MINES ParisTech ARMINES

CENTER FOR ENERGY AND PROCESSES - CEP

Inventory of Direct and Indirect GHG Emissions from Stationary Air Conditioning and Refrigeration Sources, with Special Emphasis on Retail Food Refrigeration and Unitary Air Conditioning

CARB Agreement No. 06-325

ARMINES Reference 70796

Provisional Final Report

ANNEX

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June 2008

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ANNEX 1 – List of visited stores

Store Category	Major Brands		Numer of stores visited
Large Supermarket	Costcowhole sale		2
	Target		2
	Walmart		7
	Walmart Supercenter		4
		Total	**15**
Grocery Store	Albertson		6
	Stater Bros		3
	Bristol Farms		3
	Food 4 less		3
	Raleys		3
	Ralphs		3
	Safeway		3
	Vons		4
	Wholefoods		5
	SuperAfood		3
	SuperSuperWarehouse		2
		Total	**38**
Minimarket	Smart &Final		3
		Total	3
Convenience store	7/11		5
	AM-PM		3
	Local Convenience stores		4
		Total	**12**
Liquor Store	local liquor stores(B&B Jr Market, Village liquor store, Picomarket, Sam's Liquor,…)		
		Total	**5**
Pharmacy	CVS		3
	RiteAid		3
	Walgreen		4
		Total	**10**
Gas Station	Small Gas Station (76, Chevron, Mobile, Exxon, Arco)		14
	Large Gas Station (Mobile,Walmart Center)		4
		Total	**18**
Hotel	Best Western, Hilton, Marriott, Holiday Inn		
		Total	**8**
Motel	America's Best Value Inn, Super 8 Motel, Comfort Inn		
		Total	**5**
Bakery		**Total**	**1**
Butchery		**Total**	**4**
Fishmonger		**Total**	**2**
Bar &Restaurants	Bar, Restaurants,FastFood, Cinema, Bowling		**1**
Number of stores visited			**122**

ANNEX 2

Inventories of the worldwide fleets of refrigerating and air-conditioning equipment in order to determine refrigerant emissions. The 1990 to 2003 updating. ADEME/ARMINES Agreement 04 74 C0067–
Excerpts from the Final Report of December 2005 – Version 3, July 2006

Section 1 and Annexes 1 and 2 to Section 1

CONTENTS

Method of calculation, data and databases

1.1 Calculation method for emission prevision of refrigerants

The Tier 2 method, as defined in the IPCC guidelines [IPCC96, IPCC 06] proposes a calculation for HFC refrigerant emissions from equipment:

- during the manufacturing process,
- during the lifetime, and
- at the end of life of equipment.

This approach of looking at refrigerating equipment from cradle to grave (see Figure 1.1) covers all possible emissions but needs to be further worked out in order to give consistent results.

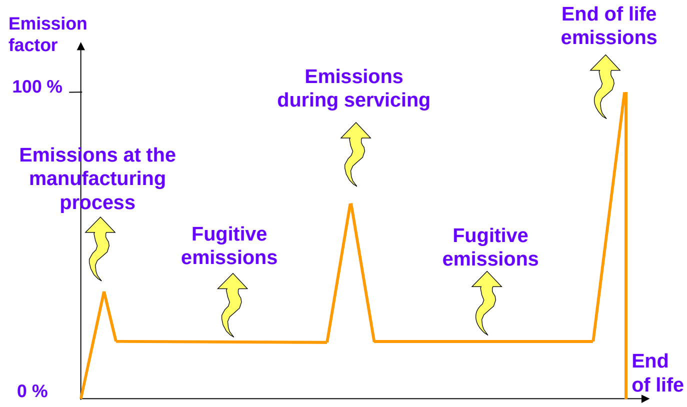

Figure 1.1 – Types of emissions from cradle to grave from refrigerating equipment.

The equations are coming from the draft version of the 2006 IPCC Guidelines (second draft, August 2006) and have taken into account the work done by the CEP during the last eight years. They are presented in Annex 1. The equations used are the same as the ones in the previous study [INV06], the main improvement being the introduction of retrofit, meaning that the lifetime of equipment is differentiate from the lifetime of the type of refrigerant charged in the equipment.

The same method is being used for the refrigerant inventories and emission forecasts for the French Government [BAR05, PAL04a, PAL04b, and PAL03] delivered to the CITEPA, which is the technical body in charge of French inventories of greenhouse gases to be delivered to UNFCCC.

♦ Emissions at the manufacturing process

When equipment is mass-produced, the direct emissions are usually very small. For field-assembled systems, the emissions during the installation phase are higher but not substantial. The main source of emissions related to charging and topping up of refrigerating equipment are mainly **the emissions due to refrigerant handling.**

One will find refrigerant handling in more than just the manufacturing process of the equipment. There needs to be included:

- splitting the bulk refrigerant in large containers into smaller volumes of refrigerant,
- losses related to connecting the smaller refrigerant volumes to the equipment, and
- **capacity "heels".**

The capacity "heels" represent the main loss during refrigerant handling. The “heels’ consist in fact by of the vapor inside the container, which cannot be extracted due to the pressure equilibrium between the vapor (the vapor heel) and the liquid phase remaining in the refrigerant volume (the liquid heel). Based on the recovery policy and the experience of the main refrigerant distributor in France, it can be derived that those “heels” represent between **2 and 10 % of the total amount of refrigerant sales.** This includes the charge of new equipment and the recharge of all the existing fleets of refrigerating equipment.

Note: the English word **fleet** covers the total number of equipment, e.g., for mobile air conditioning in cars, for refrigerating trucks, for reefers and refrigerating containers. It seems to be much more difficult to use the word fleet for domestic refrigerators, for refrigerating equipment in industrial processes and for stationary air conditioning systems. It is therefore proposed to use the French word "parc", which is easily understood in English and the following definition then applies: **"parc" is the total number of pieces of equipment in a category or sub-domain independent of their vintage.**

One of the improvements applied to the 1996 Tier 2 method of the IPCC Guidelines is the inclusion of the emissions from the container heels in the total sales of refrigerant.
Note: this improvement has been included in the 2006 IPCC Guidelines.

- **Emissions during the lifetime of the equipment**

Leaks during the lifetime of equipment depend on the type of application, e.g., domestic refrigerators show very low emission rates during their lifetime. On the contrary, many commercial, centralized refrigeration equipment and refrigerated transport systems are highly emissive. **Emission previsions need to be based on feedback via field data,** and field data from each country will substantially improve a number of global assumptions made in this study. In large commercial facilities or in industrial processes, the most precise approach for the determination of emissions is the collection of receipts and/or invoices for refrigerant delivered for system maintenance and for recharges.

In order to yield accurate results, the mobile air conditioning systems require very sophisticated methods. It is very common to form groups of vehicles of different vintages where the remaining refrigerant is carefully recovered from the system and subsequently measured by accurate weighing. By determining the difference between the initial refrigerant charge and the recovered charge, average levels of refrigerant emissions can be established.

- **Emissions from equipment at end of life**

Emissions from equipment at end of life depend on one hand on the regulatory policies in different countries, on the other hand on the recovery efficiency. For the inventory determination method, it is essential to have correct information regarding the lifetime of equipment, and annual market data for a number of years in the past, equal to the lifetime of the product. This point is crucial for almost every type of application due to:

- The rapid change in the application of refrigerant types, which changes are related to changing Montreal Protocol control schedules, and particularly to more stringent regional or national regulations,
- The rapid market growth of certain types of equipment, e.g. mobile air conditioning systems during recent years in Europe, or the rapid annual growth in China,
- The change in how recycling policies at the end of life of the equipment are regulated.

Taking into account
(1) the large numbers of equipment,
(2) the large variation in equipment type,
(3) the refrigerant charge amounts, and
(4) the different refrigerant types and their GWPs,
a large database has to be constructed, on an application by application basis. For each application, **the "parc" has to be derived for all the years covering the lifetime of this type of equipment**. Moreover, as the determination of inventories is performed on an annual basis, the updating of the database is a necessary factor to take into account.

1.2 Refrigerants and regulations

The use of CFCs, HCFCs or HFCs and other refrigerants is related to control schedules, which have been continuously adjusted since the Montreal Protocol has been ratified. For the developed countries (the non-Article 5(1) countries as defined in the Montreal Protocol), the phase-out of CFCs and HCFCs will be earlier than in the developing countries (the Article 5(1) countries). Moreover, where it concerns non-Article 5(1) countries, the European Union has accepted a much tighter control schedule for phasing out (CFCs in the past and) HCFCs.

The rapid CFC phase out in Europe and also the interdiction of use of CFCs for servicing have led to a significant uptake of intermediate blends (HCFC-based blends) for the retrofit of a number of refrigerating systems using CFCs. The retrofit allows to keep the residual value of equipment until its usual end of life. It is likely that the same behavior of equipment owners will be followed for the progressive phase out of HCFCs, which will be replaced by intermediate blends of HFCs. Based on these facts, RIEP includes retrofit options where the refrigerant can be changed during the equipment lifetime.

♦ **Non-Article 5(1) countries**

The CFC phase-out schedule as valid for the non-Article 5(1) countries is presented in Figure 1.2. Via the EU regulation 3093/94 CFCs were phased out one year before the phase-out defined in the Montreal Protocol, i.e. on 31 December 1994.

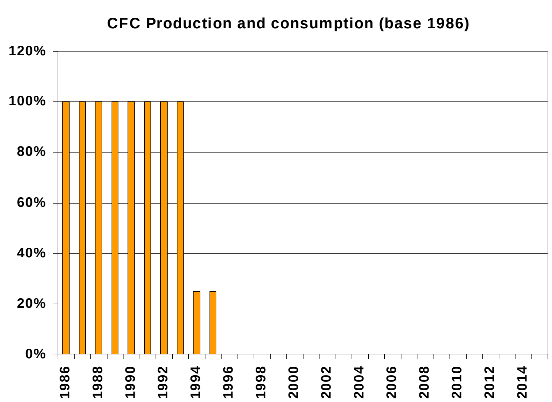

Figure 1.2 – CFCs phase out in non Article 5(1) countries.

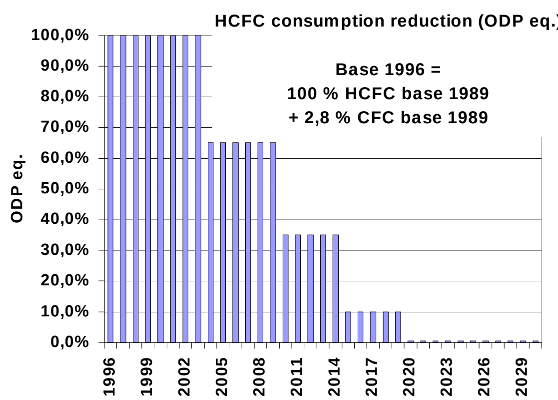

Figure 1.3 – HCFCs phase out in non Article 5(1) countries (except EU).

