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CFC Alternative Refrigerant Technologies

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# Estimated Retrofit and Replacement Costs for Army Air-Conditioning and Refrigeration Equipment Presently Using Chlorofluorocarbons

by
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Recent studies have verified that the emission of man-made 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 requiring minimal use of CFCs and halons.

Using baseline information calculated for the Army's air-conditioning and refrigeration (AC&R) equipment inventory based on site studies of three Army installations, information from the 1989 *Red Book*, and cost data from AC&R manufacturers, this study provides cost estimates for the replacement and/or retrofit of this equipment. A realistic estimate of the total cost of eliminating CFC use in Army facility AC&R equipment is $150 million, based on expected retrofit of a portion of the inventory.

Retrofits may be more economical for relatively new equipment. However, the industry-wide guidelines necessary to implement large-scale refrigeration system retrofits are not yet available.

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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 requiring minimal use of CFCs and halons.

Using baseline information calculated for the Army's air-conditioning and refrigeration (AC&R) equipment inventory based on site studies of three Army installations, information from the 1989 *Red Book*, and cost data from AC&R manufacturers, this study provides cost estimates for the replacement and/or retrofit of this equipment. This report includes estimates for the elimination of all Army CFC usage by replacement and retrofit.

A realistic estimate of the total cost of eliminating CFC use in Army facility AC&R equipment is $150 million, based on expected retrofit of a portion of the inventory. Retrofits may be more economical for relatively new equipment. However, the industry-wide guidelines necessary to implement large-scale refrigeration system retrofits are not yet available. The estimates here will help the Army meet CFC regulatory requirements in the context of rapidly developing alternative technologies, on a cost-effective schedule.

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## FOREWORD

This research was performed for the U.S. Army Center for Public Works (USACPW), Fort Belvoir, VA, under project 4A162784AT45, "Energy and Energy Conservation," Work Unit EX-XM3, "CFC Alternative Refrigerant Technologies." The technical monitor was Chris Irby, CECPW-FU-M.

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## 1 INTRODUCTION

### Background

The stratospheric ozone layer prevents most of the ultraviolet (UV) radiation from the sun from reaching the earth's surface. The ongoing depletion of this shield and increased UV penetration will profoundly affect the ecology of terrestrial life—likely resulting in increased skin cancer in humans as well as disturbing the balance of microorganisms that will ultimately affect the natural food chain. The depletion of ozone in the stratospheric layer and the identification of chlorofluorocarbon (CFC) refrigerants as contributors to this depletion has resulted in legislation mandating a phaseout of their production (U.S. Clean Air Act Amendment of 1990). In response to this requirement, the Department of Defense (DOD) issued a policy (DOD Directive 6050.9, 13 February 1989), the Army issued a letter (Headquarters, Department of the Army [HQDA] LTR 200-90-1, 27 July 1990), and the U.S. Army Center for Public Works (USACPW)* issued a Technical Note (TN 420-54-01, 26 June 1991), requiring minimal use of ozone-depleting substances and the elimination of their direct and unnecessary release into the atmosphere. Complete phaseout of CFC use in DOD is set for October 2000.

The large inventory of air-conditioning and refrigeration (AC&R) equipment owned and maintained by the U.S. Army uses a significant amount of the CFC refrigerants scheduled for phaseout. As a result, the Army is faced with the challenge of meeting the CFC regulatory requirements in a timely and economical manner within the context of rapidly developing alternative technologies. Eliminating the use of CFC refrigerants requires either their replacement with non-CFC equipment or conversion of existing equipment to non-CFC use. To help the Army meet this challenge, USACPW and the U.S. Army Construction Engineering Research Laboratories (USACERL) are working with industry to advance CFC alternative refrigerant technology and transfer the technology to the field.

### Objective

The objective of this study is to provide an estimate of the cost of eliminating the usage of CFCs in AC&R equipment owned and maintained by the U.S. Army. The estimate includes the possibility of converting part of the existing equipment inventory with CFC refrigerants to the use of non-CFC refrigerants. The estimates obtained can be used to plan retrofit/replacement budgets and schedules and to identify specific areas for further studies.

### Approach

As a first step in the Army's effort toward a timely and economic transition to non-CFC refrigerants, USACERL has compiled an Army-wide inventory data of AC&R equipment based on three U.S. Army

*The U.S. Army Center for Public Works is the former U.S. Army Engineering and Housing Support Center.

installations (Sohn, Homan, and Sliwinski) and AC&R inventory lists in the 1989 *Red Book*.** In the present study, this inventory data and the cost data provided by AC&R equipment manufacturers are used to estimate the cost of converting or replacing all AC&R equipment presently using CFC refrigerants. Estimates produced by two U.S. Army Training and Doctrine Command (TRADOC) installations are compared with the estimates produced by the methodology presented in this report. Finally, the uncertainty in the cost estimate is analyzed to provide a realistic confidence level. Appendix A contains the Fiscal Year (FY)89 and FY90 *Red Book* AC&R inventory data for the Army by Major Command, and Appendix B has a detailed illustration of the calculation procedure used to arrive at the cost estimates.

## Scope

This report estimates the retrofit and replacement costs necessary for elimination of CFC usage in Army facility AC&R equipment only. The Army's use of CFCs as solvents, firefighting agents, cleaning agents, in foam insulation, and as refrigerants in vehicle air-conditioning (AC) systems are beyond the scope of this report.

## Mode of Technology Transfer

It is recommended that the information in this report be used to refine the DOD/DA policy on CFC issues such as development of criteria for conversion or replacement of CFC equipment. A portion of this draft report has been quoted for a briefing of the Assistant Secretary of the Army (ASA) for a policy development on budget programming. Portions of this report will be included in a Technical Bulletin for installation Directorate of Public Works (DPW) staff for developing their compliance cost estimate for the CFC-related regulations.

** 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).

## 2 ESTIMATION OF RETROFIT AND REPLACEMENT COSTS

The projections developed in this report are based on the study conducted by USACERL in cooperation with USAEHSC, *Chlorofluorocarbon Uses in Army Facility Air-Conditioning and Refrigeration* (Sohn, Homan, and Sliwinski). Results of the study included the determination of type, capacity, age, and refrigerant usage of AC&R equipment on Army installations. The study included collection of detailed equipment inventories from three typical Army installations (Fort Jackson, SC [TRADOC], Red River Army Depot, TX (U.S. Army Materiel Command [AMC]), and Fort Campbell, KY [FORSCOM]) and compilation of AC&R equipment data contained in the FY89 *Red Book* (refer to the USACERL report for a detailed description of the *Red Book*). The data obtained from the three site visits and the *Red Book* was used to project estimates of AC&R equipment age, capacity, and refrigerant usage for the entire Army.

Development of the projected retrofit and replacement costs will be presented in two separate sections, one for AC equipment and the other for refrigeration equipment. However, the general methodology used to arrive at the desired cost estimates is quite similar for both types of equipment. The approach used in this investigation is illustrated in Figure 1. The capacity data reported in the *Red Book* along with refrigerant and equipment usage data from the USACERL technical report [TR] FE-93/14 mentioned above are used to estimate the quantities of refrigerants used by AC equipment and the capacities of categories of refrigeration equipment. Then, with average equipment size data, the number of units using each type of refrigerant can be estimated. Finally, this information can be used with estimates of retrofit and replacement costs obtained from equipment manufacturers to estimate the compliance cost for the Army equipment inventory. Note that calculating the number of average-size units and multiplying by the cost per unit is equivalent to estimating the average cost per unit of capacity. However, the intermediate step of estimating the number of units clarifies the size of the inventory.

The Army-wide AC&R equipment inventory data as reported in the *Red Book* (1989,1990) is shown in Table 1. The data is reported in tons capacity.* Notice the slight increase in AC inventory capacity and the decrease in refrigeration inventory capacity from FY89 to FY90.

