the inventory.

Comparison With Red Book Data

The comparison between the *Red Book* data and the site survey data is shown in Table 8. Trends are similar to those observed at Fort Jackson and RRAD. Agreement between overall categories is acceptable, even though discrepancies exist in the breakdown of these total quantities. The largest discrepancy in terms of total tons is for the sum of K15120 and K15140. This difference is very likely due to window units not accounted for in the Austin Peay study or in the site survey. Assuming a similar proportion of window units as found at Red River Army Depot, the difference is easily accounted for.

Horsepower data for the refrigeration categories shows considerable disagreement. The figure found by the site survey is about half family housing refrigerators and the other half small refrigerators used by food service and domestic refrigerators used in locations other than family housing. The figure reported by the site survey has been rechecked to ensure that none of the equipment was double counted. It is possible that the *Red Book* is in error or that the estimated average horsepower per refrigerator used by the site survey was higher than that used in determining the *Red Book* figure. The site survey estimated the average refrigerator horsepower as 1/3 hp.

Table 8

Comparison of *Red Book* and Site Study Data (Fort Campbell)

TDAC	Description	Units	Study	Redbook
J51000	AC plt (all tonnage)	Ton cap	27,538	29,283
J52000	Cold storage plt (incl. ice manuf.)	Hp cap	250	302
K15100	Air-cond and chill water plts	Ton cap	18,482	17,933
K15111	Air-cond plts (>100 tons)	Ton cap	715	11,837
K15112	Air-cond plts (26-100 tons)	Ton cap	5,210	3,405
K15113	Air-cond plts (5-25 tons)	Ton cap	3,127	2,691
K15114	Chilled water plts (>100 tons)	Ton cap	9,430	
K15115	Chilled water plts (25-100 tons)	Ton cap		
K15130	Heat pump (>5 tons)	Ton cap		
K15120	Air-cond plts (<5 tons)	Ton cap	5,831	11,351
K15140	Heat pump (<5 tons)	Ton cap	3,225	
K15220	Cold storage plt (incl ice mfg)	Hp cap	250	302
K15300	Refrigeration	Hp cap	2,871	1,357
K15211	Refrigeration (>5 hp)	Hp cap	159	
K15212	Refrigeration (<5 hp)	Hp cap	2,712	1,357

Results

The results of the Fort Campbell site survey are summarized in Figure 6 and Tables 9 and 10. Figure 6 shows the quantity of each type of refrigerant in use at Fort Campbell. Table 9 shows the type of refrigerants being used by the equipment within each Technical Data Activity Code. Observations are similar to those of the two other site surveys:

1. AC equipment of less than 100 tons capacity uses HCFC-22 almost exclusively.
2. Refrigeration systems use CFC-12, HCFC-22, and R-502.

Table 10 shows the number of units included in each age category. This table does not include all of the equipment at Fort Campbell. Notice that a large portion of air-conditioners of less than 100 tons capacity are over 15 years old. These may need replacement in the near future. A similar observation can be made for the family housing air-conditioning units. This suggests that recovery and recycling of the refrigerant in these units as they are replaced may be economically feasible.

