MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE TEAP CHILLER TASK FORCE

MAY 2004

Montreal Protocol
On Substances that Deplete the Ozone Layer

Report of the
UNEP Technology and Economic Assessment Panel
Chiller Task Force

May 2004

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Executive Summary

Decision XIV/9 requested the Technology and Economic Assessment Panel:

- to collect data and assess the portion of the refrigeration service sector made up by chillers;
- to identify incentives and impediments to the transition to non-CFC equipment;
- to prepare a report.

The TEAP started its efforts in 2003 but was not able to collect enough data from Article 5(1) countries to submit the report in 2003. It established a Chiller Task Force in 2003 to prepare a report for submission to the Parties in 2004; the Task Force consisted of eight Refrigeration TOC members and three members from outside the RTOC. The four main chiller manufacturers from the US were represented on the Task Force.

This report is the result of the work of the Task Force, which met in Boulder, USA, in January 2004, and in Washington, D.C., April 2004. As a result of these meetings draft reports were conceived for internal and for TEAP review.

After having presented an overview of the different chiller types and the capacity ranges for each of those chillers, the report presents details on centrifugal, screw, scroll, reciprocating and absorption chillers.

Three options are considered to minimise emissions of CFC chillers:

- The first option is to continue to operate them using containment procedures and equipment, whilst maintaining the chillers in proper operating conditions to avoid emissions typical of old and poorly maintained units;

- The second option is to convert CFC chillers into non-CFC-chillers by retrofitting existing chillers with non-CFC refrigerants. Retrofitting existing chillers to use non-CFC refrigerants was a common practice early in the CFC phase-down period. Retrofitting is less common now because most of the appropriate retrofits have been completed, particularly in non-Article 5(1) countries, and because CFC chillers still in operation are generally more than 10 years old;

- The third option, replacement, is normally the most attractive economically. Virtually all chillers operating with CFC refrigerants range in age from 10 to 30 years old and have design levels of efficiency significantly lower than chillers now in production. In many cases, replacement of a CFC chiller with a modern high-efficiency non-CFC chiller can offer a payback within a few years because of energy cost savings, improved reliability, and lower maintenance costs. This will, of course, depend on operating conditions, which are related to application specific requirements.

Today's average chillers use about 35% less electricity than average chillers produced just two decades ago and the best chiller today - operated on HCFC-123 or HFC-134a - uses half the electricity of the average 1976 chiller. However, building cooling-efficiency not only depends on the chiller compressor energy efficiency, but also on the design of the water/air side and the refrigeration circuit. The prospective gains from replacement of the chiller may be affected (and sometimes limited) by the condition of the rest of the circuit, which is not associated with ODS phase-out. This implies that a replacement programme may include re-design of the entire circuit, pumps, etc.

The average full-load large-chiller system-specific power per ton of refrigeration in Article 5(1) countries varies from 0.71 to 0.64 kW/ton refrigeration capacity (equivalent to COP values (kW/kW) of 5.0 and 5.5, respectively). This is most likely due to the slower replacement of older CFC chillers in Article 5(1) countries. Replacing these chillers would reduce energy consumption and greenhouse gas emissions since the new chillers would be more energy efficient and have lower refrigerant leak rates.

A World Bank/ICF report available to the Task Force presented information on centrifugal chillers installed in the Article 5(1) countries in 2001/2002. The total number of chillers mentioned in this report amounts to 15,000 in a number of representative countries, with a total of about 20,000 units in all Article 5(1) countries. The CFC centrifugal chillers in the Article 5(1) countries are assumed to consume -or emit- about 1,500 tonnes of CFCs per year (higher estimates exist, as in the World Bank report, at more than 2,200 tonnes). Although significant, this would still amount to less than 2-3% of the total 2001/2002 CFC consumption in the Article 5(1) countries. Although this gives a first order of magnitude, this issue is very important and was therefore further investigated in the second part of the report.

As requested in the relevant decision, the report gives a number of impediments and incentives for the transition out of CFC chillers. Impediments include cost issues, lack of information at the level of decision makers, uncertainty about the future, national energy policies, obstacles for decision making, perceived risks etc. Incentives include economic payback issues, performance contracting, training programs, government incentives, revolving fund possibilities, policy support, building programs for energy efficiency, financial rewards etc. It is also described what a transition out of CFCs at the national level would imply, specifically related to training in maintenance and containment, and also to recovery and re-use as they are key parts at the national level.

The report describes four ongoing programs for the replacement of CFC chillers in Article 5(1) countries, i.e., Cote d'Ivoire, Thailand, Mexico and Turkey. These chiller programs have provided valuable information and are helping in further developing the global chiller replacement programs. In all cases, energy savings constitute the major incentive for replacement. In Cote d'Ivoire it concerns the replacement of virtually all chillers installed. It should, however, be realised that a large number of the remaining CFC based chillers in the other three countries might not meet the stringent criteria set in the programs and might not provide the same high energy savings as in the ongoing projects. It is important to note that the replacement of all CFC chillers in these three countries will require significant more capital than contemplated in the programs, and therefore some centrifugal chillers will eventually have to be replaced at the owners' initiative. This situation is reinforced by the fact that a large number of CFC based chillers might now be between 20 and 30 years old and should be replaced by the owners over the coming years. On the other hand, recovering CFC from dismantled CFC chillers means that enough CFC will be available for longer time for the servicing of the chillers that remain operative. Hence, a good recovery program might allow recovering of CFC for servicing of remaining chillers, and as a result the phase-out of the total inventory of CFC based chillers in countries with such recovery programs might take place over a longer period.

Three case studies (for India, Brazil and the People's Republic of China) are given which describe the composition of the centrifugal chiller market, the CFC inventories, the emissions and the servicing needs compared to the total servicing needs for refrigeration. Figures for India indicate that 25% of the charge in chillers is lost per year, or 7% of the total refrigeration needs for servicing (2001-2002). In Brazil the figures are 30% losses per year, which amount to 5% of the total annual servicing needs; in China the losses are about 20%, which are about 9% of the total refrigeration servicing needs (years 2001-2002).

Several project proposals submitted and approved by the Multilateral Fund's Executive Committee were also considered. They have been screened regarding the reported number of chillers in a country, the related annual servicing needs, and the percentage that they represent of the total needs for servicing. In most countries, the vast majority of the chillers installed use CFC-11. In some countries the percentage of CFC-12 chillers is larger and can amount to 40 - 45%. The data reported are somewhat confusing as sometimes they are (1) based on the assumption that the losses can be calculated as15% of the chiller inventory, while in other cases they are (2) based on field data, which often yield higher percentages. The latter vary from 20% to higher than 50% of the total chiller CFC inventories in a country (comparable to the figures for India, Brazil and China). New estimates were calculated for the number of CFC centrifugal chillers in the Article 5(1) countries and their annual losses, which were based on the screening made of these Projects. The number given in a first instance, based on the World Bank Report (20,000 chillers in all Article 5(1) countries), could therefore be decreased to about 15,000 chillers in all Article 5(1) countries. Chiller leakage in tonnes can be assumed to be smaller than 2% of the total CFC consumption in all Article 5(1) countries (status 2001-2002).

When studying project proposals to determine the refrigerant needs for chillers, there are significant uncertainties related to:

- whether the real number of chillers installed has been identified and under- or over-estimated;

- whether consumption has been derived based upon standard figures for inventories and servicing, based upon service market data, or estimated from criteria developed by the agency preparing the project (there is again the potential for under or over estimating).

It seems justifiable to assume that ***5-10%*** of the total consumption for the refrigeration servicing needs of an Article 5(1) country is needed for chiller servicing. This will depend on the infrastructure of the country, the climate, the infrastructure (different sub-sector sizes) for refrigeration servicing, the practices applied by servicing personnel etc. It should be emphasised that these figures are valid for the years 2001-2002, and it is likely that percentages will change substantially if servicing of sub-sectors will be addressed, whilst chiller programs remain on the shelf. However, a change in servicing practices and transition to non-CFC chillers (replacements) may also have a significant impact.

In the near future, replacement programs may (and will) continue, but these will certainly not be able to replace all CFC centrifugal chillers within a short period. However replacement of all CFC chillers is not a prerequisite to the phase-out of CFC-11 consumption and is unlikely to occur in Article 5(1) countries, which may follow a replacement pattern similar to that which has emerged in non-Article 5(1) countries. Countries will need to plan for reductions in CFC-11 sector consumption in the chiller sub-sector (possibly through already-approved refrigerant management plans or national CFC phase-out plans). This planning will need to include:

- an inventory of the existing CFC chillers;

- the impact in terms of reduced CFC-11 consumption of an improvement in servicing practices, and recovery and re-use of the refrigerant;

- determination of the amount of refrigerant which will become available from the dismantling of older or less efficient chillers to extend the operating life of newer, existing CFC chillers beyond 2010;
- determination of the quantities (if any) of CFC-11 or CFC-12 that may become available from other sources, and consideration of the opportunities for the stockpiling of certain amounts of CFCs;
- on the above basis, formulation of a replacement policy which includes the likely replacement rate, the numbers of remaining CFC chillers that may be kept in operation after 2010, stockpiling and other relevant issues.

1 Introduction

The Parties in Decision XIV/9 decided as follows:

"To request the Technology and Economic Assessment Panel to collect data and assess the portion of the refrigeration service sector made up by chillers and identify incentives and impediments to the transition to non-CFC equipment and prepare a report;

To request the Technology and Economic Assessment Panel to submit the report to the 2003 Open-ended Working Group meeting for their consideration;"

The Technology and Economic Assessment Panel composed a group of chiller experts, worked on the reports in 2003 but was not able to collect enough information where it relates to specific numbers for Article 5(1) countries. It therefore requested the Parties in 2003 /UNE03/ to delay the submission of the report to 2004.

This report is the result of efforts carried out during December 2003-April 2004 by a Chiller Task Force, established by the TEAP in 2003.

The Task Force consisted of the following members:
Lambert Kuijpers, co-chair, co-chair TEAP and co-chair RTOC
Radhey Agarwal, co-chair, member TEAP and co-chair RTOC, IIT Delhi
Jim Crawford, member RTOC, Trane
Ken Hickman, member RTOC, York
Roberto Peixoto, member RTOC, IMT, Brazil
Marc Barreau, member RTOC, Atofina
Holger Koenig, member RTOC, Axima
Aryadi Suwono, member RTOC, University Bandung (IN)
Hugh Crowther (Julian deBullet), McQuay
Bill Walter, Carrier
Erik Pedersen, member HTOC, World Bank

The report summarises information on all chillers but concentrates on CFC chillers, which are normally of the centrifugal type, installed until the mid-nineties. In fact, the report concentrates on CFC centrifugal chillers installed in the Article 5(1) countries.

It does not consider HCFC-22 chillers and new centrifugal chiller types using HCFC-123 or HFC-134a, except as a replacement option for CFC centrifugal chillers, with a much increased energy efficiency.

The structure of the report is as follows:

- Chapter 2 describes all different chiller types and options to minimise refrigerant consumption;
- Chapter 3 describes conversions and presents information on chillers in Article 5(1) countries, for a large part as given in a report for the World Bank /ICF03/;
- Chapter 4 deals with refrigerant use, as well as with chiller inventories;
- Chapter 5 describes the environmental impact of different centrifugal chillers and shows the improvement possible when replacing CFC chillers by non CFC ones;
- Chapter 6 gives impediments/barriers and incentives for the transition from CFC chillers to non-CFC chillers;
- Chapter 7 presents the Chiller Phase-out Programs for Mexico, Thailand and Turkey;
- Chapter 8 presents case studies for India, Brazil and the People's Republic of China;
- Chapter 9 presents a summary of data derived from project proposals submitted to the Multilateral Fund for a large number of Article 5(1) countries. In the concluding remarks in this chapter, a number of observations are given. It summarises the figures for chiller inventories, leakage and servicing needs in the Article 5(1) countries and considers the latter figure against the total servicing needs of Article 5(1) countries in the years 2000-2002;
- In the conclusions, presented in chapter 10, some items observed in the first chapters are given. It also summarises the findings. Some future strategies to keep chillers in operation are being briefly considered.

2 Chillers

2.1 Chiller Types

Chillers are refrigeration systems that cool a water or a water/antifreeze mixture, which is circulated for use in building comfort air-conditioning, industrial processes, or food preservation. Two types of chillers are manufactured - vapour compression chillers and absorption chillers.

Vapour compression chillers generally are driven by electric motors. The principal components of a vapour compression chiller are a compressor, a liquid cooler (evaporator), a condenser, a refrigerant, a refrigerant expansion device, a motor, and a control unit.

The source of input energy for absorption systems is heat provided by steam, hot water, a fuel burner, or any other heat sources. In absorption chillers the compressor and motor of the vapour compression cycle are replaced by two heat exchangers (a generator and an absorber) and a solution pump. The refrigerant in these systems commonly is water and the absorbent is lithium bromide. Small absorption chillers may use an alternate fluid pair; ammonia as the refrigerant and water as the absorbent.

2.2 Applications

Air conditioning chillers cool water, which is pumped to water-to-air heat exchangers (e.g., air handlers or fan coil units) that cool individual spaces in commercial and institutional buildings. In the case of thermal storage systems chillers can cool a coolant (water/ anti freeze mixture) that is sent to thermal storage tanks or directly to fan coil units. These systems control both the temperature and the humidity of the air circulated in the building spaces to provide comfortable conditions for the occupants.

Industrial chillers are used to control the temperature of fluids in industrial processes. Such processes include applications such as drying of ink in printing plants, controlling fluids undergoing chemical reactions in chemical and petrochemical plants, and inlet air cooling for gas turbine power generators.

Food processing chillers cool food products during processing to facilitate proper handling and to preserve them. These chiller applications are distinguished from refrigeration systems by the temperature levels. Food processing chillers provide water or water/antifreeze mixture temperatures that typically fall within the range +/- 10°C.

2.3 Chiller Industry Overview

Vapour compression chillers are identified by the type of compressor they employ. These are classified as centrifugal compressors or positive displacement compressors. The latter category includes reciprocating, screw and scroll compressors. Absorption chillers are identified by the number of heat input levels they employ; i.e., single-effect or double-effect absorption chillers, and whether they are direct-fired by fuel, or use steam or hot water as the heat energy source.

Table 2-1 lists the cooling capacity range offered by each type of chiller.

Table 2-1: Chiller Capacity Ranges /UNE02/

Chiller Type	Capacity Range (kW)
Scroll and reciprocating water-cooled	7 – 1,600
Screw water-cooled	140 - 2,275
Positive displacement air-cooled	35 - 1,500
Centrifugal water-cooled	350 - 30,000
Centrifugal Air-Cooled	630 - 1,150
Absorption	Less than 17.5, and 140 - 17,500

Centrifugal chillers were the most common type of chillers above 700 kW capacity for many years. Reciprocating compressors were used in smaller chillers. The use of CFCs was primarily limited to large centrifugal compressors and these form the main subject of this report.

Beginning in the mid-1980s screw compressors became available as alternatives to reciprocating compressors in the range from 140 kW to 700 kW and as alternatives to centrifugal compressors up to about 2275 kW. Scroll compressors were introduced about the same time and have been used as alternatives to reciprocating compressors in the range from 7 to about 100 kW.