### Air-Conditioning Equipment Methodology

The estimated total quantity of refrigerant used by AC equipment is the total capacity in tons multiplied by the average pounds of refrigerant per ton capacity. The ratio has been found to be approximately 2.0 lbs/ton for AC equipment. Using the total estimated quantity of refrigerant, the usage of each type of refrigerant can be calculated using the distribution shown in Table 2. These figures include the refrigerant used by all sizes of AC equipment. This approach has been used instead of directly using the *Red Book* data from each category since the USACERL TR FE-93/14 found that the AC capacities were often not listed in the correct categories. Refer to the TR for a further discussion of this.

The USACERL TR FE-93/14 found that only AC units of greater than 100 tons capacity used CFC refrigerants; units of less than 100 tons capacity used HCFC-22 (hydrochlorofluorocarbon-22) almost exclusively. Therefore it was assumed that all CFC refrigerants are being used by units having over 100 tons capacity. Some units of greater than 100 tons capacity were found to be using HCFC-22; at this time HCFC-22 is an acceptable refrigerant. However, the recently adopted Copenhagen amendments include a phaseout schedule for HCFC refrigerants beginning with a consumption freeze in 1996. The only unit

*1 ton = 12,000 Btu/hr; 1 lb = 0.454 kg

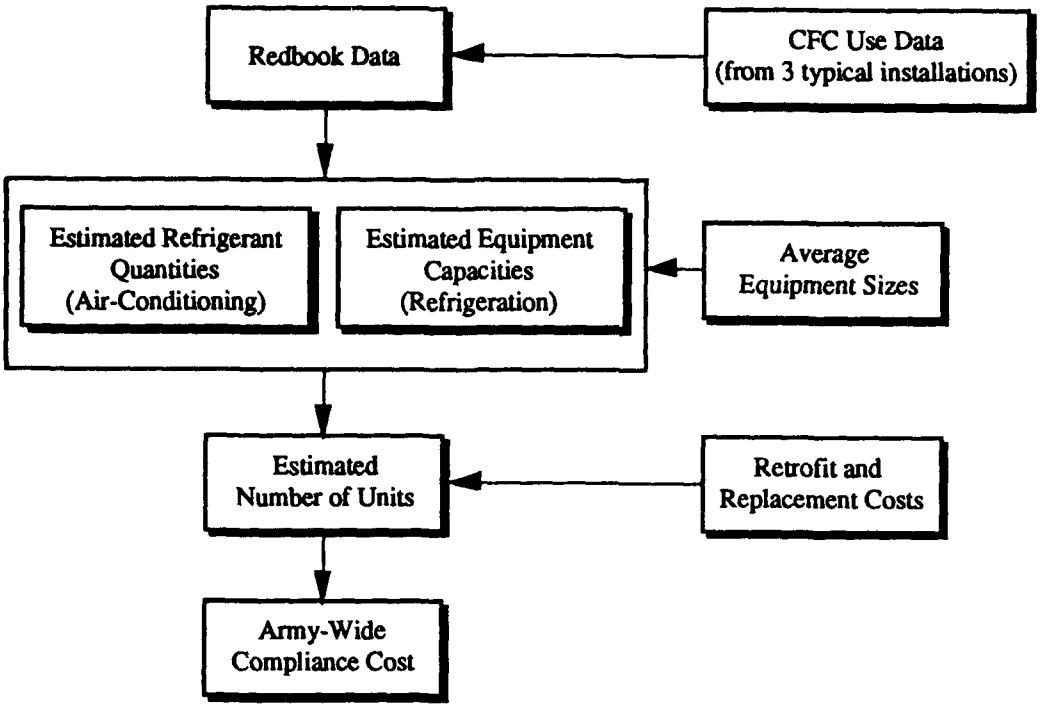


**Figure 1. Methodology for Estimate of Compliance Cost.**

with less than 100 tons capacity found in the usage study to be using a CFC refrigerant was a 99 ton R-502 unit located in a flight simulator at Fort Campbell. The effect of including this unit is seen in the small R-502 fraction shown in Table 2. Since this unit is very much an exception and the quantity is very small, the use of R-502 in AC equipment will be neglected. Equipment using R-500 will be considered as part of the equipment requiring retrofit or replacement since R-500 is an azeotropic mixture of CFC-12 (73.8 percent by mass) and R-152a (26.2 percent by mass).

The average size of machines using each of these types of refrigerants has been obtained from the Air-Conditioning and Refrigeration Institute (ARI) (Denny, August 1991) and is shown in Table 3. These sizes are consistent with the equipment observed at the three installations examined in the USACERL TR FE-93/14.

To convert the refrigerant quantities to capacity, the ratio of refrigerant charge to unit capacity is required. This ratio was obtained for units of greater than 100 tons capacity from data gathered during the site studies conducted as part of the USACERL TR FE-93/14. The lbs/ton ratio was calculated from a single parameter curve fit of the refrigerant charge and capacity of 18 large AC units. The calculation is illustrated in Figure 2. Notice that the average lbs/ton ratio is 2.2. This ratio is close to that used by many in the industry for this size of equipment, 2 lbs/ton. This similarity points to the accuracy of that study's calculation.

Calculation of the estimated number of chillers using each type of CFC refrigerant is now possible. The quantity of each CFC refrigerant is divided by the average chiller size for that refrigerant and the average lbs/ton ratio. One finds that chillers using CFC-11 make up a majority of the machines requiring either retrofitting or replacing. Determining the most cost-effective approach for meeting the CFC requirements of these machines will be of considerable benefit to the Army.

**Table 1**

**U.S. Army AC&R Equipment Inventory Data***

| Category | Capacity (FY89) | Capacity (FY90) |
|---|---|---|
| AC >100 tons | 511,205 | 517,299 |
| AC 26-100 tons | 73,166 | 88,089 |
| AC 5-25 tons | 82,662 | 85,941 |
| AC <5 tons | 200,780 | 214,935 |
| Heat pump | 12,734 | 11,755 |
| Total = | 880,547 tons | 918,019 tons |
| | | |
| Cold Storage (hp) | 25,029 | 20,375 |
| Refrig >5 hp | 85,091 | 81,930 |
| Refrig <5 hp | 15,985 | 18,586 |
| Total = | 126,105 hp | 120,891 hp |

*Source: FY90 *Red Book*, USAEHSC.

**Table 2**

**Breakdown of Refrigerant Usage in Air-Conditioning Equipment**

| Refrigerant | Fraction* |
|---|---|
| CFC-11 | 0.262 |
| CFC-12 | 0.024 |
| HCFC-22 | 0.612 |
| CFC-113 | 0.003 |
| R-500 | 0.098 |
| R-502 | 0.001 |

*Source: Sohn, Homan, and Sliwinski.

Table 3

Average Size of Chillers Using CFC Refrigerants

| Refrigerant | Average Size* |
|---|---|
| CFC-11 | 550 tons |
| CFC-12 | 800 tons |
| CFC-113 | 220 tons |
| R-500 | 1300 tons |

*Sources: ARI and Sohn, Homan, and Sliwinski.

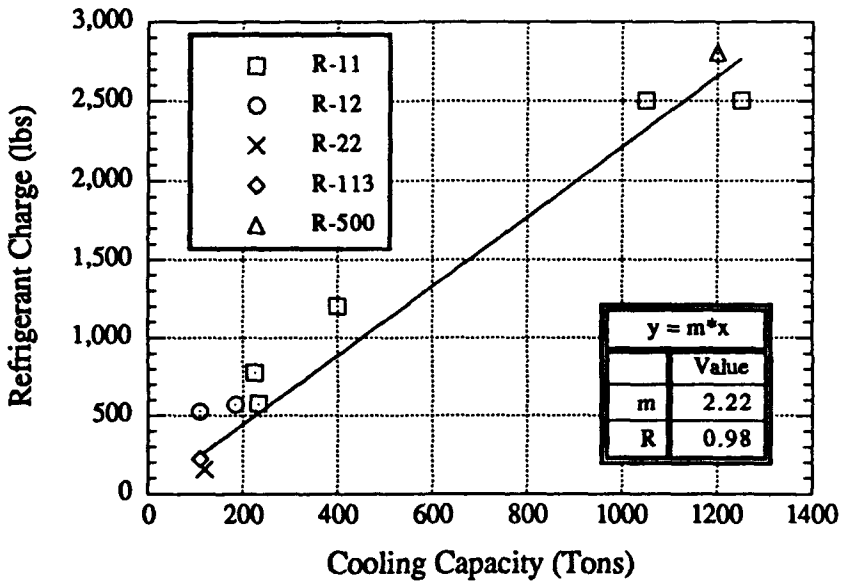


**Figure 2. Refrigerant Charge vs Cooling Capacity.**

USACERL TR FE-93/14 found that 75 percent of all AC equipment is less than 10 years old. This can be used as a first estimate for determining which units should be replaced or retrofitted. Units less than 10 years old can be assigned for retrofit and units greater than 10 years, for replacement. However, note that this may not be the optimum dividing point from an economic or practical standpoint for every installation. Therefore, this report presents the estimated costs for the complete range of replacement percentages, 0 to 100 percent. The issue of whether to retrofit or replace a particular machine is a local decision based on economics and technical considerations. Future studies can assist in this evaluation.