As indicated in Figure 1.3, the HCFC consumption base levels refer to the 1989 HCFC consumption plus 2.8% 1989 CFC consumption, ODP-weighted. On the basis of a certain ODP for HCFC-22 and CFCs (0.055 and 1.0 respectively), the factor of 2.8% means that if all CFCs would be replaced by HCFC-22, about 55% of the CFC consumption in tonnes would be replaced by HCFC-22.

Figure 1.3 clearly shows that, even for non-Article 5(1) countries, brand-new equipment can be manufactured, charged with HCFC-22 and sold until 31 December 2009. Typically, the U.S. and many developed countries continue to use HCFC-22 for air-conditioning equipment.

As indicated in Figure 1.4, the EU regulation has changed the baseline level for the HCFC consumption by reducing the additional quantities of ODP weighted CFCs by nearly 30% (from 2.8 to 2.0%). Moreover, the time of the HCFC phase-out is been brought forward by about 7 years.

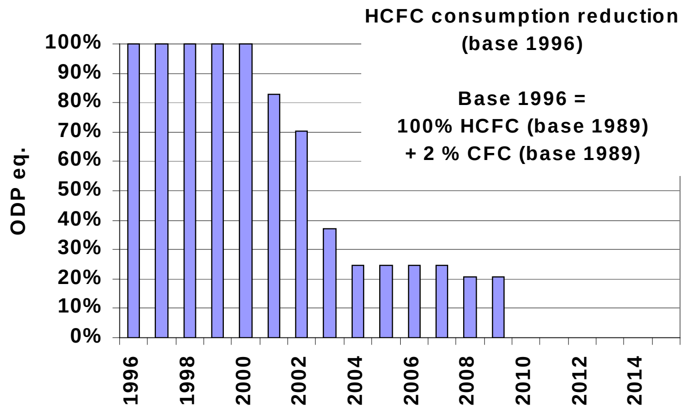

Figure 1.4 - European Union - (European regulation 2037/2000).

- **Article 5(1) Countries**

The CFC consumption and production (see Figure 1.5) for Article 5(1) countries has a delay compared to non-Article 5(1) countries of actually 14 years (1996 compared to 2010). There is an additional possibility of production and consumption of 10% compared to the 1996 level for Basic Domestic Needs of the developing countries where production can take place in the developed countries.

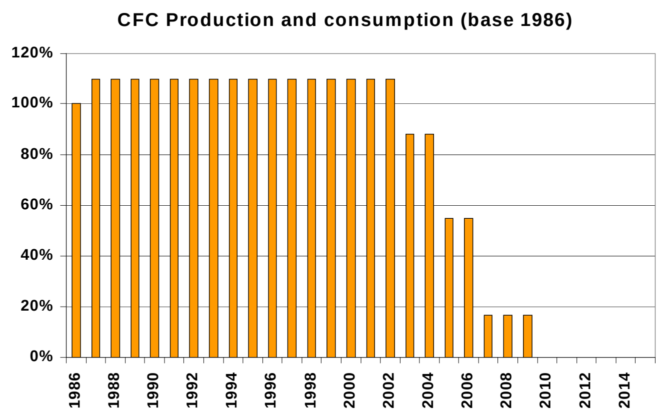

Figure 1.5 - CFC phase-out for Article 5 Countries.

For the HCFC phase-out the Montreal Protocol schedules are a bit more complicated. Where it concerns the freeze in consumption, Article 5(1) countries have a delay of about 15 years (freeze by 2016). Where it concerns the phase-out it actually is a 10-year delay period (phase-out in 2040 versus 2030) for the developing compared to the developed countries.

All these different constraints based upon global control schedules and more stringent regional and national regulations imply different refrigerant choices in countries and country groups. The refrigerant choices need to be taken into account on an application by application basis. In this project additional data have been used that have been derived from country reports as well as data that were available in publications.

1.3 Refrigerant GWPs from the Second and the Third Assessment Report of the IPCC

Table 1.1 lists the main refrigerant types in use: CFCs, HCFCs, HFCs, ammonia, and different blends, many of them being intermediate blends used for retrofit of CFC equipment. Table 1.1 has been updated taking into account all new blends as declared to ASHRAE 34. The most used of those blends are R-401A, R-409A, and R-413A for the replacement of CFC-12, R-402A and B, and R-408A for the replacement of R-502. The use of those blends can be verified at the global level by the declarations of sales by AFEAS of HCFC-124 and HCFC-142b, which are specific components of those intermediate blends. The list is nearly exhaustive, and takes into account more than 99% of all refrigerant types used. **The GWP values as given in the Second Assessment Report of the IPCC (SAR)** are used for the calculations of the equivalent CO_2 emissions of refrigerants.

Table 1.1 – GWP, physical of refrigerants [TOC03, IPCC06].

Refrigerant		**Physical data**				**GWP**		
Number	Chemical formula or blend composition – common name	Molecular mass	NPB (°C)	TC (°C)	Pc (Mpa)	GWP 2nd AR 1996	GWP 3rd AR 2001	% 2nd /3rd
11	CCl3F	137.37	23.7	198.0	4.41	3 800	4 600.0	21
12	CCl2F2	120.91	-29.8	112.0	4.14	8 100	10 600.0	31
22	CHClF2	86.47	-40.8	96.2	4.99	1 500	1 700.0	13
32	CH2F2-methylene fluoride	52.02	-51.7	78.1	5.78	650	550.0	-15
115	CF3CClF2	154.47	-38.9	80.0	3.12	9 300	7 200.0	-23
116	CF3CF3-perfluoroethane	138.01	-78.2	19.9	3.04	9 200	9 200.0	0
123	CHCl2CF3	152.93	27.8	183.8	3.66	90	120.0	33
124	CHClFCF3	136.48	-12.0	122.3	3.62	470	620.0	32
125	CHF2CF3	120.02	-48.1	66.2	3.63	2 800	3 400.0	21
134 a	CH2FCF3	102.03	-26.1	101.1	4.06	1 300	1 300.0	0
143 a	CH3CF3	84.04	-47.2	72.9	3.78	3 800	4 300.0	13
152 a	CH3CHF2	66.05	-24.0	113.3	4.52	140	120.0	-14
245 fa	CHF2CH2CF3	134.05	15.1	154.1	4.43	820	950.0	16
290	CH3CH2CH3 - propane	44.10	-42.1	96.7	4.25	20	20.0	0
401 A	R-22/152a/124(53/13/34)-MP39	94.44	-34.4	105.3	4.61	973	1 127.4	16
401 B	R-22/152a/124(61/11/28)-MP66	92.84	-35.7	103.5	4.68	1 062	1 223.8	15
402A	R-125/290/22(60/2/38)-HP80	101.55	-49.2	76.0	4.23	2 250	2 686.4	19
402B	R-125/290/22(38/2/60)-HP81	94.71	-47.2	83.0	4.53	1 796	2 108.4	17
403A	R-290/22/218(5/75/20)	92	-47.8	87	4.7		3 000	
403B	R-290/22/218(5/56/39)	103.2	-49.2	79.7	4.32		4 300	
404A	R-125/143a/134a(44/52/4)	97.60	-46.6	72.1	3.74	3 260	3 784.0	16
405A	R-22/152a/142b/C318(45/7/5.5/42.5)	111.9	-32.6	106.1	4.29		5 200	
406A	R-22/600a/142b(55/4/41)	89.9	-32.5	116.8	4.96		1 900	
407A	R32/125/134a(20/40/40)	90.1	-45	82.3	4.52		2 000	
407B	R32/125/134a(10/70/20)	102.9	-46.5	75	4.13		2 700	
407C	R-32/125/134a(23/25/52)	86.20	-43.8	87.3	4.63	1 526	1 652.5	8
407D	R-32/125/134a(15/15/70)	91	-39.2	91.4	4.47		1 500	
407E	R-32/125/134a(25/15/60)	83.8	-42.7	88.5	4.7		1 400	
408A	R-125/143a/22(7/46/47)-FX-10	87.01	-45.5	83.3	4.42	2 649	3 015.0	14
409A	R-22/124/142b(60/25/15)-FX-56	97.43	-35.4	106.9	4.69	1 288	1 535.0	19
Refrigerant		**Physical data**				**GWP**		

Number	Chemical formula or blend composition – common name	Molecular mass	NPB (°C)	TC (°C)	Pc (Mpa)	GWP 2nd AR	GWP 3rd AR	%
						1996	2001	2nd /3rd
410A	R-32/125(50/50)-Suva9100;AZ-20	72.58	-51.6	72.5	4.95	1 730	1 975.0	14
411A	R-1270/22/152a(1.5/87.5/11)	82.4	-39.5	99.1	4.95		1 500	
412A	R-22/218/142b(70/5/25)	92.2	-38	107.2	4.9		2 200	
413A	R-218/134a/600a(9/88/3)	104	-30.6	98.5	4.07		1 900	
414A	R-22/124/600a/142b(51/28.5/4/16.5)	96.9	-32.9	112.7	4.68		1 400	
415A	R-22/152a(82/18)	81.9	-37.2	102	4.96		1 400	
416A	R-134a/124/600(59/39.5/1.5)	111.9	-24	107	3.98		1 000	
417A	R-125/134a/600(46.6/50/3.4)	106.7	-39.1	87	4.04		2 200	
418A	R-290/22/152a(1.5/96/2.5)	84.6	-41.6	96.2	4.98		1 600	
419A	R-125/134a/E170-77/19/4)	109.3	-43.8	79.2	4		7 900	
420A	R-134a/142b(80.6/19.4)	101.7	-24.2	107.2	4.11		1 500	
421A	R-125/134a(58/42)	111.7	-35.5	82.4	3.88		2 520	
422A	R-125/134a/600a(85.1/11.5/3.4)	113.5	-43.2	75.4	3.92		3 040	
500	R-12/152a(73.8/26.2)	99.30	-33.6	102.1	4.17	6 014	7 854.2	31
502	R-22/115(48.8/51.2)	111.63	-45.3	80.7	4.02	5 494	4 516.0	-18
503	R-23/13(40.1/59.9)	87.25	-87.5	18.4	4.27	11 700	13 198	13
504	R-32/115(48.2/51.8)	79.25	-57.7	62.1	4.44	5 131	3 994.7	-22
505	R-12/31(78.0/22.0)	103.48	-30.0	117.8	4.73	6 318	8 268.0	31
506	R-31/114(55.1/44.9)	93.69	-12.3	142.2	5.16	4 131	4 400.0	7
507A	R-125/143a(50/50)-AZ-50	98.86	-47.1	70.9	3.79	3 300	3 850.0	17
600a	CH(CH3)2-CH3 - isobutane	58.12	-11.6	134.7	3.64	20	20.0	0
717	NH3 - ammonia	17.03	-33.3	132.3	11.33	< 1	< 1	
744	CO2	44	-78.4	31	7.38		1	

NBP = normal boiling point; Tc = critical temperature; Pc = critical pressure; GWP = global warming potential (for 100 yr integration).