Centrifugal Chillers

Centrifugal chillers were mainly manufactured in the United States, and in some countries in Asia and Europe. Prior to 1993, these chillers were offered with CFC-11, CFC-12, R-500, and HCFC-22 as refrigerants (R-500 being a mixture of CFC-12 and HFC-152a). Of these, CFC-11 was the most common. With the implementation of the Montreal Protocol, production of chillers using CFCs or refrigerants containing CFCs (such as R-500) essentially ended in 1993. Centrifugal chillers using HCFC-22 rarely were produced after the late 1990s.

The refrigerant alternatives for CFC-11 and CFC-12 or R-500 are HCFC-123 and HFC-134a respectively. These refrigerants began to be used in centrifugal chillers in 1993 and continue to be used in 2004 in new production chillers.

The table below shows the range of cooling capacities offered for centrifugal chillers with each of these refrigerants, together with approximate values for the refrigerant charge in each case. The refrigerant charge for a given cooling capacity varies with the energy efficiency level of a chiller; higher efficiency levels often are associated with larger heat exchangers and therefore larger amounts of refrigerant charge.

Table 2-2: Centrifugal Chiller Refrigerants and Charge Levels /AFE97, ADL02/

Refrigerant	Capacity Range (kW)	Approx. Charge (kg/kW)
CFC-11	350 - 3,500	0.28
CFC-12	700 - 4,700	0.35
R-500	3,500 - 5,000	0.35
HCFC-22	2,500 - 30,000	0.23
HCFC-123	700 - 13,000	0.40
HFC-134a	350 - 14,000	0.36

Positive Displacement Chillers

Chillers employing screw, scroll, and reciprocating compressors are manufactured in many countries around the world. Water-cooled chillers generally are associated with cooling towers for heat rejection from the system. Air-cooled chillers are equipped with refrigerant-to-air finned tube condenser coils and fans to reject heat. The selection of water-cooled vs. air-cooled chillers for a particular application varies with regional conditions and owner preferences.

Screw chillers generally employed HCFC-22 as the refrigerant when they were first produced in the mid-1980s. In the last several years, HFC-134a chillers have been introduced by a number of manufacturers, in some cases replacing their HCFC-22 product offerings. Screw chillers using R-407C are being marketed and screw chillers using the higher-pressure refrigerant R-410A have been introduced recently. Air-cooled screw chillers and water-cooled chillers below 700 kW commonly employ evaporators with refrigerant flowing inside the tubes and chilled water on the shell side. These are called direct-expansion (DX) evaporators. Chillers with capacities above 700 kW generally employ flooded evaporators with the refrigerant on the shell side. These flooded evaporators are similar to those used in centrifugal chillers, which require higher charge levels as shown in Table 3-2. Screw chillers using ammonia as the refrigerant are available from some manufacturers.

They are found primarily in northern European countries and the quantities produced are small compared to chillers employing HCFCs or HFCs.

Scroll chillers are produced in both water-cooled and air-cooled versions using DX evaporators. Refrigerants offered include HCFC-22, HFC-134a, R-410A, and R-407C.

Reciprocating chillers are produced in both water-cooled and air-cooled versions using DX evaporators. Air-cooled versions have increased market share in recent years. Prior to the advent of the Montreal Protocol, some of the smaller reciprocating chillers (under 100 kW) were offered with CFC-12 as the refrigerant (as well as the large centrifugal equipment). Most of the smaller and nearly all the larger reciprocating chillers employed HCFC-22 as the refrigerant. After the Montreal Protocol, new reciprocating chillers employed HCFC-22, R-407C, and to a small extent, HFC-134a. Some water-cooled reciprocating chillers were manufactured with ammonia as the refrigerant but the number of these units is very small compared to the number of chillers employing the other refrigerants.

The table 2-3 below shows approximate charge levels for positive displacement chillers of each type with several refrigerants. This table contains data from /UNE02/ with some adjustment to reflect current practice.

Table 2-3: Positive Displacement Chiller Refrigerants and Charge Levels

Refrigerant and Chiller Type	Evaporator Type	kg/kW
HCFC-22 and HFC -134a screw and scroll chillers	DX	0.27
R-410A and R-407C scroll chillers	DX	0.27
HCFC-22 and HFC-134a screw chillers	Flooded	0.35
HCFC-22 reciprocating chillers	DX	0.26
R-717 (ammonia) screw or reciprocating chillers	DX	0.04-0.20
R-717 (ammonia) screw or reciprocating chillers	flooded	0.20-0.25

Absorption Chillers

Absorption chillers are manufactured primarily in Asia - Japan, China, and Korea. A few absorption chillers are manufactured in North America. Absorption systems have higher initial cost and lower operating efficiency than vapour compression chillers. They can be cost-effective in applications where waste heat or steam is available, where adequate electricity is not readily available to power air conditioners for summer cooling loads, or where high electricity cost structures, including demand charges, make gas-fired absorption a lower-cost alternative.

Single-effect absorption chillers driven by hot water or steam have been produced for many years. They are outnumbered by double-effect machines driven by steam or directly fired by gas. Double-effect absorption chillers began to be produced in large numbers in Asia (primarily in Japan) for the regional market during the 1980s. Double-effect chillers began to be produced in North America shortly afterward, commonly through licensing from the Asian manufacturers. It should be noted that large quantities of small gas-fired absorption chillers with capacities below 17.5 kW are produced in Europe and North America using the ammonia-water cycle.

2.4 Current Technical Options to Minimise CFC Requirements

Retention/Containment

One option for operators of CFC-containing chillers is to continue to operate them using containment procedures and equipment, maintaining the chillers to minimise emissions. If necessary, additional CFC refrigerant may be available in non-Article 5(1) countries from existing stockpiles or refrigerant recovered and recycled from units-retired from service, no longer requiring CFCs-, or from refrigerant reclaimed. In most of the Article 5(1) countries, CFC is likely to be available until 2010. After 2010, procedures for obtaining additional CFCs would be the same as in non-Article 5(1) counties after 1995.

Retrofitting

One option for making a transition from CFC chillers to non-CFC-chillers is to retrofit existing chillers with non-CFC refrigerants. The manufacturer of the chiller should be consulted when a retrofit is under consideration. The manufacturer can provide the necessary conversion parts and can provide essential advice about the requirements for a successful retrofit and the expected effects on chiller performance.

CFC-11 centrifugal chillers can be converted to operate with HCFC-123 as their refrigerant. The retrofit process requires modifications or replacement of the compressor. Elastomeric components of the chiller such as seals may also have to be replaced.

CFC-12 and R-500 chillers can be modified to accept HFC-134a as a refrigerant. Impeller and gearbox replacement may be needed; a complete removal of mineral oil from the system is required. A new lubricant, commonly a polyolester (POE) synthetic oil, is used to replace the mineral oil employed with CFC-12 and R-500. Oil filter-dryer materials must be changed. Another alternative is to employ a "drop-in" replacement refrigerant for CFC-12 systems. R-416A, a refrigerant blend, is available for this purpose and can be used with mineral oil in the system. The performance changes that occur with an R-416A substitution have not been documented by laboratory tests.

For positive displacement chillers, CFC-12 can be replaced by HFC-134a. The chiller system must be thoroughly flushed to remove mineral oil. A synthetic lubricant, typically a POE, replaces the mineral oil. Filter-dryers and possibly elastomeric components must be replaced to assure materials compatibility with the HFC refrigerant and POE lubricant. Several refrigerant blends containing HCFC-22 (R-401A, R-401B, R- 409A) are offered as "drop-in" replacements for CFC-12. For any of these retrofit refrigerants, there may be changes in the cooling capacity and energy efficiency of the system that should be evaluated on a case-by-case basis as part of the decision that a retrofit is viable.

Retrofitting existing chillers to use non-CFC refrigerants was a common practice early in the phase-out period. Retrofitting is less common now because most of the appropriate retrofits have been completed, particularly in non-Article 5(1) countries. Replacement may be a more attractive alternative.

Replacement

Virtually all chillers operating with CFC refrigerants range in age from 10 to 30 years old and have design levels of efficiency significantly lower than chillers now in production (see the next section). In many cases, replacement of a CFC chiller with a modern high-efficiency non-CFC chiller can offer a payback within a few years because of energy cost savings, improved reliability, and lower maintenance costs. New chillers also provide significant stratospheric ozone protection and global warming reduction benefits compared to existing CFC chillers.

The most commonly used new refrigerants for centrifugal chillers in large building air conditioning applications are HFC-134a and HCFC-123. For positive-displacement chillers, a wider selection of refrigerants is offered: HCFC-22, HFC-134a, R-407C, and R-410A. The HFCs and HFC blends are ozone-safe, but emissions of these refrigerants are relatively potent as far as their global warming contribution is concerned. HCFC-123 is not a potent greenhouse gas, but does have an ozone-depleting potential. Table 2-4 presents the environmental data for these refrigerants.

Table 2-4: Environmental Data for Chiller Refrigerants /UNE02, IPC96/

Refrigerant	ODP	GWP (100 year)
HCFC-22	0.055 (0.034)	1700
HCFC-123	0.020 (0.012)	120
HFC-134a	0.000	1300
R-407C	0.000	1700
R-410A	0.000	2000

Note: ODP values are the regulatory values (in brackets the scientific values are given)

Note: R-407C is a mixture of HFC-32, -125 and -134a (23/25/52), R-410A is a mixture of HFC-32 and HFC-125 (50/50)

The Montreal Protocol calls for HCFC production for use in new equipment in developed countries to cease in 2020 with continuing production for a small "service tail" until 2030. Consumption of HCFCs in Article 5(1) countries is scheduled to be frozen in 2016 at 2015 levels and phased out in 2040.

2.5 Trends in Energy Efficiency

Energy efficiency is the primary environmental consideration for non-CFC chillers. While refrigerants each have a Global Warming Potential (GWP), refrigerants do not contribute to global warming unless they are released to the atmosphere. Properly maintained chillers of modern design emit less than 1% of their refrigerant charge each year. The dominant global warming effect caused by chiller operation is the CO_2 emitted in the combustion of fossil fuels generating the electricity to drive them, if electricity is produced by thermal power plants combusting fossil fuels. High chiller efficiencies reduce the impact on global warming proportionally.

Table 2-5 shows the increased efficiency of centrifugal chillers from 1976 to 2000. Values prior to 1994 represent CFC chillers while values for 1994 and beyond are for HCFC-123 or HFC-134a chillers.

Table 2-5: Technical Progress in Energy Efficiency of New Large Chillers--1976 to 2000

YEAR	Average New System Efficiency		State-of-the-Art New System Efficiency	
	Full Load COP	Integrated Part Load Value (IPLV)	Full Load Constant Speed COP	IPLV (with Variable Frequency Drive (VFD) and/or Dual Compressors)
1976	3.9	--	4.4	--
1979	4.4	--	4.9	--
1980	4.9	--	5.1	--
1990	5.0	5.2	5.6	5.9
1991	5.1	5.4	5.8	6.1
1992	5.4	5.6	5.8	6.4
1993	5.6	5.8	6.4	6.9
1994	5.6	5.9	6.7	7.6
1995	5.7	6.0	6.7	8.3
2000	5.9	6.3	7.3	9.5

Note: efficiency is expressed in (kW refrigeration)/(kW electric input)

Full load COP indicates the ratio (kW refrigeration) to (kW electric input) when the chiller is running at its full load design point. The Integrated Part

Load Value (IPLV) is the value that represents the COP when operating at part load conditions.[1]

Table 2-6 shows the minimum efficiency levels established beginning on October 29, 2001 by ASHRAE Standard 90.1 (1999). The COP and IPLV values specified in the standard are to be measured according to procedures established under the ARI Standards 550, 560 or 590 as appropriate for each type of chiller. These efficiency values can be considered to be baseline values for 2001 and beyond, and in fact, are a voluntary set of US standards. Chillers with higher efficiency are available in most categories, usually at higher cost than the baseline systems.

Table 2-6: Efficiency Requirements for Chillers (ASHRAE Standard 90.1-1999)

Equipment type	Size Category	Minimum Efficiency
Air-cooled, with condenser	Under 525 kW 525 kW and higher	2.80 COP; 2.80 IPLV
Air-cooled, without condenser	All capacities	3.10 COP; 3.10 IPLV
Water-cooled reciprocating	All capacities	4.20 COP; 4.65 IPLV
Water-cooled screw and scroll	Under 525 kW 525 kW to 1049 kW 1050 kW and higher	4.45 COP; 4.50 IPLV 4.90 COP; 4.95 COP 5.50 COP; 5.60 IPLV
Water-cooled centrifugal	Under 525 kW 525 kW to 1049 kW 1050 kW and higher	5.00 COP; 5.00 IPLV 5.55 COP; 5.55 IPLV 6.10 COP; 6.10 IPLV
Air-cooled absorption single-effect	All capacities	0.60 COP
Water-cooled absorption single-effect	All capacities	0.70 COP
Absorption double-effect, Indirect-fired	All capacities	1.00 COP; 1.05 IPLV
Absorption double-effect, Direct-fired	All capacities	1.00 COP; 1.00 IPLV

Today's average chillers use about 35% less electricity than average chillers produced just two decades ago and the best chiller today uses half the electricity of the average 1976 chiller. Building owners typically can pay back the investment cost of replacing an old CFC chiller in three to five years in virtually all locations that cool for more than three months a year (of course this also depends on electricity prices). It will be clear that the replacement of a low-efficiency chiller in a country with a relatively cool climate (low cooling needs during less than two months per year, still at reasonable energy efficiency) and low electricity prices (or subsidised prices) has a payback of a totally different order of magnitude.

[1] Both full load and IPLV are defined by the ARI Standard 550/590-1998. Full load chilled water delivery temperature is specified to be 44 °F (6.5 °C) and condenser inlet water temperature is 85 °F (29 °C). The temperature ranges for the evaporator and condenser both are 10 °F (5.5 K).

Even when the total investment would be higher, replacement chillers integrated with chiller controls and chilled water system retrofits can pay for themselves in as little as two or three years, with a typical return on investment of 20% to 35% in locations with high seasonal cooling loads and/or high electricity prices.

However, it needs to be clearly stated that building cooling-efficiency not only depends on the chiller compressor energy efficiency, but also on the design of the water/air side and the refrigeration circuit. The prospective gains from replacement of the chiller may be affected (and sometimes limited) by the condition of the rest of the circuit, which is not associated with ODS phase-out. Possible redesign and replacement of heat exchangers, pumps, etc. is also one of the factors that will influence the economic payback period. Investments in elements not related to the compressor may be of the same order of magnitude as the investment in the chiller compressor itself.

One other factor which also deserves mentioning here is that a higher investment in a chiller will result in greater chiller efficiency and it depends on a number of local economic and climate conditions (the latter influencing the running time per year and the operational cycle) how the payback period will be affected. Generally, the added cost of the highest efficiency chillers is paid back through energy savings alone.

3 Global CFC Chiller Inventories

3.1 Background and Assumptions

Estimating the CFC chiller inventories globally is the first step to estimating the service refrigerant requirements. Although chillers have been, and are, made in capacities ranging from a few kW to 30,000 kW, the use of CFCs has been limited to the large centrifugal machines in the range of 1000 to 10,000 kW. The two dominant CFC refrigerants (CFC-11 and CFC-12) are relatively low pressure refrigerants, which were used with centrifugal compressors. The smaller chillers use higher-pressure refrigerants and positive displacement compressors. These smaller chillers are made in large numbers in Europe and Asia as well as the United States.

