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COOL-FIT Cooling Systems LCA

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Uster, July 2006

Report

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Imprint	
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Executive Summary

As a reaction to the Montreal and Kyoto-Protocol the use of HFC refrigerants in supermarket refrigeration systems and cold store cooling devices is reduced by switching from direct cooling to secondary circuits. These systems make use of innovative solutions based on prefabricated and insulated plastic pipes. This study assesses the environmental impacts of the COOL-FIT piping system (ABS pipe with PUR insulation) and compares it to state-of-the art solutions based on metal piping. The environmental impacts are assessed on a life cycle basis. This perspective considers all aspects from "cradle to grave" starting with the extraction of e.g. metal ore and crude oil, the pipe production, the operation of the supermarkets and cold stores as well as their final disposal, i.e. all related environmental aspects are included and assessed as completely as possible.

The impacts considered are the Cumulative Energy Demand (distinguishing between renewable and non-renewable sources), climate change, abiotic resource depletion, ozone depletion, human and fresh water ecotoxicity, acidification, eutrophication and photochemical ozone creation. The Total Equivalent Warming Impact (TEWI), a traditional measure in the refrigeration industry, is discussed in addition.

This study compares:

- Different **piping materials** for cooling systems: copper, low-alloy steel, chromium steel and ABS (COOL-FIT) for a di 79 mm cooling pipe (chapter 3 „Piping").
- Different **cooling systems for supermarket applications**: copper and ABS (COOL-FIT) pipes in a typical supermarket with different designs and different combinations of HFC refrigerants (chapter 4 "Supermarket").
- Different **cooling systems for cold store applications**: low-alloy steel, chromium steel and ABS (COOL-FIT) pipes in a large cold store installation with ammonia as refrigerant (chapter 5 „Cold store").

In the supermarket configuration copper pipes with onsite Armaflex insulation are compared to factory-insulated COOL-FIT pipes using typical configurations of direct/indirect cooling and HFC refrigerants.

	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5
Piping / Insulation	copper/Armaflex	copper/Armaflex	copper/Armaflex	ABS/PUR (COOL-FIT)	ABS/PUR (COOL-FIT)
Type of circuit (MT/LT)	2L / DX	2L / DX	2L / DX	2L / 2L	2L / 2L
Refrigerant (MT/LT)	R134a/R404A	R404A/R404A	R22/R22	R22/R404A	R134a/R404A

***MT**: Medium (fridge) temperature* — ***LT**: Low (freezer) temperature*
***2L**: Secondary circuit* — ***DX**: Direct expansion circuit*

The cold store configuration is completely based on an indirect layout. Since ammonia is used as the refrigerant, the cold store design is different to the supermarket design.

	Layout CS-1	Layout CS-2	Layout CS-3
Piping / Insulation	steel / PUR	chromium steel/ PUR	ABS / PUR (COOL-FIT)
Type of circuit	2L	2L	2L
Refrigerant	ammonia	ammonia	ammonia

***2L**: Secondary circuit*

The data used in this study stems from sources considered as reliable such as literature, the ecoinvent database and personal communications with cooling system experts. Additionally, factory data was received covering the production of COOL-FIT pipes. The operation data for the COOL-FIT layouts had to be based on assumptions, however. Necessary assumptions were taken in such a way that the results have rather a bias to the disadvantage of the COOL-FIT

layouts. Therefore, the assumptions for the performance of the COOL-FIT layouts can be considered as somewhat pessimistic, while the traditional layouts represent most likely a realistic view.

A threshold is used in the interpretation of the results in order to draw a distinction between significant and non-significant differences between the layouts. The threshold of superiority is defined as follows:

1. the difference in an indicator is at least 5% and
2. the probability of superiority (deduced from a Monte Carlo Analysis) is at least 90% for the same indicator based on a comparison of layout S-1 and S-5 (supermarkets) and layout CS-2 and CS-3 (cold stores)

Piping Material

The first comparison is solely based on the piping material and, therefore, disregarding some constraints resulting from the choice of the material (e.g. ABS piping can only be used in secondary systems). The differences between the materials are clearly noticeable (Figure 1 and Figure 2). The ABS pipes (COOL-FIT) have a better environmental performance mainly in indicators related to toxicity. However, if recycled material is used to manufacture COOL-FIT pipes the performance can be significantly improved also with regard to the remaining environmental impact indicators. The additional contribution of overseas transport for COOL-FIT pipes to a location in the USA is only small in all indicators (comparison of the bar to the right and second to the right in each indicator of Figure 1 and Figure 2).

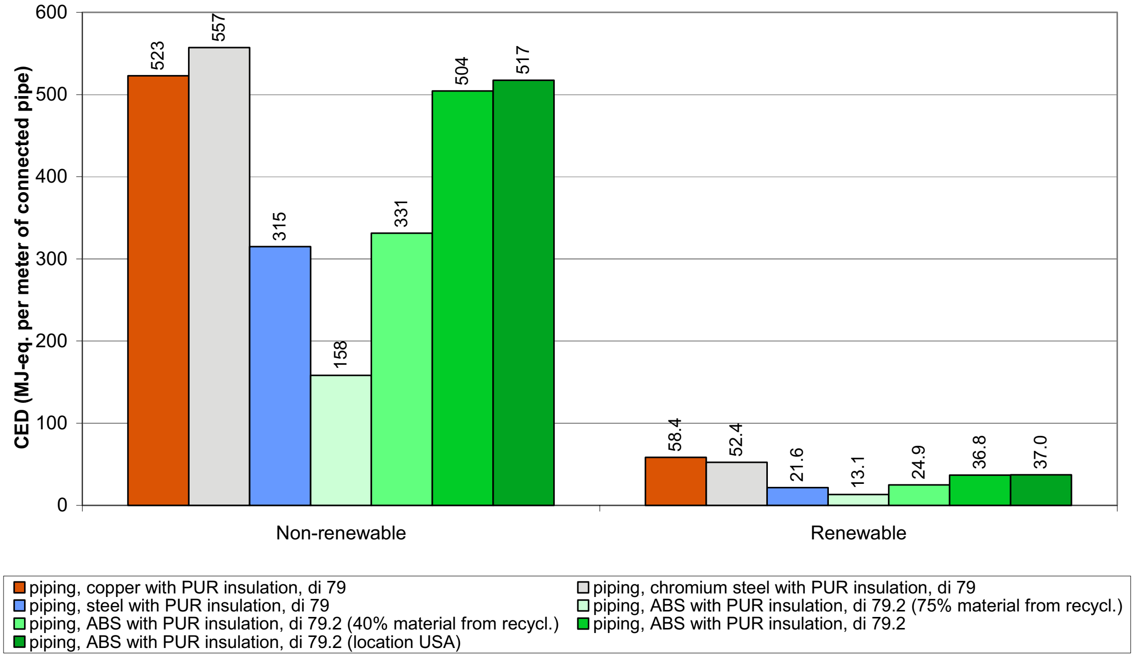

Figure 1: Absolute values of the cumulative energy demand (renewable and non-renewable) of the four pipe materials (incl. connections, transport to the installation site, pipe supports and end of life treatment).

It is important to note that a comparison of the piping material excluding its use in cooling systems does not account for some important differences in systems, namely the difference in energy consumption of direct and indirect cooling systems and the difference in the refrigerant charges and losses.

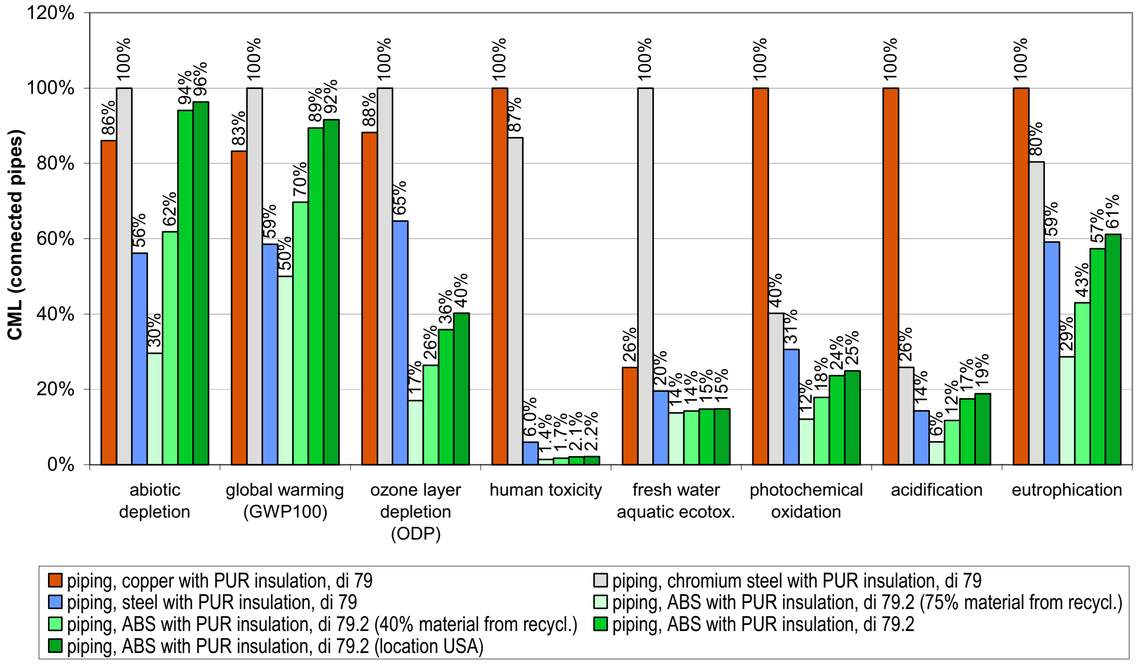

Figure 2: Percentage representation of the impact assessment of pipes installed in a cooling system (incl. transports, pipe supports, installation, disposal) with CML 2001. The highest value in each indicator is set to 100%.