The GWP calculation for blends is based on the GWP values of the pure refrigerants, and their mass concentration in the blend. It has been preferred to not round the GWP numbers for blends so that their origin can still be traced. For propane and isobutane no official GWP values have been presented in the IPCC Third Assessment Report, and the rounded value of methane (23) has been taken for all HCs.

1.4 Consistency and improvement of data quality

Using the Tier 2 method, the consistency in the emission forecast cannot be directly verified. **The first essential cross check can be done via deriving the annual market of the different refrigerant types** based on the initial charge of brand-new equipment (on an application by application basis) and on the recharge at servicing of the different "parcs" of equipment. By merging those two data series, it should be possible to derive the size of the market for every refrigerant type **and to compare those data to the official data submitted by manufacturers and distributors.**

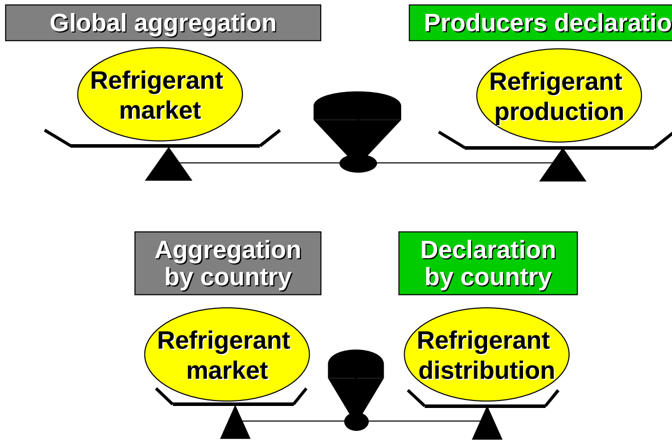

Figure 1.6 – Cross check of the annual refrigerant market derived from the initial charges and the recharges with the declarations made by refrigerant producers.

The cross-checks can be performed both on a country by country basis and globally (see Figure 1.6).

If the refrigerant inventories and the related emissions are adequately determined, the difference between the figures submitted and the calculated refrigerant sales will be small. If not, additional analyses are required.

- **Consistency for refrigerating equipment at the global level**

To reach a high accuracy in the sizes of the refrigerant inventories, the first step required is to gather reliable data for the equipment numbers. Fortunately, annual statistical data are available for nearly all mass-produced equipment. Some data have been published by manufacturer associations, and some (marketing studies) can be purchased from specialized companies. The data on annual equipment sales allow deriving figures on production and sale at the national level for nearly all the OECD countries, and also at the global level, when they are based on production data (see Figure 1.7).

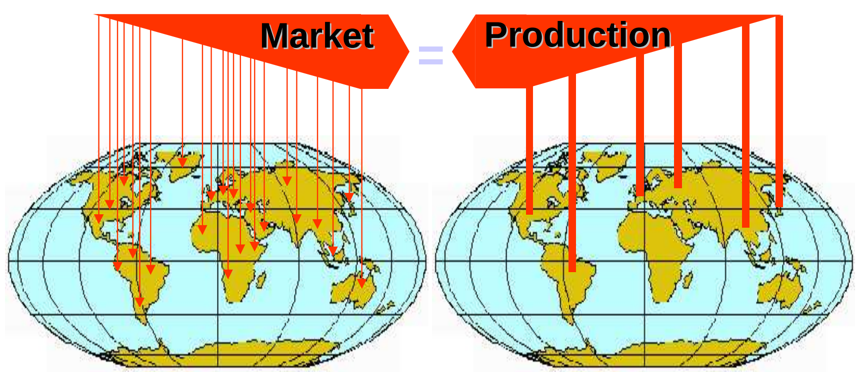

Figure 1.7 – Cross check between markets and production quantities.

At the global level, for a given year one can postulate "Production = Sales" (except for the small amount of equipment produced but not yet sold). For domestic refrigerators, stationary air conditioning systems, chillers, cars, trucks, buses, reefers… annual numbers of production and sales are available. Application of these numbers avoids double counting, which would happen easily when national inventories are merged, particularly if methods of determination are different.

- **Inventories of all refrigerant types and the method of aggregation**

The schedule for phasing out CFCs and HCFCs depends for the larger part on country regulations (see section 1.2). Even if only HFC inventory reporting is required under the UN Framework Convention on Climate Change (UNFCCC), it is required to have information on the emission predictions and on the changes in refrigerant use. Only in this way the size of the "banks" of all types of refrigerants charged in the different types of equipment can be determined. The --changing-- trends in the selection of the refrigerant need to include the quantities of hydrocarbons (HCs) and ammonia, which are both being used as HFC replacement options in the European Union.

As shown in Figure 1.8 the bottom-up approach used defines:

- the annual sales of brand-new equipment and the amount of refrigerants charged in this equipment,
- the determination (dependent on their lifetime) of all the fleets or parcs, which yields a cumulative value for the refrigerant bank for the specific application,
- the determination of the refrigerant market for servicing (dependent on the leak factor), and thereafter all the different domains are aggregated
- refrigerant by refrigerant,
- country by country,

by country groups and globally.

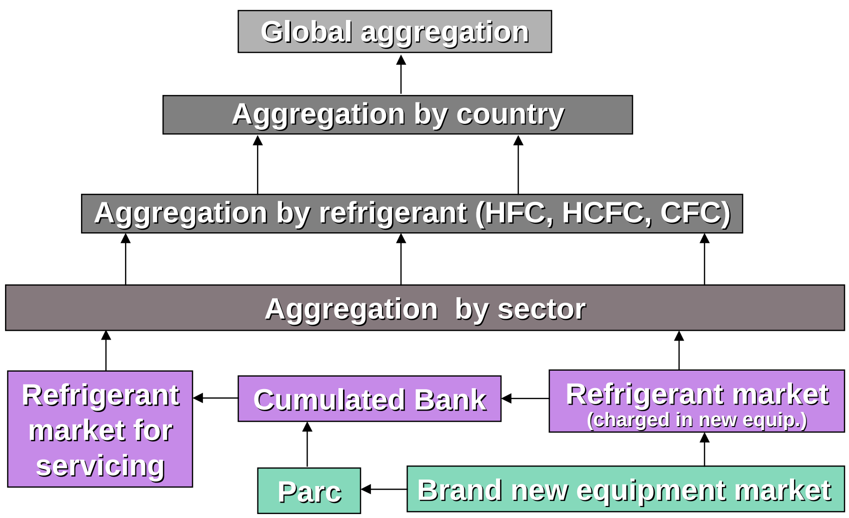

Figure 1.8 – Determination of the refrigerant markets.

This method of cross-check has been adopted in the quality assurance process of the updated version of the IPCC Guidelines 2006.

1.5 Tools for refrigerant inventories and emission previsions

To determine the annual emission forecasts for all categories of refrigerating equipment, it is necessary to create the tools that allow cumulative improvements in the data quality. The large number of data to be handled necessitates:

- to program in a database language
- to perform calculations based on reality data
- to create user friendly interfaces
- to transfer the results to tables written in spreadsheet language, which tables are based on the prescribed Common Reporting Format (CRF) of the IPCC for HFCs.

For the first year, such a database needs to “create” the "parcs" of all the different categories and sub-categories of refrigerating equipment. For the years thereafter the updating process requires less efforts and basically consists of the following input data:

- the annual equipment market for each category in the reference year
- the type of refrigerant used in brand-new equipment, and possibly also information on conversion from CFCs or HCFCs to HFCs or other refrigerants
- the emission factors.

All those elements allow to perform:

- calculations of emissions from all existing parcs of equipment,
- calculations of emissions from all types of decommissioned equipment
- a calculation of the amount of refrigerants which are recovered or reclaimed
- a calculation of the refrigerant banks per category of equipment
- a calculation of the annual refrigerant market sales, per refrigerant type.

As soon as better data become available, the database can be updated in a transparent manner. National, regional or global data reviews are necessary in order to control the quality of the inventory determinations.

A database enables the development of data acquisition in a single way: **improvement**, because it creates storage of data on the refrigerants in use inside the parcs of equipment that have been calculated.

1.5.1 Refrigeration equipment and refrigerant bank database

RIEP is connected to another database, CDB (Country Data Base), which has been developed as the source for economic, demographic, and technical data for both countries and country groups (see Annex 1).

RIEP is written in the ACCESS language, and deals with the separate countries, for any given year. Based on inputs from the user interface, RIEP can calculate the emissions during the equipment lifetime (see Figure 1.9). For these calculations, data have to be used for each year of the lifetime of a given equipment type or category.

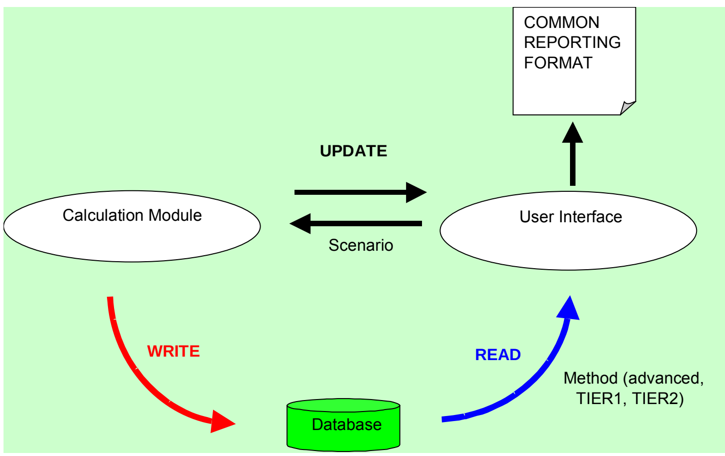

Figure 1.9 – Scheme of the application of the RIEP program.

1.5.2 Country Data Base

As indicated in Figure 1.10, if one selects a certain year and either the national or the regional level, the CDB can produce data on:

- demography,
- energy production and consumption,
- agriculture, and
- economy, including commerce.

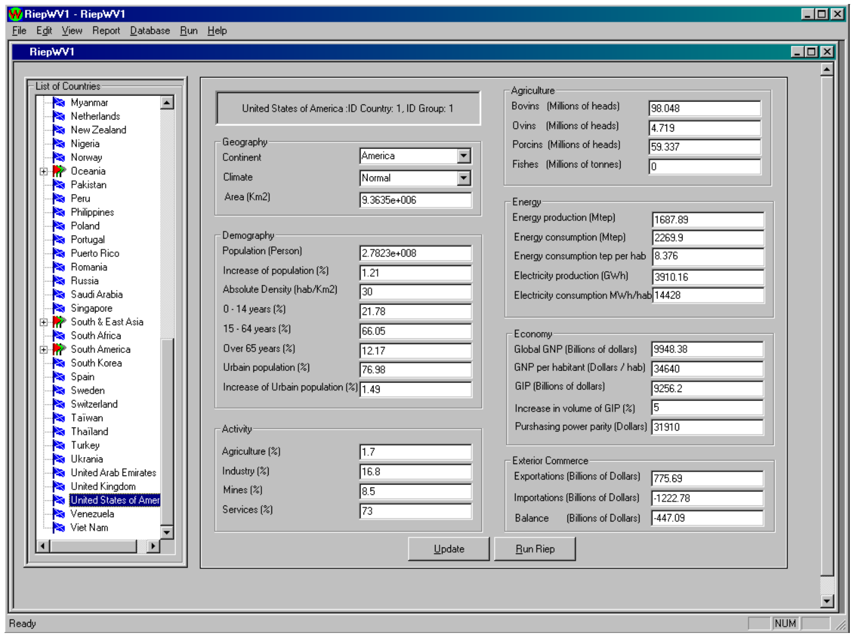

Figure 1.10 – Example of a screen of the United States of America CDB.