The larger, centrifugal chillers were traditionally made mostly in the USA, with later production in Europe and more recent production in Asia. The four U.S. based companies and their European affiliates discontinued the uses of CFCs starting in 1993 in advance of the Montreal Protocol requirement for phase out of CFCs for new equipment production by 1/1/1996. HCFCs and HFCs have been used in new centrifugal chillers since then. This report assumes that, globally, there has been no appreciable production of new CFC chillers since the end of 1993.

The life expectancy of chillers is variously cited as 25-30 years. This does not mean that all chillers are expected to be in service for 25-30 years, but that they are capable of remaining in service "on average" 25 to 30 years. The notion of "average" in this context is not well defined. Some observers seem to have in mind the median life, and others seem to refer to the statistical mean of the life. In fact, there is insufficient data readily available to narrow it down more closely than that. The significant point is that, by the nature of the machinery, chillers can be kept in service almost indefinitely with proper service and occasional overhaul. They are removed from service when there is some compelling reason to do so, such as:

- When the skills or service parts need to perform an overhaul exceed local resources,
- When a machine fails and the economics of replacement are more favourable than the economics of repair [i.e., When cost to repair or overhaul is not considered a good value],
- When a building is decommissioned or demolished,
- When a CFC chiller is replaced with one using another refrigerant.

In general, the older the machine when there is need for major service, the more likely that one or more of these factors will come into play and lead to replacement of the chiller.

3.2 Global Chiller Estimate

The ARI (Air-conditioning and Refrigeration Institute) tracks manufacturer's chiller shipments and this data is shown in Table 3-1 for 1980 through 2003.

Using 1993 as the conversion date from CFCs to other alternatives, around 59,000 CFC chillers had been shipped since 1980. Of the 59,000, 14,500 had been exported outside of North America.

ARI has estimated that there were approximately 80,000 CFC chillers in the United States in 1993. This includes about 41,000 chillers built between 1983 and 1993 mentioned above plus 39,000 chillers built prior to 1983.

Table 3-1: Large Tonnage Liquid Chiller Shipments by ARI Section Manufacturers

Year	USA	Canada	Other Exports	Total
2003	3133	269	2340	5742
2002	3499	242	2052	5793
2001	4245	246	2680	7171
2000	4720	180	2831	7731
1999	4136	193	2200	6529
1998	4696	208	2654	7558
1997	4738	175	3714	8627
1996	4980	157	4060	9197
1995	5026	180	4238	9444
1994	4238	121	2774	7133
1993	3304	143	2508	5955
1992	2991	160	1671	4822
1991	2674	176	1632	4482
1990	3348	336	1310	4994
1989	3432	297	1259	4988
1988	3191	241	975	4407
1987	2774	183	787	3744
1986	3113	203	410	3726
1985	2913	187	389	3489
1984	2407	121	435	2963
1983	2503	106	521	3130
1982	2317	182	598	3097
1981	3137	239	948	4324
1980	3275	253	1080	4608

Note: Data provided from ARI LTLC-2-M Large Tonnage liquid chiller section reports of manufacturer's shipments, 1983 to 2003.

If the total number of CFC chillers built shown in Table 3-1 is doubled to account for chillers built prior to 1980, the total global inventory would be 118,000. This value seems to support the 1995 UNEP /UNE95/ estimate of 130,000 CFC chillers in the mid-1990s. Table 3-2 shows the estimated CFC chiller inventory in the mid-1990s.

Table 3-2: Estimated Global CFC Chiller Inventory in the mid-1990s

USA	Canada	Europe	Other	Total
80,000	6,000	10,000	24,000	120,000

Note: the number of chillers in "other" countries includes the chillers in Korea

3.3 CFC Chiller Retirements to Date

ARI tracks CFC chiller conversions and replacements for the United States, which are shown in Table 3-3 as of March 2003. Table 3-3 shows that 45% of the CFC chillers installed in the US is still in operation, nine years after the production of CFC chillers was halted.

Table 3-3: U.S. CFC Chiller Conversions, for Year 2003 and Forecast for Future Years /ARI03/

	Conversions	Replacements	Total	% of 80,000
Prior to 1/1/03	8,697	32,492	41,189	51
1/03 to 1/1/04	187	2,398	43,774	55
1 /04 to 1/1/05	294	2,947	47,015	59
1/ 05 to 1/1/06	264	3,056	50,335	63

It should also be mentioned here that CFC based chillers cannot be serviced in the European Union member states (including the states that acceded by 1 May 2004). This implies that, once a chiller needs maintenance and servicing of the refrigeration circuit, it needs to be replaced in Europe (or retrofitted, but retrofit of older chillers is no real option anymore).

Anecdotal information indicates that CFC conversions are occurring at a much slower pace in Article 5(1) countries. Chillers in Article 5(1) countries are operated for as long as possible and generally only replaced after a catastrophic failure, when servicing becomes uneconomical.

The location of these chillers is easier to identify generically than in detail. Large chillers will tend to be located in large cities and resort areas in temperate, or hot-arid or hot-humid climates. The principal installation sites are hotels, office buildings and industries that require the use of large quantities of chiller water. Furthermore, it is reasonable to expect that the engineering department of a large hotel or other major building using a large chiller will be generally well trained and competent to operate and service the equipment, regardless of whether the country is a developed or Article 5(1) country. If a building owner will incur the expense of installing and operating a central air conditioning plant, it is reasonable to assume that, by in large, he will also accept the expense of maintaining the plant in a serviceable condition.

3.4 CFC Chiller Population in Article 5(1) Countries

Information on CFC chiller populations in specific Article 5(1) countries is limited. The following is a summary of available information, taken from one reference /ICF03/. The reference /ICF03/ mentions that the table (Table 3-4) represents incomplete and potentially incorrect data. However, it is also mentioned that it does provide an order of magnitude estimate for the number of CFC chillers in service in Article 5(1) countries. The loss rate in table 3-4 seems to be a fixed number of 37.5% for most cases; 37.5% might be a possibly credible average, but it is likely to be (too) high. The data on which the table is based on are at least several years old, and does not include the impact of the retirement of CFC chillers. However, it is believed that the retirement numbers have been small.

There are about 100 more Article 5(1) countries, which have not been mentioned in the table. The majority of them will have a small number of chillers installed, however, the number of chillers may well be over 5,000 in these countries. Assuming that 80% of CFC chillers in Article 5(1) countries are still running, it is expected that there are currently between 15,000 and 20,000 CFC chillers in operation in Article 5(1) countries.

Further estimates based on project proposals submitted to the Multilateral Fund are given in chapter 7.

Table 3-4: Estimated Current CFC Chiller Inventories by Country /ICF03/

country	CFC chillers (number)	Refrigerant inventory	Refrigerant losses	Annual losses (Percent)
Argentina	300	120	60	50%
Botswana	80	80	32	12%
Chile	170	68	25	36.76%
China	1750	1225	460	37.55%
Colombia	450	180	68	37.78%
Croatia	54	14	3	21.43%
Egypt	670	268	100	37.31%
Fiji	5	2	3	150.0%
Guatemala	100	40	15	37.50%
India	1100	596	171	28.69%
Indonesia	1300	520	195	37.50%
Malaysia	1500	600	225	37.50%
Mexico	1500	600	225	37.50%
Philippines	800	320	120	37.50%
South Africa	250	38	14	36.84%
Syria	32	13	13	100.0%
Thailand	1500	600	225	37.50%
Turkey	2500	500	188	37.60%
Venezuela	500	200	100	50.0%
Total	**14,561**	**5945**	**2222**	**37.38%**

4 Chiller Refrigerant Use

This chapter addresses inventories (large and small chillers) and overall figures for charge and use (Article 5(1) and non-Article 5(1) countries).

4.1 Chiller Production and Shipments

The global inventory of chillers is quite elusive. Good estimates are available for some developed countries as a result of industry association or government statistics programs. Other developed and Article 5(1) countries lack such programs and leave considerable uncertainty in any estimate. Some Article 5(1) country inventories are believed to be reasonably well characterised as a result of activities associated with the Montreal Protocol, particularly studies done by the Implementing Agencies under the Montreal Protocol, for the Multilateral Fund.

Historically, large chiller production and use have been dominated by North America, making the data from the Air Conditioning Refrigeration Institute in the United States a particularly valuable resource for these large chillers. Similar data exists for smaller vapour-compression chillers in North America, but does not represent a significant fraction of the global market as is the case for large chillers. The gap here can be filled to some extent by other sources such as reports by BSRIA, which are available in part on the internet. Absorption chiller production has traditionally been strongly influenced by Europe, particularly Italy. In recent years, the Asian market and production have expended significantly.

Large chillers are the emphasis of this chapter because they are the chillers that principally have used CFC-11 and CFC-12 refrigerants. Although smaller chillers have used some CFC-12, they have been dominated by HCFC-22, and are now transitioning to various HFCs for new production. Small absorption chillers principally use ammonia as the refrigerant and water as the absorber. Large absorption chillers use lithium bromide as the absorber and water as the refrigerant.

Large vapour compression chillers, which traditionally used CFC-11 or CFC-12, and now use HCFC-123 or HFC-134a exist in tens of thousands on units in the global installed base. Small vapour compression chillers exist in the hundreds of thousands. Absorption chillers exist in the low hundreds of thousands.

Relative to the role of developed country data in estimating the Article 5(1) country situation, the ICF-World Bank report /ICF03/ observes that:

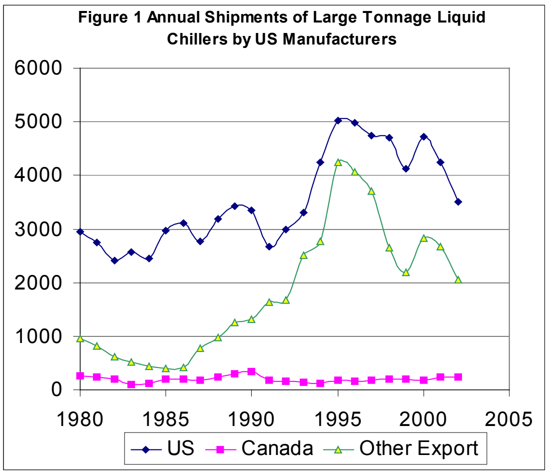
- “Developed countries are major suppliers to Article 5(1) country chiller markets [ed. and this was even more true during the period when the developed countries were producing CFC chillers]”.
- “Developed country chillers data is valuable for comparison purposes, both serving as an indicator of future Article 5(1) country replacement and new chillers market and providing a basis for estimating and evaluating Article 5(1) country data”.

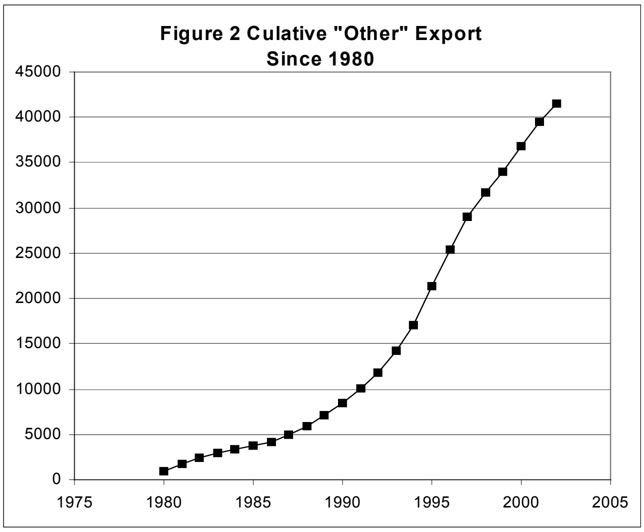
The United States was the principal producer of large chillers throughout the period when CFCs were used as refrigerants. Therefore, the ARI statistics play a particularly important role in characterisation of the global inventory.

Figure 4-1 shows the ARI statistics for shipments of large tonnage liquid chillers by US manufacturers from 1990 through 2002. The three curves show the domestic shipments, shipments to Canada and shipments to other countries. The shipments to other countries are shown in cumulative form in Figure 4-2. Numbers can also be found in Table 3-1.

The cumulative production of large chillers by US manufacturers from 1980 through 1993, the last year of CFC chiller production, was 53,890, of which 14,286 were exported to countries other than Canada.

The curve of figure 4-2 shows a rather sharp up-turn around 1980 or shortly thereafter. This is probably due primarily to the improved economies of countries to which exports were shipped, complemented by replacement of very old CFC chillers with new non-CFC chillers.





4.2 Chiller Charge

The inventory of charge in the installed base can be calculated as follows:

Refrigerant inventory = No. of Chillers • Average cooling capacity [kW] • average charge per unit capacity [kg/kW]

For example, if there are 1,000 chillers in a particular country with an average charge of 0.25 kg/kW and an average capacity of 1400 kW, then the refrigerant inventory in large chillers in that country would be:

1,000*1400(kW)*0.25(kg/kW)=350 tonnes

4.3 Charge per Unit Capacity

The average refrigerant charge in centrifugal chillers using CFCs is about 0.25 kg/kW for CFC-11 and about 0.35 kg/kW for CFC-12 /ICF03, UNE95/. The larger charge for CFC-12 is due, at least in part, to the higher molecular weight and the higher operating pressures of CFC-12 relative to CFC-11.

The exact mix of CFC refrigerants in use in any particular country is not well known. During the CFC era, those entities, which purchased centrifugal chillers from North America, or were influenced by North America, most likely purchased CFC-11 chillers. Those who purchased from Europe, or were influenced by Europe, most likely purchased R-12 chillers. It is estimated that roughly 90% of the global population of CFC chillers employ CFC-11 and the other 10% employ CFC-12.

With this weighting, the average charge of CFC centrifugal chillers would be between 0.27 and 0.30 kg/kW, which is used in the present analysis. In case the percentage CFC-11 is much lower (as has been the case in Europe and the exports from Europe), the average (weighted) charge would be 0.34 kg/kW.

Conversion Factors

1 T, MT = one metric ton
= 1000 kg
= one tonne

1 RT = one refrigeration ton
= 12,000 BTU/hr.
= 3.516 kW

1 kW = 0.2844 RT
= 3413 BTU/hr

1 kg/kW = 7.753 pound/ refrig. ton

4.4 Average Cooling Capacity

The average cooling capacity of the installed base of chillers is

Average Cooling Capacity = sum of the capacity of all units ÷ the total number of units

Because Imperial units are widely used in the air conditioning industry and in the statistics for the industry, a few conversion factors between Imperial units and metric units are given in the sidebar.

Despite some possibly significant exceptions, it is assumed that the average cooling capacity of large chillers is fairly uniform world-wide. The average used by ICF in their study for the World Bank /ICF03/ is 400 RT (1400 kW).

Somewhat different estimates can be found from the ARI statistics, which give unit shipments by capacity ranges. Examination of these ARI statistics indicates that the average capacity of new centrifugal chillers has drifted upwards over the last 20 years from 435 RT (1520 kW) in 1982, to 466 RT (1630 kW) in 1992 and 589 RT (2060 kW) in 2002. To some degree this may be somewhat coincidental, but there are identifiable causes for some upward shift.

- Some very large buildings have been built in recent years requiring more chiller capacity.
- The number of very large chillers has increased.
- The screw chiller has come to play a much larger part in the market and has displaced centrifugal chillers at the lower end of the capacity range.

The first two of these factors may be more significant in developed countries than in Article 5(1) countries, and the third factor has played more of a role since the CFCs have been phased out for new production. So the values that deserve most attention are those for 1982 to 1992 and they are only moderately above the ICF figure /ICF03/ of 400 RT (1400 kW).