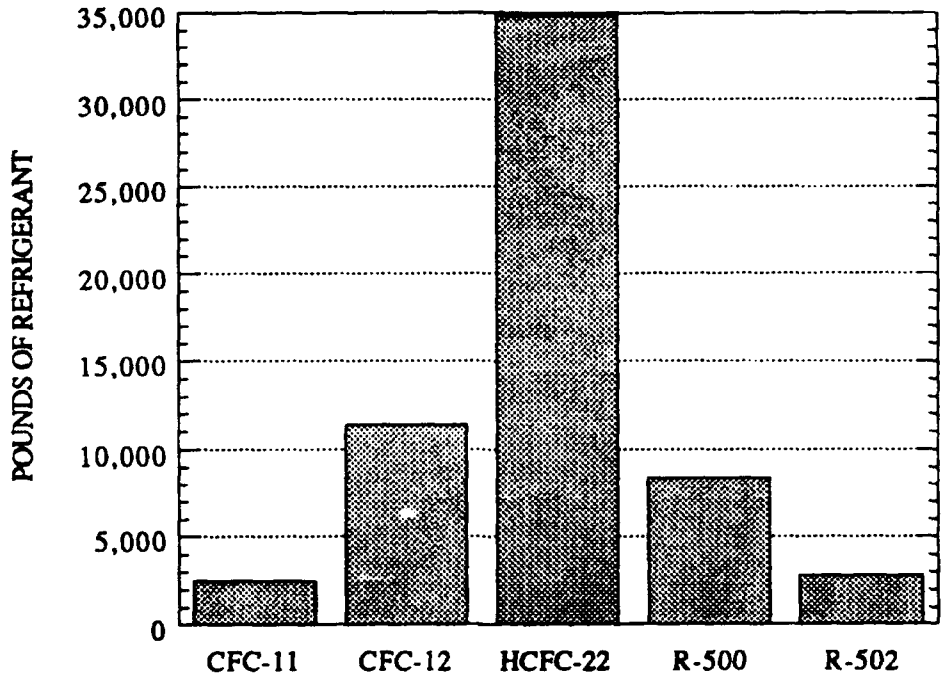

Figure 6. Refrigerant Usage at Fort Campbell.

Table 9

Distribution of Refrigerant Usage by TDAC

TDAC	Description	CFC-11	CFC-12	HCFC-22	R-500	R-502
K15111	Air-cond plts (>100 tons)			1,190		
K15112	Air-cond plts (26-100 tons)		916	8,119		
K15113	Air-cond plts (5-25 tons)		58	5,859		
K15114	Chilled water plts (>100 tons)	2,500			8,400	
K15115	Chilled water plts (25-100 tons)					
K15130	Heat pump (>5 tons)					
K15120	Air-cond plts (<5 tons)			11,685		
K15140	Heat pump (<5 tons)			6,450		
K15220	Cold storage plt (incl ice mfg)			600		600
K15211	Refrigeration (>5 hp)			960		900
K15212	Refrigeration (<5 hp)		10,389			1,029
Totals	**(lb of refrigerant)**	**2,500**	**11,363**	**34,863**	**8,400**	**2,779**

Table 10

Age Distribution of AC&R Equipment (Fort Campbell)

Age	A/C>100 Tons	A/C<100 Tons	Family Housing	Refrigeration
0-5 yr	6	168	0	950
6-10 yr	0	110	849	292
11-15 yr	3	53	2155	2
15+ yr	1	118	55	2

3 DATA ANALYSIS

Methodology

The final step was the development of a method to use the collected information to predict the type and amounts of refrigerants being used in the Army's AC&R equipment. The method involved estimating:

1. Total pounds of refrigerant based on capacities given in *Red Book*
2. The amount of each type of refrigerant using calculated distribution data from the site study.

The basis for these projections will be the data reported by the *Red Book* in the K account. The K account was chosen as a result of the comparison between *Red Book* data and data collected during the three site studies, which showed that the overall quantities in the K account are the most reliable indicator of equipment capacity at a post.

Type and Amount of Refrigerants in the Army

The first step requires the determination of the ratio of pounds refrigerant to capacity. This ratio can then be used to calculate an estimate of refrigerant usage in the following manner:

$$\text{Pounds Refrigerants} = \text{Tons Capacity} \times (\text{Pounds Refrigerant/Tons Capacity}) \qquad \text{[Eq 1]}$$

This ratio was determined from data gathered during the site studies. The data used was the capacity and refrigerant charge of equipment obtained from equipment nameplates and/or original equipment manufacturers. This data was used to calculate the ratio of refrigerant charge to capacity for equipment in each of the air-conditioning TDACs. The desired ratio is the slope in a single parameter, least squares fit of the data. Calculations include the determination of a regression coefficient, R, for each curve fit. The regression coefficient is an indication of the "goodness" of the fit. A value of R near 1.0 indicates a good fit of the curve to the data.

Figure 7 illustrates this procedure. The figure shows the data obtained for large chillers of capacity greater than 100 tons, specifically, TDAC K15111 and K15114. These two TDACs were grouped together even though the first lists air-conditioning units and the other chilled water units since there is no difference between the machines used for these purposes. Notice that the slope is approximately 2 lb/ton, which is an industry "rule of thumb." Similar calculations have been carried out for the remaining air-conditioning TDAC's. A summary of these is provided in Table 11.