Supermarket

As already shown by other studies, electricity is the single most important factor determining the results. It was assumed that the efficiency (and hence the electricity consumption) of a layout is primarily determined by the choice of refrigerant (measured data from Swiss supermarkets were used). Furthermore, it was assumed that indirect expansion circuits have a 10% higher electricity consumption compared to direct expansion and that COOL-FIT piping does not lead to a lower electricity consumption due to better insulation properties, although this might be the case. As a result of these assumptions and the high relevance of electricity in the assessments a direct comparison is only possible for layouts with identical or at least similar refrigerants. This implies that layout S-1 can directly be compared with S-5, while a comparison of the partly similar layouts S-2 and S-3 with S-4 needs care.

The differences found in the preceding pipe comparison (Figure 2) do not contribute significantly to the result when the operation is also considered. The electricity consumption explains most of the environmental impact of a supermarket cooling system installation. As a consequence, the sensitivity to a variation of the electricity consumption by 10% leads to a change between 8% and 10% in the cumulative energy demand (CED) indicators (Figure 3) whereas for most of the CML and TEWI indicators the range is between 6% and 9% (Figure 4 and Figure 5). Therefore, the differences found in the CED can almost completely be attributed to the assumptions concerning the electricity consumption, while this effect is slightly less pronounced in the case of the CML and TEWI assessment.

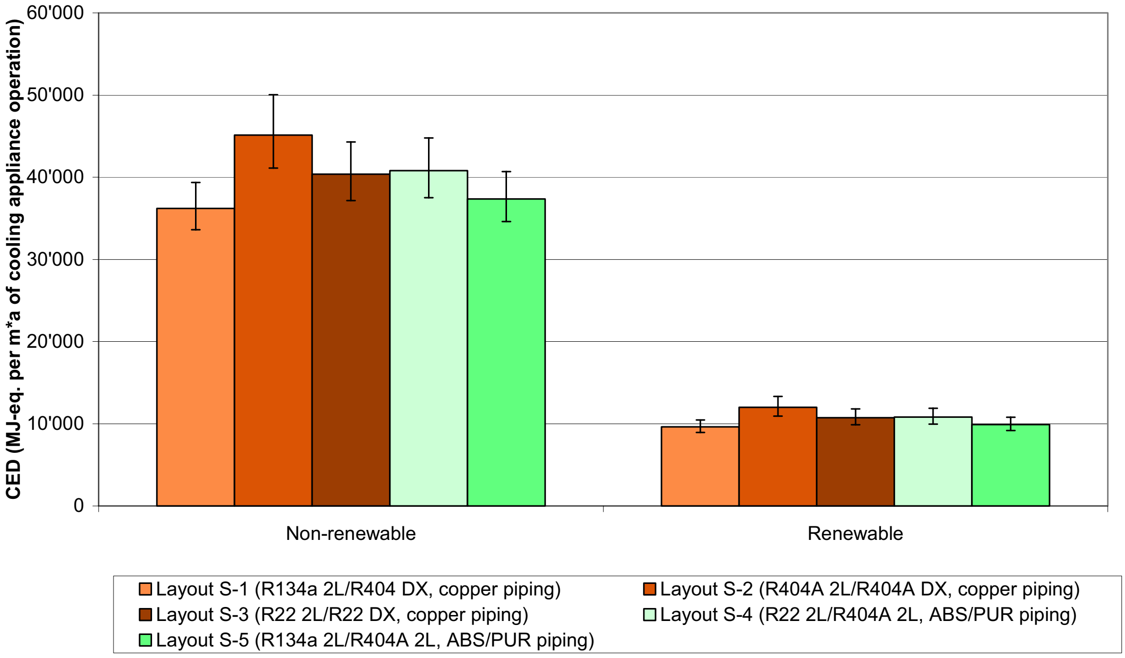

Figure 3: Absolute values of the cumulative energy demand (renewable and non renewable) of the five supermarket layouts operated in Switzerland. The error bars represent a ±10% variation of the electricity consumption.

Since modern cooling systems and HFC refrigerants were assumed, the impact of the refrigerant turned out to be lower than had to be expected from previous studies. The impact of the refrigerant is mainly relevant in *global warming* and *ozone layer depletion*. The completely indirect COOL-FIT systems show a better performance with regard to these two impacts as compared to the standard configuration. The slightly higher electricity consumption (+3 %) is outweighed by the substantially lower refrigerant charges and losses. The infrastructure (components) of the cooling system shows a low influence in most cases. This includes the choice of the piping except for the *human toxicity* and *freshwater aquatic ecotoxicity* indicators where the COOL-FIT layouts have a slight advantage over the copper piping. In the case of *global warming, ozone layer depletion* and *human toxicity* COOL-FIT outperforms the copper layouts to a significant extent according to the criteria used in this study.

The higher impacts due to a higher energy demand in the completely indirect cooling configurations (layout S-4 and S-5) are often compensated by lower impacts due to substantially reduced refrigerant losses and a lower impact from the cooling system installation. The latter is particularly relevant in *human toxicity*, *photochemical oxidation potential* and *acidification*. However, in the case of the latter two indicators the small superiority of COOL-FIT noticeable in Figure 4 can not be designated a significant difference.

Assuming the supermarket to be operated in the USA instead of Switzerland the results change to an even more pronounced prevalence of the electricity consumption in the indicators due to the higher share of fossil fuels in the electricity mix. The Swiss mix with its large share from renewables has a comparatively low environmental impact. This leads to the effect that the difference between COOL-FIT and copper concerning *global warming* is not significant anymore, while *ozone layer depletion* and *human toxicity* remain significant. The COOL-FIT configurations show better TEWI values than the standard configurations because of higher refrigerant loss rates in US supermarkets. Comparing layout S-1 and S-5 the reduction amounts to about 13% in favour of the COOL-FIT layout S-5.

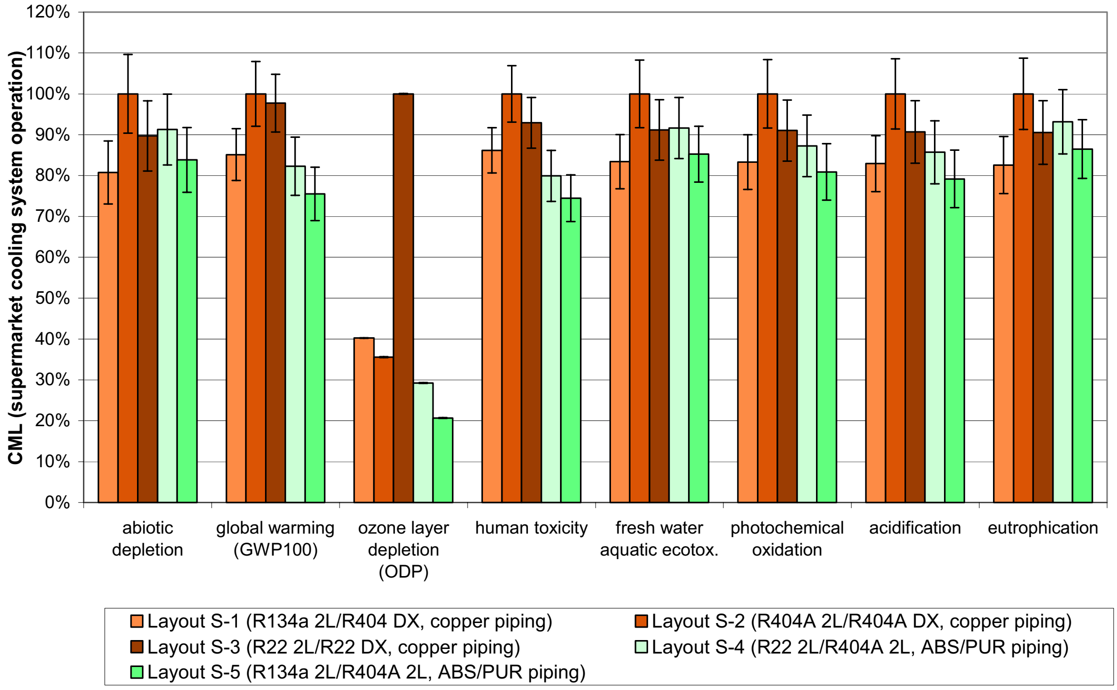

*Figure 4: Percentage representation of the impact assessment of the operation of cooling devices (m*a) according to the five supermarket layouts with CML 2001. The highest value in each indicator is set to 100%. The error bars represent a ±10% variation of the electricity consumption. The supermarket is operated in Switzerland.*