For convenience and to accommodate the capacity growth mentioned, a reference nominal *average capacity of 1400 kW is used* in the remainder of this report.

Table 4-1: Developed Country CFC Chiller Counts, Charge Inventories and Refrigerant Annual Losses

Country/Region	Number of CFC Chillers	Refrigerant Inventory (tonnes)	Refrigerant Losses (tonnes)
United States	36,800	14,426	1082
Canada	2,160	847	64
Europe	4,600	2189	164
Japan	7,000	2744	206
TOTAL	50,560	20,206	1516

4.5 Refrigerant Charge Inventory

The refrigerant charge inventory is calculated using the equation shown above. Results have already been given in Table 3-4.

4.6 Refrigerant Usage

Refrigerant usage is accounted for by six factors, which include some overlap. These are:

1. Leakage during shipping, operation and standby,
2. Periodic purge of non-condensable gases (for systems with low pressure refrigerants)
3. Rupture due to failure of a pressure vessel or piping,
4. Venting of refrigerant charge during service
5. Inadvertent or unavoidable losses during service
6. Loss or venting at end of life.

These factors are highly variable among different installations and among different countries, and estimates of average values are also highly variable.

5 Environmental Impact

5.1 Refrigerant Emissions

Refrigerant emissions from chillers can be the result of leakage during operation and maintenance as well as the result of refrigerant loss during service and at end of life. Loss during service and at end-of-life would include vented refrigerant and fugitive emissions such as residual charge in components, off-gassing of lubricant, etc. Older machines tend to have higher leak rates because they use less sophisticated technology to conserve and contain refrigerant. There is also more likely to be wear on seals or moving parts that would contribute to leakage, and the purge system on low pressure machines would not be the modern high efficiency technology.

Credible values for the fraction of the charge that might be expected to be emitted from CFC chillers range from about 5%/year for equipment 10-20 years old to 7.5%/year for equipment 20-30 years old. There are very few CFC chillers under 10 years old and very few over 30 years old, so emissions factors for these chillers are not needed.

Detailed surveys conducted for the World Bank have higher estimates of the number of chillers in Article 5(1) countries than implied by the ARI data and chiller manufacturers /ICF03/. For purposes of this analysis it has been assumed that the 50,000 chillers identified by ARI are in non-Article 5(1) countries and that up to 20,000 more chillers are in Article 5(1) countries as described below (data derived from Table 3-4). Note that this estimation technique may double count several thousand chillers that may be included in both the ARI and World Bank estimates.

For purposes of estimation, it has been assumed that large chillers (≥350kW) in Article 5(1) countries have leak rates two and one half times greater than in North America where there are strict controls on service training and certification, prohibitions on venting, and other environmental stewardship, regulatory and market incentives. At that leak rate, emissions of 20,000 large chillers in Article 5(1) countries are comparable to the 50,000 large chillers in non-Article 5(1) countries, i.e., approximately 1,500 tonnes annually each (see also Table 4-1).

Less is known about the number of small (non-centrifugal) CFC chillers (<350 kW), particularly in the Article 5(1) countries; it is therefore impossible to make estimates of emissions and the service needs for this equipment. A very rough first estimate is that emissions from small CFC chillers in Article 5(1) countries may be of the same order of magnitude as the emissions from large chillers (approximately 1,500 tonnes annually). However, it is being assumed that these small chillers are not really chillers in the sense of equipment providing comfort cooling; they may well be considered under commercial refrigeration and cold storage. For the purpose of this report the small CFC chillers/ refrigeration equipment will not be further considered. Generally, the majority of small chillers for comfort cooling use HCFC-22.

Thus, the total global emissions from large CFC chillers is approximately 3,000 tonnes annually, or about 3-4% of total –global- current CFC emissions. In the case of Article 5(1) countries it may represent less than 2-3% of their emissions.

5.2 Energy Efficiency

As indicated in chapter 2, energy efficiency is the primary environmental consideration for chillers. The dominant global warming effect is caused by the CO_2 emitted in the combustion of fossil fuels generating the electricity to drive them. Today's chillers use about 35% less electricity compared to average chillers produced just two decades ago and the best chiller today uses half the electricity of the average 1976 chiller.

However, as mentioned above, building cooling-efficiency depends not only on the chiller compressor energy efficiency, but also on the design of the water/air side and the refrigeration circuit. The gains from replacement of the chiller may be affected by the condition of the rest of the circuit, which is not associated with ODS phase-out. Replacement of important components may be necessary when replacing the chiller compressor.

One other factor, which should also be repeated here is that a higher investment in a chiller will result in greater chiller efficiency (either strictly coming from the compressor or from the circuit as a whole). It depends on a number of local economic and climate conditions how the payback period will be affected.

5.3 Average Energy Efficiencies in Article 5(1) Countries

World Bank-ICF /ICF03/ data indicates that the average full load large chiller system specific power per ton of refrigeration in Article 5(1) countries varies from 0.71 to 0.64 kW/ton (equivalent to COP values (kW/kW) of 5.0 and 5.5, respectively). This is most likely due to the slower replacement of older CFC chillers in Article 5(1) countries since the chillers in Article 5(1) countries are either imported from developed countries or manufactured in a Article 5(1) country in collaboration with a manufacturer in a developed country.

Replacing these chillers would reduce energy consumption and greenhouse gas emissions since the new chillers would be more energy efficient and have lower refrigerant leak rates.

Table 5-1 has been taken from the ICF report /ICF03/ to give an impression of the country dependent -average- COPs (in kW/kW) and the difference with the best efficiency recorded so far.

Table 5-1: Chiller efficiencies by Article 5(1) country, differences with best COP (%), and improvements in energy efficiency expected since the values were recorded (1996-2001)

Country	**Av. Efficiency (kW/kW)**	**Difference With best COP**	**Improvement**
Argentina	5.0	48%	
Bangladesh	4.6	54%	
Brazil	5.0	46%	8%
Central America	5.6	30%	
China	4.8	53%	7%
Dominican Republic	5.5	34%	
Egypt	5.3	38%	
Hong Kong	5.2	42%	
India	5.0	48%	5%
Indonesia	5.3	37%	6%
Korea	4.6	59%	
Kuwait	4.3	70%	
Macao	4.5	62%	
Malaysia	5.2	42%	9%
Mexico	5.3	38%	9%
Philippines	5.0	47%	5%
Saudi Arabia	4.6	57%	
Singapore	5.2	36%	11%
Thailand	5.0	48%	7%
Trinidad	4.6	61%	
Turkey	4.9	47%	14%
United Arab Emirates	4.6	55%	
Venezuela	5.3	40%	
Vietnam	5.0	49%	
Average	**5.0**	**48%**	**4%**
World-wide average	**5.9**	**25%**	**3%**
Best efficiency (COP)	**7.3**	**-**	**7%**

5.4 Overall Climate Change Impact

The climate change impact of chillers is determined by evaluating the impact of refrigerant emissions and the impact of power plant emissions, which generate the electricity used to drive the compressors. Burning fossil fuels to generate electricity results in emissions of carbon dioxide, which is the predominant greenhouse gas. Refrigerant emissions can impact ozone depletion, global climate change or both, depending on the refrigerant used.

Efforts to minimise the environmental impact of chillers require designs that minimise refrigerant emissions and maximise energy efficiency.

Prior to 1993 most chillers used CFC-11, CFC-12 or HCFC-22 as the refrigerant. These compounds are ozone depleting substances and particularly the CFCs have high global warming potential (see Table 2-4 for ODP and GWP information). Refrigerants available today have zero or very low ozone depletion potential. HFC-134a and HCFC-123, which are the most common refrigerants used in today's large chillers, are greenhouse gases but also allow for the design of energy efficient equipment thus reducing carbon dioxide emissions from the burning of fossil fuels to generate electricity. The HFCs and HCFCs have significantly lower global warming potentials than the CFCs they replaced.

There are still a significant number of CFC chillers in operation around the world. These chillers tend to have higher leakage rates than the newer HCFC and HFC chillers and tend to be less energy efficient thus having a greater impact on global warming and ozone depletion than would be the case if they were replaced with newer technology.

As noted above, the assessment of the global warming impact of building cooling systems must consider both direct and indirect contributions. The direct contribution results from refrigerants emitted to the atmosphere and the impact is relative to their global warming potential (GWP). The indirect contribution is the total amount of greenhouse gas emitted from generating the electricity to power the chiller during its lifetime (i.e. carbon dioxide generated by burning fossil fuels). The combined effect of direct and indirect impact is referred to and measured as the Total Equivalent Warming Impact (TEWI). The calculated TEWI is dependent upon equipment lifetime, emission losses, and the time horizon chosen to calculate the GWP /AFE02/.

Table 5-2 below illustrates refrigerant emissions, energy use, and TEWI for chillers using CFC-11, CFC-12, HCFC-123 and HFC-134a refrigerant.

Generally, by applying HCFC-123 for CFC-11, the TEWI can be reduced by about 50% and by applying HFC-134a for CFC-12 a reduction of about 70% can be achieved (note that the /IPC96/ GWP value of 8500 for CFC-12 has been used). The reduction will be strongly dependent on the amount of operating hours assumed; 2000 hours has been taken as a reasonable average.

Table 5-2: Sample TEWI Calculation for Chillers

Refrigerant emissions	**CFC-11**	**CFC 12**	**HCFC 123**	**HFC 134a**
Average refrigerant charge (kg)	394	492	562	506
Annual leak rate	16%	16%	1%	1%
Annual emissions per chiller (kg, unweighted)	63	79	5.62	5.06
Refrigerant Ozone Depleting Potential (ODP)	1	1	0.02	0
Annual emissions per chiller (ODP-weighted kg)	63	79	0.11	0
Chiller lifetime (years)	25	25	25	25
Lifetime ODS emissions (ODP tonnes)	2	2	0.003	0
Refrigerant GWP (100 year time horizon)	4,000	8,500	120	1,300
CO_2 equivalent emissions (tonnes)	6,304	16,728	17	164
Global Warming Indirect Impact				
Refrigeration capacity (refrigeration tons)	400	400	400	400
kW per ton	0.8	0.8	0.55	0.55
Hours in use per year	2,000	2,000	2,000	2,000
kWh per chiller per year	640,000	640,000	440,000	440,000
CO2 equivalent per chiller per year (tonnes)[2]	416	416	286	286
Total CO_2 energy use emissions per chiller (tonnes)	10,400	10,400	7,150	7,150
Total Equivalent Warming Impact (TEWI), tonnes CO_2 equivalent	16,704	27,128	7,167	7,314

[2] Based on 0.65 kg CO_2/kWh.

6 Incentives and Impediments to Chiller Transition out of CFCs

6.1 CFC Chiller Replacement - Incentives

Key incentives to replace CFC chillers are the cost savings and other benefits obtained by replacing older chillers (and their technology) with new energy-efficient technology and its environmental benefits. This section discusses both non-governmental and governmental incentives that can make replacement chillers more attractive to prospective purchasers.

Economic payback

One incentive for replacing CFC chillers is the economic payback obtained by owners who remove old, lower-efficiency CFC chillers and replace them with new higher-efficiency non-CFC chillers that reduce annual energy costs. Other benefits are increased reliability and lower maintenance costs.

Performance contracting

Performance contracting is a method for financing energy enhancements such as chiller replacements. A third party provides the technical assistance and capital investment to replace CFC chillers and increase the energy efficiency of building systems. In return, the third party receives a portion of the financial rewards from the energy savings for a number of years. Performance contracting requires expectations of economic stability, a level of trust, and supporting infrastructure (e.g., utility supply and billing practices) that may be hard to assure in some countries.

Training and educational programmes

Engineers in Article 5(1) countries should be given the opportunity to learn about non-CFC chillers and the benefits that can be obtained by owners and operators when old CFC chillers are replaced. Engineers also should learn about ways to enhance the energy savings obtainable from other modifications of existing air-conditioning systems and their controls. Service and operating personnel should receive training on ways to minimise refrigerant emissions from chillers and how to operate the chilling system to achieve the energy savings that helped to justify the replacement of CFC chillers. Training in these areas can reduce concerns about "new technology" embodied in non-CFC chillers and their controls, and help assure that the energy savings and emission reductions expected from the chiller replacement are actually achieved.

Incentives provided by governments and other outside agencies

Owners of CFC chillers may be further encouraged to replace them by incentives provided by governments and outside agencies, and/or regulations imposed by governments. Here are a number of examples:

Loans (funds offered at concessional or commercial interest rates)

Loans for the full installed cost of a new chiller, or a significant part of this cost, can overcome a lack of financing available to owners of CFC chillers. A conventional loan program may not be as attractive as the next option below.

Revolving loan fund, coupled with technical assistance

A revolving loan fund with repayments by borrowers from their energy cost savings seems preferable to pure loans or grants because revolving loans may be conceptually more attractive to the countries/agencies providing the loans. The revolving loan should incorporate a provision that expert technical assistance will be provided along with the loan to assure that the chiller/building changes are well conceived.

Policy support, including new building codes/standards if needed

Government actions, if enforced, can encourage replacement of CFC chillers or reduction of emissions from them.

Building programs for energy efficiency

Formal programs to encourage the design and construction of energy-efficient buildings, or the modification of existing buildings and their systems, can encourage CFC chiller owners to replace them in order to achieve "green building" recognition. Well-publicised demonstration programs can show decision makers what can be done and encourage them to follow the examples.

Financial rewards for private investments

Confidence that investments in CFC chiller replacements will be protected, and not nationalised or otherwise seized, is required to justify investments that are paid back only over a period of years. To the extent that the CFC chillers to be replaced are owned by multinational companies operating in a host country, further conditions are necessary: open borders for investment and import of goods and services, and an ability for foreign investors to repatriate their earnings from the chiller replacement investment.

6.2 CFC Chiller Replacement - Impediments

Cost issues

Life cycle cost is cited in many papers and reports as the proper basis for making a decision about purchasing an energy-saving chiller. However, first cost is an immediate problem that an owner must overcome. Life cycle cost is the result of an estimating process which forecasts a future that may seem uncertain (or unimportant) to the decision-maker. Even in the developed countries, a great number of chillers are sold to customers focusing on first-cost only. Thus, the decision often becomes whether to continue to run an existing chiller until it fails or is legislated out of operation, -- or to try to justify buying a lowest-cost replacement chiller because the consequences of existing chiller failure are too great. In Article 5(1) countries, financing may be difficult to obtain or may carry discouragingly-high interest rates, tilting the risk analysis to favour keeping the existing chiller as long as possible.

In certain countries such as e.g. China, where CFCs are still produced, their low cost may be an impediment to chiller replacement. However, this does not generally apply, since in India and Mexico, two producing countries, domestic prices are quite high due to industry and/or government policies, and they could act as an incentive for replacement. In most Article 5(1) countries the cost of servicing chillers is relatively low so the machines are kept in operation well beyond their normal operating life.

High import duties, if present, increase the cost to the prospective buyer of replacement chillers and thwart government intentions to reduce energy consumption and eliminate CFCs.

Lack of information in the hands of decision-makers

The people who make the investment decisions may not be sufficiently aware of the ongoing costs to operate and maintain their chillers and the options to reduce these costs. The decision-makers also may be unaware of, or unconcerned about, the environmental consequences of CFC emissions from their chillers.