Based on earlier discussion, the lb/ton ratio should be used for the entire size range of air-conditioning equipment. This has been accomplished by scaling each of the regression coefficients by the percentage of that equipment type found at the three site surveys. Table 12 shows this calculation. Note that the outcome is an overall ratio of 2 lb/ton. The determination of this ratio allows for the calculation of the total pounds of refrigerant used in U.S. Army air-conditioning equipment:

$$\text{Total lb of refrigerant} = (2.0 \text{ lb/ton}) \times (880{,}542 \text{ tons}) = 1{,}761{,}000 \text{ lb}$$

The final group of TDACs for which this ratio must be calculated is Cold Storage (K15220), Refrigeration >5 hp (K15211) and Refrigeration <5 hp (K15212). The scarcity of data for these categories

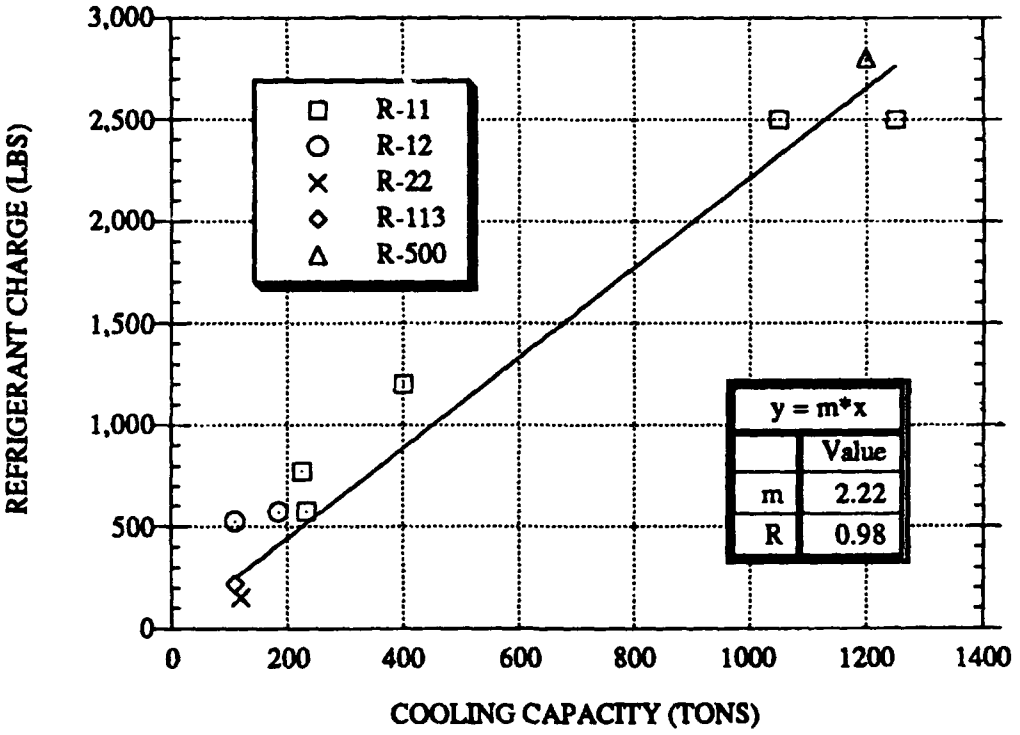

Figure 7. Refrigerant Charge vs. Cooling Capacity.

Table 11

Regression Equation Summary

TDAC	Data Points	Slope	R
K15111, K15114	18	2.2	0.98
K15112, K15115	55	2.0	0.81
K15113	134	1.7	0.88
K15120	37	1.8	0.75
K15140	9	2.6	0.56

Table 12

Air-Conditioning Charge/Capacity Ratio

TDAC	Capacity Fraction		lb/ton Ratio		Scaled Ratio
Air-cond plts (>100 tons)	0.562	×	2.2	=	1.2
Air-cond plts (26-100 tons)	0.194	×	2.0	=	0.4
Air-cond plts (5-25 tons)	0.075	×	1.7	=	0.1
Air-cond plts (<5 tons)	0.122	×	1.8	=	0.2
Heat pump (>5 tons)	0.000	×	0.0	=	0.0
Heat pump (<5 tons)	0.048	×	2.6	=	0.1
	Overall lb/ton ratio			=	**2.0**

requires a slightly different approach. The desired coefficient is determined by dividing the total refrigerant quantity by the total refrigeration capacity as found in the three site studies:

lb/hp ratio = (27,477 lb refrigerant/4636 hp capacity) = 5.9 lb/hp

Multiplying the total reported refrigeration capacity for all U.S. Army installations as reported in the *Red Book* yields the estimate of refrigerant use:

Total lb of refrigerant = (5.9 lb/hp) x (126,105 hp) = 744,000 lb

The final step requires the determination of the refrigerant type distribution for the air-conditioning group and refrigeration group. From this the estimated quantity of each type of refrigerant in the U.S. Army AC&R equipment inventory can be calculated (Table 13). The desired estimates of refrigerant usage in the U.S. Army are shown in the rightmost column of Table 13. The overall quantity of refrigerant, including all types, is 2.51 million lb. Of this, 1.39 million lb (55.4 percent) are chlorofluorocarbon-based. This information is further illustrated in Figure 8. In order of decreasing usage by the Army, the refrigerants are:

1. HCFC-22
2. CFC-12
3. CFC-11
4. R-500
5. R-502
6. CFC-113.

Age of AC&R Equipment

A composite age distribution of AC&R equipment was based on data obtained from the three site studies.

As in each of the three site studies, the age data is broken up into four categories. The age distribution obtained in this manner is shown in Figure 9, which was generated from the data in Table 14.

Table 13

Estimation of Army Wide Refrigerant Usage

Refrigerant	Air-Conditioning [1,761,000 lb Total] Fraction	Air-Conditioning [1,761,000 lb Total] Estimated	Refrigeration [744,000 lb Total] Fraction	Refrigeration [744,000 lb Total] Estimated	Estimated Totals
CFC-11	0.262	461,382			461,382
CFC-12	0.024	42,264	0.755	561,720	603,984
HCFC-22	0.612	1,077,732	0.062	46,128	1,123,860
CFC-113	0.003	5,283			5,283
R-500	0.098	172,578			172,578
R-502	0.001	1,761	0.183	136,152	137,913
			Total lb of Refrigerant		**2,505,000**

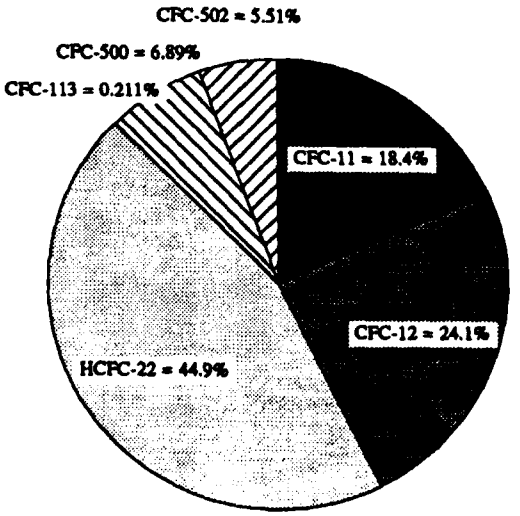

Figure 8. Total Estimated Refrigerant Usage in the U.S. Army.