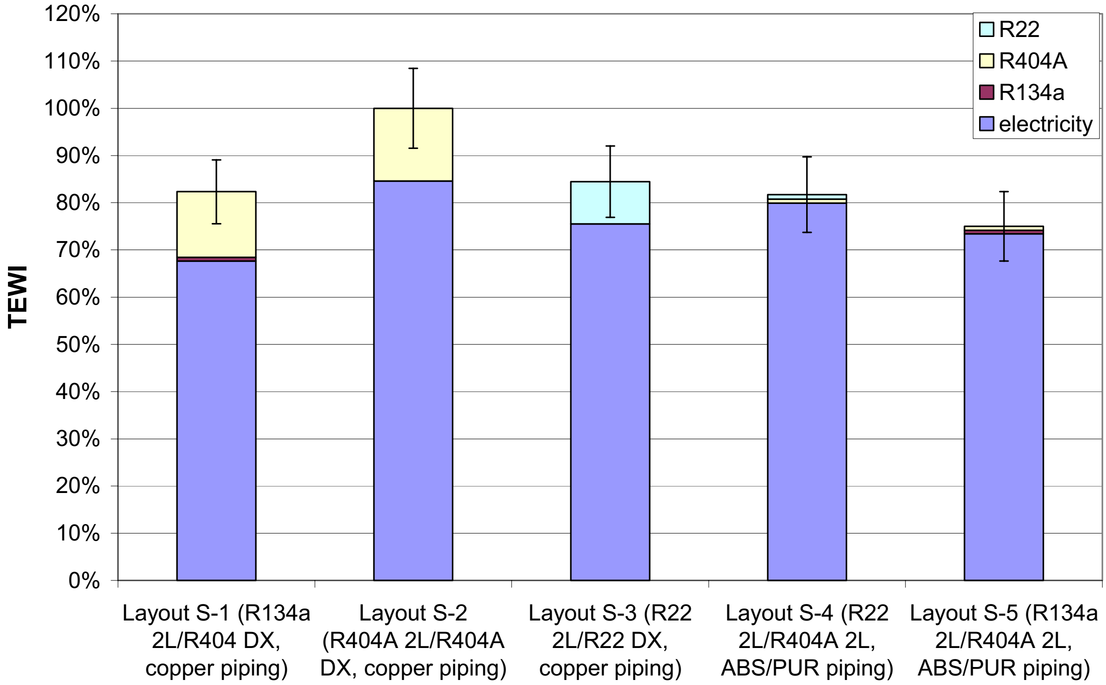

Figure 5: The results from the TEWI assessment for the five supermarket layouts. The values represent one meter of cooling device operation over the whole lifetime. The error bars represent a ±10% variation of the electricity consumption. The supermarket is operated in the USA.

Cold store

The main findings from the supermarket are also true for the cold store installation. The electricity consumption is dominant in all indicators and even to a greater extent than it was the case for the supermarket cooling systems. A 10% variation of the electricity consumption leads to a change between 7% and more than 9% in all environmental impact indicators (Figure 6 and Figure 7).

The release of toxic substances in the life cycle of the production of chromium steel results in a higher impact for layout CS-2 in the toxicity indicators (Figure 7). The other two layouts contain less chromium steel and are, therefore, lower. However, this difference is not significant under the criteria used in this study.

With the exception of the two toxicity indicators there is almost no difference between the three layouts. Since equal cold generation and insulation properties were assumed (and as a result equal electricity consumption), the difference between the three cold store layouts amounts to less than 0.3% for the remaining indicators and, as a consequence, is barely visible.

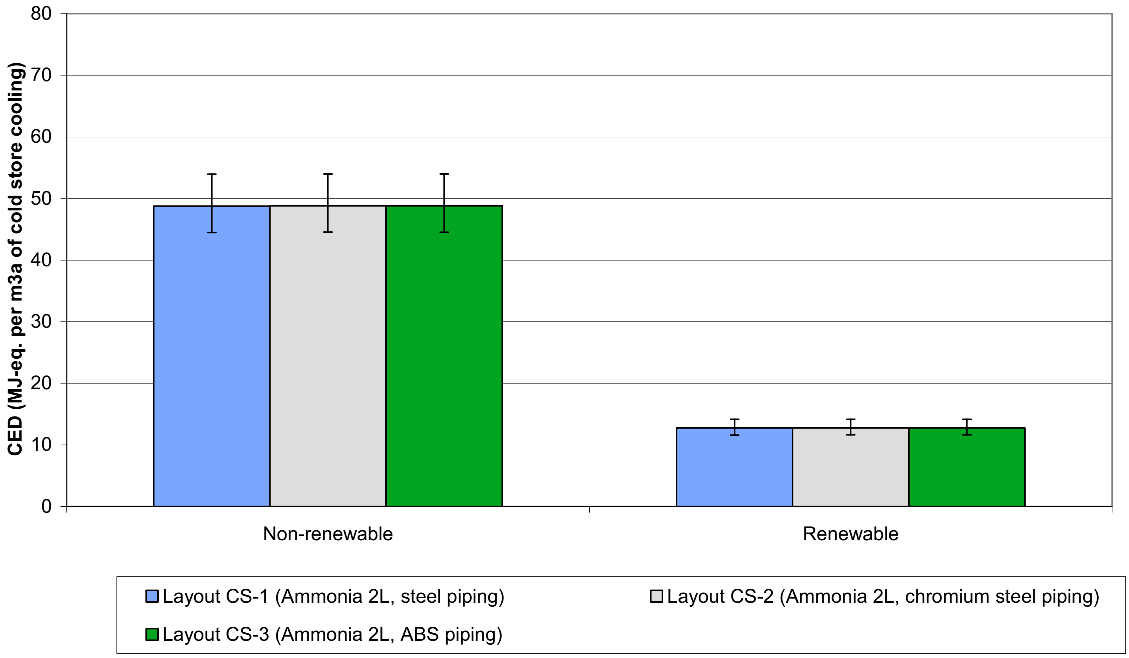

Figure 6: Absolute values of the cumulative energy demand of the three cold store layouts operated in Switzerland for renewable and non-renewable energy. The error bars represent a ±10% variation of the electricity consumption.

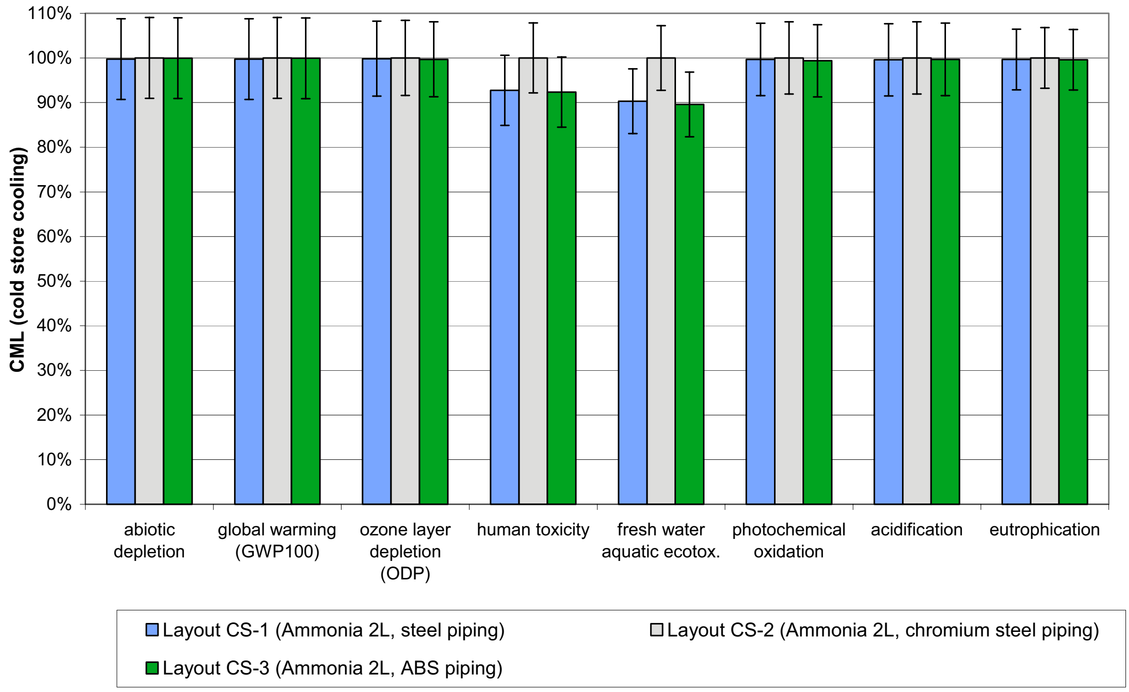

Figure 7: Percentage representation of the impact assessment of the operation of the cold store cooling systems assessed with CML 2001 (normalised values). The highest value in each indicator is set to 100%. The error bars represent a ±10% variation of the electricity consumption.