The alternatives available for AC equipment using each of the common refrigerants is shown in Figure 3. As stated earlier, units with a capacity of less than 100 tons use HCFC-22 almost exclusively, a refrigerant that regulations currently accept. For large chillers, the figure shows that it may be possible to retrofit units using CFC-11, CFC-12, or CFC-500. Units using CFC-113 will need to be replaced since the properties of CFC-113 (compared to the alternative refrigerants) make a retrofit impossible. Units using HCFC-22 can be left as is for now. Two AC equipment manufacturers have been contacted for estimates of the cost necessary to replace units typical of those used in the Army. Table 4 summarizes the cost estimates for the alternatives outlined in Figure 3. Note that the replacement costs shown are for equipment costs only. To account for installation costs, including labor, these figures are multiplied by

**Table 4**

**Estimated Retrofit and Replacement Costs for Average Size Chillers**

| Existing Unit | | Replacement | | Retrofit | |
|---|---|---|---|---|---|
| **Size** | **Refrig.** | **Cost*** | **Refrig.** | **Cost*** | **Refrig.** |
| 550 tons | CFC-11 | $160 - $180 | R-123/R-134a | $35 | R-123 |
| 800 tons | CFC-12 | $230 - $250 | R-123/R-134a | $65 | R-134a |
| 220 tons | CFC-113 | $50 - $100 | R-123/R-134a | † | |
| 1300 tons | R-500 | $250 - $400 | R-123/R-134a | $85 | R-134a |

* Cost is given in thousands.

† Retrofit of this unit is not recommended.

a factor of 1.5 in this investigation—the installation cost is assumed to be 50 percent of the equipment cost.

In the current market, the Trane Co. is recommending refrigerant R-123 as an alternative for CFC refrigerants. R-123 has properties similar to CFC-11, making a retrofit of the CFC-11 chillers possible. The cost, however, varies depending upon the age and configuration of the machine (Wendl, January 1993). Retrofit of a CFC-11 machine could cost from $5,000 to $50,000. The lower end of the range is applicable for units less than 2 years old since many of these machines have been designed to be compatible with alternative refrigerants. The modifications necessary to retrofit such machines will be minimal. The price quoted in Table 4 for a retrofit is an estimate for a 5-year-old machine. Converting older machines to the new refrigerant will likely require replacement of all gaskets, a new impeller, replacement of motor varnish, and possibly even a new motor. Necessary modifications (and therefore

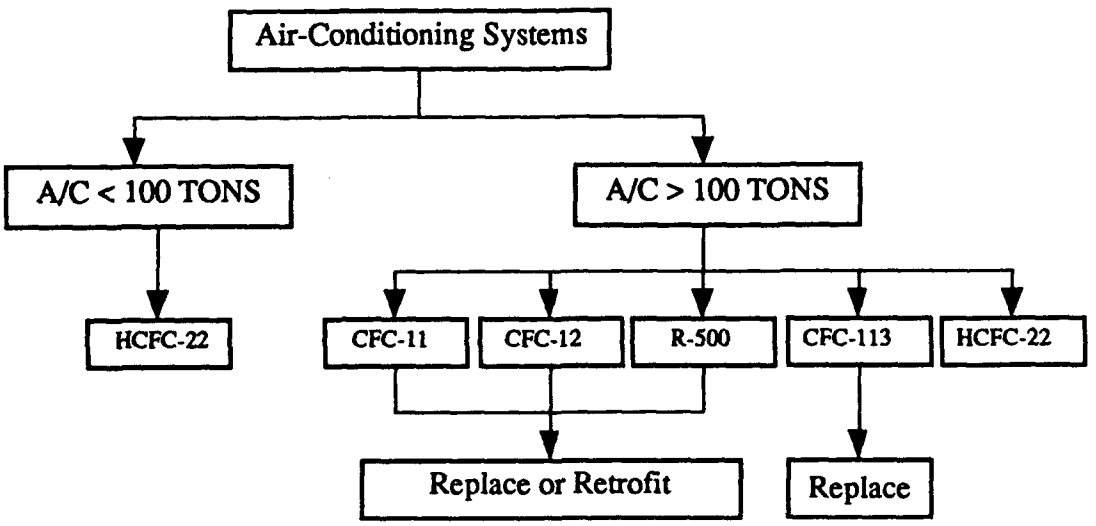


**Figure 3. Retrofit and Replacement Options for Refrigerants Used in Air-Conditioning Systems.**

cost) will depend on the age and configuration of the machine. Machines converted for use with a new refrigerant can also be expected to lose some capacity since the complete system is not optimized for the new refrigerant. The reduction in capacity could range from 5 to 20 percent.

Retrofit and replacement options have also been obtained from a McQuay Co. representative (Bilsland, January 1993). McQuay recommends R-134a as an alternative for CFC refrigerants. The cost for new machines using R-134a and retrofits to R-134a are as shown in Table 4. Both CFC-12 and R-500 machines can be retrofitted to R-134a. The ability to retrofit the large R-500 machines will result in considerable savings for the Army. The retrofit costs are only estimates, actual costs will vary depending on the age and configuration of the machine.

The cost for retrofit and replacement of existing equipment using CFC refrigerants can be calculated based on the cost information shown in Table 4, the estimated number of units, and the age summary from USACERL TR FE-93/14. Note that all CFC-113 machines have been assigned for replacement. It should be re-emphasized that the costs are for large chillers only (capacity greater than 100 tons). However, as mentioned earlier, these are the only units that need be considered for retrofit/replacement since almost all AC equipment of less than 100 tons does *not* use CFC refrigerants.

### Cold Storage and Refrigeration Equipment Methodology

The inventory data reported in the *Red Book* is the basis for the estimate of retrofit and replacement costs of refrigeration and cold storage equipment using CFC refrigerants—the same as for AC equipment. The Army-wide cold storage and refrigeration (cold storage equipment has higher capacity hp than refrigeration) inventory data reported in the *Red Book* was previously shown in Table 1. The capacity data is given in horsepower (hp).*

The inventory study produced estimates of the refrigerant usage for all refrigeration equipment systems in the Army. The estimate includes refrigerant used by cold storage systems, large refrigeration systems (greater than 5 hp compressor), and small refrigeration systems (less than 5 hp compressor, including household refrigerators). Due to the different refrigerant use distribution for each of these groups, retrofit and replacement costs are estimated for each group separately.

Similar to the AC categories, USACERL TR FE-93/14 found that the two refrigeration categories were not representative of the installed inventory. The USACERL TR found that actual refrigeration capacity agreed better with the sum of the two categories, not the capacity reported in each category. Further discussion of this can be found in USACERL TR. As a result, the sum of the two refrigeration categories is divided using data obtained by the USACERL study. The breakdown is shown in Table 5. The household refrigerators are separated from the other refrigeration equipment because they need not be considered for retrofit or replacement even though they use CFC-12. This is due to the fact that household refrigerators rarely require repairs and the refrigeration system is hermetically sealed. Most often, they are run until they malfunction and are then replaced. Household refrigerators using R-134a will soon be available and can be used to replace existing units as they become inoperable.