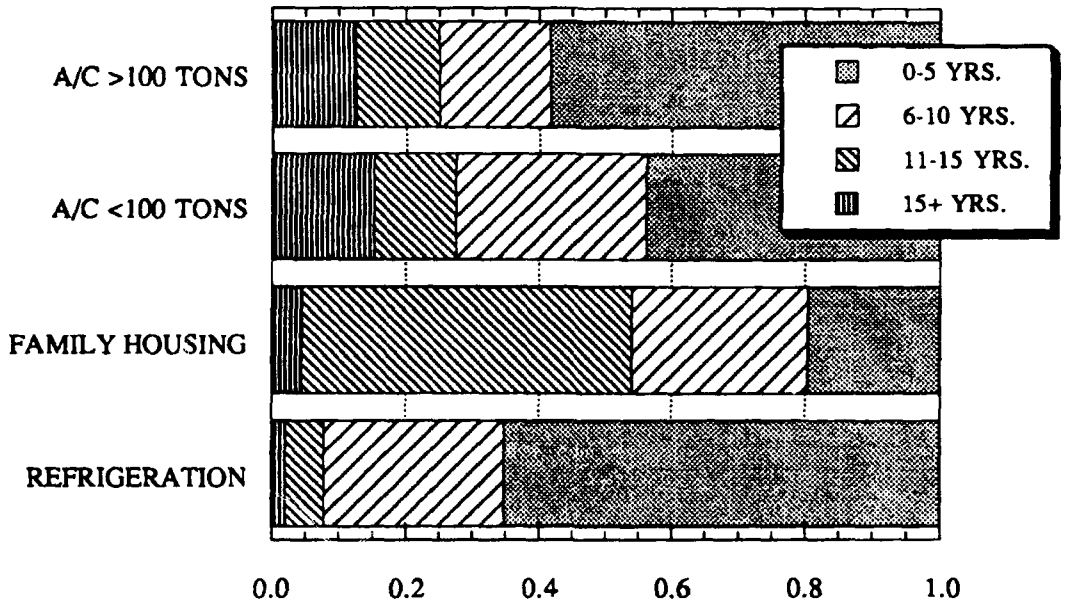

Figure 9. Age Distribution of AC&R Equipment (Three Site Studies).

The first category—air-conditioning units having capacity greater than 100 tons—has a large majority of relatively new units. This age factor suggests that it may be feasible to retrofit or recycle these units to keep them in operation. Units of less than 100 tons are generally shown to be less than 10 years old. These units use HCFC-22 almost exclusively; since HCFC-22 is not scheduled to be phased out for a number of years, these units can remain in use. Similarly, family housing equipment can remain in use since these machines also use only HCFC-22. The final bar in Figure 9 shows the age of refrigeration equipment as found in the USACERL study. Once again, much of the equipment is shown to be relatively new, an important note since many of these machines use CFCs. However, small units (those less than 5 hp) are often designed to be used with CFC-12, HCFC-22, and R-502. It may be possible to simply change the type of refrigerant used in these small units with only a slight sacrifice in performance.

Discussion of Results

There are two basic types of air-conditioning units: (1) the water cooler with either a positive displacement compressor (such as a reciprocating or screw compressor) or a centrifugal compressor, and

Table 14

Age Distribution of AC&R Equipment (Three Site Studies)

Age	A/C >100 Tons	A/C <100 Tons	Family Housing	Refrigeration
0-5 yr	14	501	853	1166
6-10 yr	4	328	1150	483
11-15 yr	3	141	2155	102
15+ yr	3	174	193	37

(2) the unitary air-conditioner, which employs a positive displacement compressor. Units with positive displacement compressors use HCFC-22 almost exclusively. The centrifugal chiller is always used for large cooling loads (from 100 tons to over 8000 tons), and typically uses CFC-11, although some use CFC-114, R-500, or HCFC-22.

Army installations with central cooling plants (such as Fort Jackson) are equipped almost exclusively with centrifugal chillers, and large buildings are cooled by chilled water from the central plants. The other buildings are cooled by unitary air-conditioning units, including window air-conditioners. In installations with no major central cooling plants, such as RRAD and Fort Campbell, most of the buildings are cooled by unitary air-conditioning units. (HCFC-22 is the refrigerant for the unitary air-conditioning units.)

According to a market share study of CFCs for refrigeration (Kruse 1989), in the United States, the share of HCFC-22, CFC-11, CFC-12, and others are 78.6 percent, 11.0 percent, 10.2 percent, and 0.2 percent, respectively. Chiller population estimates supplied by the Air-Conditioning and Refrigeration Institute (Denny 1991) are approximately 80 percent, 10 percent, 5 percent, 4 percent, 1 percent, and less than 1 percent, for units using CFC-11, CFC-12, CFC-500, HCFC-22, CFC-114, and CFC-113, respectively, based on a total estimated population of 73,000 units. Along with estimates of average capacity provided for these units by ARI, the distribution of refrigerant usage for large chillers was estimated. This information and the distribution obtained from the site surveys, are shown in Table 15. The comparison is quite favorable considering the small number of installations surveyed.