General findings

The direct influence from the cooling system infrastructure is in general small for all layouts, except for the human toxicity and freshwater aquatic toxicity indicators, where the toxic properties of copper and chromium steel show a certain relevance. The main driver in most indicators is the electricity consumption, while the refrigerant loss shows some importance in *global warming, ozone layer depletion* and *TEWI*.

Although the choice of piping system does not influence the electricity consumption or the refrigerant emissions directly, it does so indirectly. COOL-FIT can only be used in indirect configurations and comes as preinsulated pipes. This entails the following effects, which are relevant to the environmental assessment:

1. indirect cooling systems have a lower energy efficiency due to the additional heat transfer step
   → increased environmental impact for COOL-FIT systems (based on experience by experts a 10% higher electricity consumption in the low temperature section compared to the equivalent with direct cooling is assumed)
2. indirect cooling systems have lower refrigerant emissions due to lower loss rates, and also significantly reduced charges
   → decreased environmental impact for COOL-FIT systems (data based on a literature review)
3. better insulation of the pipes would lead to less cold loss and, finally, to a lower electricity consumption
   → decreased environmental impact for COOL-FIT systems (this reduction was not considered due to lack of data, but the effect can be deduced from the sensitivity analysis on the electricity consumption)

If it can be proven in the future that the electricity consumption of a cooling system with COOL-FIT is lower than with a comparable traditional layout, this would directly improve the results in most environmental impact indicators.

At the moment the results of the environmental assessment of the cooling systems, be it a supermarket or a cold store, show little difference in most indicators and layouts. In some indicators the traditional layouts seem to perform better in others the COOL-FIT ones. According to the criteria of superiority (at least 5% difference and a probability of superiority greater than 90%) the COOL-FIT layouts are not inferior in any of the indicators compared to traditional layouts. Furthermore, COOL-FIT is superior in the indicators *global warming, ozone layer depletion and human toxicity* in the case of supermarket operation in Switzerland. Supermarket operation in the USA leads to *ozone layer* and *human toxicity* as indicators with a significant superiority of COOL-FIT layouts.

The cold store cooling systems are even more dominated by the electricity consumption. Consequently, the differences between the layouts are even smaller and none of the indicators showed a significant difference.

As outlined above, the comparison of the COOL-FIT with the copper layouts (supermarket) and steel and chromium steel layouts (cold store) is not a clear and straightforward task. The aspects influencing the results – or the ones thought to at the beginning of the project - are summarised in the following (stated in order of importance):

- **electricity consumption** is highly relevant in all indicators, except *ozone layer depletion* in the supermarket assessment. Indirect systems have higher electricity consumptions, while improved insulation of the piping leads to a reduction. Both aspects play an important role when it comes to the COOL-FIT systems. While the first aspect to the disadvantage of COOL-FIT was considered, the second one – probably being to the benefit of COOL-FIT layouts – was not. The location of the supermarket is insofar of importance as the environmental impact per kWh depends on the country's electricity mix. The higher the environmental impact per kWh of electricity the less importance other aspects become (assessments for Switzerland – low impact – and for the USA – comparatively higher impact – were conducted).
- **refrigerant emissions** become relevant in the indicators *global warming, ozone layer depletion* and *TEWI* and particularly when HFC refrigerants are used. Indirect layouts have an advantage towards this aspect since the loss rates as well as the refrigerant charges are lower compared to direct cooling. However, this is at the cost of a higher electricity consumption as mentioned before.
- **life cycle toxicity of the materials used** is of some relevance in *human toxicity* and *freshwater aquatic toxicity*. The material used for the COOL-FIT pipes causes lower environmental impacts compared to copper and chromium steel in this respect.
- **transport distance of the pipes** is of minor importance. Even a transport from Europe to USA has only a small influence on the environmental impact of the installation and an even smaller one when also operation is considered.
- **recycling** of the COOL-FIT pipes at the end of life does hardly improve the environmental performance. Instead the use of recycled materials in the production of the pipes would lead to a certain environmental improvement of the cooling system installation.

It has been realised that the environmental impacts from the electricity consumption are dominating the results. When it comes to the cold store, no significant difference was identified between the layouts since the environmental impact of the piping material and the refrigerant loss is of too little importance compared to electricity consumption. In the case of the supermarket in Switzerland a superiority of COOL-FIT in three out of ten indicators and equality in the remaining seven has been shown. The somewhat higher importance of the material mainly due to a shorter life-span compared to the cold store and environmentally more important refrigerant losses lead to the discovered differences between traditional and COOL-FIT supermarket layouts.

A cooperation of Georg Fischer with the best refrigeration engineers is crucial to combine the benefits of the piping system with those of the most efficient cooling equipment.

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List of Abbreviations

2L	Secondary loop; indirect cooling circuit
ABS	Acrylonitrile Butadiene Styrene
CED	Cumulative Energy Demand - a LCIA-method
CML	LCIA-method developed by the Centruum voor Milieukunde Leiden
CO_2	Carbon Dioxide
DX	Direct expansion; direct cooling circuit
GF	Georg Fischer
GWP or GWP_{100}	Global Warming Potential with 100 years of integration time (as CO_2 equivalents)
HCFC	Hydrochlorofluorocarbons
HDPE	High-Density Polyethylene
HFC	Hydrofluorocarbons
ISO	International Organisation for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low-Density Polyethylene
m^2	square meter
m^3	cubic meter
NH_3	Ammonia
ODP	Ozone Depleting Potential (as R11 equivalents)
PUR	Polyurethane
R134a	1,1,1,2-Tetrafluoroethane (also HFC-134a)
R22	Chlorodifluoromethane(also HCFC-22)
R404A	A mixture of three refrigerants with zero ozone depleting potential
t	metric ton (1000 kg)
tkm	ton-kilometres

1. Goal

1.1. Introduction

As a reaction to the Montreal and Kyoto-Protocol the use of HFC refrigerants in supermarket refrigeration systems and cold store cooling devices is reduced by switching from direct cooling to secondary circuits. These systems make use of innovative solutions based on prefabricated and insulated plastic pipes.

Georg Fischer Piping Systems commissioned this study in April 2005 in order to gain insight into the environmental performance of their new COOL-FIT piping system compared to traditional piping systems.

1.2. Outline of the Study

This study focuses on two common cooling system installations. The first one is a supermarket installation based on partly halogenated refrigerants and the second one is a cold store using ammonia as refrigerant. The cold store has a significantly higher cooling capacity. The supermarkets are not compared with the cold stores, but only among their kind of cooling system installation. The comparison will concentrate on the types of piping. Especially the evaluation of COOL-FIT piping in relation to conventionally insulated steel and copper piping is of interest. The following aspects are covered:

- Comparison of the **environmental impact of different types of piping** (i.e. COOL-FIT vs. traditional metal pipes) connected and installed, but without other cooling devices or operation
- Comparison of the **environmental impacts of a typical supermarket** with piping in copper (mixed direct and indirect cooling circuits) and in COOL-FIT (only indirect cooling)
- Comparison of the **environmental impacts of a cold store** with piping in steel, chromium steel and COOL-FIT (all systems are based on indirect cooling)
- **Differences between an installation located in Switzerland and the USA** are addressed with respect to the leakage rate and the electricity mix in the operation phase
- Calculation of the TEWI (Total Equivalent Warming Impact) of the supermarket cooling systems
- Estimation of the effects of recycling in comparison to the disposal of the COOL-FIT pipes

LCA (Life cycle assessment) is chosen as the method to evaluate the environmental performance. This perspective considers all aspects from “cradle to grave” starting with the extraction of e.g. metal ore and crude oil, the pipe production, the operation of the supermarkets and cold stores as well as their final disposal, i.e. all related environmental aspects are included and assessed as completely as possible.

The initiators of this study are several supermarket chains and also government organisations that have requested TEWI and environmental impact data for cooling systems based on COOL-FIT piping.