Using the refrigerant distribution shown in Table 6, the estimated capacity of equipment using each type of refrigerant is calculated. CFC refrigerants are used in the majority of refrigeration and cold storage equipment.

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*1 hp = 745.7 W.

**Table 5**

**Breakdown of Refrigeration Capacity**

| | Fraction |
|---|---|
| Large refrig. units (>5 hp) | 0.106 |
| Small refrig. units (<5 hp) | 0.126 |
| Household refrigerators | 0.768 |

*Source: Sohn, Homan, and Sliwinski.

The next step is estimating the number of units. The average size of units in each category has been determined from the equipment used at the three installations examined by USACERL. The average sizes are shown in Table 7. The estimated number of units using each type of refrigerant is found by dividing the total capacity by the average size of equipment in the category.

Using the same criteria as for AC, refrigeration units older than 10 years are assigned for replacement and units less than 10 years are to be retrofitted, if possible. Of the refrigeration units at the three installations studied by USACERL (TR FE-93/14), 90 percent were less than 10 years old. This suggests that a large number of units could be considered for retrofit instead of replacement.

The options available for equipment using each of the refrigerants are illustrated in Figure 4. All three types of equipment use CFC-12, CFC-502, and HCFC-22. Based upon discussions with equipment suppliers, it may be possible to retrofit CFC-12 units. Replacement of CFC-502 units has been assumed to be necessary, although some systems are being retrofitted with R-22, SUVA HP62, HP80, or HP81 in the private sector. Replacement prices from a local equipment supplier are shown in Table 8. Retrofit costs were estimated at 1/3 to 1/2 of replacement costs.

The cost of changing cold storage and refrigeration equipment to non-CFC refrigerants can be estimated using the above information. All R-502 units have been assigned for replacement because the alternative to R-502 is currently uncertain. It is unknown whether the R-502 replacement will be suitable for retrofitting existing machines. As for AC equipment, R-134a will be used as the CFC-12 replacement.

**Table 6**

**Fractional Refrigerant Usage by Equipment Category**

| | CFC-12 | HCFC-22 | R-502 |
|---|---|---|---|
| Refrigeration Units (Capacity <5hp) | 0.792 | 0.02 | 0.188 |
| Refrigeration Units (Capacity >5hp) | 0.384 | 0.171 | 0.445 |
| Cold Storage (including ice mfg.) | 0.853 | 0.073 | 0.074 |

*Source: Sohn, Homan, and Sliwinski.

Table 7

**Average Size of Refrigeration Equipment in Each Equipment Category**

| Category | Average Size* |
|---|---|
| Refrigeration (Capacity <5 hp) | 2.5 hp |
| Refrigeration (Capacity >5 hp) | 7.5 hp |
| Cold Storage (including ice mfg.) | 35 hp |

*These are the average sized units for the category as observed during the Sohn, Homan, and Sliwinski study.

Currently, new R-134a-based machines are becoming available on the market as are guidelines for the CFC-12/R-134a retrofit. Equipment manufacturers are conducting tests to determine the feasibility of this retrofit. Satisfactory results from these tests must predate any large-scale conversions of CFC-12 equipment to R-134a. These results will be important to the Army because of their savings potential.

## Estimate of Total Costs

The Army's estimated cost of compliance with present CFC phaseout schedules was determined using the methodology presented in the previous paragraphs. An initial cost estimate can be made based on the assumption that the age of equipment examined during the inventory study is representative of the majority of equipment in the Army and that all equipment less than 10 years old can be retrofitted using

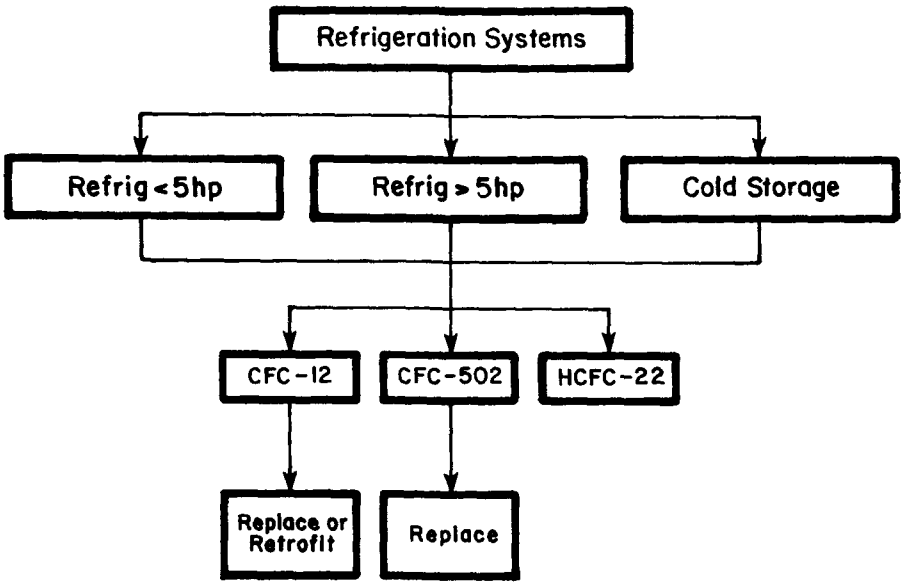


**Figure 4. Retrofit and Replacement Options for Refrigerants Used in Refrigeration Systems.**

**Table 8**

**Estimated Replacement Cost for Average Size Refrigeration Units**

| COST | | | |
|---|---|---|---|
| **2.5 hp unit** | **7.5 hp unit** | **35 hp unit** | **Explanation** |
| $1,500 | $3,500 | $20,000 | basic system |
| + $500 | + $500 | | misc. parts |
| $2,000 | $4,000 | | |
| x 1.25 | x 1.25 | | new refrig. increase |
| $2,500 | $5,000 | | |
| + $2,000 | + $2,500 | x 1.5 | installation |
| $4,500 | $7,500 | $30,000 | |

the new refrigerants. Under these assumptions, and using FY89 data, the projected cost is $76.8 million. Refer to Appendix B, Army-wide Retrofit and Replacement Cost Calculations, for tabular views of the calculation process.

However, the initial cost estimate is open to question given the uncertainty in the actual age of the Army equipment inventory and the undetermined dividing point between retrofit and replacement. Thus bounds for the total estimated cost can be calculated by examining the change in total cost with fraction of equipment replaced. This approach is useful since the estimated equipment age and retrofit/replacement dividing point only serves to define the proportions of the inventory that should be replaced and retrofitted.

The total cost for FY89 and FY90 inventory data and the separate cost for AC&R systems (FY89 data only) are shown versus replacement percentage in Figure 5. The total cost line, although it appears to be one line, is actually both the line for FY89 and FY90. The cost estimates using data from the 2 years are basically the same. The graph should be interpreted the following way: at 100 percent replacement none of the equipment using CFC refrigerants is retrofitted, and conversely at 0 percent replacement all CFC-based equipment (using refrigerants that can be retrofitted) is retrofitted. Some of the equipment will be suitable for retrofit, the majority will require replacement. In Figure 5, the lower bound on the total cost is approximately $45 million and the upper bound approximately $190 million. The lower bound will not be reached because some units will have to be replaced. The initial cost estimate of $76.8 million, viewed in light of the information shown in Figure 5, appears quite optimistic.

A more realistic estimate of the total cost of *eliminating* CFC use in Army facility AC&R equipment is $150 million. This is a realistic estimate since part of the inventory will likely be retrofitted, although the extent will be dependent on retrofit/replacement strategy, market conditions, and the actual condition of the AC&R equipment inventory.