The Country Data Base (CDB), which has been constructed for the determination of global inventories covers 62 countries and 8 regions, which each contains a portion of the remaining 110 countries (see annex 1).

For countries where only few specific equipment data is available, some of the general data mentioned above can be used to create ratios between refrigerating equipment, national economy and population. From the CDB, it is possible to run the RIEP program. The CDB is also written in Access and interfaces are handled in the C^{++} language.

India and Brazil are analyzed per se because of their economic growth. Moreover taking into account the integration of the 10 new European countries, Europe is followed as Europe 25. Russia is also followed per se, Oceania has been merged with other Asia and Australia is followed per se. The database has been used for the Supplementary Report [UNE05] and specific groupings have been done for non Article 5(1) countries and Article 5(1) countries.

1.6 Review process

The results of the previous report [INV03] have been thoroughly used in the IPCC TEAP report [IPC05] and in the Supplement to the IPCC/TEAP report [UNE05]. Data have been analyzed by a number of experts, among them L. Kuijpers, A. MacCulloch, M. Mc Farland, S. Solomon, F. Keller, N. Campbell, and many others. Their comments have been fruitful and the main changes or improvements have been as follows:

- The sharing between CFC-11 and CFC-12 for chillers in many countries was not well set in the previous version with a too high share of CFC-12; in fact the "US model" where CFC-11 was predominant had a strong influence in all Asian countries.
- R-502, which was significantly used in commercial refrigeration in Europe was much less used in the U.S. So HCFC-22 was underestimated in the U.S. inventory, and R-502 overestimated. Corrections have been done and as it is seen in Section 2 the correction has been effective due to the quite good match between AFEAS data on CFC-115 (CFC only used in R-502) and RIEP calculations.
- The phase in of HFCs in stationary air conditioning in the U.S. has been overestimated whereas HCFC-22 was nearly the only refrigerant in use until the end of 2005.

Independently of those modifications, the main other modifications based on new data are:

- the integration of retrofit blends for the replacement of CFCs,
- a new method of calculation for the number of refrigerate trucks based on the evolution of food products followed by the FAO database,
- modification of the emission model for mobile air conditioning systems, which is no longer taking into account a percentage, but the value expressed in g/yr because it has been demonstrated that emissions are not directly related to the refrigerant charge.

One of the best review process if that the document is used by international experts and that the emissions as presented are compared to atmospheric concentration. This work has begun with the two papers published in the International Journal of Refrigeration with P. Ashford, A. Mc Culloch and L. Kuijpers [ASH04a, ASH04b, ASH04c]. Other review papers are under preparation in order to develop the correlation between atmospheric concentration and emissions of refrigerants.

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[UNE05] UNEP, 2005: Supplement to the IPCC/TEAP Report, November 2005.

[UNE03] 2002 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Option Committee (RTOC). 2002 Assessment. March 2003. ISBN 92-807-2288-3.

Equations used for the Calculation Method

The calculation method complements the Tier 2 method as recommended by the IPCC, by cross checking:

- the sum of refrigerant quantities charged in brand-new equipment and those recharged for servicing purposes in all the different refrigerating systems, with
- the annual national market sales of refrigerants as declared by the refrigerant manufacturers and distributors.

The method includes the following calculations:

- the refrigerant « bank » at year ***t*** charged into the parc of systems of each of the six system categories (taking into account the refrigerant changes as a result of regulations which could apply),
- the emissions of each system category, based on the understanding where the emissions occur (at system charge, during operation, during servicing and at the system's disposal).

The six categories of systems have been selected following the division used by the UNEP[1] Refrigeration Technical Options Committee [UNEP03]. The refrigerating chain includes:

- domestic refrigeration
- commercial refrigeration
- refrigerated transports
- refrigerated warehouses, food storage and industrial processes.

Air conditioning includes two sub-groups:

- air to air systems and water chillers
- mobile air conditioning.

All these categories must again be split in sub-groups.

Calculation method (Tier 2a) (extract from the draft of the IPCC Guideline 2006 Draft)

Note: here only HFCs are addressed. In RIEP all types of refrigerants are taken in account.

Refrigerant emissions at a year **t** from the six categories of refrigeration and air conditioning systems, result from:

1. emissions related to the management of refrigerant containers: $E_{containers,t}$
2. emissions related to the refrigerant charge :connection and disconnection of the refrigerant container and the equipment to be charged: $E_{charge,t}$
3. emissions from the six banks during operation (fugitive emissions and ruptures): $E_{operation,t}$
4. emissions during servicing: $E_{servicing,t}$
5. emissions at system disposal: $E_{disposal,t}$

All these quantities are expressed in kilograms and have to be calculated for each type of HFC used in the six different application categories.

$$E_{total,\,t} = E_{containers,t} + E_{charge,\,t} + E_{operation,\,t} + E_{servicing,\,t} + E_{disposal,\,t} \qquad \text{Equation 1}$$

[1] United Nations Environment Programme

Methods for estimating average emission rates for the above-mentioned domains need to be calculated on a refrigerant by refrigerant basis for all equipment whatever their vintage.

1.1.1.1 Refrigerant management of containers

The emission related to the refrigerant container management comprises all the emissions related to the refrigerant transfers from bulk containers (typically 40 tonnes) down to small capacities where the mass varies from 0.5 kg (disposable cans) to 1 tonne (containers) and also from the remaining quantities --the so-called refrigerant "heels" (vapour and /or liquid)-- left in the various containers, which are recovered or emitted.

$E_{containers,t} = RM_t \bullet (c)$ Equation 2

where:

$E_{containers,t}$	=	emissions from all HFC containers in year t expressed in kilograms
RM_t	=	the HFC market for new equipment and servicing of all refrigeration application in year t expressed in kilograms
c	=	Emission factor of HFC container management of the current refrigerant market expressed in percentage

The emissions related to the complete refrigerant management of containers are estimated between 2 and 10 % of the refrigerant market.

Refrigerant charge emissions of new equipment

The emissions of refrigerant due to the charging process of new equipment are related to the process of connecting and disconnecting the refrigerant container to and from the equipment.

$E_{charge,t} = M_t \bullet (k)$ Equation 3

where:

$E_{charge,t}$	=	emissions during system manufacture/assembly in year t expressed in kilograms
M_t	=	The amount of HFC charged into new equipment in year t (per application category) expressed in kilograms
k	=	assembly losses of the HFC charged in new equipment (per application) expressed in percentage

Note: the emissions related to the process of connecting and disconnecting during servicing are covered in Equation 5 for servicing.

The amount charged (M_t) should include all systems which are charged in the country, including those which are produced for export. Systems that are imported pre-charged should not be considered.

Typical range for the emission factor k varies from 0.1 % to 2 %. The emissions during the charging process are very different for factory assembled systems and for field-erected systems where emissions can be up to 2 %.

Emissions during operation

Annual leakage from the refrigerant banks represent fugitive emissions, i.e. small leaks from fittings, joints, shaft seals, … but also ruptures of pipes or heat exchangers leading to partial or full release of refrigerant to the atmosphere. The following calculation formula applies:

$E_{operation,\ t} = B_t \bullet (x/100)$ Equation 4

where:

$E_{operation,\ t}$	=	amount of HFC emitted during system operation in year t expressed in kilograms
B_t	=	amount of HFC banked in existing systems (per application) in year t expressed in kilograms
x	=	annual leakage rate of HFC of each application bank during operation expressed in percentage

In calculating the refrigerant "bank" (B_t) all systems in operation in the country (produced domestically and imported) have to be considered on an application by application basis.

Emissions during servicing

Equation 5 takes into account the discontinuous process of servicing. Besides component failures, such as compressor burn-out, equipment is serviced mainly when the refrigerating capacity is too low due to loss of refrigerant from fugitive emissions. Depending on the application, servicing will be done every year or every three years, or sometimes not at all during the entire lifetime such as in domestic refrigeration applications. For some applications, leaks have to be fixed during servicing and refrigerant recovery may be necessary, so the recovery efficiency has to be taken into account when the refrigerant is recovered.

$$E_{servicing,\ t} = \sum_{a=1}^{\frac{d}{z}} M_{t-az} \bullet s \bullet (1-\eta_{rec})$$ Equation 5

where:

$E_{servicing,t}$	=	amount of HFC emitted during system servicing in year t expressed in kilograms
D	=	average equipment lifetime expressed in years
S	=	residual charge of HFC in equipment requiring recharge expressed in percentage
M_{t-az}	=	the amount of HFC charged into the equipment either at manufacturing or after each servicing per application domain expressed in kilograms
a	=	number of recharges during the equipment lifetime d expressed in round numbers (lies in the interval [0-d/z])
Z	=	$\dfrac{1-\frac{s}{100}}{\frac{x}{100}}$; number of years elapsed before equipment recharge expressed in round numbers
η_{rec}	=	recovery efficiency, which is the ratio of recovered HFC referred to the HFC contained into the system

The importance of Equation 5 lies in deriving the annual refrigerant quantities needed for servicing. Knowing the annual refrigerant needs for servicing per application allows the determination of the national refrigerant market by adding the refrigerant quantities charged in new equipment.

When technical data are not available, Equation 5 could be simplified drastically and replaced by Equation 6.

$E_{servicing,\ t} = B_t \bullet (j/100)$ Equation 6

where:

$E_{servicing,t}$	=	amount of HFC emitted during system servicing in year t expressed in kilograms
B_t	=	amount of HFC banked in existing systems (per application) in year t expressed in kilograms
J	=	annual leakage rate of HFC of each application bank during servicing expressed in percentage

Emissions at disposal

The amount of refrigerant released from scrapped systems depends on the amount of refrigerant left at the time of disposal, and the portion recovered. From a technical point of view, the major part of the remaining fluid can be recovered, but recovery at end of life depends on regulations, financial incentives, and environmental concerns.