1.3. Target Audience

The primary audience of the study is Georg Fischer Piping Systems itself and its clients. The results may also be used for marketing purposes. Hence, the publication of the report to a wider audience concerned with cooling systems or piping in general - or at least parts of the report - is intended. Since this study will contain comparative assertions that are disclosed to the public, critical review is conducted to comply with ISO 14040.

2. Scope (General)

This chapter provides the aspects of the scope that are valid for the piping, the supermarket and the cold store. It covers the choice of impact assessment methods (chapter 2.1), the data used and its quality (chapter 2.2) as well as the critical review procedure (chapter 2.3). The remaining aspects of the scope definition (functional unit, system boundaries) are mentioned in the respective subchapters of piping (chapter 3), supermarket (chapter 4) and cold store (chapter 5).

2.1. Impact Assessment Methods

2.1.1. Selection of the Methods

To be in accordance with the ISO standards a comparison on an aggregated single score indicator is not allowed. The evaluation needs to be conducted on the basis of impact categories. Three different methods are used in this study for the evaluation:

1. The **CML 2001** impact assessment method with Western European normalisation (Guinée et al. 2001a; b) is chosen for this study, since global warming (GWP) and ozone depletion potential (ODP) are of special interest and concern when it comes to cooling systems.
2. To pay attention to the energy consumption, which might be an important topic in this study, the non-renewable as well as the renewable indicator from the Cumulative Energy Demand (**CED**) method according to Frischknecht et al. (2004b) are chosen.
3. **TEWI** is chosen as an additional assessment method in the case of the US supermarket assessment, because this indicator is of common use in North America.

2.1.2. Cumulative Energy Demand (CED)

The CED (also called KEA - kumulierter Energieaufwand) describes the consumption of fossil, nuclear and renewable energy sources throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. plastic or wood as construction or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Boustead & Hancock 1979; Pimentel 1973). A CED assessment can be a good starting point in an assessment due to its simplicity in concept and its easy comparability with CED results in other studies. However, it does not directly valuate environmental impacts and, as a consequence, cannot replace an assessment with the help of a comprehensive impact assessment method such as CML 2001.

The following two CED indicators are used:

- CED, non-renewable [MJ-eq.] – fossil and nuclear
- CED, renewable [MJ-eq.] – hydro, solar, wind, geothermal, biomass

2.1.3. Environmental Impacts According to CML 2001

The Dutch “Centruum voor Milieukunde Leiden“ developed the CML method. This method uses a problem-oriented (mid-point) approach to assess the environmental impact. The effect of a substance is determined relative to a reference substance (e.g. CO_2 is the reference in the global warming indicator). To determine these relations, often complex modelling is used. When it comes to modelling ecotoxicity, these models contain still large uncertainties. CML is a method assessing explicitly the effects on the environment and on living things (toxicity).

The current edition - includes the latest updates from April 2004 – is used in its baseline specification (Guinée et al. 2001a; b). Deviating from this the marine aquatic toxicity is not considered because of known flaws in the impact assessment method (Frischknecht et al. 2004b, p.27). Additionally, terrestrial ecotoxicity is not included, because of contradicting literature sources concerning Cr (VI) emissions from wooden poles of the electricity transmission network, which leads to Cr (VI) soil emissions dominating the indicator and, hence, leading to results without informative value.

The following eight CML indicators are used (the reference substance is indicated in brackets):

- abiotic depletion [kg Sb eq.] – based on ultimate reserves and extraction
- global warming [kg CO_2 eq.] – GWP100
- ozone layer depletion (ODP) [kg CFC-11 eq.] – ODP with infinite time integration
- human toxicity [kg 1,4-DB eq.] – toxicity potential with infinite time integration
- fresh water aquatic ecotoxicity [kg 1,4-DB eq.] – toxicity potential with infinite time integration
- photochemical oxidation [kg ethene eq.] – high NO_x POCP
- acidification [kg SO_2 eq.] – average European acidification potential
- eutrophication [kg PO_4^{3-} eq.] – generic eutrophication potential

2.1.4. Total Equivalent Warming Impact (TEWI)

The Total Equivalent Warming Impact (TEWI), is a traditional environmental indicator in the refrigeration industry. However, there is no exact instruction in any of the three TEWI-reports (Fischer et al. 1991; Fischer et al. 1994; Sand et al. 1997) on which GWP values the calculation of the TEWI shall be based. However, with the second TEWI report (Fischer et al. 1994) they started to mainly report TEWI-values based on GWP100 from the latest IPCC-report. Since the TEWI value is only calculated for a supermarket located in USA, the same assumptions as in the newest TEWI report are used (these assumptions are also used in more recent studies like Arthur D. Little 2002):

- Calculation of the global warming potential according to the GWP-values from the 2001 IPCC report (IPCC 2001)
- Using the 100 years integration time horizon (GWP100)
- An American CO_2 emission rate[1] of 0.65 kg CO_2/kWh electricity according to the third TEWI report (Sand et al. 1997)

The TEWI value is normally calculated for the whole life-span of the installation. Since the functional unit of the supermarket is “linear meter of cooling device per year”, the TEWI value has to be calculated on that basis, but will be multiplied with 15 years to account for the whole life-span. The TEWI concept does not consider the whole life cycle, but only direct CO_2 emissions from electricity production and the global warming effect of direct refrigerant losses from the cooling system.

2.2. Data and Data Quality Requirements

The primary sources of background inventory data for the environmental evaluation in this study are:

[1] This rate depends on the location of the cooling system, of course. Since the TEWI concept is only applied to US-American supermarkets in this study this value is also included in the assumptions.

- the report "Umweltrelevanz natürlicher Kältemittel" (Frischknecht 1999a), wherefore real data on supermarket cooling systems were collected
- the ecoinvent data V1.2, which contains inventory data for many basic materials and services

If both sources provide data for a certain process, priority was given to the ecoinvent data, which was assumed to be more up to date, more thoroughly reviewed and, therefore, more reliable. This aspect is relevant on one hand for the production of the refrigerants (only R125, R143a and R404A are taken from Frischknecht (1999a) and on the other hand for the welding.

Not only did Frischknecht (1999a) collect real operation data on supermarkets, but he also provides inventory data for many processes specific to cooling systems such as refrigerants, dry cooler, etc. that were used in this study. Although the report is a couple of years old it can be easily adapted to present day situation when the following aspects are considered:

1) the cooling system technology has not significantly changed in the meantime, but a more prevalent use of indirect circuits in today's installations to minimize the refrigerant charges has become common use
2) the refrigerants used nowadays tend to have low (or even zero) ozone depletion potential
3) there were improvements towards lower refrigerant leakage rates (also a consequence of a more frequent use of indirect circuit

The first two points are addressed by selecting the relevant supermarket layouts for this report and have no influence on the data itself. The third point, the leakage rate, was updated with information from literature and personal communications from companies installing cooling systems (see Appendix A3).

The main background database is ecoinvent data V1.2 (published corrections until 23 Jan. 2006 are implemented), which has 2000 as the base year for the processes. It is a database containing consistent life cycle inventory data (LCI) for more than 2'700 processes from the energy, transport, building materials, chemicals, paper and pulp, waste treatment and agricultural sector. It is a project by the ETH[2] domain, Swiss Federal Offices and some private partners that collected these data over a period of several years. In this study mainly the processes on electricity, the metals, the plastics and the transports are taken from this database.

Additional processes specific to this study and, therefore, not contained in Frischknecht (1999a) or the ecoinvent database were deduced from information retrieved by questionnaires, from (environmental and technical) publications and personal communications. These processes were inventoried according to the ecoinvent methodology. The most important implication from this concerns the use of the cut off approach. This means that no credits for recycled materials are given and, as a consequence, the recycled materials enter the system free of environmental burden.

Every effort has been made to get reliable and up to date data. However, not all data sources – and not even all data from one source – are equally reliable. This has been considered by using the same uncertainty approach as in the ecoinvent project – every single flow of a process is attributed an uncertainty. This information is used to calculate the significance of the differences in the impact indicators for selected pairs of layouts.

2 Swiss Federal Institute of Technology

In case of choices on how to use certain data and data sources, or when there were assumptions to be made, they were rather taken to the disadvantage of the COOL-FIT layouts. The environmental impact of COOL-FIT is, therefore, more likely to be over- than underestimated. As a consequence, a small difference in favour of the COOL-FIT or the traditional layouts can already be seen as a superiority if at the same time the uncertainty assessment leads to a high probability of this superiority. For the interpretation of the results superiority is defined as follows:

1. the difference in an indicator is at least 5%
2. the probability of superiority (deduced from a Monte Carlo Analysis, which takes dependent uncertainties into account) is at least 90% for the same indicator based on a comparison of layout S-1 and S-5 (supermarkets) and layout CS-2 and CS-3 (cold stores)

2.3. Critical Review

According to the goals described in chapter 1, this study can be considered as a *"comparative assertion that is disclosed to the public"*. For such LCA studies a critical review is mandatory according to the ISO standards. The study has been critically reviewed by Dr. Arthur Braunschweig, E2 Management Consulting, who was selected by Georg Fischer Piping Systems at the beginning of the project. The critical review process was, therefore, an interactive one with feedback after the goal and scope definition and the finalisation of data investigation and again at the end of the project, when the results and conclusions were available. The full review report is available in Appendix A11.