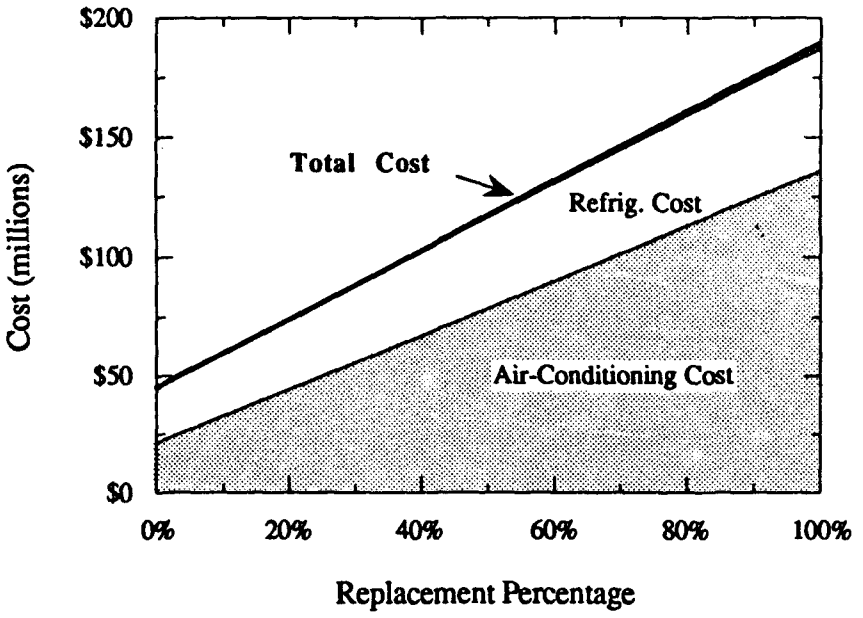


**Figure 5. Estimated Retrofit and Replacement Costs vs Replacement Percentage.**

# 3 COMPARISON WITH EXISTING ESTIMATES

In this chapter, comparisons are made between cost studies various installations conducted themselves and estimates produced by the methodology presented in this report. These comparisons are valuable for verifying the acceptability of the estimates obtained in the present study. However, the comparisons should be viewed within the context of the uncertainties in both the installation cost studies and the estimates presented in this study. Recall that the basis of the estimates in this report are the data contained in the *Red Book*, combined with equipment data from three of the nearly 200 Army installations, and estimates of retrofit and replacement costs for average size units obtained from equipment suppliers. The present study uses generalizations to arrive at an overall result for the Army, and therefore can be expected to produce inexact numbers at the installation level. Installation studies, although conducted with exact equipment inventories, use equipment prices in their calculations that are not contracted prices. The prices can vary and fluctuate. In addition, their studies were conducted a few years ago, and therefore, may not reflect current equipment prices.

## Fort Leonard Wood

A CFC-phaseout plan has been developed by personnel at Fort Leonard Wood, MO (U.S. Army Training and Doctrine Command [TRADOC]). The plan lists the estimated costs for replacement of all equipment using CFC refrigerants. The costs included in the phaseout plan are shown in Table 9.

The equipment categories shown in Table 9 are different than those used in the present study. However, the first two categories are the same as those used in this study, and are compared first. The comparison is illustrated in Figure 6. The figure shows the estimates obtained using the methodology of this report for the two categories, (1) AC and cold storage and (2) all AC, cold storage, and refrigeration equipment. The difference between the two is very small because the amount of refrigeration capacity reported by Fort Leonard Wood in the *Red Book* is rather small. The inventory data reported in the *Red Book* for Fort Leonard Wood is shown in Table 10. The bubble in Figure 6 indicates the estimated cost for replacement of chilled water and cold storage systems reported in the Fort Leonard Wood study. The Fort Leonard Wood estimate is adequately bounded on either side by the study estimate range.

**Table 9**

**Fort Leonard Wood CFC Phaseout Plan Cost Estimates**

| Equipment Description | Estimated Cost |
|---|---|
| Chilled water systems (AC) | $1,825,000 |
| Cold storage units | $480,000 |
| Commercial refrigerators, ice machines, freezers | $550,000 |
| Walk-in coolers, freezers | $120,000 |
| Ice water, beverage, food counters | $330,000 |
| Air dryers | $227,000 |
| | Total = $3.5 million |

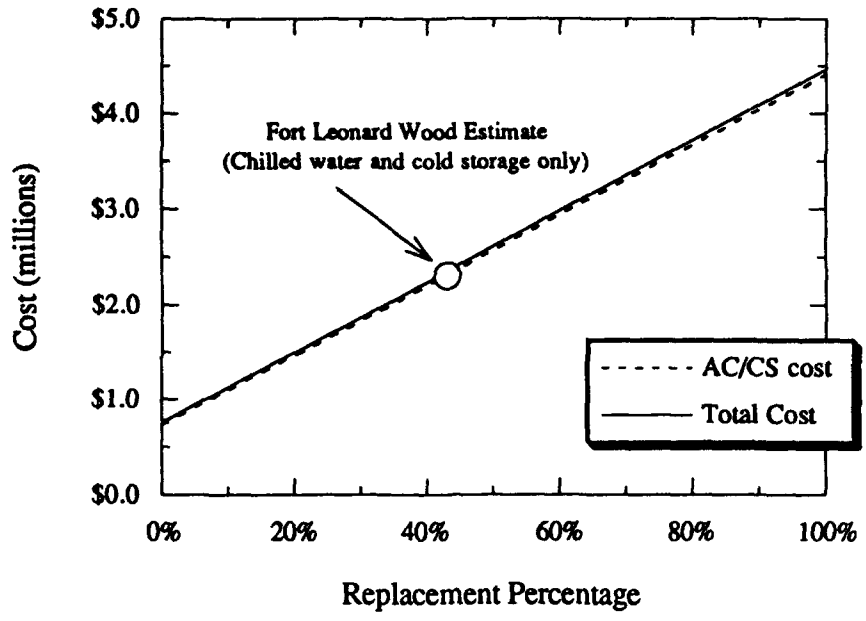


**Figure 6. Estimated Replacement and Retrofit Costs vs Replacement Percentage for Fort Leonard Wood.**

**Table 10**

**Fort Leonard Wood AC&R Inventory Data***

| Category | Capacity |
|---|---|
| AC >100 tons | 8,900 |
| AC 26-100 tons | 4,500 |
| AC 5-25 tons | 2,517 |
| AC <5 tons | 9,047 |
| Heat pump <5 tons | 60 |
| Total = | 25,024 tons |
| | |
| Cold Storage (hp) | 330 |
| Refrig >5 hp | |
| Refrig <5 hp | 215 |
| Total = | 545 hp |

* Source: FY90 *Red Book*, USAEHSC.

The next comparison is one of overall costs. The total estimated cost reported in the Fort Leonard Wood study is $3.5 million. The total estimated cost calculated by the method of this report is $4.5 million (100 percent replacement). The two estimates do not include the same equipment and not all of the equipment included in the Fort Leonard Wood study needs to be replaced. Units such as beverage, food counters, ice machines, and commercial refrigerators are often hermetically sealed and rarely develop leaks. Exclusion of these units would narrow the gap between the two estimates, providing an even more favorable comparison.

## Fort Jackson

A report titled *CFC Reduction Study and Procedures for Selected Facilities* was completed in June 1991 by PM&A Consulting Engineers under contract to USACE, Savannah District. The study included an inventory of AC&R equipment at Fort Jackson, a schedule for the replacement of CFC refrigerants in use, and cost estimates for replacement/retrofit of the major AC&R systems. The cost estimates included in the study are shown in Table 11.

Similar to the approach used for the Fort Leonard Wood estimates, the *Reduction Study* results can be compared to the estimate from the present study. The *Red Book* data used to calculate the cost estimate for Fort Jackson is shown in Table 12. The comparison between the estimates is shown in Figure 7. The broken line is the cost for AC, cold storage and refrigeration (greater than 5 hp only). The solid line is the cost for all equipment using CFCs. The *Reduction Study* estimate includes nearly the same equipment as that indicated by the broken line and is shown as the bubble on this line. The *Reduction Study* estimate does not include approximately two-fifths of the refrigeration capacity greater than 5 hp. Inclusion of this refrigeration capacity would bring the *Reduction Study* estimate to roughly $1 million. Figure 7 shows that the *Reduction Study* is within the estimate range of the present study.