To estimate emissions at system disposal, the following calculation formula is applicable:

$$E_{disposal,\ t} = M_{(t-d)} \bullet s_d \bullet (1-\eta_{rec}) \qquad \text{Equation 7}$$

where:

$E_{disposal,t}$	=	amount of HFC emitted at system disposal in year t expressed in kilograms
$M_{(t-d)}$	=	amount of HFC initially charged into new systems installed in year (t-d) expressed in kilograms
S	=	residual charge of HFC in equipment requiring recharge expressed in percentage.
D	=	average equipment lifetime expressed in years
η_{rec}	=	Recovery efficiency, which is the ratio of recovered HFC referred to the HFC contained into the system

In estimating the amount of refrigerant initially charged into the systems (M_{t-d}), all systems charged in the country (for the domestic market) and systems imported precharged should be taken into account.

Quality assurance/quality control

In order to conduct a quality control for Tier 2 method, it is possible to compare the annual national HFC refrigerant market as declared by the chemical manufacturers or the refrigerant distributors with the annual HFC refrigerant needs as derived by the Tier 2 method. The following formula leads to this verification.

$$R_t = \sum_{6} S_{prod} \times m_t + \left(\sum_{a=1}^{\frac{d}{z}} M_{t-az} \times \left((1-s) + s(1-\eta_{rec}) \right) \right) \qquad \text{Equation 8}$$

where:

R_t	=	HFC needs in year t expressed in kilograms
S_{prod}	=	national production of equipment using HFC refrigerant for the six application domains
S	=	residual charge of HFC in equipment requiring recharge expressed in percentage
M_t	=	elementary charge of HFC in each type of equipment expressed in kilograms
M_{t-az}	=	the amount of HFC charged into the equipment either at manufacturing or after each servicing expressed in kilograms
A	=	number of recharges during the equipment lifetime d expressed in round numbers (lies in the interval [0-d/z])
Z	=	$\dfrac{1-\frac{s}{100}}{\frac{x}{100}}$; number of years elapsed before equipment recharge expressed in round numbers
η_{rec}	=	recovery efficiency, which is the ratio of recovered HFC in relation to the HFC contained into the system

The first Σ corresponds to the refrigerant charge of new refrigerating and air conditioning system produced in the country at the current year t including exports.

The second Σ corresponds to the refrigerant charge used for servicing.

The term $s(1-\eta_{rec})$ represents the recovered refrigerant.

The annual refrigerant market as declared by chemical manufacturers or refrigerant distributors RD is calculated by Equation 9.

$$RD_t = R_{prod\_t} - R_{\exp\_t} + R_{imp\_t} + R_{recl\_t} \qquad \text{Equation 9}$$

where

R_{prod_t}	=	quantities of HFC refrigerant production expressed in kilograms
R_{exp_t}	=	quantities of HFC refrigerant produced in the country and exported expressed in kilograms
R_{imp_t}	=	quantities of imported HFC refrigerant expressed in kilograms
R_{recl_t}		quantities of HFC refrigerant recovered and reprocessed for sale as new HFC refrigerant in kilograms

All quantities are calculated for the current year t.

Comparing R_t that is the HFC refrigerant needs as derived from the inventory method and RD_t the HFC refrigerant market as declared by refrigerant manufacturers and distributors gives a clear quality control of the inventory method, and also of the global emissions. R_t and RD_t are calculated for each HFC type.

List of Countries and country groups for refrigerant inventories

Calculations are performed independently for eighty entities: seventy countries and ten country groups.

Table A2.1 – List of countries and country groups where refrigerant inventories are performed

AFRICA*	Egypt	LITTLE EUROPEAN COUNTRIES*	Saudi Arabia
Algeria	Estonia	Luxembourg	Singapore
Argentine	Finland	Malaysia	Slovakia
Australia	France	Malta	Slovenia
Austria	Germany	Mexico	SOUTH & EAST ASIA*
BALKANS*	Greece	MIDDLE EAST*	South Africa
Bangladesh	Hong kong	Morroco	SOUTH AMERICA*
Belarus	Hungary	Myanmar	South Korea
Belgium	Iceland	Netherlands	Spain
Brazil	India	New Zealand	Sweden
Bulgaria	Indonesia	Nigeria	Switzerland
Canada	Iran	Norway	Taiwan
CENTRAL AMERICA & CARIBBEAN*	Ireland	PACIFIC ISLAND COUNTRIES*	Thailand
CENTRAL ASIA*	Israel	Pakistan	Turkey
Chile	Italy	Peru	Ukrania
China	Japan	Philippines	United Arab Emirates
Colombia	Kuwait	Poland	United Kingdom
Cyprus	Latvia	Portugal	USA
Czech Republic	Libya	Romania	Venezuela
Denmark	Lithuania	Russia	Viet Nam

Country groups are indicated by *, and calculations are performed for the integral values of these groups.

Table A2.2 details the composition of each country group.

Table A1.2.2 – Country groups

AFRICA	Angola, Benin, Botswana, Burkina, Burundi, Cameroon, Cape Verde, Central Africa, Chad, Comoros, Congo, Congo RD, Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Guinea Equatorial, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Rwanda, Sao Tome, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
BALKANS	Albania, Bosnia, Croatia, Kosovo, Macedonia, Moldova, Serbia Montenegro
CENTRAL AMERICA & CARIBBEAN	Antigua, Aruba, Bahamas, Barbados, Belize, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haïti, Honduras, Jamaica, Nicaragua, Panama, St Vincent, Trinidad & Tobago
CENTRAL ASIA	Afghanistan, Armenia, Azerbaijan, Georgia, Kazakstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
LITTLE EUROPEAN COUNTRIES	Andorra, Liechtenstein, Monaco, San Marino
MIDDLE EAST	Bahrain, Irak, Jordan, Lebanon, Oman, Palestine, Qatar, Syria, Yemen
PACIFIC ISLAND COUNTRIES	Fiji, Kiribati, Mariannes, Marshall Islands, Micronesia, Nauru, Niue, Palau, Papua New Guinea, Tonga, Vanuatu, West Samoa
SOUTH & EAST ASIA	Bhutan, Brunei, Cambodia, DP N Korea, Lao, Macao, Maldives, Mongolia, Nepal, Sri Lanka
SOUTH AMERICA	Bolivia, Ecuador, Guyana, Paraguay, Surinam, Uruguay

ANNEX 3

End of life curves

Lifetime of equipments is defined as a retirement function [KOO98].

The retirement function, also known as survival curve, is used to estimate the rate of retirement of equipments. In the linear function, no equipment retire in the first 2/3 of their average life time, and all units are retired by 4/3 of their average life time. The relation between age/average lives and appliance survival factor is shown in Figure 1.2. Expressed as equations, this function is as follows:

If age < [2/3 x (average life)] then 100% survive
If age > [2/3 x (average life)] and age < [4/3 x (average life)]
then [2 – 1.5 x (age) / (average life)] survive
If age > [4/3 x (average life)] then 0% survive

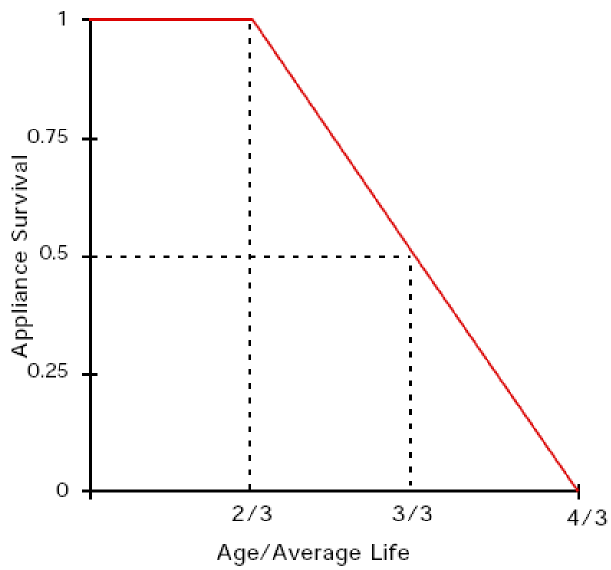

Figure 1.2: Appliance survival function.

Annex 4

Method of calculations of the refrigerating capacity of the food industry

A4.1 Global cooling capacity for all meats

The refrigerant inventory for the meat sub-domain has been determined using meat production figures. The FAO database gives a very detailed description of the meat demand and production for all the countries since 1961.

Cooling process for meat

The vast majority of four-footed animals are slaughtered in commercial slaughterhouses under supervision. The small portion still slaughtered on the farm has not been taken into account.

After killing, bleeding, skinning, evisceration, the meats (M1) are cooled, then either cut and packaged for frozen meat (M2) or stored in one piece if for fresh meat (M3) (see Figure A6.1).

The quantities M1, M3 and M4 are known from the FAO database. For frozen meat, the quantities are directly included in the frozen food demand, which has been analysed as one specific entity (see section 6.6).

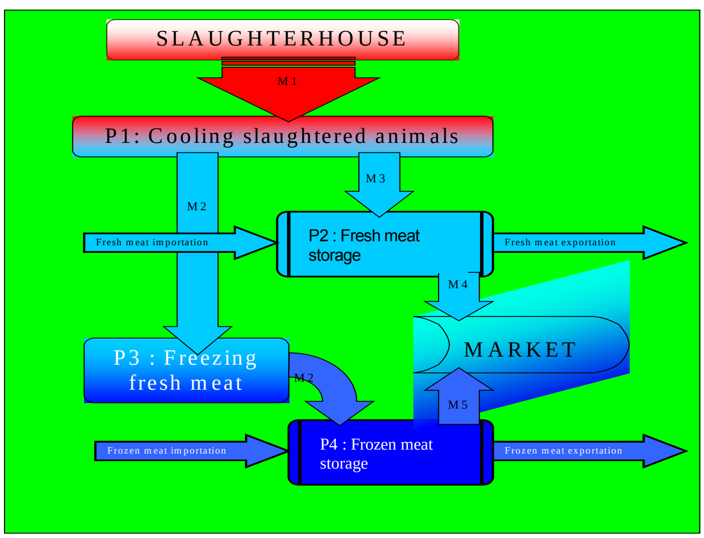

Figure A4.1- Cooling and freezing for production and storage

Based on the different meat masses, the following refrigerating capacities are defined:

- P1 and P2 are the cooling capacities for fresh meat chilling and storage, respectively
- P3 and P4 are the cooling capacities for meat freezing and frozen meat storage, respectively.

A4.1.1 Cooling Model for Beef

The cooling capacity for meat is based on the maximum needed capacity at peak load, which in fact is the design criterion for refrigerating equipment. Peak load occurs at the beginning of meat chilling, just after the slaughter when carcasses have their highest temperature.

Figure A4.2 shows the exponential curve of beef carcass temperature drop. The chill rate is $\Delta\theta$ / Δt, but the peak load corresponds to the maximum slope α . ($\Delta\theta$ / Δt), which is required for sanitary issues.