3. Piping

3.1. Scope

This scope chapter only covers the aspects specific to the piping and its installation (i.e. functional unit, system boundaries). The remaining and more general parts are covered in the main scope chapter (chapter 2).

3.1.1. Functional Unit

The comparison is based on the function of the pipes to transport a certain amount of cooling liquid and preventing the loss of cold at the same time. 79 mm was chosen as the inner diameter of the pipes to be compared, since it is a size used in both the supermarket as well as the cold store. The insulation thickness and material (PUR) are chosen identical for all pipes, therefore, the pipes also perform comparable with concern to the loss of cold.

The functional unit is, therefore, defined as 1 meter of a PUR insulated pipe with an inner diameter of 79 mm, which is installed and connected at the location of its use.

3.1.2. System Boundaries

The production, the transports, the pipe specific installation work (pipe connections, pipe supports) and the disposal of the pipes are included in the system boundaries. However the cooling devices as well as the operation phase are not included. These aspects are covered in the supermarket chapter (chapter 4) and the cold store chapter (chapter 5).

3.2. Life Cycle Inventory (LCI)

3.2.1. Main Data Sources

The data stem mainly from the following sources:

Questionnaires:

- +GF+ Deka, 35232 Dautphetal, Germany – production of the ABS pipes for COOL-FIT
- Løgstør Rør A/S, 9670 Løgstør, Denmark – applying the PUR insulation and HDPE jacket pipe to the ABS pipes
- Henkel, Düsseldorf, Germany – producing the ABS cement and cleaner

Literature:

- Umweltrelevanz natürlicher Kältemittel (Frischknecht 1999a; b)
- The Georg Fischer brochure ”Technical Information and Product Range COOL-FIT ABS” (Georg Fischer 2004)
- Safety datasheets by Henkel on the cement and cleaner (Henkel 2005a)

There is some overlapping in data between Frischknecht (1999a) and ecoinvent data 1.2. As mentioned in chapter 2.2 priority is given to the ecoinvent data in these cases.

3.3. Background Processes

3.3.1. Data Inventoried by Frischknecht (1999a)

The processes in Frischknecht (1999a; 1999b) were mainly reported per kW or per kg. This was recalculated to get processes in more common units like e.g. meter for pipes or one unit of a machine.

Where applicable the datasets were extended by processes that have become available in the meantime. This concerns the metal related processes, where “drawing pipes”, “sheet rolling”, “section bar rolling”, “zinc coating” and “welding” were added where appropriate. Furthermore, the production process, which was already inventoried in Frischknecht (1999b), but based on the environmental reports of 1997, was updated using the most recent reports from Bitzer (Bitzer 2004a; b). For the details on this update refer to chapter 3.3.3.

In order to have a better structured and more flexible inventory it was necessary to separate the processes related to the installation of the pipes from the supermarket infrastructure dataset into an independent dataset.

The datasets used and their corresponding names in this study are summarised in Table 1. The detailed data – as it is used in this study – can be found in the appendix.

Table 1 Overview of the corresponding dataset names used in Frischknecht (1999b) and in this study.

Names in Frischknecht (1999b)	Names in this study
Plattenwärmetauscher NH3	plate heat exchanger, corrosion resistant, at plant
Rohrbündelwärmetauscher HFC	tube heat exchanger, at plant
Rückkühler Supermarkt	dry liquid cooler, supermarket, at plant
Kältemittelsammler	refrigerant receiver, at plant
Ventilator	fan, for dry liquid cooler, at plant
Verteilleitungen Kupfer	pipe, copper with Armaflex insulation, for supermarket, at plant
Kompressor Bitzer	compressor Bitzer, at plant
Infra Supermarkt *(pipe installation part)*	installation, distribution pipes, welded pipes, in supermarket
Infra Supermarkt *(non-pipe installation part)*	cooling system, 104 kW
Kühlmöbel Supermarkt	operation, cooling devices
Entsorgung Supermarkt	disposal, cooling system 104 kW

3.3.2. Butyl Acetate

Butyl acetate is not included in the ecoinvent data V1.2, but a chemical used in the production of Tangit ABS cement. Vinyl acetate, which is produced by the same type of reaction as butyl acetate, is included in ecoinvent data V1.2 (Hischier 2004: part II). The difference is that instead of ethylene butanone is used in the reaction with acetic acid. The butyl acetate process for this study is created using the same assumptions on heat, electricity, cooling water consumption and solvent losses as the vinyl acetate in the ecoinvent database (see appendix A5.4 for the detailed process data).

3.3.3. Manufacturing Process Cooling System Devices

The process on manufacturing cooling system devices is based on three factories in Germany belonging to the Bitzer company. The data stems from the respective environmental reports (Bitzer 2004a; b). Data on the following three factories (including their main products) were reported:

- Sindelfingen (head office, development and construction division, compressors, pressure vessels)
- Hailfingen (liquid receivers, oil separators, condensers)
- Schkeuditz (reciprocating compressors, devices for refrigeration and air conditioning installations)

The data presented in Table 2 is the sum of the three factories. The final process "manufacturing process, cooling system device" was normalized to 1 kg of metal in the end-product (see appendix A5.5). Assumptions – especially on the way of disposal – were necessary to fill gaps of information.

Table 2: The data on which the process "manufacturing process, cooling system device" is based.

			Remarks / Assumptions
Annual Production (approx.)	13'338	t	Refers to amount of metal in end-product
Resources			
Industrial Area (partly vegetated)	74'263	m^2	About 11% of the area is vegetated, the remaining 89% are assumed to be covered with factory halls
Energy carriers			
Heat from light fuel oil	21'999'600	MJ	End energy assumed
Heat from natural gas	21'294'817	MJ	End energy assumed
Electricity	11'773'000	kWh	Medium voltage
Input products			
Water-based varnish	111'140	kg	Water-based alkyd paint assumed
Epoxy resin varnish	1'350	kg	
Auxiliary materials	139'870	kg	Mainly machine oil
Wood	125	m^3	Considered only as input since recycled
Paper and cardboard	167'100	kg	Considered only as input since recycled
Packaging film	25'390	kg	Considered only as input since recycled
Water consumption	24'624'000	kg	Decarbonised water assumed
Waste disposal			
Waste water	24'624	m^3	Equal to amount of tap water
Waste oil	16'554	kg	Disposal in hazardous waste incinerator
Municipal waste	114'944	kg	Incinerated
Special (hazardous) waste	286'486	kg	Disposal in hazardous waste incinerator

3.4. Foreground Processes

3.4.1. Tangit ABS Adhesive and Cleaner

The COOL-FIT pipes and fittings are connected using special cement. In order to have good results in cementing, the surfaces to bond are cleaned with a special cleaner, which is similar in formulation to the adhesive. According to the safety data sheets the main content is butanone and butyl acetate for the Adhesive (Henkel 2005a), respectively butanone and acetone for the Cleaner (Henkel 2005b). More detailed data was obtained through the questionnaire, which is summarised in Table 3 (Adhesive) and Table 4 (Cleaner). To consider also for the building and land use, the dataset of a general chemical plant from the ecoinvent database was applied additionally (appendix A6.3).

The solvent emissions during the application are not considered in this process, but in the pipe installation in chapter 3.4.5. According to the questionnaire 100% of the solvents are released to the air.

Table 3: The input data for the production of the Tangit ABS cement (Data provided by Henkel)

	per kg of Tangit ABS cement		Remarks
Input materials			
Methyl ethyl ketone	0.55	kg	delivery by lorry (100km)
Butyl acetate	0.20	kg	delivery by lorry (100km)
Several organic solids	0.25	kg	delivery by lorry (100km)
Electricity (low tension)	0.010	kWh	German electricity mix
Water	0	l	Process is water free
Emissions and Waste			
Carbon Dioxide	0.0015	kg	Solvent emissions during production are burnt (estimation for maximum value)
Municipal waste	0.0006	kg	Landfilled (10km of transport)
Adhesive waste	0.0025	kg	to hazardous waste incineration (20km of transport)
Packaging			
Tin can	0.132	kg	Container for the adhesive
Cardboard	0.051	kg	for shipping

Table 4: The input data for the production of the Tangit ABS/PVC cleaner (Data provided by Henkel)

	per kg of Tangit ABS/PVC cleaner		Remarks
Input materials			
Methyl ethyl ketone	0.5	kg	delivery by lorry (100km)
Acetone	0.5	kg	delivery by lorry (100km)
Electricity (low tension)	0.0023	kWh	German electricity mix
Water	0	l	Process is water free
Emissions and Waste			
Carbon Dioxide	0.0013	kg	Solvent emissions during production are burnt (estimation for maximum value)
Municipal waste	0.0004	kg	Landfilled (10km of transport)
Solvent waste to recycling	0.0013	kg	to hazardous waste incineration (20km of transport)
Packaging			
Tin bottle	0.141	kg	Container for the cleaner
Cardboard	0.036	kg	for shipping

3.4.2. COOL-FIT Pipes, Fittings and Nipples

Transports

COOL-FIT pipes and fittings are preinsulated at the factory. There are three types of material used: 1) *ABS* for the pipe, 2) *PUR* (rigid foam) for the insulation and 3) *HDPE* for the jacket pipe. The ABS part of the pipes is produced at a factory in Germany by DEKA GmbH, whereas the fittings are made in Switzerland. The insulation and the jacket pipe of both, the pipes and the fittings, are added in Denmark. From there a) *the pipes* are directly delivered to the clients and b) *the fittings* are sent to the centre of distribution in Switzerland. All these transports are conducted by lorry. An overview of the transport processes can be seen in Figure 8. The distances between the locations are summarised in Table 5.