Uncertainty about the future and poor current financial conditions

World and local economies in many Article 5(1) countries have been volatile and unpredictable. This situation breeds conservatism in making non-essential capital investments. Also, if there are uncertainties about potential environmental restrictions on refrigerants now being used in new chillers (e.g., the concern raised by several countries about HFCs), this encourages a wait-and-see approach to chiller replacement.

National energy policies and lack of enforced building codes

If there are no government pressures to replace CFC chillers, reduce emissions, or reduce energy consumption, decision makers focus only on their own individual situations which often favour delaying investment.

If the prices for electricity are very cheap (or are kept at very low levels due to government intervention), the energy efficiency issue is irrelevant and is actually an impediment for change (e.g., in countries in the Middle East, in Venezuela).

Decision-making obstacles

Facility management or operating personnel may understand the benefits of CFC chiller replacement, but they may not have a significant voice in the investment decision-making process for their commercial building. Instead, the managers of the building who plan the investments may consider money spent on equipment upgrades to be a controllable cost to be minimised, and think of energy costs as uncontrollable - something they must accept.

Perceived risks

The replacement of chillers must be carried out with planning and skill to avoid disruption of building operations. New equipment, with newer technology (e.g., controls) brings a risk that operating and maintenance people will not have the skills to keep it operating satisfactorily. Keeping older CFC chillers in service may be considered by management to be a wiser plan than taking on the risk of business disruption. Novel financing arrangements such as performance contracting or complex loans may be considered to be undesirably complicated for the financial structure of the business.

6.3 Transition Out of CFC Chillers at the National Level

If one would plan transitioning out of CFC chillers at the national level, one would need to address training in maintenance and containment, and also recovery and re-use as these are key parts of the process at the national level. The hierarchy of measures for a national transition would be

(a) training and education in maintenance and containment, and essential equipment such as high efficiency (refrigerated) purges, to enable continued use of existing equipment with low leakage rates until the end of their useful life (as judged by the owner);

(b) natural retirement/replacement of old chillers at the end of their useful (physical) life (as judged by the owners) and recovery of refrigerant for use in other chillers;

(c) replacement of old chillers on economic grounds (as judged by the owners on the basis of energy efficiencies) and recovery of refrigerant for use in other chillers;

(d) replacement of chillers prior to the end of their economic life through assistance from the Multilateral Fund (where eligible under Fund rules) to meet Protocol targets or because of refrigerant shortages.

This implies that CFC chillers would and could continue operation in Article 5(1) countries well beyond the 2010 CFC phase-out date. This is consistent with the situation in non-Article 5(1) countries where the report above indicates that 45 percent of CFC chillers in the US are still in use, 9 years after the phase-out of the manufacturing of CFC chillers. From Table 3-3 it can be derived that the use of CFC chillers in the US could be phased out by 2015, provided a business as usual scenario would apply. Since the manufacturing of CFC chillers has been phased out globally around 1995, the lifetime of the chillers in operation in Article 5(1) countries by 2010 would be in the range of 15-35 years, at least. In view of the age of these CFC chillers, it is likely that most chillers --if not all-- will have been replaced around 2020 as a result of normal economic activity. Here one should definitely take into account the further increased energy efficiency of new chiller equipment by 2020, which would be an important incentive for replacement. Information derived from Multilateral Fund rules is that replacement of equipment at the end of its physical or economic life is not supported by the Multilateral Fund.

7 CFC Chiller Projects in Article 5(1) Countries - Case Studies

7.1 Chiller Projects in Article 5(1) Countries

In order to address the issue of phasing out the use of CFC in chillers and reduce or eliminate the demand for CFC for servicing, the World Bank has developed two demonstration projects, (a) one in Thailand and (b) one in Mexico. It also developed an integrated CFC chiller phase-out as part of a Refrigeration Sector Plan for Turkey. France, in a bilateral project with Cote d'Ivoire, also developed a chiller replacement project that will eventually replace 50 chillers. Through the three World Bank projects, a total of 46 chillers have now been replaced with non-ODS chillers at total costs of over 5 million dollars. More important, these three projects have provided valuable experiences on chiller replacement programs. Among the findings are that chillers replacements to a large extent can be financed through energy savings, but financing the up front investment remain the key issue and can only be removed through demonstrating the energy savings and viability of the concept. Some brief information on the French and the three World Bank projects is given below:

7.2 Case – Cote d'Ivoire

France started a bilateral program to replace 50 centrifugal chillers in Cote d'Ivoire. Cote d'Ivoire has already implemented a part of its Refrigerant Management Plan; the fourth item in the plan concerns the phase-out of CFC use in centrifugal chillers. 57 water-cooled CFC centrifugal chillers are currently in operation in Cote d'Ivoire in 24 large central air conditioning systems in industries and buildings. A sector overview was made before the project was started, of which the results are given below.

The overview identified 35 CFC-11 centrifugal chillers (installed 1969-1989) with a total inventory of 16.4 tonnes and 22 centrifugal CFC-12 chillers (installed 1977-1990) with a total inventory of 13.7 tonnes (total for CFC-11 and -12 being 30.1 tonnes). In the project proposal it is mentioned that the CFC-11 chillers emit 2.5 tonnes per year, the CFC-12 chillers 2.45 tonnes per year (which would be in the order of 15% of the inventory per year). On the basis of the use of 5 tonnes per annum, it is mentioned that these chillers will emit to the atmosphere about 40 tonnes of CFCs until the end of their life cycle.

The project proposal also mentions a total consumption of 18 tonnes of CFCs per year (likely to include servicing), i.e. the total consumption per year is 60% of the chiller inventory.

Compared to the total consumption of 214.5 tonnes in the sector, 5 tonnes represent 2.2% of the total and 18 tonnes represent 8.4% of the total servicing needs in the refrigeration sector.

The project also mentions that recent energy audits on 12 sites including centrifugal chillers have shown that energy savings could be done, in improving building management and electric system with short payback period (about one year). Replacement of CFC centrifugal chillers by new non-ODS chillers allows energy savings but with a long payback period (10 to 25 years). But actions combined with the improvement of cooling towers and air handling equipment improve cost efficiency leading to a payback period of 3-8 years. The potential energy savings are 40 GWh/year, which has a reduction impact on the atmosphere of 6500 tonnes of carbon emissions per year.

In combining the financial resources of ODS and greenhouse gas emission reduction programs and of energy savings, this project --implemented by AFD, the Agence Française de Developpement--, will allow:

- Replacement of 50 CFC centrifugal chillers by HFC-134a screw chillers or other non ODS energy efficient chillers and the reduction of 40 tonnes of CFC emissions in the coming years;
- Energy efficiency actions and rehabilitation of 22 large air conditioning and refrigeration systems including centrifugal chillers leading to energy savings of 40 GWh/year, with a reduction of 6,500 tonnes of carbon emissions per year;
- Reduction of 10 MW of peak load electrical demand, and related investment savings in power plants (US$ 15 million if hydro power plants or US$ 4 million if thermal power plants).

The project duration will be 4 years, the project impact 18 ODP tonnes (where the ODS use in the sector is equal to 214.5 tonnes) and the total project cost equals US$ 16,119,158.

7-1: Project Cost for the Cote-d'Ivoire Project

Replacement of centrifugal chillers	***US$***
New chillers and accessories	5 472 800
Installation and engineering	820 920
Transportation	273 640
Costs of installed new chillers	**6 567 360**
Other actions	
Improvement of building management and electric system	1 992 241
Improvement of cooling towers and pumps	2 217 294
Improvement of air handling and controls	3 196 286
Subtotal	**13 973 181**
Miscellaneous (10% TI)	1 397 318
Promotion, energy audits, project design, technical assistance and follow up	698 659
Training	50 000
TOTAL COST OF PROJECT	**16 119 158**

Table 7-2: Financing Arrangement for the Cote-d'Ivoire Project

Sources	*Qty chillers*	*Subsidy/unit (US$)*	*US$*
Multilateral Fund of Montreal Protocol	50	20 000	1 000 000
Fonds Francais de l'Environnement Mondial (10% TI)			1 611 915
Other sources (owners directly or through existing banking system)			13 507 243
TOTAL COSTS			**16 119 158**

7.3 Case -- Thailand

The Thai Chiller Demonstration Project was the first chiller project. The Multilateral Fund of the Montreal Protocol and the GEF jointly financed the project. The main objective was to improve energy efficiency and combine greenhouse gas reduction at the same time phasing out CFC, remove perceived technological risks and demonstrate financial and technical viability of building chiller replacements through revolving funds. It was planned to finance up replacement of 20 chillers with loan from a revolving fund based on well define and agreed criteria.

Based on studies carried out as part of the preparation for the project, it was estimated (in a first review) that Thailand had a total population of around 2,500 CFC based chillers. All chillers are imported mainly from US suppliers. The suppliers operating in Thailand are normally also providing service and maintenance to the chillers installed by them. Like most other markets, the chiller suppliers change over to non-CFC chillers around 1996 and it is assumed that all chillers installed after 1997 are non-CFC chillers. Through the studies carried out, it is also found that the majority of CFC based chillers are installed during the 20 year period from the mid-seventies to the mid-eighties.

The project targeted chillers with a cooling capacity larger than 250 RT, a power consumption higher than 0.8 kW/RT and a maximum of 15 year old, assumed to be equal to less than 130,000 hours of operation. A total of 17 chillers has been replaced through the program at a total costs of US$ 2.1 million. Ten of the replaced chillers were installed in hotels, two in shopping malls, three in a factory and the rest in office buildings. HCFC-123 was selected as refrigerants for thirteen of the chillers and HFC-134a for the remaining four.

The total amount of CFC contained in the chillers was 9.16 tonnes of CFC or on average 1.18 kg CFC per RT capacity (i.e. 0.33 kg/kW capacity). A total of 6.89 tonnes of CFC was recovered from the replaced chillers. The energy expected savings achieved, based on the specifications provided by the suppliers, was in average 0.39 kW/ton. The measurements after installation have shown that the efficiency of the chillers was at or better that the specifications.

Table 7-3: Summary of the Thai chiller project information

Total number of CFC chillers	2500
CFC Chillers replaced by the program	17
Total program costs	2.153 million
Average size of replaced chillers	455 RT
Average costs of replaced chiller costs	US$ 126,696
Average costs per RT	US$ 278/ RT
Average amount of CFC per replaced chiller	528 kg
Average CFC recovered for recycling per replaced chiller	405 kg
Average amount of CFC recovered for recycling by RT	0.89 kg/RT
Average energy savings per RT	0.38 kW/RT

The project was funded through a loan to the owners covering the full costs of the chiller. The repayment was based on the calculated energy savings, which resulted in a pay back period of less than 4 year. In order to establish the expected energy savings, the project undertook an independent energy audit of the chillers/buildings employing a measurement and verification protocol to establish the baseline for loan repayment. As the repayment was direct linked to energy savings, each of the new chillers was monitored through a data-logging system, providing full information on performance and energy consumption of the new chillers.

The project has shown that (i) the owners are able to pay back the loan through energy savings, (ii) the expected amount of CFC that could be recovered and used for servicing of remaining CFC chillers was around 75% of the installed amount and finally, (iii) the program is now competing with similar programs in Thailand. This means that the perceived barriers have been removed and other loan program are competing while offering even better terms.

Assuming that the remaining CFC based chillers will have to be replaced over the next 10 years, the total investments if done through a revolving fund the up-front capital needed would be probably be around US$ 100 million. It should, however, be noted that the youngest CFC based chillers would be around 10 years old and the oldest more than 30 years old. Hence many of the chillers would be replaced anyhow, where the building owners would do the investments.

7.4 Case -- Mexico

From the study carried on global chiller market, it is estimated that Mexico has a population of around 2,500 CFC based chillers all installed before 1996/1997.

The Mexican Chiller Demonstration Project was financed through a combination of MLF UK bilateral contribution, development loan from another donor country and chiller owner contributions. The objectives of the Mexico Chiller Concessional Lending Pilot Project were (i) to test various loan conditions to finance the replacement of 20 CFC chillers with energy-efficient CFC-free systems; (ii) to assess the sustainability of a revolving fund created by the project; (iii) to reduce technology risks and the uncertainty associated with the level of electricity savings; and (iv) to encourage borrowing for early chiller replacement.

The total cost of the project was estimated at US$2.3million of which US$1million was provided as a grant to Mexico by the United Kingdom from its bilateral contribution to the Multilateral Fund. The remaining US$1.3million was provided as counterpart funding from two sources: (i) US$1million from the Fideicomiso para el Ahorro de Energía Electrica (FIDE), and (ii) $300,000 co-financing from chiller owners. In addition, FIDE contributed additional $200,000 solely to fund energy efficiency activities related to the chiller project. The initial grant funds and the funds recovered into the revolving fund will be used exclusively for chiller replacements. A limit of outside funding of US$100,000 was set as the cost for each chiller replacement. Chiller owners funded installation, transport and insurance of chillers.

The loan program established included the following terms:

- loans to be repaid over a three year period,
- loans are interest free for chillers less than 20 years old and 2% for older chillers.

A total of 12 chillers instead of the originally planned 10 chillers were replaced at costs of US$ 1,392,300. Based on the data available from the 12 replaced chillers, it has been found that the energy savings are at or more than initially estimated, and that the owners have been willing to co-finance the replacement of the chillers. A total of 7.8 tonnes of CFC has been recovered from replaced chillers and is used for servicing of existing chillers. At the same time the annual consumption for servicing has been reduced by around 800 kg.

Technology risks were reduced by soliciting performance-based bids from chiller suppliers and installation firms. To enable the measurement of electricity savings, the project undertook an independent energy audit of the chillers/buildings employing a measurement and verification protocol to establish a baseline.

Table 7-4: Summary of the Mexican chiller project information

Total number of CFC chillers	2500
CFC Chillers replaced by the program	12
Total program costs	1.392 million
Average size of replaced chillers	398 RT
Average costs of replaced chiller costs	US$ 108,800
Average costs per RT	US$ 273/ RT
Average amount of CFC per replaced chiller	680 kg
Average CFC recovered for recycling per replaced chiller	680 kg
Average amount of CFC recovered for recycling by RT	1.71 kg/RT
Average energy savings per RT	NA

Due to the experiences from the first chillers financed, the loan repayment as per the project design go into a revolving fund and continue to finance replacement of other existing CFC based chillers.

Assuming that the remaining CFC based chillers will have to be replaced over the next 10 years, the total investments if done through a revolving fund the up-front capital needed would be probably be around US$ 90 million. It should, however, be noted that the youngest CFC based chillers would now be around 10 years old and the oldest already more than 30 years old. Hence, many of the chillers would be replaced by the owners anyhow and the investments would be done by the building owners.

7.5 Case -- Turkey

The Turkey Chiller Replacement Program is part of the overall ODS refrigeration sector plan for Turkey financed by the Multilateral Fund of the Montreal Protocol. The main objectives are to reduce the service demand and recover CFC from replaced chillers in order to service remaining CFC based chillers in Turkey. As Turkey has set up a revolving fund for the ODS phase-out, Turkey co-finance the refrigeration sector plan and especially the chiller replacement program.

It is estimated that a total of 1400 CFC chillers exist in Turkey of which ***150 to 200*** are larger centrifugal chillers. Based on the preparatory work for the chiller replacement program, a survey has been carried out and chiller import data obtained as well as information directly from the chiller suppliers presently operating in Turkey. The survey has been followed up by workshops for the building/chiller owners presenting the chiller replacement program. A total of over 80 chillers for replacement through the program have been identified so far.