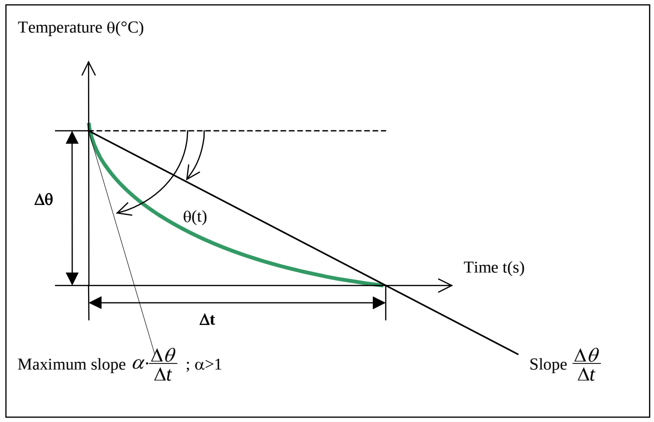

Figure A4.2 - Cooling model of beef

From Figure A4.2 the maximum product cooling capacity P_{meat} can be calculated, i.e., by using the equation below.

$$P_{meat} = \frac{\alpha \cdot M \cdot c \cdot \Delta\theta}{\Delta t} \qquad \text{(A6.1)}$$

where:

P_{meat} meat maximum cooling capacity (kW)

α coefficient for the determination of the maximum rate of chill (see Figure A4.2),

c average heat capacity (kJ/kg K)

$\Delta\theta$ / Δt temperature difference for a given time difference (K/s).

The water evaporated from the beef carcass condenses and freezes on the evaporator coils requiring additional capacity due to frost formation. The rate of water evaporation is proportional to the rate of meat being cooled; and the corresponding cooling capacity can be calculated by the equation below:

$$P_{frost} = \beta \cdot \frac{\alpha \cdot M}{\Delta t} \cdot H_{sol} \qquad \text{(A4.2)}$$

where :

$\frac{\alpha \cdot M}{\Delta t}$ maximum rate of chilled meat

H_{sol} = ice heat of solidification = 335 kJ/kg

β<1, part of water lost from the chilled meat

Miscellaneous loads such as conveyors, air infiltration, personnel, fan motors, lights, and equipment heat losses need to be taken into account. The latter loads are proportional to the maximum cooling capacity M.

$$P_{misc} = \gamma \cdot M \qquad \text{(A4.3)}$$

where:

γ(W/kg) is the factor for maximum miscellaneous losses.

The total cooling capacity is :

$$P_{tot} = P_{meat} + P_{frost} + P_{misc}$$

$$\Rightarrow P_{tot} = \frac{\alpha \cdot M \cdot c \cdot \Delta\theta}{\Delta t} + \beta \cdot \frac{\alpha \cdot M}{\Delta t} \cdot H_{fusion} + \gamma \cdot M$$

Thus the cooling capacity per unit of mass is:

$$p = \frac{P_{tot}}{M} = \frac{\alpha \cdot c \cdot \Delta\theta}{\Delta t} + \beta \cdot \frac{\alpha}{\Delta t} \cdot H_{fusion} + \gamma \qquad \text{(A4.4)}$$

where
p specific cooling capacity (W/kg).

- **Coefficient values for chill and holding coolers**

Chilling of the beef carcass is performed in two different coolers. First the rapid cooling is performed in the chill cooler, and then cooling takes place at a reduced rate in the holding cooler. The density of the carcass is significantly lower in the holding cooler (45kg/m^3) than in the chill cooler (60kg/m^3). So, if referred to the mass of a chilled carcass, the ratios of miscellaneous heat losses are different. Taking into account that for large storage the volumetric G factor amounts to 30 W/m^3, this leads to

γ_1 = 0.5 W/kg for chill cooler, and

γ_2 = 0.677 W/kg for holding cooler.

- **Coefficient for chill cooler**

Dressed beefs are split into half carcasses (the average half carcass mass is around 150 kg) and the average specific heat c is around 3.14 kJ/kg K [ASH98].

α is determined according to the curve of average carcass temperature of meat cooling versus time (Figure 4.3),

Δt = 20 h and $\Delta\theta$ = 28°C, the first 4 hours (= 0.2 Δt) the temperature decreases by 11.2 K (= 0.4$\Delta\theta$) therefore α = 2.

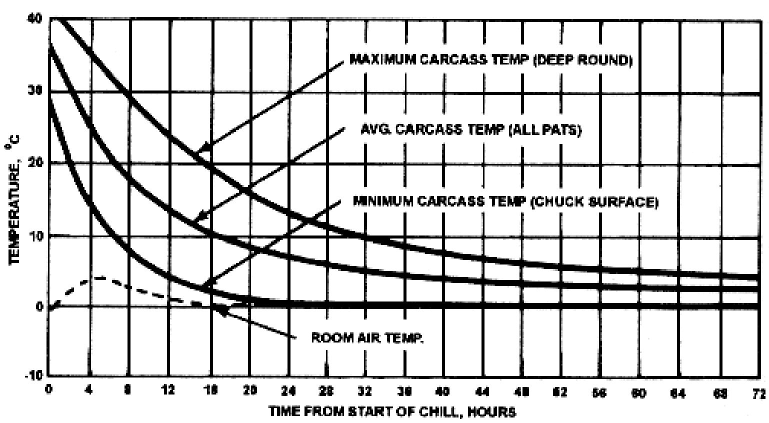

Figure A4.3 - Beef chilling curves [ASH98]

β = 0.03 represents typically 3% of the chilled mass [ASH98] ; γ = 0.5 W/kg (see above).

In summary, for Δt = 20h = 72 000 seconds and $\Delta\theta$ = 28°C , α = 2, β = 0.03, γ = 0.5.
And p_1 = 3.2214 W/kg (**ratio 1**)

- **Holding cooler coefficient**

Equation (1) is applicable here. The temperature drop is lower for a longer time, and the water evaporation speed is low, leading to the following coefficient.
(α = 1.2, β = 0.0035 = 0.35%, γ = 0.667 W/kg, $\Delta\theta$ / Δt = 4.17 K/24h)

$p_2 = 0.866\ W/kg$ (**ratio 2**)

A6.1.2 Cooling capacity for ancillaries

Besides cooling, freezing, storing, many other operations are needed in meat processes, like cutting, packing, examining, expedition…. The cooling needs here are proportional to the size of the slaughterhouse and so also proportional to the annual capacity of meat being processed.

Based on a detailed case study of a large French slaughterhouse [CLO96], the typical ancillary cooling capacities are presented in Table A4.1.

Table A4.1 – Ancillary cooling capacities

Designation	Nb	Unit Capacity (kW)
Offal process room		16
Offal refrigeration	2	27
White offal storage		26.5
Wastes	3	16.5
Blood tank		16
Hides	3	13.5
Exam		7
Pre-check room		10.5
Check room		10.5
Input room		7
Food for animals		4
Complement storage	2	22
Large part cutting	3	13
Expeditions	3	16.5
Storage before cuts	2	16.5
Offal process room (2)		13
Cutting room 1		46.5
Cutting room 2		13
Offal storage room		13
Offal packing room		16.5
Packaging		14
Vacuum storage		14
Packaging consignment		12.5
Consignment	3	12.5
Passageways	3	4
Total	599 kW	

30,000 tons are processed in this slaughterhouse annually. From this case study the ancillary ratio is fixed.

$$p_3 = \frac{599}{30000} = 0.02\ kW/at^*$$ (**ratio 3)**

** at : is the meat annual production in tons*

p_3 is calculated and it is based on the total quantity of processed meat, not taking into account the characteristics of the different cooling rooms, and this ratio is therefore used for the annual meat production.

A4.1.3 Generalization to all types of meat

Meat cooling, whatever the type of meat, is very similar due to the sanitary specifications. The carcass shall be cooled down as quickly as possible, the limit is linked to the meat hardness.

Due to physiological changes after slaughtering, heat is generated inside the body and tends to increase its temperature to around 41°C when the carcass enters the chilling cooler.

HACCP (Hazard Analysis and Critical Control Point) [ASH98] recommends that red meat carcasses be chilled to 5°C within 24 hrs, and that this temperature be maintained during storage, shipping, and product display.

Heat capacities of meats vary with the percentage of fat and moisture, but an average heat capacity 3,1 kJ/(kg. K) is used for calculations of all meats [ASH98].

Meats are divided in three groups according to the carcass size that influences the cooling time:

- first group with an average mass per carcass of 150 kg, e.g. beef, veal, horse
- second group with an average mass per carcass of 60 kg, e.g. pig, mutton, lamb, goat …
- third group with an average mass per poultry of 4 kg, e.g. turkey, chicken, duck, goose….

The beef cooling model is used as a general model and the different coefficients for each group are given in Table A4.2.

Table A4.2 - Physical properties and ratios for cooling capacity calculations

	Group I	**Group II**	**Group III**
Parameters/ratios	Beef, veal, horse meat	Goat, Mutton, lamb, Pig	Chicken, duck, goose, birds, rabbit, turkey
α	2	1.5**	1.2**
C (J/(kg.K))	3,140	3,140	3,140
$\Delta\theta$ (K)	30	30	30
Δt (h)	20	12**	6**
β	0.03	0.03	0.03
γ(W/kg)	0.5	0.5**	0.5**
Fresh meat cooling ratio (W/kg)	3.326	4.05	5.733
Fresh meat storage ratio (W/kg)	0.866	0.866**	0.866**
Ancillary cooling capacity kW/at*	0.02	0.02**	0.02**

*at = annual ton **Estimation

A4.1.4 Calculation of the national installed cooling capacity for meat

The FAO web-site presents statistics on the annual production, imports and exports of meat. Production figures relate to animals slaughtered within national boundaries regardless of their origin. These figures are used as inputs in the country database for all countries, years and types of meats. The format is a uniform table of countries by year and it is adopted for all types of meat. Table A4.3 shows other constants needed to estimate the installed cooling capacity.

Table A4.3 –Working time assumptions

	Constants
Slaughterhouse coefficient of use	0.8
Warehouse coefficient of use	0.6
Residence time in the warehouse (days)	2
Working days per year (slaughterhouse)	300
Working days per year (warehouse)	360

The national installed cooling capacity is calculated based on the national demand of all countries and for all types of meat.

The installed cooling capacity takes into account three terms:

- meat cooling
- meat storage, and
- ancillary cooling capacities.

♦ **National fresh meat cooling capacity**

The national installed cooling capacity for fresh meat cooling is calculated by the following equation:

$$P_1 = \frac{M_p . p_1}{\tau . \lambda}$$

Where:

P_1 national installed cooling capacity for fresh meat (kW)
M_p annual meat production obtained from the FAO database per country (annual tons)
p_1 ratio of fresh meat cooling (W/kg) (see Table 6.2)
τ working days per year (slaughterhouse) (see Table 6.3)
λ coefficient of use of the slaughterhouse (see Table 6.3).

♦ **National cooling capacity for fresh meat storage**

The national installed cooling capacity for fresh meat storage is calculated by the following equation:

$$P_2 = \frac{M_p . p_2 . \sigma'}{\tau' . \lambda'}$$

Where:

P_2 national installed cooling capacity for fresh meat storage (kW)
M_p annual meat production obtained from the FAO database per country (annual tons)
p_2 ratio of fresh meat storage (W/kg) (see Table 4.2)
σ' Storage residence time (day)
τ' working days per year of the warehouse (see Table 4.3)
λ' coefficient of use of the warehouse (see Table 4.3).