The nipples are produced at the same place as the pipes (Deka, Germany), but don’t need to be insulated. Hence, they are directly sent to the centre of distribution in Schaffhausen (Figure 8).

The routes of transport are different for ABS pipes with an outer diameter of 110 mm and larger, since they are not produced by Deka. However, the largest size needed in the cold store and supermarket layouts was 90 mm. Therefore, this aspect had not to be tracked any further.

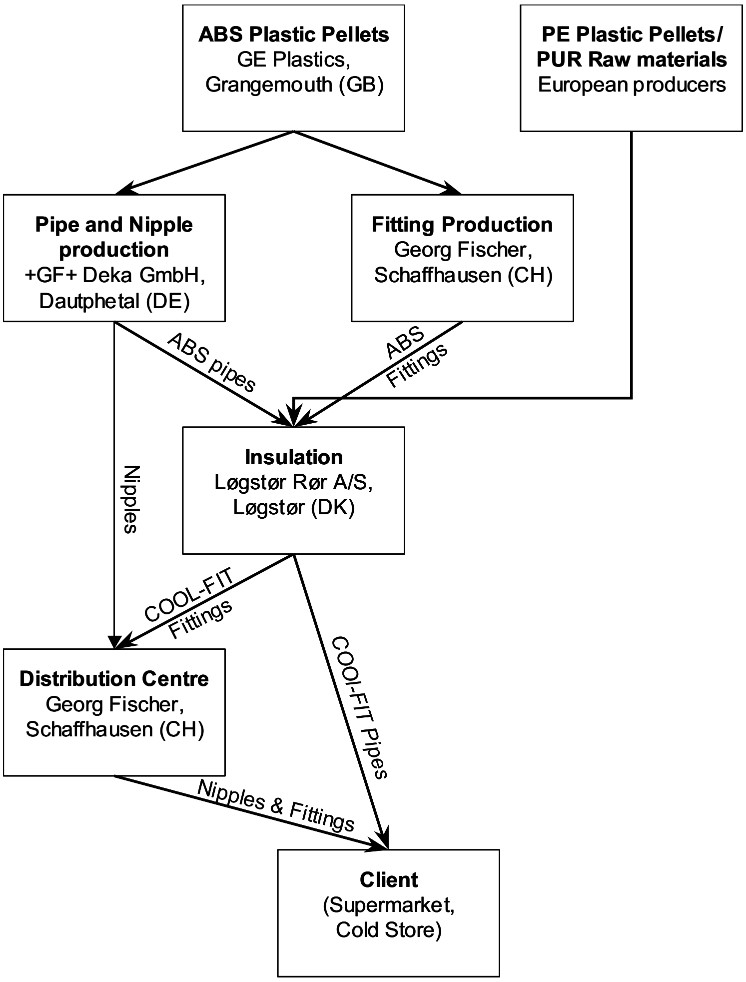

Figure 8: The routes of transport for the basic materials in the production of COOL-FIT pipes, fittings and nipples. All transports are conducted by lorry

Table 5: Distance matrix for the transports in Figure 8. The route of transport for a certain value is from the location in the row to the location in the column. Distances are in kilometre. Empty cells: there are no transports between those places
SD: standard distance, i.e. 100 km by lorry, 200 km by rail (Frischknecht et al. 2004a)

From: \ To:	GF Schaffhausen	Løgstør DK	GE Plastics, Grangemouth	GF Dautphetal (DEKA)	European Plastic Producer	Client (supermarket in CH)
GF Schaffhausen		1270				100
Løgstør (DK)	1270					1300
GE Plastics, Grangemouth	1610			1365		
GF Dautphetal (DEKA)	460	865				
European Plastic Producer		SD				
Client (supermarket in CH)						

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Production of ABS Pipes

The pipes are produced at Deka in Germany. A questionnaire was sent to Deka to obtain site-specific production data. Since there is an environmental management system in operation, accurate and up to date data on auxiliary production inputs, packaging, outputs and wastes were received (Table 6 and appendix A6.1).

Table 6: Manufacturing process of the ABS pipes at Deka in Germany.

	per metric tonne of ABS pipe		Remarks
Industrial area, partly vegetated	5.2	m^2	Questionnaire
Office building	0.35	m^3	Questionnaire; Assumptions: multi-story, story height 2.5m
Production hall and storehouse	2.4	m^2	Questionnaire
Plastic film for packaging	22	kg	Questionnaire
Electricity (low tension, DE)	638	kWh	Questionnaire
Light fuel oil, burned in industrial furnace	348	MJ	Questionnaire (in litre), converted to MJ using a density of $0.86 kg/dm^3$ and 42.6MJ/kg (Jungbluth 2004)
Tap water	0.14	m^3	Questionnaire
Waste water	0.085	m^3	Questionnaire
Waste water vapour	0.053	m^3	Difference between consumption and waste water
Domestic waste (similar)	8.4	kg	Questionnaire
Special waste	0.32	kg	Questionnaire

Insulation of the ABS pipes

The pipes are insulated with PUR and protected with a HDPE jacket pipe at Løgstør in Denmark. A questionnaire was sent to Løgstør to obtain site-specific data. Since the production of the COOL-FIT pipes constitutes only a small part (approx. 2%) of the total production, the data is often an average of the whole production. Løgstør produces almost exclusively preinsulated pipes, however. Thus, the averaged values received are supposed to be representative for the COOL-FIT share.

Due to the different shares of HDPE and PUR in pipes of different sizes, two processes 1) jacket pipe (HDPE) and 2) foaming (PUR) are developed. An allocation of the production means had to be performed. Since the data obtained was already an average, it was decided to make the allocation according to the PUR and HDPE consumption in one year. They were almost equal (20'033 kg vs. 20'100 kg). Therefore, half of the general production means are attributed to PUR foaming and the other half to the jacket pipe production (based on weight). An overview of the resulting data is summarised in Table 7 and used in the insulation as well as the jacket pipe processes (appendix A6.4). The share of input materials is almost equal and the losses are slightly lower than the values reported in Hischier (2004: Part II). The electricity consumption is distinctly higher because the value used does not only consider the direct consumption of the production machine, but also the indirect electricity needed for supporting machines and also office consumption is considered.

Table 7: Production process of insulating the ABS pipes at Løgstør in Denmark

	per kg PUR or HDPE in pipe		Remarks
General production data			
Industrial area, partly vegetated	0.22	m^2	Questionnaire
Area covered by buildings	0.027	m^2	Questionnaire, mostly production hall assumed
Water consumption	0.021	m^3	Mail Andersen (Løgstør)
Scrap at production	1.5	%	Mail Andersen (0.5% scrap, 1% waste from cutting the ends)
Plastic film for packaging	*0.050*	kg	***per meter pipe*** (Data from Georg Fischer Piping Systems)
Electricity consumption (low tension)	3.5	kWh	Mail Andersen, Danish electricity mix
Heat (from district heating)	6.9	MJ	Mail Andersen
Foaming			
Polyurethane (PUR)	1.015	kg	Questionnaire
- Polylol	0.35	kg	Questionnaire
- Isocyanate	0.63	kg	Questionnaire
- Cyclopentane	0.039	kg	Questionnaire
Loss of cyclopentane	10	%	Mail Andersen (5-10%)
CO2 (from foaming)	0.0063	kg	Mail Andersen (1.5% water in polyol, reaction with cyanate produces CO_2)
Jacket Pipe			
HDPE pellets	1.015	kg	Questionnaire

Nipples and Fittings

Fittings represent only a small share in relation to the COOL-FIT pipes in a supermarket and the more in a cold store installation. This is also true for the non-insulated and even smaller nipples. Therefore, a simplified approach was chosen to consider the nipples and fittings in the inventory. Their inventory was simply approximated by calculating an equivalent pipe length (Table 8) and then multiplying with the process inventory of the respective pipe diameters. For the supermarket an average fitting was calculated. In the case of the cold store the average corresponds to the 90 degree bends, which were used most frequently.