**Table 11**

**Fort Jackson CFC Reduction Study Cost Estimates**

| Equipment Description | Estimated Cost |
|---|---|
| Chilled water systems (AC) | $494,000 |
| Cold storage units | $67,000 |
| Refrigeration units > 5 hp capacity | $204,000 |
| | Total = $765,000 |

Table 12

Fort Jackson AC&R Inventory Data*

| Category | Capacity |
|---|---|
| AC >100 tons | 12,031 |
| AC 26-100 tons | ~ |
| AC 5-25 tons | ~ |
| AC <5 tons | 3,001 |
| Heat pump <5 tons | ~ |
| Total = | 15,032 tons |
| | |
| Cold Storage (hp) | 525 |
| Refrig >5 hp | 1,054 |
| Refrig <5 hp | ~ |
| Total = | 1,579 hp |

*Source: FY89 *Red Book*, USAEHSC.

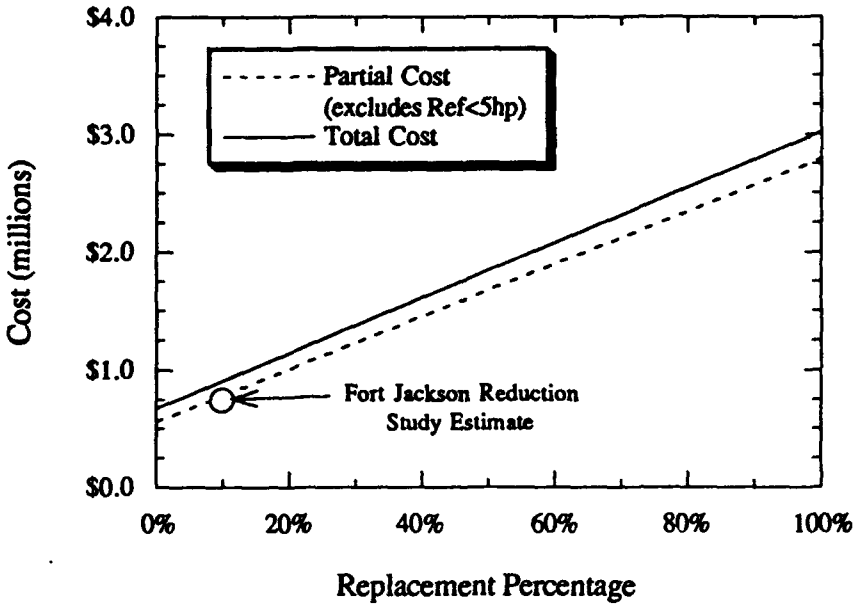


**Figure 7. Estimated Replacement and Retrofit Costs vs Replacement Percentage for Fort Jackson.**

# 4 ANALYSIS OF ESTIMATE UNCERTAINTY

The estimated costs for elimination of CFC refrigerants in facility AC&R systems were examined as a function of replacement percentage since the actual condition of the entire Army inventory is unknown. In this chapter, the uncertainty in the cost estimate as a function of replacement fraction is examined. The purpose is to provide a realistic confidence interval for the estimate. The analysis follows a method presented by Coleman and Steele (1989).

Consider a general case in which a result, r, is a function of J variables $X_i$:

$$r = r(X_1, X_2, \ldots, X_j) \qquad \text{[Eq 1]}$$

then the uncertainty in the result, $U_r$, is given by:

$$U_r = \left[ \left( \frac{\partial r}{\partial X_1} U_{X_1} \right)^2 + \left( \frac{\partial r}{\partial X_2} U_{X_2} \right)^2 + \ldots + \left( \frac{\partial r}{\partial X_j} U_{X_j} \right)^2 \right]^{1/2} \qquad \text{[Eq 2]}$$

where the $U_{Xi}$ are the uncertainties in the variables $X_i$.

The total cost for elimination of CFCs in AC equipment is given by:

$$\text{Total Cost} = \sum_{i=1}^{3} g\, c\, \frac{p_1}{p_2} \frac{n_i f_i}{s_i} + \sum_{i=1}^{3} (1-g)\, c\, \frac{p_1}{p_2} \frac{r_i f_i}{s_i} + c\, \frac{p_1}{p_2} \frac{n_4 f_4}{s_4} \qquad \text{[Eq 3]}$$

where the subscript i indicates the refrigerant type (CFC-11, CFC-12, CFC-500, or CFC-113). The first term on the right side of the equation is the replacement costs for CFC-11, CFC-12, and CFC-500 chillers, the second term is the retrofit costs for the same types of chillers, and the third term is the replacement costs for all CFC-113 chillers. The variables are defined as:

- $c$ = total AC capacity given in the *Red Book*
- $g$ = the fraction of equipment replaced
- $p_1$ = lbs/ton ratio for all AC equipment (2.0)
- $p_2$ = lbs/ton ratio for chillers (2.2)
- $n_i$ = cost of replacing chiller using refrigerant i
- $r_i$ = cost of retrofitting chiller using refrigerant i
- $s_i$ = average size of chiller using refrigerant i
- $f_i$ = fraction of AC capacity using refrigerant i

The total cost is therefore a function of the following variables:

$$\text{Total Cost} = f(c,p_1,p_2,n_j,r_j,f_j) \qquad \text{[Eq 4]}$$

each of which has an associated uncertainty. The estimated uncertainties are shown in Table 13.

The total cost for elimination of CFCs in refrigeration equipment is given by:

$$\text{Total Cost} = \sum_{j=1}^{3} g\,\frac{n_j b_{1j} c_j}{s_j} + \sum_{j=1}^{3} (1-g)\frac{r_j b_{1j} c_j}{s_j} + \sum_{j=1}^{3} \frac{n_j b_{2j} c_j}{s_j} \qquad \text{[Eq 5]}$$

where the index j indicates the categories refrig<5hp, refrig>5hp, and cold storage. The first term on the right side of Equation 5 is the cost for replacement of CFC-12 machines, the second term is the retrofit of CFC-12 machines, and the third term is replacement of CFC-502 machines. The variables are defined as:

$g$ = the fraction of equipment replaced
$n_j$ = cost of new equipment in category j
$r_j$ = cost of retrofitting equipment in category j
$b_{1j}$ = fraction of equipment in category j using CFC-12
$b_{2j}$ = fraction of equipment in category j using CFC-502
$c_j$ = total capacity of equipment in category j
$s_j$ = average size of equipment in category j

where $c_j$ is the *Red Book* refrigeration capacity multiplied by a factor, $f_j$, for refrig<5hp and refrig>5hp. For cold storage $c_j$ is the capacity reported in the *Red Book*. Therefore, the total cost is a function of the following variables:

$$\text{Total Cost} = f(k,l,n_j,r_j,f_j,b_{ij}) \qquad \text{[Eq 6]}$$

where k and l (see Table 14) are the *Red Book* refrigeration and cold storage capacities, respectively. The estimated uncertainties in each of the variables are shown in Table 14.

The uncertainty in the total cost for elimination of CFC usage in Army facility AC&R equipment is shown as a function of replacement percentage in Figure 8. The dotted lines indicate the extent of the region in which the true value is expected to fall based upon the uncertainties in the variables shown in Tables 13 and 14.