♦ **National installed cooling capacity for ancillaries**

The national installed cooling capacity for ancillaries is calculated by the following equation:

$$P_3 = \frac{M_p \cdot p_3 \cdot}{\lambda}$$

Where:

P_3 national installed cooling capacity for fresh meat storage (kW)

M_p annual meat production obtained from FAO database per country (annual tons)

p_3 capacity ratio of ancillaries (kW/annual tons) (see Table 4.2)

λ coefficient of use of the factory (see Table 4.3)

♦ **Verification with the French Inventory report [PAL02]**

After aggregation of all installed parcs for all groups of meat, the total installed parc for France is listed in Table A4.4

Table A4.4 - France refrigerating parc for meat industry

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total installed cooling capacity (MW)	341.84	351.69	355.14	367.39	378.44	389.98	393.25	398.32	392.94	384.99

In Inventory Reports for France issued previously, another method was used to determine the installed cooling capacity.

If the energy consumption in refrigeration for the meat industry is known (i.e., 1228 GWh per year), assuming a COP of 2, a factory working time of 300 days per year and 16 hours per day, the calculated installed capacity is 512 MW for the year 1998. Referred to the installed cooling capacity listed in Table 4.4, the error made is 22.15%.

A4.2 Global cooling capacity for dairy industry

A4.2.1 Calculation of installed cooling capacity

The refrigerant inventory for the dairy sub domain is determined using the dairy production and sales. The FAO database gives a very detailed description of the dairy demand and production for all the countries since 1961.

Frozen dairy products are not considered in this section, they are aggregated in the frozen product domain.

Figure A4.4 gives the link between different figures available in FAO Database for dairy process.

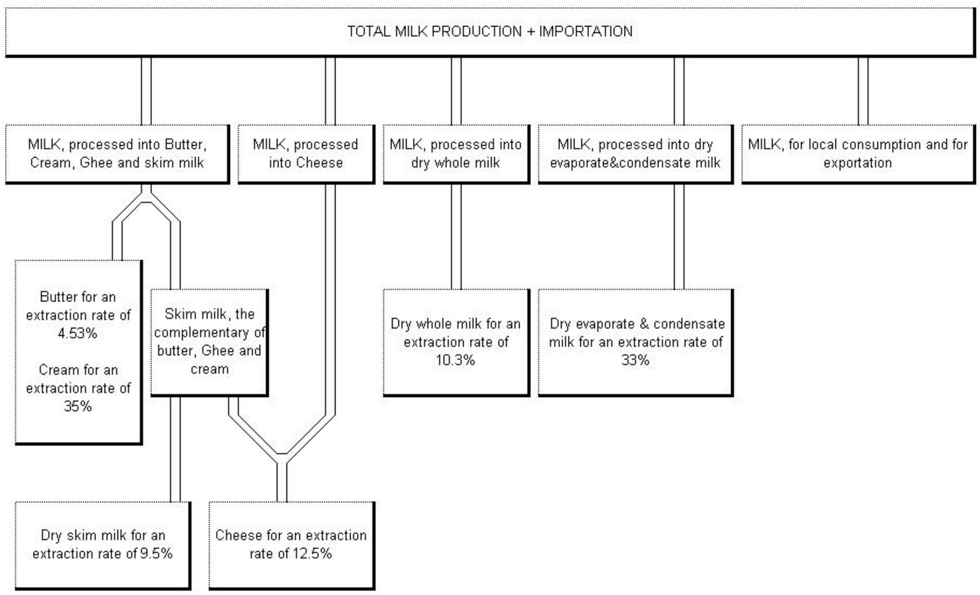

Figure A4.4 - The FAO link between different dairy processes

Milk undergoes the cooling in the farm, is transported by insulated trucks, and is treated in the factory where it will be processed into different dairy products.
The major refrigerated process for milk are:

- farm refrigeration (milk tank)
- bacteria treatment (pasteurization, UHT…)
- fermentation (depending on dairy product).

A4.2.2 Milk tank installed cooling capacity

For the milk cooling at the farm, the following rules for cooling are applied:

- cooling from 35 to 5°C in 2 hours
- no frosted milk in the tank, even partial
- allowable temperature increase equal to 5K if a second milking is added to the milk tank.

To avoid every risk of the milk temperature decreasing below the frosting point, 4°C is the lowest controlled temperature for direct expansion milk tanks (which are the most widespread). Some milk tanks use ice accumulation technology to maintain a lower temperature, between 0 and +1°C. The above mentioned two types of milk tanks show similar performances. For both types, the law for cooling can be considered as linear.

At 4°C, the milk cannot be conserved in milk tanks at the farm longer than two days, because of bacteria proliferation.

The cooling model for a milk tank is similar to the cooling model for meat:

$$p_{milk} = \frac{\alpha \cdot c \cdot \Delta\theta}{\Delta t} + \gamma \qquad \text{(A4.5)}$$

with :

$\Delta\theta$ = 30°C pour Δt = 2h = 7200 sec

α = 1 (temperature curve is linear cause of cooling time is short in respect of temperature drop)

c = 4 kJ/(kg.K) [ASH98].

Calculation of miscellaneous heat losses

γ has been evaluated taking into account the insulation of typical milk tanks. Calculations show that γ = 0.033 W/kg, which is negligible and it is therefore not taken into account in the formula. Based on those assumptions, the milk capacity ratio p_{milk} can be derived as follows:

p_{milk} = 16,7 W/kg (**ratio 4**)

Milk capacity ratio verification

For France the average milk tank volume installed amounts to 3000 litres. Data sheets of a standard milk tank are obtained from literature [INTVMZ]. This reference gives the nominal volume of a typical direct expansion milk tank and its installed compressor power (2500 l; 15.47 kW). Assuming a COP of 2.5, the cooling capacity amounts to 38.67 kW. The milk capacity ratio calculated with the data mentioned yields a figure of 15.47 W/kg. The difference with the milk capacity ratio calculated using (equation 4.5) is about 8%, which is acceptable.

The milk capacity ratio will therefore be calculated using a ratio of 4.

Installed cooling capacity for Average National Daily Milk Production (ANDMP)

To establish the world installed cooling capacity for milk tanks, it is necessary to determine the Average National Daily Milk Production. Knowing the annual milk production from the FAO, (i) with a maximum residence time of two days, (ii) in which a maximum of four milkings are considered (two milkings a day), and (iii) a maximum filling ratio of 0.7 of the milk tank, (which is an average value taking into account the annual variation from 0.6 to 0.8), the Average National Daily Milk Production for a given country is calculated as follows:

$$M_{ANDMP} = \frac{M_p . \sigma}{n . \tau . \rho}$$

where:

M_{ANDMP} average national daily milk production (ANDMP) (kg)
M_p annual milk production obtained from FAO database (annual kg)
σ maximum residence time (days)
n number of milkings in a milk tank
τ number of days per year
ρ filling ratio

Parameters	
Days per year	360
Max residence time (day)	2
Cooling ratio W/kg	16.7
Number of milkings	4
Filling ratio	0.7

Table 4.5 – ANDMP parameters

The national installed cooling capacity for milk tanks is then:

$$P_{milk} = M_{ANDMP} \cdot p_{milk}$$

A4.2.3 Milk bacterial process and cooling

For pathogenic bacteria elimination, several milk processes are applied: pasteurisation, UHT…. This process consists of:

- heating the milk;
- maintaining it at high temperature during the necessary time for complete pathogenic bacteria elimination,
- cooling it to 4°C.

Refrigeration is only related to the milk cooling from 35°C to 4°C, since the milk cooling from temperatures higher than 35°C is done either by cold water or, better, by regeneration in a milk / milk heat exchanger.

Several cooling techniques are used, chilled water being the most widespread for large milk facilities.

Pasteurisation and cooling take place in the same heat exchanger, which includes three zones:

- a heating zone for the pasteurisation,
- a central zone where the homogenised cold milk is heated by the counter current of pasteurised hot milk (regeneration process),
- a cooling zone where the milk is cooled by chilled water.

To determine the cooling capacity for the national pasteurisation, the following formula is used:

$$P_{past} = \eta \times (\frac{M_p}{\tau'}) \times Cp \times \Delta\theta$$

$$P_2 = \frac{\eta}{\lambda} \times (\frac{M_p}{\tau'}) \times Cp \times \Delta\theta = \frac{M_p \times p_{past}}{\lambda} \quad (4.6)$$

Where

P_{past} national cooling capacity for pasteurisation (kW)
η heat loss factor
λ coefficient of use
M_p milk annual production obtained from FAO database (annual tons)
τ' factory working time in seconds
Cp heat capacity of milk
$\Delta\theta$ temperature drop (°C)
$\frac{M_p}{\tau'}$ average mass flow rate of the factories

Table A4.6 - Cooling parameters after pasteurization

Factory working days per year (days)	300
Factory working hours per year (hours)	16
Temperature drop (°C)	31
Cp (kJ/kg.K)	4
Heat loss factor η (Indirect systems + Other installations)	1.4
Coefficient of use λ (real mass flow rate / dimensional mass flow rate)	0.8

$\Rightarrow p_{past}$= 0.01256 W/annual kg.

A4.2.4 Fermentation and cooling

Some dairy products need to be stored in refrigerated rooms for fermentation, but the residence time differs from one product to another and from one country to another. Table A4.7 lists different chosen parameters for the calculation of cooling in fermentation rooms.

The national cooling capacity for fermentation rooms is calculated as follows:

$$P_{ferm} = \frac{M_p \cdot p_{ferm} \cdot \sigma}{\tau . \phi}$$

where

- P_{ferm} national installed capacity for fermentation rooms (kW)
- M_p annual dairy product obtained from FAO database (annual tons)
- p_{ferm} volumetric cooling ratio for fermentation (W/m^3)
- ϕ minimum storage ratio of products in 1 m^3 of warehouse (kg/m^3)
- σ staying delay in factory warehouse (day)
- τ working days per year of factory warehouse.

Table A4.7 – Fermentation and storage parameters

	Butter and Ghee	Cheese	Cream
Temperature (°C)	5	5	5
Cooling ratio (W/m^3)	30	30	30
Storing ratio (kg/m^3)	300	500	300
Residence time (days)	5	30	5

A4.3 Global cooling capacity for wine and beers

The FAO database includes global wine and beer production figures. In order to derive the installed cooling capacities from the wine and beer production figures, two cooling models have been developed.

A4.3.1 Wine cooling model

The wine cooling model is based on a detailed case study of a winery where the cooling capacities and production are known. From [CLO96], Table A4.8 has been established using the annual production figure of 75,000 hl.