The chiller replacement program provide financing on the following terms; 75% loan and a 25% grant financing, repayment of 5 payments over a three year period starting 6 month after the installation of the new chiller has been installed, zero interest and a 3% administration fee. A total of 18 chillers at costs of US$ 1,483,284 have been replaced as part of the program. Due to the different climate conditions in Turkey compared to Thailand and Mexico, the chillers are only operating during the summertime. Hence the overall annual savings are obviously less than for the two other countries where the chillers are operating year round. However, the program has shown that it is still possible to finance the chiller replacements through energy savings, just that the payback period is longer. Over 6 tonnes of CFC have been recovered and used for servicing and future servicing.

Due to the objectives of the Turkey chiller program as part of the refrigeration sector plan, the Turkey chiller also focused on the service demand for CFC chillers. It was found that the demand for CFC-11 based chillers was significant higher than the CFC-12 based chillers. Based on the information obtained, the leakage rate for CFC-11 is expected to be 25% or higher while the leakage rate for smaller CFC-12 chillers are less than 15%.

Assuming that the remaining CFC based chillers will have to be replaced over the next 10 years, if investments were done through a revolving fund, the up-front capital needed would be probably be around US$ 10 million.

Table 7-5: Summary of the Turkey chiller project information

Total number of CFC chillers	200
CFC Chillers replaced by the program	18
Total program costs	1.483 million
Average size of replaced chillers	474 RT
Average costs of replaced chiller costs	US$ 118,850
Average costs per RT	US$ 251/ RT
Average amount of CFC per replaced chiller	395 kg
Average CFC recovered for recoiling per replaced chiller	395 kg
Average leakage rate per chiller	81 kg/chiller
Average amount of CFC recovered for recycling by RT	0.83 kg/RT
Average energy savings per RT	0.25 kW/RT

7.6 Observations based on the three pilot programs

The three World Bank chiller programs have provided valuable information and are helping in further developing the global chiller replacement programs. It should, however, be realised that a large number of the remaining CFC based chillers in the three countries might not meet the stringent criteria set in the program and might not provide the same high energy savings. It should also be realised that replacing all CFC chillers in the three countries will require significant more capital and the centrifugal chillers will eventually have to be replaced at the owners' initiative.

In evaluating the programs and designing new programs, it also needs to be taken into account that by recovering CFC from dismantled CFC chillers, the CFC will be available for longer time for the servicing of remaining chillers. It should also be considered that a larger number of CFC based chillers might now be between 20 and 30 years old and will be replaced by the owners over the coming years. Hence a good recovery program might allow recovering of CFC for servicing of remaining, newer chillers and the phase-out of the total inventory of CFC based chillers in countries might take place over a longer period.

As shown through the French and the three World Bank programs, energy savings constitute the major incentive for replacement. Hence linkages to the carbon emission reduction and energy savings programs exist. The World Bank is presently looking into this avenue for future chiller replacement programs.

Table 7-6: Summary Table for the Three World Bank Chiller Projects

	Mexican chiller project	**Thai chiller project**	**Turkey chiller project**
Objectives	Demonstration project for chiller replacement showing it can be financed through energy savings	Remove market barriers by showing it is possible to finance chiller replacement through energy savings	Reduce CFC demand and recover CFC for servicing through energy savings
Estimated total CFC chiller population in the country	Not known	App 2,500 CFC chillers	App 1,400 CFC chillers Hereof app. 200 centrifugals
Number of chillers replaced by the project	12 chillers	17 chillers	18 chillers (1st round: 6 and 2nd round: 12)
Financing	MLF financed UK bilateral project implemented through the Bank	Co-financed by MLF and GEF 50% MLF financed and 50% MLF financed	Financed through the Turkish revolving MP fund and MLF
Total cost (as of Dec 2003)	US$ 1,392,300	US$ 2,153,836	US$ 1,483,284
Total MLF funding allocated	US$ 500,000	US$ 995,000	US$ 1,000,000
Financed by owners	US$ 692,300	US$ 1,258,836	US$ 483,284
Repayment terms	Fixed duration of 3 years and no interest	Linked to energy savings and no interest	Fixed duration, 5 instalments and no interest. First payment starts 6 months after installation completed.
Repayment period	3 years	Depending on energy savings	3 years
Interest	0% , 2% for older than 20 year old chillers	0%	0%
Management fee			3%
Criteria for chiller replacement financing	CFC centrifugal chiller Past financial performance of the chiller owner Meeting set financial criteria	CFC centrifugal chiller Power consumption higher than 0.8 kW/TR Cooling capacity higher than 250 TR Less than 15 year old*	CFC centrifugal chillers Owner willing to participate Financial qualified
Average costs per chiller	US$ 108,800	US$ 126,696	US$ 118,850 (1st round)
Average costs per RT	US$ 27.34	US$ 16.37	
Total RT	3,980 RT (based on 10 chillers)	7,740 RT	2,843 RT (1st round)
Average RT	398 RT	455 RT	474 RT (1st round)
Average costs per RT			251 US$/RT (1st round)
CFC emission reduction per year	812 kg (estimate)	2,271 kg	730 kg CFC-11 (1st round)
CFC recovered and recycled from replaced chillers	7,800 kg (estimate 6,787 kg)	9,160 kg	2,415 kg CFC-11 (1st round)

	Mexican chiller project	**Thai chiller project**	**Turkey chiller project**
CFC emission reduction per RT			0.26 kg CFC-11/RT (1st round)
CFC recovery per RT			0.85 kg CFC-11/RT (1st round)
Energy savings per RT	NA	0.38 kW/RT	NA
Energy saving per year	7,387,902 kWh/year	2,941,000 kWh/year	NA
CO2 emission reduction (due to reduced energy consumption)	NA		NA
CO2 emission reduction (due to reduced leakage)	NA	4.310 ktC/year	NA
Energy Consumption Reduction (MWh/year)	7,387 (12 chillers)	15,503 (17 chillers)	
CO_2 Emission KtC per year		113.25 (17 chillers)	
Leakage Reduction (ODP Tons per year)		38.615 (17 chillers)	

8 Further Case Studies for India, Brazil and PR China

8.1 Case Study – India

8.1.1 Background

As an Article 5.1 country under the Montreal Protocol, India is committed to phase-out the production and consumption of CFCs for all applications by the year 2010. This does not restrict or control the use of existing CFC-based equipment, including chillers, as long as that equipment can be kept in operation without the need for virgin CFCs.

8.1.2 Chillers

India is one of the large CFC-consuming Article 5(1) countries where many types of refrigeration and A/C equipment are manufactured and CFC and HCFC chemicals are produced. Chillers are manufactured using large centrifugal compressors, screw compressors and reciprocating compressors. In India, the term "chiller" is used to include all types of refrigeration and air-conditioning units which use non-hermetic compressors ranging in capacity from 7 kW to above 3500 kW.

8.1.3 Chiller Capacity and the Choice of Compressor

Choice of the type of compressor is a function of the refrigerating capacity and the application. Reciprocating compressors are commonly used up to about 450 kW; screw compressors from 350 kW to 1000 kW; and centrifugal compressors from 700 kW to 10,000 kW.

8.1.4 Choice of Refrigerant

The majority of existing chillers in India use CFC-11; a small number use CFC-12. In recent years, chillers have been installed using HCFC-22, HFC-134a and HCFC-123. For the largest units, the main refrigerant choices are HFC-134a and HCFC-123.

8.1.5 Population and characteristics of chillers installed in India

A research study was undertaken by the World Bank /Win02/ to study the chiller population in India and its characteristics. In this study, chillers were broadly divided into three categories: large [above 350 kW], medium [70 to 350 kW] and small [less than 70 kW]. Chillers in the medium category mainly use HCFC-22. Since the thrust of the present study is CFC based centrifugal chillers, HCFC-22 chillers are not considered further here.

It is difficult to estimate the actual numbers of small-size units. The World Bank study indicates that the population is in the range of 60,000 to 100,000 units. These small units mainly use CFC-12 as refrigerant. Although they are called chillers in India, in most other countries these units are defined as refrigeration units and are normally not considered to be "chillers". Therefore, these units are not considered further in the present study.

In the case of the large-chiller category, the chiller population is in the range of 1000-1200 units. More than 90 percent of them use CFC-11. A very small percentage uses CFC-12. Table 8-1 gives the approximate number of chillers by capacity and age.

Table 8-1: Approximate number of Chillers with their Capacity and Lifetime

Capacity (kW)	Chillers (number)	Current Age in Years					
		<10 Yr.	10-15 Yr.	15-20 Yr.	20-25 Yr.	25-30 Yr.	>30 Yr.
700-850	325	100	60	65	60	30	10
850-1200	185	85	60	40	-	-	-
1200-1600	125	60	35	30	-	-	-
1600-1900	105	45	45	15	-	-	-
1900-2300	320	20	75	95	95	30	5
>2300	60	50	5	5	-	-	-
All Ranges	**1120**	**360**	**280**	**250**	**155**	**60**	**15**

From Table 8-1, a total installed refrigerating capacity of 1,641 MW can be derived.

In India, chiller installation increased in the 1980s and 1990s. There are approximate 360 chillers less than 10 years age and 280 between 10-15 years. If one calculates the percentage of the total capacity that is less than 15 years old and the percentage of the number of chillers that is less than 15 years old, it amounts to 60% in both cases.

8.1.6 Chiller Replacement Rate

In India, as in most Article 5(1) countries, the relatively low cost of servicing vs. replacement of chillers leads to extended service lives. Chillers are maintained beyond their expected service life by replacing system components, including major compressor parts. The ready availability and low cost of CFCs are further impediments to replacement.

So far, no broad replacement strategy has been developed for CFC chillers in India. Hardly any chillers are replaced except for those, which have exceeded their useful service life, which may be 40 years or longer. The World Bank /Win02/ study forecasts that the demand for recycled CFCs for servicing large capacity chillers will continue till 2027.

8.1.7 Refrigerant Leak Rate

The refrigerant leak rate depends on the age of the chillers and the number of annual hours of operation.

Centrifugal chillers using CFC-11 have a relatively low annual recharge requirement compared to CFC-12 chillers. However, since virtually all large chillers in India are operated on CFC-11, the precise leak rates for CFC-12 are less important.

A World Bank study indicates that the leak rate of CFC-11 chillers rises from almost zero for new chillers to about 0.3 kg/kW/year after 30 years. That study indicated that the recharge requirement ranged from 0.012 kg/kW/year for a one-year old chiller to 0.34 kg/kW/year for chillers older than 30 years. It is, however, doubtful whether the recharge requirement is so much dependent on the lifetime of the chiller. The estimated average recharge for CFC-11 chillers may be taken as 0.05 kg/ kW /year because the average chiller age is less than 15 years.

Chillers normally have a leakage of 15% per year. Emissions from the purge unit can be low. In India it will be between 5 and 15% per year. If one assumes servicing about once every 4 years, and 20% of the charge lost during servicing, this results in 5% of the charge lost each year, on average. The total servicing need is therefore 15-20% of the charge. Furthermore ruptures occur in chillers, where all refrigerant is lost. This may happen in 10% of the installed chillers each year. Exact figures for India are unknown and warrant further investigation.

Chillers are assumed to have a charge of 0.25-0.30 kg/kW for 700 to 1500 kW capacity, decreasing to lower than 0.25 kg/kW for 5 to 10 MW capacity.

8.1.8 Consumption of CFCs in the Chiller Servicing Sector

Large numbers of refrigeration and air-conditioning units are in service in India including large capacity chillers. These chillers have a total installed refrigerating capacity of 1,641 MW and a total charge (assuming an average charge of 0.28 kg/kW) of about 460 tonnes. If one uses the figure of 0.28 kg/kW for the average charge, and 23-25% of the charge as the average leakage per year, this would yield service needs of about 110 tonnes of CFC-11, with small amounts of CFC-12 because the CFC-12 chiller population is small. Due to uncertainty, an extra allowance should be made for accidents and sudden ruptures. If ruptures occurred in 10% of the chillers each year, this would require an additional 46 tonnes of CFC-11, which would bring the total servicing needs to 33-35% of the total inventory.

Because the total CFC refrigerant needs for servicing in India amount to 1582 tonnes per year (year 2001), the servicing needs for chillers (year 2001) is about 7.0 % of the total (and would be 9.9 % of the total if the loss of charge in the case of accidents were taken into consideration).

8.2 Case Study – Brazil

8.2.1 Background

Brazil's country program was approved at the 13th Meeting of the Executive Committee in July 1994. As a Party covered by Paragraph 1 of Article 5 of this Protocol, Brazil has ratified the London and Copenhagen Amendments.

As an integral part of the implementation of the Montreal Protocol, UNDP was charged with the elaboration of Brazil's National CFC Phase-out Plan, a broad strategy for phasing out the remaining CFC consumption. This Plan was approved in July 2002. UNDP is now assisting Brazil in its implementation. Existing legislation calls for the phase out CFC-11 and CFC-12 consumption by the end of 2007. To help reduce the consumption of virgin CFCs during the service and repair of refrigeration and air conditioning equipment and systems, a nation-wide CFC refrigerant recovery and recycling programme will be implemented. One of the projects included in this programme is related to the centrifugal chillers service sub-sector where CFC-11 and CFC-12 refrigerants are used. UNDP will provide support to maintenance and technical assistance companies to recover and recycle CFCs.

8.2.2 Choice of Refrigerant

HCFC-22 is the most commonly used refrigerant in chillers in Brazil because most the chillers are medium capacity and use reciprocating compressors.

The import of centrifugal chillers using CFC-11 and CFC-12 stopped after 1993. Since then, the machines exported to Brazil by the principal international manufacturers use HFC-134a and HCFC-123. These refrigerants replaced CFC-12 and CFC-11, respectively. However, because of the long useful life of the CFC chillers, which is around 30 years, there are still a large number of CFC chillers in Brazil

8.2.3 Population and Characteristics of Chillers

There are around 700 CFC-based centrifugal chillers used in industrial process refrigeration and building air conditioning in Brazil. The distribution of these among capacities and refrigerants is shown in Table 8-2.

Centrifugal chillers are not manufactured in Brazil. The leading companies importing HCFC-123 and HFC-134a centrifugal chillers to replace CFC chillers are Carrier, Trane, York, and LG. HCFC-22 operated chillers continue to be available. The Brazilian subsidiaries of the chiller suppliers act as agents, carrying out service and repairs, and stocking spare parts.

The remaining chillers consist mainly of HCFC-22 operated installations using reciprocating and screw compressors, combined in some cases with direct expansion systems. The use of ammonia is restricted to industrial refrigeration facilities.

According to the Brazil's National CFC Phase-Out Plan [NPOP], the amount of CFC refrigerant used in 2000 for servicing these machines was 88 tonnes. This consumption includes the "top-up" of refrigerant losses during equipment operation as well as the venting of all, or part, of the refrigerant charge during service and repair activities. The use of CFCs for the cleaning of systems during repair, as well as the overcharging of refrigerant, may also contribute to this consumption.