**Table 13**

**Estimated Uncertainties in AC Cost Variables**

| Variable | Uncertainty |
|---|---|
| c | ± 75,000 tons |
| p1, p2 | ± 10% |
| ni, ri | ± 30% |
| fi | ± 20% |

**Table 14**

**Estimated Uncertainties in Refrigeration Cost Variables**

| Variable | Uncertainty |
|---|---|
| k | ± 15,000 hp |
| l | ± 7,500 hp |
| nj, rj | ± 30% |
| fi | ± 25% |
| rij | ± 20% |

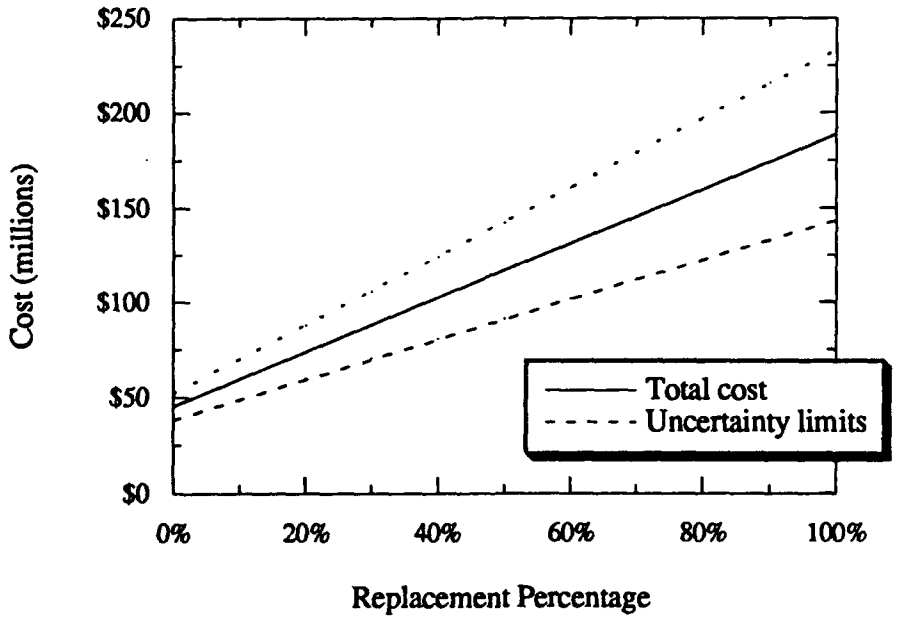


**Figure 8. Estimated Limits of Uncertainty in Total CFC Elimination Cost.**

# 5 CONCLUSIONS

Examining the data gathered from the 1989 *Red Book*, an inventory of three typical Army installations, and information from AC&R manufacturers, this study has calculated a range of cost estimates for the replacement and retrofit of Army AC&R equipment. The study concludes the following:

- AC equipment of less than 100 tons capacity uses HCFC-22 almost exclusively. This equipment does not need to be replaced now.
- Retrofit and replacement options for AC equipment are new technologies that are now available.
- Non-CFC alternatives for some refrigeration systems are now available.
- The industry-wide technical guidelines necessary to implement large-scale retrofits for refrigeration systems are not yet available.
- Refrigeration equipment such as commercial refrigerators and freezers need not be replaced since these units are typically hermetically sealed and rarely develop leaks. These units can be replaced at the end of their lifetime with CFC-free units.
- The total cost for elimination of CFC usage in Army facility AC and refrigeration equipment is $190 million for *complete replacement* of existing equipment. A total cost of $150 million is a realistic final estimate based on the expected retrofit of a portion of the inventory. The total cost as a function of replacement percentage is shown in Chapter 2.
- The Fort Jackson and Fort Leonard Wood cost studies compare favorably with the estimates presented in this report.

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## APPENDIX A: FY89 and FY90 Red Book AC&R Inventory Data

**Table A1**

**Technical Data Activity Code Definitions**

| TDAC | DESCRIPTION | UNITS |
|---|---|---|
| K15100 | AIR COND AND CHILL WATER PLTS | TON CAP |
| K15111 | AIR COND PLTS ( >100 TNS) | TON CAP |
| K15112 | AIR COND PLTS(26-100 TNS) | TON CAP |
| K15113 | AIR COND PLTS (5-25 TNS) | TON CAP |
| K15114 | CHILLED WATER PLTS ( >100 TNS) | TON CAP |
| K15115 | CHILLED WATER PLTS (25-100 TNS) | TON CAP |
| K15130 | HEAT PUMP ( > 5 TONS) | TON CAP |
| K15120 | AIR COND PLTS ( < 5 TNS) | TON CAP |
| K15140 | HEAT PUMP ( < 5 TONS) | TON CAP |
| K15220 | COLD STORAGE PLT (INCL ICE MFG) | HP CAP |
| K15300 | REFRIGERATION | HP CAP |
| K15211 | REFRIGERATION ( > 5 HP) | HP CAP |
| K15212 | REFRIGERATION ( < 5 HP) | HP CAP |

## Table A2

## FY89 Red Book 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 | |
| US MILIT ACAD | | | | | | | | | 660 | | 593 | 693 | |
| US ARMY JAPAN | 7,656 | 149 | 6,397 | | | | | | 3,685 | | | 761 | |
| EIGHTH US 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 |

**Table A3**

**FY90 Red Book 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 | 735 | 282 | 1,096 | 282 | 153 | | | | | | | | |
| HEALTH SERV CMD | 36,411 | 890 | 19,497 | 286 | 472 | | | | 7,393 | | 890 | 2,863 | 1,232 |
| MIL DIST OF WA | 15,536 | 360 | 8,332 | 2,372 | 13,543 | | | | 4,036 | 21 | 278 | 209 | 906 |
| MIL TRAF MGT CMD | 2,104 | 1,125 | 1,340 | 243 | 105 | | | | 630 | 43 | 825 | 759 | |
| FORCES CMD | 216,233 | 16,195 | 131,780 | 31,703 | 22,451 | 1,096 | 658 | 1,311 | 65,813 | 3,956 | 5,498 | 18,780 | 9,283 |
| ARMY EUROPE | 1,914 | 4,673 | 19,443 | 508 | 2,135 | | | 334 | 5,337 | | 1,824 | 12,984 | 4,465 |
| SOUTHERN CMD | 2,180 | 1,050 | 5,740 | 3,508 | 1,382 | 1,573 | 429 | | 11,600 | | 1,050 | 40 | 100 |
| WESTERN CMD | 18,495 | 1,757 | 15,794 | | | | | | 2,701 | | 59 | 1,960 | |
| ARMY MTRL CMD | 103,20 | 3,049 | 132,193 | | | | | | 20,585 | | 2,393 | 18,127 | |
| US MILIT ACAD | 6,222 | | 6,161 | | | | | | 660 | | 693 | | |
| US ARMY JAPAN | 10,917 | 250 | 6,832 | | | | | | 4,085 | | 149 | 798 | |
| EIGHTH US ARMY | 28,805 | 4,141 | 14,168 | | | | | | 3,297 | | 1,741 | 4,559 | |
| INTEL & SEC CMD | 587 | 68 | 500 | | | | | | 87 | | 68 | 112 | |
| TRNG & DOC CMD | 288,744 | 4,848 | 146,075 | 43,656 | 43,545 | 2,029 | 2,479 | 2,151 | 87,871 | 3,939 | 4,682 | 20,739 | 2,598 |
| INFO SYS CMD | 8,610 | 225 | 3,650 | 1,965 | 2,155 | | | | 840 | | 225 | | 2 |
| TOTALS | 740,700 | 38,913 | 512,601 | 84,523 | 85,941 | 4,698 | 3,566 | 3,796 | 214,935 | 7,959 | 20,375 | 81,930 | 18,586 |

## APPENDIX B: Army-wide Retrofit and Replacement Cost Calculations

**Table B1**

**Estimated Refrigerant Usage in Air Conditioning Equipment**

| Refrigerant | *Fraction | x | Total lb† | = | Pounds |
|---|---|---|---|---|---|
| CFC-11 | 0.262 | | 1,760,000 | | 585,000 |
| CFC-12 | 0.024 | | 1,760,000 | | 55,000 |
| HCFC-22 | 0.612 | | 1,760,000 | | 895,000 |
| CFC-113 | 0.003 | | 1,760,000 | | 5,000 |
| R-500 | 0.098 | | 1,760,000 | | 218,000 |
| R-502 | 0.001 | | 1,760,000 | | 2,000 |

* Source: Sohn, Homan, and Sliwinski.

† Calculated from FY89 Red Book data.