Table A4.8 - Cooling data of the typical case

Cooling stage	Cooling capacity (kW)	Product capacity (hl)	Ratio: cooling capacity/product capacity (W/kg)	Ratio: annual production/product capacity	Ratio: cooling capacity/annual production (W/annual kg)
Wine-making process	70	25000	0.028	3	0.0093
Tartaric stabilization ultra-cooling	50	25000	0.020	3	0.0067
Storage	175	75000	0.0233	1	0.0233

From Table A6.8 the total cooling ratio of wine can be derived as 0.03933 W/annual kg.

The average time for wine-making process is one week for red wine and 15 days for white wine. The average time for tartaric stabilisation is 15 days [CLO96]. For the case under study, the storage is air-conditioned because during summer the ambient temperature is very high and the storage temperature must be kept under 21°C. This case is not applicable to all wineries, therefore the storage cooling ratio has been multiplied by a factor α less than 1, α = 0.4 (40% of wineries use air conditioning in their wine storage).

P_{wine} = 0.03 W/annual kg (**ratio 5**)

A4.3.2 Beer cooling model

Wort cooling

The following formula is used for the national wort cooling capacity: $P_{wort} = \frac{\eta}{\lambda} \times (\frac{M_p}{\tau'}) \times Cp \times \Delta\theta$

Where
P_{wort} national wort cooling installed capacity (kW)
η losses multiplier factor (η = 1.4)
λ coefficient of use (real flow rate/ dimensioned flow rate, λ=0.8)
M_p beer annual production obtained from FAO database (annual tons)
τ' factory working time in seconds (the factory works 300 days/yr and 16 hrs/day)
Cp wort heat capacity (Cp = 4 kJ/(kg.K) [ASH98])
$\Delta\theta$ temperature drop (°C) ($\Delta\theta$ = 31°C [ASH98])
$\frac{M_p}{\tau'}$ average wort mass flow rate.

$p_{wort} = 0.01256$ W/annual kg (**ratio 6**)

Fermentation
Beer ratio fermentation amounts to 0.0033 W/annual kg which has been taken from [ASH98].

p_{ferm} = 0.033 W/annual kg (**ratio 7**)

A4.4 Global cooling capacity for flake ice for fresh fish conservation

The cooling capacities applied and the refrigerant types used on board of fishery vessels are taken into account in considerations of the refrigerated vessel fleet. But, once the fish is delivered for sale, fresh fish conservation is essentially performed on flake ice.

The ratio of ice used for fish conservation, IFR, is:

IFR = mass of ice / mass of fish = 0.5 (0.25 for cooling and 0.25 for lost [RGF02]).

The National Fresh Fish Annual Production (NFFAP) data are coming from the FAO database.

The capacity ratio for producing flake ice is:
Ice Cooling Capacity Ratio, ICCR = 6.95 W/kg [ASH98].

Average number of catches (catching days) per year: 300 catches per year.

The national installed cooling capacity for production of flake ice for fish conservation is calculated as follows:

$$P_{fish} = \frac{NFFAP}{\tau'} xICCRxIFR \text{ (W)}$$

where
τ' is the number of catching days per year (300)
NFFAP (kg/yr)
ICCR (W/kg).

A4.5 Global cooling capacity for frozen food

A4.5.1 Frozen food production

Annual frozen food production is not yet available from the FAO Database, but export and import data are available, and they allow to establish the world frozen food production using the Kaminsky ratios [KAM95] for annual consumption of frozen food per capita as presented in Table A4.9, and using the equation:

Production = Consumption + Export – Import

Table A4.9 – Annual consumption of frozen food per inhabitant [KAM 95]

Countries	USA, Denmark	UK, France, Sweden	Germany, Switzerland	Norway, Austria, Belgium, Finland, Spain, Australia, Japan, The Netherlands	Italy, Hungary, Poland, ex-URSS and others
Annual consumption/ habitant (kg)	> 40	30 – 40	20 – 30	10 – 20	< 10

For each group presented in Table A4.9, linear interpolation with the mean GDP of the corresponding country allows the determination of the annual consumption per capita.

In the FAO database import and export figures are available for: Ice cream, Potato frozen, Sweet corn frozen, Cephalopods Frozen, Crustaceans Frozen, Demersal Frozen Fillets, Demersal Frozen Whole, Fish fillet chilled frozen, Fish Frozen Whole Fillet, Fish shellfish frozen, Freshwater Frozen Whole, Freshwater Frozen Fillets, Marine nes Frozen Fillet, Marine nes Frozen Whole, Mollusc Frozen, Pelagic Frozen Fillets, Pelagic Frozen Whole.

Based on previous calculations, the world frozen food production as determined is presented in Table A4.10.

Table A4.10 - World frozen food production

Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Production (10^6 t)	26.51	27.28	27.38	27.34	27.56	27.04	27.42	28.35	28.13	29.71	29.36
Year	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	
Production (10^6 t)	32.14	32.78	32.90	35.93	37.37	36.27	38.38	39.80	38.40	38.54	

[KAM95] estimates the world frozen food production by the beginning of 1990 at a level of 30 million tons. The calculated value for this year is 7% higher (table 4.10).

A4.5.2 Frozen food cooling model

Based on data from a manufacturer of a blast freezer [SBL], it can be given that the freezing ratio per kg of frozen food per hour is of 121.472 W/(kg h). This value has been used for all types of food.

The frozen food production is considered as continuous production during 16 hours per day and 300 days per year. The factory use coefficient equals 0.8. The national installed capacity for frozen food is calculated according to Figure A4.5.

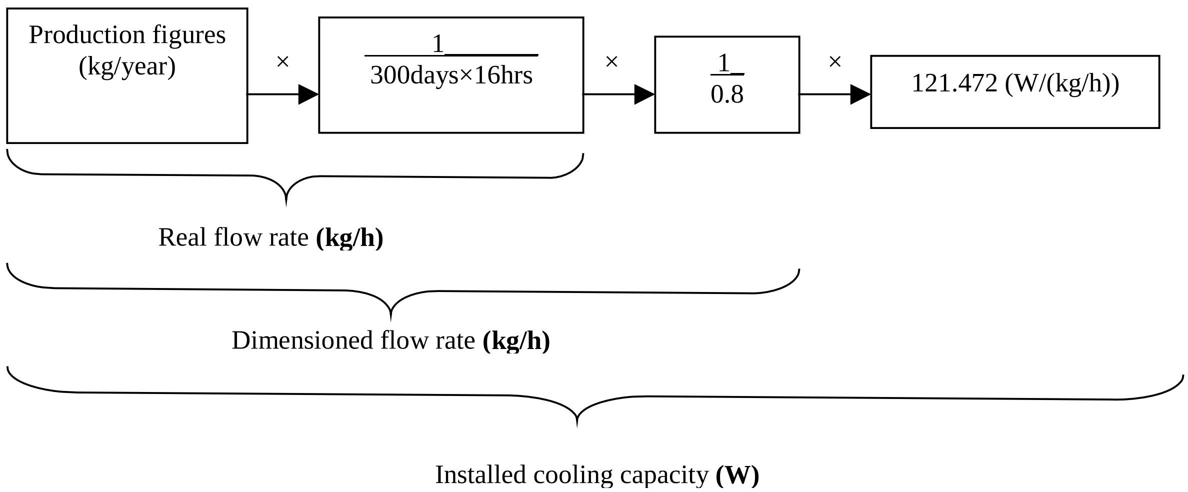

Figure A4.5 – Flow sheet for national installed capacity for frozen food.

The national installed capacity ratio p_{frozen_food} is

$$p_{frozen\_food} = 0.0316 \text{ W/annual kg}$$

For the factory storage, the same parameters are used.

A4.6 Installed cooling capacity for cold storage

In this section cold storage means all cold storage except the storage in food processing facilities. The refrigerated volumes correspond to low and medium temperature storage, specialised and multipurpose cold stores and fruit packing stations. The cold storage volume estimates by country are based on ratios that have been elaborated on for different developed countries [KAM95, GLO92-93]. Based upon these ratios additional calculations have been performed in order to refer the cold storage volume to the GDP. Figure A6.6 indicates the evolution of the cold storage referred to the GDP as a function of time (1930-2000).

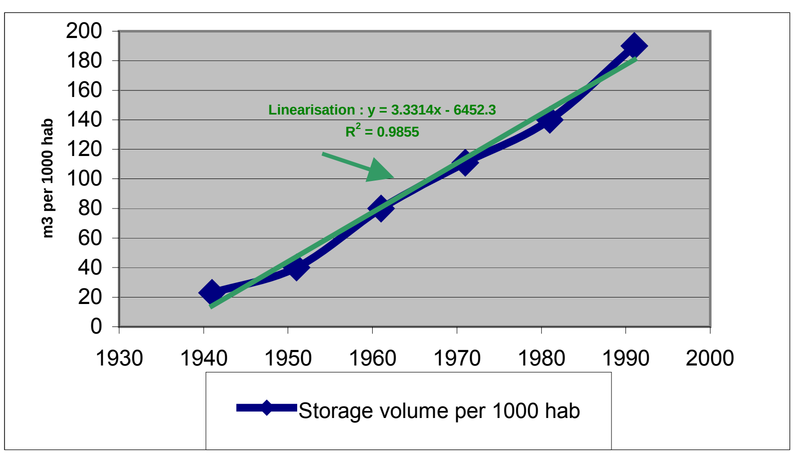

Figure A4.6 – The US typical storage volume example [KAM95]

A saturated linear extrapolation with the US storage volume per capita and the mean GDP allows the establishment of the storage volume per capita for each country (Figure A6.7). The extrapolation with the US storage increased volume per year and the GDP standard deviation makes it possible to establish the storage-increased volume for each country. Extrapolations have been done for year 1961 and have been projected to the year 1999 using the storage-increased volume per year and the population figures.

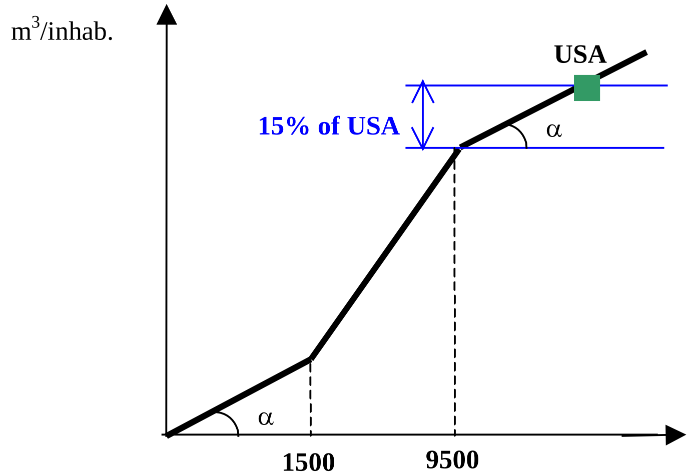

Figure A4.7 – Saturated linear extrapolation based on USA typical example

Low temperature cooling capacity over total cooling capacity is calculated taking into account the frozen food consumption per inhabitant.

Medium and low temperatures cooling capacities referred to the cold storage volume are known from the report [ADE00].