Table 8-2: CFC Centrifugal Chillers in Brazil

Quantity	**Average Capacity (kW)**	**Refrigerant**	**Inventory (tonnes)**
120	1800	CFC-11	60
300	1100	CFC-11	90
220	1350	CFC-12	100
60	1700	CFC-12	40
700 (total)			**290 (total)**

8.2.4 Chiller Replacement Rate

CFC chillers were installed up until 1993. The majority of the existing CFC chillers were installed in the late 1980's and early 1990's. While some older CFC based chillers have been replaced by non-CFC chillers during the last 8 years, this was because the chillers had become old and were worn out, rather than for environmental reasons. Very few CFC chillers have been retrofitted to non-CFC refrigerants. As the average lifetime of a chiller in Brazil is around 30 years, a substantial number of CFC chillers installed between 1982 and 1993 will still have remaining anticipated working lifetimes of 5 to 16 years when CFCs are phased-out in Brazil in 2007.

Some CFC-11 chillers face replacement because retrofit to use HCFC-123 is technically difficult and it is not always a cost-effective option. It may also not be cost-effective to retrofit older CFC-12 chillers. Chiller replacement is very costly. Even retrofit of those chillers that from can be feasibly retrofitted from CFC-11 to HCFC-123, or from CFC-12 to HFC-134a incurs costs that are far from insignificant.

In order to reduce the economic impact of CFC phase-out, it is important to take all possible measures to prolong the lifetime of the existing chillers and the strategy for that is based on the containment, recovery and recycling [R&R] of CFCs during service and repair. Replacement or retrofit must also be addressed through an "Incentive Programme".

The general R&R activity may provide adequate supplies of CFC-12 depending on the demand for refrigeration and other applications. The quantity of CFC-11 equipment which can be kept operational will have to be "adjusted" based on the amount recovered from CFC-11 chillers being retired, and the pressure for replacement, which may be greater than for CFC-12.

A CFC chiller R&R project will provide centrifugal chiller maintenance and technical assistance companies with machines for CFC-11 and CFC-12 recovery and recycling, and special tanks for storage of the recovered and recycled refrigerant.

8.2.5 Consumption of CFCs in Servicing Sector

The consumption of CFCs for the servicing of centrifugal chillers in 2000 amounted to 88 ODP tonnes, being 28 tonnes of CFC-11 and 60 tonnes of CFC-12. Since the total Brazilian CFC consumption for servicing is 1760 tonnes this amount of 88 tonnes equals 5% of the total.

Note: This amounts to about 19% of the bank for CFC-11 and 43% of the bank for CFC-12 in chillers. This suggests that there may be as much of a shortage of CFC-12 as of CFC-11.

8.2.6 Leakage Rate of Refrigerant

If one assumes the average leakage of 20% of the charge per chiller per year this represents 58 tonnes per year. The difference between this figure and the estimated consumption of 88 tonnes/year (which equals 30% of the total inventory) is accounted for by several factors. In addition to rupture with total loss of charge, the leakage rate in several regions of Brazil and in other Article 5(1) countries is much higher than the average values obtained from the manufacturers and the technical literature. Current maintenance practices do not always take account of CFC conservation and even include some intentional emissions.

Some enterprises involved with the maintenance of centrifugal chillers are not adequately equipped, and they do not take care to prevent refrigerant emissions. There are also intentional emissions when contaminated refrigerant is recovered and the company does not have proper tanks to store it.

Another important question is related to the purge units. Normally these components do not receive the necessary attention and maintenance by the technicians, leading to unnecessary refrigerant emissions during their operation.

8.3 Case Study – People's Republic of China

The air conditioning sector started developing in China from the 1960s onward with demand in the early stages existing primarily for domestic air-conditioners.

In due course, central air-conditioning systems using different types of compressors were installed. These included centrifugal type, screw type, reciprocating type and scroll type compressors. However, chillers based on screw type and reciprocating type compressors had not been produced on a large scale until 1980s. Centrifugal type chillers are mainly used to achieve a cooling capacity larger than 2,000 kW, appropriate for a building area larger than 20,000 m2. Such chillers have the highest ratio of energy efficiency, with their efficiency values lower than 0.55-0.65 kW/RT for present day standards (in comparison, the efficiency values of screw type and piston type chillers are 0.7 kW/RT and 1.0 kW/RT respectively).

Most of the centrifugal chillers for public air-conditioned building have been imported, and a few have been produced domestically. The major foreign manufacturers were Trane, York and Carrier. The two major domestic producers are the Shanghai First Refrigeration Machinery Factory (SFRMF) and the Chongqing General Machine Corp. Ltd. (CGMC). SFRMF discontinued manufacturing refrigeration chillers as part of the implementation of the Chinese Industrial and Commercial Refrigeration ODS Phase-Out Sector Plan, funded by the Multilateral Fund of the Montreal Protocol. Chongqing CGMC has continued the manufacturing of the centrifugal type non-CFC chillers.

8.3.1 Refrigerant Used

Prior to 1996 the refrigerant used in both domestic produced and imported centrifugal chillers was either CFC-11 or CFC-12. Chongqing stopped the production of CFC chillers around the year 2000 and all chillers manufactured by CGRMC are now either using HCFC-22, HCFC-123 or HFC-134a. The import of CFC based chillers stopped in 1997.

8.3.2 Population of Chillers in China

In 2000, a survey was undertaken by a working group under SEPA, consisting of experts from SEPA and the Institute of Air-conditioning under the China Academy of Building Research. The survey showed that there were around a total of 2,400 centrifugal chillers produced domestically and imported during the period 1988 to 1997, with an estimated amount of CFCs contained in the chillers of about 1,500 metric tonnes.

A follow up study was conducted in 2001. In this study, the total number of CFC-11 chillers was estimated to be nearly 3710, of which 1909 had been imported and the remaining had been domestically produced. The number of CFC-12 based chillers identified in the same study was 338, of which 231 had been imported.

8.3.3 Leakage Rate

Imported chillers are generally serviced by the suppliers through servicing contracts. Based on the information provided from the companies Trane, York and Carrier, the leakage rate has gone from 15% for chillers installed in the 1980s, to 10% for chillers installed in the beginning of the 1990s and less than 5% after 1995 (this is also strongly related to the conversion of CFC chiller manufacturing to HCFC and HFC chiller manufacturing). The annual leakage rate for domestically produced chillers in China is normally higher than 15%. Domestic produced chillers are also normally serviced and recharged by the suppliers through service contracts.

Based on the information collected from the suppliers in 2001, it is estimated that the total installed amount (inventory) of CFC-11 in centrifugals is 2,334 tonnes and 141 tonnes for CFC-12 (year 2001). The estimated CFC-11 consumption for servicing is 467 tonnes with 248 tonnes for imported and 219 tonnes for domestically produced chillers. Similarly, the estimated CFC-12 consumption for servicing is 44 tonnes, with 28 tonnes and 16 tonnes, respectively, for imported and domestically produced chillers.

The above implies that the total leakage amounts to 511 tonnes of refrigerant. Compared to the total amount needed for servicing, which is assumed to be in the range 4-6000 tonnes, this amount for chiller servicing would be 9% (consumption 2001-2002).

8.3.4 Comments

China is presently developing a CFC service sector plan in which servicing of chillers are included. The service sector plan will be based on good practice for servicing, using of recycling equipment and recovering CFCs from retired refrigeration equipment and stockpiles to be set up before the CFC production stops in China. There are no replacement programs in place or planned for chillers in China. Chillers is expected to be replaced when they are “retired’ and CFC will be recovered and used for servicing under the sector plan.

9 Other Article 5(1) Country Chiller Data

9.1 Projects

So far, several country phase-out projects have been submitted to the Executive Committee of the Multilateral Fund, and have been approved (these include programs for Thailand and Turkey, see above). In these projects, the refrigeration sector is extensively considered, including the servicing sector. However, where it concerns chiller servicing, amounts are given in many project proposals where it is difficult to derive how they have been determined and/or have been compared with data from the field. In other cases, the number of chillers identified is given, and consumption is derived on the basis of leakage amounts per annum.

9.2 Chiller Numbers

There is one source for chiller inventory numbers /ICF03/, which gives numbers which are stated to be derived from project proposals etc. In this report it is mentioned that there may be 15,000 chillers installed in the Article 5(1) countries; however, this sum is a result of the numbers of chillers identified in 19 Article 5(1) countries and must be an underestimate. It should be stated, however, that the numbers of chillers for certain countries may be correct if they are derived from project proposals rather then from extrapolations using e.g. GDP values. Nevertheless, the estimates in the ICF report /ICF03/ seem to be rather inaccurate and often (too) high.

There is one other source /Clo04/, which can be used for deriving the number of chillers in Article 5(1) countries. It gives the number of chillers for the Article 5(1) countries, on the basis of the fact that the total of 80,000 CFC centrifugal chillers installed in the USA would be two third of the world chiller population, i.e. there would have been installed 40,000 chillers in the rest of the world. A rough determination of the chillers in Japan, Korea, Europe and Australia would yield a number of less than 20,000; this implies that more than 20,000 CFC centrifugal chillers would have been installed in the Article 5(1) countries. This number does not take into account retirement of chillers. A subdivision in this reference /Clo04/ was made using either (a) knowledge from import or BSRIA data /BSRIA/, or (b) a correlation based upon the GDP of the different countries to refer to the number of chillers.

- E.g. the BSRIA report 2002 gives for Brazil 41 units in 1999, 46 units in 2000 and 47 units in 2001, these units all being non-CFC chillers. If one would assume a market growth between 2 and 3 % per year between 1974 and 1999, values in the order of 700-850 can be calculated. This is consistent with the number of 700 chillers given in the Brazil case study;

- E.g. the BSRIA report 2002 gives for India 12 units in 1999, 14 units in 2000 and 14 units in 2001. Even with a constant market (no market growth) for the period 1974-1999, the number of CFC centrifugal chillers calculated for India would be between 200 and 300. This is not consistent with the figure of 1100 centrifugal chillers given in the India case study. Only a significant increase of the market before 1999 would result in much higher numbers, which is unlikely. The question is why the BSRIA figures show an underestimation.

Taking into account the above, the study by Clodic /Clo04/ will not be taken into further consideration.

9.3 Inventories and Leakage

Where it concerns the data on inventories, the values found in project proposals for Article 5(1) countries are generally 250-650 kg for an average chiller, with leakages from 15% up to higher values per year. Overall, it can be mentioned that, per 100 chillers, the annual refrigerant consumption is given as:

- 5-7 tonnes per year, if it is calculated via leakage assumptions (not involving total recharge during servicing, or charging after accidents);
- 5-25 tonnes per year, if data comes from country sources (a) with a given number of chillers, without extensive considerations on leakage or (b) without a precise number, just as an overall estimate.

There are several exceptions as highlighted in specific country proposals below.

The percentage of the servicing needs for chillers in the total needs for servicing refrigeration equipment depends on the type of country (whether there is much servicing in other sub-sectors such as MACs, commercial refrigeration etc.). A number of specific cases are briefly dealt with below.

Once one considers these figures, the question arises, for each of the countries, which of the options (1) replacement or (2) continuing operation –using amounts from recover and recycle- is the most preferable one. This very much depends on the lifetime distribution of chillers in a given country. This question cannot be answered in this chapter.

Argentina

The consumption of CFC chillers is reported at 40 tonnes for the year 2001, with a total servicing amount of 1192 tonnes for the same year. No number of chillers has been given, but the number would be in the range of 260-600 dependent on the assumptions for leakage and maintenance amounts. This represents a 3.1% share in the total in 2001.

In the project proposal, estimated amounts for refrigeration service are given through 2009, at 500 tonnes, which would imply that chillers would consume more than 10% of the service amount if no measures are taken in the chiller sub-sector and no CFC chillers would be replaced.

Colombia

The consumption of CFC chillers is reported at 2.25 tonnes for the year 2002, with a total servicing amount of 852 tonnes for the same year. The chiller consumption is based upon the estimated amount of 60 chillers (40 CFC-11 based, 20 CFC-12 based chillers), with an estimated inventory per chiller of 250 kg. The amount for servicing is assumed at 15% of the charge per year. This amount, and particularly the amount for the inventories (the average capacity being 1100 kW) seems to be quite small. Taking into account the total amount of about 850 tonnes for servicing (where 736 tonnes is used for commercial refrigeration purposes) the percentage used for chillers would be less than 0.3% (even with higher estimates for inventories the percentage will remain very small).

Cote d'Ivoire (see also chapter 7)

A bilateral program (France) was started to replace 50 centrifugal chillers in Cote d'Ivoire. A sector overview was made before the project was started.

The overview identified 35 CFC-11 centrifugal chillers (installed 1969-1989) with a total inventory of 16.4 tonnes and 22 centrifugal CFC-12 chillers (installed 1977-1990) with a total inventory of 13.7 tonnes (total for CFC-11 and -12 being 30.1 tonnes). In the project proposal it is mentioned that the CFC-11 chillers emit 2.5 tonnes per year, the CFC-12 chillers 2.45 tonnes per year (which would be in the order of 15% per year).

The project proposal also mentions a total consumption of 18 tonnes of CFCs per year. This implies that the emission is different from the total refrigerant leakage emissions by more than a factor of 3, i.e., the total consumption per year is 60% of the inventory.

Compared to the total consumption of 214.5 tonnes in the sector, 5 tonnes represent 2.2% of the total and 18 tonnes represent 8.4% of the total servicing needs in the refrigeration sector.

Ecuador

In the survey conducted for this project proposal 200 chillers have been identified, with a service need of 3 tonnes per year (this implies that either the chiller number is far too high, or the servicing needs determined for the chillers are too low). Compared to the total servicing demand of 185 tonnes per year, the demand for chillers would be 1.6% (if one would increase the servicing demand according to the values mentioned above to 12 tonnes per year, the percentage would increase to 6.4%).

Jamaica

The consumption of CFC chillers is reported at 2 tonnes for the year 2000, with a total servicing amount of 67 tonnes for the same year. It would concern 30 CFC chillers, with inventories of 200-600 kg CFC-11/-12 (75% of the chillers are CFC-11 based). In the project proposal the inventory is calculated at 12 tonnes, and the servicing demand is 15% of the inventory per year, being 3% of the total servicing needs.

Malaysia

In Malaysia, 821 chillers were identified (627 CFC-11 based, 194 CFC-12 based, i.e., 76% operated on CFC-11). For servicing 102 tonnes are used, which implies a consumption of 25% of the inventory per year, assuming an inventory of 500 kg per chiller. The figure of 25% is higher than the one applied in other proposals, but may be true, if one would assume extra consumption due to servicing practices and ruptures. Given the servicing amount of 1,552 tonnes per year, this represents 6.6% of the total servicing needs. Taking into account that 1,500 tonnes is assumed to be used for MACs, it implies that 40% of the servicing amount for other than MACs would be needed for chillers (even if the 25% would be reduced to 15% a figure of 29% of the total servicing needs can be determined). The above mentioned percentages make Malaysia a special case; however, the question arises whether servicing amounts for stationary refrigeration have been adequately determined (by the way, /ICF03/ mentions 1,500 chillers for Malaysia with a consumption of 225 tonnes, which is not consistent with the project proposal).

Namibia

In Namibia, 10 CFC chillers were identified, with an estimated consumption of 0.5 tonnes per year. Given the total amount used for servicing, 21.4 tonnes, this would be 2.4% of the total amount used for servicing.

Nigeria

The servicing amount for Nigeria was determined at 1,517 ODP tonnes. No chiller numbers are mentioned in the project proposal. One reference /Clo04/ gives a number of 64 chillers which would imply a consumption in the order of 0.3% of the total needs for chillers. This is a rather low number, so it must be that the estimate for the number of chillers is too low.