Note that uncertainty in the shape of the refrigerant distribution is unavoidable due to the small sample size (3 installations sampled out of a total of 164 installations). For example, the portion of CFC-500 (8.7 percent) in the final estimate of refrigerant quantities is a result of three large centrifugal chillers located at Fort Campbell. Regardless of the actual refrigerant usage distribution, most chillers currently use CFC refrigerants (CFC-11, CFC-12, and CFC-500) and will therefore require either retrofit or replacement.

The three sites chosen for a detailed inventory are typical Army installations, and together, effectively represent the whole Army. This is supported by comparing the equipment use at the three sites with the use in the Army as a whole as given in the FY89 *Red Book* (Table 16). The site studies confirmed that the overall distribution of equipment as reported in the *Red Book* was accurate. Again, the agreement is favorable considering the small sample size and the previously identified uncertainties in the *Red Book* data.

The overall estimated quantities of refrigerants in the Army (Table 13) reflect the general trend in the United States. As expected, the portion of HCFC-22 is the largest among the types of refrigerants, followed by CFC-12 and CFC-11. The difference in overall quantities as determined by this study and given by Kruse (1989) are possibly due to the inherent difference between installed quantities and annual market share quantities.

Absorption units were excluded from the estimate since most large chillers are based on the vapor compression cycle (centrifugal and positive displacement compressors). If the number of absorption units observed at the surveyed sites was, in fact, typical of the Army as a whole, then the amount of CFCs estimated to be used by the Army as a whole would be reduced by 11 percent. This means that the CFC use estimated in this study represents an "outside estimate" of Army use. It should be recognized that absorption units contain no CFCs or HCFCs and would not be candidates for retrofit or replacement.

Table 15

Large Chiller Refrigerant Usage

	Source	
Refrigerant	USACERL	ARI
CFC-11	65.3	65.6
CFC-12	3.2	11.9
HCFC-22	6.6	11.9
CFC-113	0.6	0.0
CFC-114	0.0	0.9
R-500	24.3	9.7

Table 16

Equipment Usage at Surveyed Sites vs Overall Army

TDAC	Site Surveys (%)	FY89 Redbook (%)
Air-cond plts (>100 tons)	56.2	57.0
Air-cond plts (26-100 tons)	19.4	8.2
Air-cond plts (5-25 tons)	7.5	9.2
Air-cond plts (<5 tons)	12.2	22.4
Heat pump (>5 tons)	0.0	0.5
Heat pump (<5 tons)	4.8	2.8

4 CONCLUSIONS

This study has calculated baseline technical information for the Army's air-conditioning and refrigeration equipment inventory based on site studies of three typical Army installations and information compiled in the 1989 *Red Book*. The overall quantity of all types of refrigerants is estimated to be 2.5 million lb. Of this, 1.39 million lb (55.4 percent) are CFC-based. More than half of the Army's AC&R equipment is less than 5 years old. Except for family housing category units, most AC&R equipment is less than 10 years old. Assuming that air-conditioning units have a lifespan of at least 15 years, and that the cost of a new air-conditioning unit will far outweigh the cost of retrofitting an old unit with a non-CFC refrigerant, it may be more cost-effective to retrofit this relatively new equipment with non-CFC refrigerants than to replace it with new units that use non-CFC refrigerants. Although drop-in refrigerants and retrofitting technology are still in the developmental stage, commercialization of these technologies is expected within a few years.

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Fort Monmouth 07703
ATTN: SELFM-EH-E
Savanna Army Depot 61074
ATTN: SDSLE-VAE
Rock Island Arsenal
ATTN: SMCRI-EH
ATTN: SMCRI-TL
Watervliet Arsenal 12189
ATTN: SMCWV-EH
Red River Army Depot 76102
ATTN: SDSRR-G
Harry Diamond Lab
ATTN: Library 20783
White Sands Missile Range 88002
ATTN: Library
Corpus Christi Army Depot
ATTN: SDSCC-ECD 78419

FORSCOM
ATTN: Facilities Engr (12)
Fort Bragg 28307
ATTN: AFZA-DE
Fort Campbell 42223
ATTN: AFZB-DEH
Fort McCoy 54656
ATTN: AFZR-DE
Fort Stewart 31314
ATTN: AFZP-DEF
Ft Buchanan 00934
ATTN: Envr Office
Ft Devens 01433
ATTN: AFZD-DE
Fort Drum 13602
ATTN: AFZS-EH-E
Fort Irwin 92310
ATTN: AFZJ-EH
Fort Hood 76544
ATTN: AFZF-DE-AES Engr
Fort Meade 20755
ATTN: AFKA-ZI-EH-A