**Table B2**

**Estimation of No. of Units Using CFC Refrigerants**

| Refrigerant | lb refrig | ÷ | (Avg. size | x | lb/ton) | = | No. units |
|---|---|---|---|---|---|---|---|
| CFC-11 | 585,000 | | 550 tons | | 2.2 | | 484 |
| CFC-12 | 55,000 | | 800 tons | | 2.2 | | 32 |
| CFC-113 | 5,000 | | 220 tons | | 2.2 | | 11 |
| R-500 | 218,000 | | 1300 tons | | 2.2 | | 77 |

**Table B3**

**Large Air-Conditioning Unit Age Summary**

| Age | Fraction | Percentage |
|---|---|---|
| ≤ 10 years | 18/24 | 75% |
| > 10 years | 6/24 | 25% |

* Source: Sohn, Homan, and Sliwinski.

**Table B4**

**Estimated Retrofit and Replacement Costs for Air-Conditioning Equipment**

*Replacement Costs (Units > 10 years old)*

| Existing Unit Size | Refrig. | No. units | x | Cost/unit | = | Cost (millions) |
|---|---|---|---|---|---|---|
| 550 tons | CFC-11 | 95 | | 1.5 x $170,000 | | $24.23 |
| 800 tons | CFC-12 | 6 | | 1.5 x $240,000 | | $2.16 |
| 220 tons | CFC-113 | 11 | | 1.5 x $75,000 | | $1.24 |
| 1300 tons | R-500 | 15 | | 1.5 x $325,000 | | $7.31 |
| | | | | *Replacement Costs =* | | $34.94 |

*Retrofit Costs (Units ≤ 10 years old)*

| Existing Unit Size | Refrig. | No. units | x | Cost/unit | = | Cost (millions) |
|---|---|---|---|---|---|---|
| 550 tons | CFC-11 | 286 | | $35,000 | | $10.01 |
| 800 tons | CFC-12 | 18 | | $65,000 | | $1.17 |
| 1300 tons | R-500 | 45 | | $85,000 | | $3.83 |
| | | | | *Retrofit Costs =* | | $15.01 |

*Total Cost = Replacement Costs + Retrofit Costs = $50.0 million*

**Table B5**

**Cold Storage and Refrigeration Capacities**

| | Capacity |
|---|---|
| Cold Storage (including ice mfg.) | 25,000 hp |
| Refrigeration | 101,000 hp |

* Source: FY89 *Red Book.*

**Table B6**

**Breakdown of Refrigeration Capacity**

| | Fraction | x | Overall cap. | = | Fractional cap. |
|---|---|---|---|---|---|
| Large refrig. units (>5 hp) | 0.106 | | 101,000 hp | | 10,700 hp |
| Small refrig. units (<5 hp) | 0.126 | | 101,000 hp | | 12,700 hp |
| Household refrigerators | 0.768 | | 101,000 hp | | 77,600 hp |

* Source: Sohn, Homan, and Sliwinski.

**Table B7**

**Estimation of Capacity by Refrigerant Type**

*Refrigeration Units (Capacity < 5 hp)*

| Refrigerant | Fraction | x | Total Capacity | = | Estimated Capacity |
|---|---|---|---|---|---|
| CFC-12 | 0.792 | | 12,700 hp | | 10,000 hp |
| HCFC-22 | 0.020 | | 12,700 hp | | 300 hp |
| R-502 | 0.188 | | 12,700 hp | | 2,400 hp |

*Refrigeration Units (Capacity > 5 hp)*

| Refrigerant | Fraction | x | Total Capacity | = | Estimated Capacity |
|---|---|---|---|---|---|
| CFC-12 | 0.384 | | 10,700 hp | | 4,100 hp |
| HCFC-22 | 0.171 | | 10,700 hp | | 1,800 hp |
| R-502 | 0.445 | | 10,700 hp | | 4,800 hp |

*Cold Storage (including ice mfg.)*

| Refrigerant | Fraction | x | Total Capacity | = | Estimated Capacity |
|---|---|---|---|---|---|
| CFC-12 | 0.853 | | 25,000 hp | | 21,300 hp |
| HCFC-22 | 0.073 | | 25,000 hp | | 1,800 hp |
| R-502 | 0.074 | | 25,000 hp | | 1,900 hp |

* Source: Sohn, Homan, and Sliwinski.

**Table B8**

**Estimation of Number of Units by Refrigerant Type**

*Refrigeration Units (Capacity < 5 hp)*

| Refrigerant | Capacity | x | Capacity/unit* | = | Estimated No.of Units |
|---|---|---|---|---|---|
| CFC-12 | 10,100 hp | | 2.5 hp | | 4,035 |
| HCFC-22 | 255 hp | | 2.5 hp | | 102 |
| R-502 | 2,395 hp | | 2.5 hp | | 958 |

*Refrigeration Units (Capacity > 5 hp)*

| Refrigerant | Capacity | x | Capacity/unit* | = | Estimated No.of Units |
|---|---|---|---|---|---|
| CFC-12 | 4,120 hp | | 7.5 hp | | 549 |
| HCFC-22 | 1,835 hp | | 7.5 hp | | 244 |
| R-502 | 4,770 hp | | 7.5 hp | | 636 |

*Cold Storage (including ice mfg.)*

| Refrigerant | Capacity | x | Capacity/unit* | = | Estimated No.of Units |
|---|---|---|---|---|---|
| CFC-12 | 21,300 hp | | 35.0 hp | | 610 |
| HCFC-22 | 1,800 hp | | 35.0 hp | | 52 |
| R-502 | 1,900 hp | | 35.0 hp | | 53 |

* These are the average sized units for the category (Sohn, Homan, and Sliwinski).

**Table B9**

**Refrigeration Unit Age Summary**

| Age | Fraction | Percentage |
|---|---|---|
| ≤ 10 years | 1649/1788 | 90% |
| > 10 years | 139/1788 | 10% |

* Source: Sohn, Homan, and Sliwinski.

**Table B10**

**Estimation of Retrofit/Replacement Costs for Refrigeration Units**

***Replacement Costs***

*Refrigeration Units (Capacity < 5 hp)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 403 | | $4,500 | | $1.82 |
| R-502 | 958 | | $4,500 | | $4.31 |

*Refrigeration Units (Capacity > 5 hp)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 55 | | $7,500 | | $0.41 |
| R-502 | 636 | | $7,500 | | $4.77 |

*Cold Storage (including ice mfg.)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 61 | | $30,000 | | $1.83 |
| R-502 | 53 | | $30,000 | | $1.59 |
| | | | Replacement Cost = | | $14.7million |

***Retrofit Costs***

*Refrigeration Units (Capacity < 5 hp)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 3,632 | | $1,500 | | $5.45 |

*Refrigeration Units (Capacity > 5 hp)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 494 | | $2,500 | | $1.23 |

*Cold Storage (including ice mfg.)*

| Refrigerant | No.of Units | x | Cost/unit* | = | Estimated Cost (mill.) |
|---|---|---|---|---|---|
| CFC-12 | 549 | | $10,000 | | $5.49 |
| | | | Replacement Cost = | | $12.2 million |

***Total Cost = Replacement Costs + Retrofit Costs = $26.9 million***

* The cost/unit information has been obtained from equipment suppliers.

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AC | air-conditioning |
| AC&R | air-conditioning and refrigeration |
| AMC | U.S. Army Materiel Command |
| ARI | Air-Conditioning and Refrigeration Institute |
| ASA | Assistant Secretary of the Army |
| CFC | chlorofluorocarbon |
| DEH | Directorate of Engineering and Housing |
| DOD | Department of Defense |
| FORSCOM | U.S. Army Forces Command |
| FY | Fiscal Year |
| HCFC | hydrochlorofluorocarbon |
| HQDA | Headquarters, Department of the Army |
| LTR | letter |
| TR | technical report |
| TRADOC | U.S. Army Training and Doctrine Command |
| USACERL | U.S. Army Construction Engineering Research Laboratories |
| USAEHSC | U.S. Army Engineering and Housing Support Center |
| UV | ultraviolet |

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