Philippines

The consumption for servicing in the Philippines is given at 1,531 ODP tonnes. 60 tonnes is assumed to be used in chillers operated on CFC-11 (where a number of 193 CFC-11 chillers is given). It is mentioned that, of these 60 tonnes, 45 tonnes was used for stockpiling and flushing. It implies that the service needs for chillers would be 3.9% of the total; however, this could be reduced to about 1% of the total if proper maintenance would be applied. Compared to countries such as Malaysia and Thailand, it seems unlikely that there would be only CFC-11 based chillers in the Philippines. Increasing the amount with a similar number of CFC-12 based chillers (not mentioned) would bring the percentage to 2% if proper servicing would be applied. In conclusion, the percentage refrigerant used for chillers in the total amount for servicing in the Philippines could be in the range 1-3%.

/ICF03/ mentions 800 chillers for the Philippines with a consumption of 120 tonnes (which would be 7.8% of the total). However, these figures are not consistent with the project proposal numbers.

Thailand (see also chapter 7)

In Thailand 1,398 chillers were identified (929 less than 15 years old (status 2000), 469 older than 15 years). The annual consumption is given at 145 tonnes per year, which would be 25% of the total charge per year. Of these 145 tonnes, 130 tonnes are CFC-11, and 15 tonnes are CFC-12, which implies that more than 80% of the chillers is CFC-11 based. In the total consumption for refrigeration servicing, i.e. 2,053 tonnes (the servicing needs for MAC being 1,760 tonnes), the amount needed for CFC based chillers would be 7% of the total --if MACs would not be considered the amount used for chillers would be 50% of the servicing amount for stationary refrigeration and AC, which seems very high; this can be considered the same as for Malaysia, and the same questions can be raised--.

Turkey (see also chapter 7)

The figures for Turkey are not very clear, because 2,500 chillers on CFC-11 and CFC-12 were identified in a first instance, of which only 35% was assumed to have a capacity of 700 kW or larger (i.e., centrifugal chillers; this would imply a number of 875 large chillers). In a second and third mission, more investigations were carried out into the number of chillers; the number of chillers eventually identified varied between 125 and 150. The figure given in the project proposal for consumption is 35 tonnes per year compared to a total service consumption of 699 tonnes. This would be 5% of the total needs for servicing.

9.4 Concluding Remarks

If one studies the different project proposals, two different kinds of refrigerant needs seem to be identified:

(a) The needs to replenish the inventory with the amount lost due to leakage. This amount is often calculated, or taken from literature, and is normally in the order of 15% of the inventory. This yields a rather low percentage for the servicing needs of chillers compared to the total needs for refrigeration servicing;

(b) The needs to compensate for all losses. This amount is often determined from field data, from refrigerant suppliers data, or from surveys of chiller servicing companies. The data found vary between 20% and values higher than 35%.

This can be illustrated by the Cote d'Ivoire case. Emissions due to leakage are reported at almost 5 tonnes per year, which would be about 15% of the inventory in all chillers, and this would be 2.3% of the total refrigeration servicing needs. However, the project proposal mentions as total emissions (which can be avoided by implementing the project, where there is a small uncertainty regarding the amount of chillers considered) 18 tonnes, which is about 60% of the inventory (an exceptionally high figure) and 8.3% of the total needs for refrigeration servicing.

In summary in case (a) the amount remains under 3% of the total needs for servicing, in the second case it varies between 4 and 9%. It seems justifiable to assume that ***5-10%*** of the total consumption for the refrigeration servicing needs of an Article 5(1) country is needed for chiller servicing. This will depend on the infrastructure of the country, the climate, the infrastructure (different sub-sector sizes) for refrigeration servicing, the practices applied by servicing personnel etc. It should be emphasised that these figures are valid for the years 2001-2002, and it is likely that percentages will change substantially if servicing of other sub-sectors will be addressed, whilst chiller programs remain on the shelf. On the other hand, a change in servicing practices and transition to non-CFC chillers (replacements) may reduce the percentage of servicing needs devoted to chillers.

In these concluding remarks, it seems useful to present the table with countries as given by ICF /ICF03/ and to also mention in this table the figures identified in this study.

In some cases --if the data in the ICF study /ICF03/ seemed very high-- estimates for the number of chillers in a country were made on the basis of the consumption of CFC-11 reported to UNEP for the years 2000-2001. Consumption levels of CFC-11 were compared with the consumption of CFC-11 of those countries (in the same region, assuming similar practices) of which the number of chillers had been reported in project proposals.

In table 9-1, data are given for a number of countries, and compared to the ICF study /ICF03/. Data have been derived from a number of project proposals, and from more elaborate case studies for Brazil, India and PR China. There are considerable differences in the estimates for the number of chillers in a large amount of countries, likely due to the moment in time that the ICF data were collected.

Table 9-1: Comparison of Data Obtained in the Present Study and from /ICF03/

Country	Number of chillers	Refrigera nt inventory (tonnes)	Annual service % of inventory inferred	Chiller service refrigerant use (tonnes)	Total service refrigerant needs In country	CFC use in chiller service as % of total service
Argentina	**200-600**			**40**	**1192**	**3.4%**
	300	*120*	*50%*	*60*		
Botswana	No Proj.	Data				
	80	*80*	*12%*	*32*		
Brazil	**700**	**290**	**30%**	**88**	**1760**	**5.0%**
Chile	**90**					
	170	*68*	*36.8%*	*25*		
China	**4048**	**2475**	**20.6%**	**511**	**4-6000**	**9%**
	1750	*1225*	*37.5%*	*460*		
Colombia	**60**	**15**	**15**	**2.25**	**852**	**0.26%**
	450	*180*	*37.8%*	*68*		
Cote Ivoire	**57**	**30.5**	**8.2%**	**18**	**218.5**	**8.5%**
Croatia	No Proj.	Data				
	54	*14*	*21.43%*	*3*		
Ecuador	**200**			**3**	**185**	**1.6%**
Egypt	**70**					
	670	*268*	*37.3%*	*100*		
Fiji	No Proj.	Data				
	5	*2*	*150%*	*3*		
Guatemala	No Proj.	Data				
	100	*40*	*37.5%*	*15*		
India	**1100**	**460**	**24%**	**110**	**1582**	**7%**
	1100	*596*	*28.69%*	*171*		
Indonesia	No Proj.	Data				
	1300	*520*	*28.7%*	*195*		
Jamaica	**30**	**12**	**17**	**2**	**67**	**3.0%**
Malaysia	**821**	**410**	**25%**	**105**	**1552**	**6.8%**
	1500	*600*	*37.5%*	*225*		
Mexico	No Proj.	Data				
	1500	*600*	*37.5%*	*225*		
Namibia	**10**			**0.5**	**21.4**	**2.4%**

Country	Number of chillers	Refrigerant inventory (tonnes)	Annual service % of inventory inferred	Chiller service refrigerant use (tonnes)	Total service refrigerant needs In country	CFC use in chiller service as % of total service
Philippines	**193**			**60**	**1531**	**3.9%**
	800	*320*	*37.5%*	*120*		
S Africa	Not considered_in_this_study					
	250	*38*	*36.8%*	*14*		
Syria	No Proj.	Data				
	32	*13*	*100.0%*	*13*		
Thailand	**1398**		**25%**	**145**	**2053**	**7.1%**
	1500	*600*	*37.5%*	*225*		
Turkey	**150**			**35**	**699**	**5%**
	2500	*500*	*37.6%*	*188*		
Venezuela	**200-400**					
	500	*200*	*50.0%*	*100*		
Total				**1,120**	**16,713**	**6.77**
This study	**12,948**	(Countries investigated plus /ICF03/ data for other countries)				
/ICF03/	**14,561**					

Note: Countries considered are the countries given by /ICF03/ plus a number of additional countries investigated in this study
Note: This table does not include estimates for the chillers in the Republic of Korea, Saudi Arabia, Singapore, South Africa, UAE, etc.
Note: Data for countries considered in this study are in bold, data given by /ICF03/ are not bold and italic

The weighted average of the servicing needs for chillers in the total servicing needs of the countries has been taken from the totals determined from the various project proposals and amounts to 6.7%.

The total number of chillers estimated for the Article 5(1) countries (see chapter 3) was in the order of 20,000 (actually, this estimate was based on high figures published earlier /ICF03/). Estimates made in this study bring the number for a certain number of countries (see table 9-1) to 13,000, of which 4,000 chillers are assumed to be operated in China (this still includes 8 estimates taken from /ICF03/, which may be high).

Extrapolation of this figure to virtually all Article 5(1) countries would result in the conclusion that the number of chillers operated in Article 5(1) countries would be in the order of 15,000 (this excludes countries such as the Republic of Korea, Saudi Arabia, UAE, etc).

10 Conclusions

This report considers the servicing needs for CFC centrifugal chillers in the Article 5(1) countries. As is the case in many developed countries, there are still a significant number of CFC chillers operating in the Article 5(1) countries.

The report has been prepared on the basis of very limited data available on the chiller sector in Article 5(1) countries. In many cases, the information is incomplete and some of the data presented in the document could not be verified in the field. To address the reliability of the data, sound assumptions were made based on the experience of field experts and the situation prevailing in non-Article 5(1) countries.

The report describes the different types of chillers and notes that the transition of the average CFC centrifugal chiller will be either to screw or dual scroll compressor driven chillers or to new centrifugal chillers operated on HCFC-123 or HFC-134a. This would imply a significant reduction in direct emissions in ODP tonnes, but also a significant energy efficiency increase (i.e. a decrease of indirect global warming emissions).

Where it concerns the number of chillers in operation in Article 5(1) countries, certain studies have produced figures in the range of 15-20,000 and even higher. Material investigated for this report leads to the conclusion that the number of centrifugal chillers still in operation in Article 5(1) countries is about 15,000. Of these chillers, and actually in most countries, 90% is CFC-11 and 10% is CFC-12 based. If the majority were imported from European countries the percentage of CFC-11 centrifugal chillers would vary between 50 and 80% (which would be between 7,500 and 12,000 units).

For an individual chiller, the transition out of CFC can be accomplished in two ways, (a) via retrofits, and (b) via replacements. Retrofits have been considered in the developed countries when chillers were relatively new, retrofits are not very useful anymore when the lifetime of the chiller has exceeded 10 years, which is demonstrated by the number of retrofits in the United States in the period 1993-2003. Centrifugal chillers in the Article 5(1) countries are generally older than 10 years, and can be as old as 35 years; in this case the replacement of the centrifugal chiller (by either a centrifugal chiller or by combinations of screw chillers) is the only useful option.

In considering options for the transition out of CFC chillers at the national level, a primary objective may be to reduce current CFC-11 consumption for servicing through training and better servicing practices. Gradual replacement of the oldest/least efficient chillers first together with recovery of the refrigerant can make CFC available to prolong the service life of newer CFC-based chillers. This would assist in minimising premature retirement of chillers in a pattern similar to that adopted in non-Article 5(1) countries. It should also be considered that a larger number of CFC based chillers might now be between 20 and 30 years old and will be replaced by the owners over the coming years.

Hence a good recovery program might allow recovering of CFC for servicing of remaining chillers and the phase-out of the total inventory of CFC based chillers in Article 5(1) countries might take place over a longer period. Recovery programmes will need to focus on training and logistics since much of the equipment needed to recover CFC-11 will already be in use by the enterprises and personnel that currently service the chillers.

There are a number of impediments and incentives to the replacement of centrifugal chillers in the Article 5(1) countries. Major ones are the availability of investment capital at a (very) moderate interest rate, and the uncertainty of economic conditions throughout the payback period for the new chiller (electricity prices, government policies, the operating conditions of the entire cooling system, including pipes, pumps, cooling towers and others).

Chiller replacement programs have been approved or started in four countries, i.e. Cote d'Ivoire, Thailand, Mexico and Turkey, using grants and revolving funds and different combinations of these. Programs have addressed a certain number of chillers that were identified as primary candidates, where in Cote d'Ivoire virtually all chillers installed were addressed. It should, however, be realised that a large number of the remaining CFC based chillers in the last three countries might not meet the stringent criteria set in the program and might not provide the same high energy savings. It should also be realised that replacing all CFC chillers in the last three countries would require significant more capital and the centrifugal chillers will eventually have to be replaced at the owners' initiative, in particular where these have reached their end-of-life and are therefore not supported by the Fund.

The average CFC chiller can be characterised by a certain inventory per kilowatt capacity, and by a certain leakage (slightly dependent on whether it is operated on CFC-11 or -12). Furthermore, consumption of the chiller is influenced by servicing practices, whether part of the charge is vented, whether recovery and recycle has been implemented. Whereas the percentages for the losses per year in the developed countries varied between 10 and 25% prior to the adoption of leak minimisation practices, these percentages may go up to 30-50% and even higher in the Article 5(1) countries.

In determining the percentage of the servicing needs for centrifugal chillers in the total refrigeration needs of a country, the above mentioned figures need to be taken into consideration.

When studying project proposals to determine the refrigerant needs for chillers, there are significant uncertainties related to

- whether the real number of chillers installed has been identified and under- or over-estimated, and
- whether consumption has been derived based upon standard figures for inventories and servicing, based upon service market data, or estimated from criteria developed by the agency preparing the project (there is again the potential for under or over estimating).

It seems justifiable to assume that ***5-10%*** of the total consumption for the refrigeration servicing needs of an Article 5(1) country is needed for chiller servicing. This will depend on the infrastructure of the country, the climate, the infrastructure (different sub-sector sizes) for refrigeration servicing, the practices applied by servicing personnel etc. It should be emphasised that these figures are valid for the years 2001-2002, and it is likely that percentages will change substantially if servicing of sub-sectors will be addressed, whilst chiller programs remain on the shelf. However, a change in servicing practices and transition to non-CFC chillers (replacements) may also have a significant impact.

In the near future, replacement programs may (and will) continue, but these will certainly not be able to replace all CFC centrifugal chillers within a short period. However replacement of all CFC chillers is not a prerequisite to the phase-out of CFC-11 consumption and is unlikely to occur in Article 5(1) countries, which may follow a replacement pattern similar to that which has emerged in non-Article 5(1) countries. Countries will need to plan for reductions in CFC-11 sector consumption in the chiller sub-sector (possibly through already-approved refrigerant management plans or national CFC phase-out plans). This planning will need to include:

- an inventory of the existing CFC chillers;
- the impact in terms of reduced CFC-11 consumption of an improvement in servicing practices, and recovery and re-use of the refrigerant;
- determination of the amount of refrigerant which will become available from the dismantling of older or less efficient chillers to extend the operating life of newer, existing CFC chillers beyond 2010;
- determination of the quantities (if any) of CFC-11 or CFC-12 that may become available from other sources, and consideration of the opportunities for the stockpiling of certain amounts of CFCs;
- on the above basis, formulation of a replacement policy which includes the likely replacement rate, the numbers of remaining CFC chillers that may be kept in operation after 2010, stockpiling and other relevant issues.

The above needs further consideration, once an Article 5(1) country has met the 50% reduction from the base level (2005), and once it has to set out strategies to address the 85% reduction from the base level in 2007. Starting a number of actions following a well-outlined program may be considered as soon as possible. Given the technical aspects of the planning that needs to be carried out and the relatively organised nature of chiller maintenance, even in Article 5(1) countries, the relevant servicing industries or industry associations will need to take a leading role in these activities.

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