6th Infantry Division (Light)
ATTN: APVR-DE 99505
ATTN: APVR-WF-DE 99703

National Guard Bureau 20310
ATTN: Installations Div

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CECC-R 22060
ATTN: Engr Strategic Studies Ctr
ATTN: Australian Liaison Office

USA Natick RD&E Center 01760
ATTN: STRNC-DT
ATTN: DRDNA-F

TRADOC
ATTN: DEH (13)
Fort Monroe 23651
ATTN: ATBO-G
Carlisle Barracks 17013
ATTN: ATZE-DIS
Fort Eustis 23604
ATTN: DEH
Fort Chaffee 72905
ATTN: ATZR-ZF
Fort Sill 73503
ATTN: ATZR-E

US Army Materials Tech Lab
ATTN: SLCMT-DEH 02172

WESTCOM 96858
ATTN: DEH
ATTN: APEN-A

SHAPE 09705
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128
ATTN: ECJ4-LIE

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

CEWES 39180
ATTN: Library

CECRL 03755
ATTN: Library

USA AMCOM
ATTN: Facilities Engr 21719
ATTN: AMSMC-IR 61299
ATTN: Facilities Engr (3) 85613

USAARMC 40121
ATTN: ATZIC-EHA

Military Traffic Mgmt Command
ATTN: MTEA-GB-EHP 07002
ATTN: MT-LOF 20315
ATTN: MTE-SU-FE 28461
ATTN: MTW-IE 94626

Fort Leonard Wood 65473
ATTN: ATSE-DAC-LB (3)
ATTN: ATZA-TE-SW
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL

Military Dist of WASH
Fort McNair
ATTN: ANEN 20319

USA Engr Activity, Capital Area
ATTN: Library 22211

Norton AFB 92409
ATTN: Library

US Army ARDEC 07806
ATTN: SMCAR-ISE

Charles E Kelly Spt Activity
ATTN: DEH 15071

Engr Societies Library
ATTN: Acquisitions 10017

Defense Nuclear Agency
ATTN: NADS 20305

Defense Logistics Agency
ATTN: DLA-WI 22304

Walter Reed Army Medical Ctr 20307

US Military Academy 10996
ATTN: MAEN-A
ATTN: Facilities Engineer
ATTN: Geography & Envr Engrg

416th Engineer Command 60623
ATTN: Gibson USAR Ctr

USA Japan (USARJ)
ATTN: APAJ-EN-ES 96343
ATTN: HONSHU 96343
ATTN: DEH-Okinawa 96376

Naval Facilities Engr Command
ATTN: Facilities Engr Command (8)
ATTN: Division Offices (11)
ATTN: Public Works Center (8)
ATTN: Naval Constr Battalion Ctr 93043
ATTN: Naval Civil Engr Laboratory (3) 93043

8th US Army Korea
ATTN: DEH (12)

US Army HSC
Fort Sam Houston 78234
ATTN: HSLO-F
Fitzsimons Army Medical Ctr
ATTN: HSHG-DEH 80045

Tyndall AFB 32403
ATTN: AFESC Program Ofc
ATTN: Engrg & Srvc Lab

Chanute AFB 61868
ATTN: 3345 CES/DE

USA TSARCOM 63120
ATTN: STSAS-F

American Public Works Assoc. 60637

US Army Envr Hygiene Agency
ATTN: HSHB-ME 21010

US Gov't Printing Office 20401
ATTN: Rec Sec/Deposit Sec (2)

Nat'l Institute of Standards & Tech
ATTN: Library 20899

Defense Tech Info Center 22304
ATTN: DTIC-FAB (2)

US Army Forts
Fort Huachuca 85613
ATTN: ATZS-EHE (2)
Fort Sam Houston 78234
ATTN: AFGZ-DE-OM
Fort Jackson 29207
ATTN: ATZJ-EHO

National Training Center
ATTN: AFJ-EHE-PM 92310

AAFES
ATTN: Constr. Div.

OASA/IL&E
WASH DC 20310

Holloman AFB
ATTN: 833 CSG/DEEE