Table 8: Equivalent pipe lengths (meter pipe/piece of fitting) used to approximate the fittings and nipples. Only the fittings with the values in bold are used in this study.

	90° Bend pre-insulated [m/piece]	90° Tees prein-sulated [m/piece]	45° Elbow pre-insulated [m/piece]	Average Fitting [m/piece]	Nipple [m/piece]
Supermarket	0.171	0.225	0.086	**0.181**	**0.066**
Cold Store	0.363	-	-	**0.363**	**0.104**

In contrast to the pipes, the fittings and nipples are not directly shipped to the client but sent to the centre of distribution in Schaffhausen. Their packaging in plastic bags and cardboard boxes as well as the additional transport are, therefore, considered.

3.4.3. COOL-FIT pipes

COOL-FIT pipes are used in the supermarket and in the cold store layouts. The data is taken from the Georg Fischer brochure on the COOL-FIT pipes (Georg Fischer 2004). The average pipe for the supermarket was calculated by rebuilding the supermarket with indirect cooling in Frischknecht (1999a) and calculating the average mass per meter from the total pipe installation.

To see the influence of using recycled plastic as input material for the COOL-FIT pipes, there are three alternatives of the same pipe diameter in the comparison. It is assumed that PUR from recycled material is not feasible, but the ABS and HDPE consist of recycled plastic. In the first alternative a quota of 50% is assumed (resulting in 40% of the total mass incl. PUR), in the second 100% (resulting in 75% of the total mass) is assumed to be from recycling.

The basic data used for the COOL-FIT pipe datasets is summarised in Table 9 (input data in appendix A6.1).

Table 9: Overview of the basic data used for the COOL-FIT pipes.

Dimension di (mm)	average for supermarket	44	55.4	79.2 no recycl.	79.2 40% recycl.	79.2 75% recycl.
Pipe						
Wall thickness [mm]	- [a)]	3	3.8	5.4	5.4	5.4
ABS [kg/m]	0.29	0.46	0.73	1.48	0.74	0
ABS from recycling [kg/m]	0	0	0	0	0.74	1.48
Insulation						
Insulation thickness [mm]	- [a)]	32	27.3	28	28	28
PUR [kg/m]	0.28	0.46	0.56	0.86	0.86	0.86
PUR from recycling [kg/m]	0	0	0	0	0	0
Jacket Pipe						
Wall thickness [mm]	- [a)]	2.7	3	3	3	3
HDPE [kg/m]	0.47	0.86	1.08	1.39	0.69	0
HDPE from recycling [kg/m]	0	0	0	0	0.69	1.39

[a)] The calculation of the average pipe was based on mass per length and, therefore, no diameters or thicknesses can be calculated

3.4.4. Copper and Steel Pipes

Steel pipes (low-alloyed steel and chromium steel) are only used in the cold store layouts. There are three different pipe sizes. The inner diameter of steel, chromium steel and COOL-FIT pipes are all chosen to be identical, i.e. 44, 55 and 79 mm. The wall thickness of the steel pipes was chosen in accordance with DIN 8905, which defines 1.5mm below and 2 mm above an outer diameter of 54 mm. The steel consumption of each pipe was computed from these indications.

Foaming with PUR and a galvanised steel jacket is used for insulating the pipes. The thickness of the PUR-insulation was assumed to be the same as of the respective COOL-FIT pipes. However, since the steel of the pipe and the jacket have a higher thermal conductivity than the plastic from COOL-FIT, they are not completely equal with respect to insulation properties. Furthermore, the factory foaming of COOL-FIT under controlled conditions may result in a better insulation quality at the same thickness. Therefore, the cold loss is probably slightly higher for the steel than the COOL-FIT pipes.

Copper pipes are only used in the supermarket layouts. Due to the comparison of the pipes, there is a 79 mm copper pipe with identical properties as the steel pipes. This means PUR insulation and jacket pipe. For the supermarket the average copper pipe reported in Frischknecht (1999a) was used.

The basic data used for the steel and copper pipe datasets is summarised in Table 10 (input data in appendix A5.1). Pipe drawing, sheet rolling, zinc coating and emissions during PUR foaming are considered.

Table 10: Overview of the basic data used for the copper, steel and chromium steel pipes.

Dimension dxdi (mm)	average for supermarket	83x79	47x44	59x55	83x79
Pipe					
Material	Copper	Copper	Steel	Steel	Steel
Outer diameter [mm]	-[a)]	83	47	59	83
Wall thickness [mm]	-[a)]	2	1.5	2	2
Inner diameter [mm]	-[a)]	79	44	55	79
Weight [kg/m]	1.56	4.53	1.68	2.81	4.00
Insulation					
Material	Armaflex	PUR	PUR	PUR	PUR
Insulation thickness [mm]	-[a)]	32	27.3	28	32
Inner diameter [mm]	-[a)]	83	47	59	83
Weight [kg/m]	0.15	0.81	0.45	0.54	0.81
Steel Jacket Pipe					
Outer diameter [mm]		147.4	102	115.4	147.4
Wall thickness [mm]		0.2	0.2	0.2	0.2
Inner diameter [mm]		147	101.6	115	147
Weight [kg/m]		0.73	0.50	0.57	0.73
Surface[b)] [m^2/m pipe]		0.46	0.32	0.36	0.46

[a)] The calculation of the average pipe was based on mass per length and, therefore, no diameters or thicknesses can be calculated
[b)] information required for the zinc coating

3.4.5. Piping Installation Switzerland

The installation of the pipes is recorded in a separate process, in contrast to Frischknecht (1999b), where it was included in the infrastructure process. As the installation effort mainly depends on the pipe length and the kind of piping used, it was thought that on one hand the data handling becomes less prone to errors and on the other hand the data is easier to understand.

The following aspects of the installation work are considered in the process for the non-COOL-FIT piping:

- steel for the pipe supports
- welding of the pipes, incl. emissions to air
- transport of the pipes to the installation site (differentiated between a Swiss and a US installation site)

The COOL-FIT pipe installation process encompasses the following:

- steel for the pipe supports
- Tangit adhesive and cleaner use, incl. emissions to air
- shrink sleeve
- gap insulator
- transport of the pipes to the installation site (differentiated between a Swiss and a US installation site)

The COOL-FIT layouts need about 30% less hangings, i.e. less pipe supports, due to the lower weight of the COOL-FIT pipes on a per meter basis (Georg Fischer 2004, p.8). This results in a lower steel demand of about the same amount. The pipes themselves are not included in this process dataset. The data for the supermarket in Table 11 is based on Frischknecht (1999b) and data directly obtained from Georg Fischer Piping Systems[3]. In the case of the cold store the data is partly based on interpolation according to the pipe weight per meter or on the number of pipe connections when this was thought to be more appropriate.

[3] Personal Communications on COOL-FIT and the Cold Store by Mark Bulmer (Georg Fischer Piping Systems, Schaffhausen), several dates 2005

Table 11: The input data for the installation of pipes in the supermarket and in the cold store.

	Installation of copper pipes in supermarket [per m pipe installation]	**Installation of COOL-FIT pipes in supermarket** [per m pipe installation]	**Installation of steel pipes in cold store** [per m pipe]	**Installation of COOL-FIT pipes in cold store** [per m pipe]
Pipe support installation				
Steel [kg]	0.56	0.38	1.91	1.28
Pipe connections				
Gas welding (acetylene) [m]	1.5		0.49	
Cement (Tangit ABS) [kg/m]		0.049		0.016
Cleanser (Tangit ABS/PVC) [kg/m]		0.011		0.004
Shrink sleeve [kg/m]		0.220		0.070
Gap filler (PUR) [kg/m]		0.006		0.002
Solvent loss adhesive		100%		100%
Solvent loss cleaner		100%		100%

The transport distances used for the installation in Switzerland and in USA are shown in Table 12. It was assumed that the COOL-FIT pipes are always produced in Europe and then transported to the site. If the site is located in the USA a transoceanic transport by freight ship is added. Furthermore, it was assumed that the transport distances in the USA are the double from the ones used for Switzerland. The metal pipes are assumed to be produced in USA and do not need transoceanic transport.

Table 12: Transport distances for the installation of the pipes at a site in Switzerland and USA

	Installation of copper pipes in supermarket	**Installation of COOL-FIT pipes in supermarket**	**Installation of steel pipes in cold store**	**Installation of COOL-FIT pipes in cold store**
Transports for Swiss location				
Production → Preassembling or intermediate storage [km]	300	440	300	400
Preassembling → installation site [km]	100	100	100	100
Transports for USA location				
Production → European port [km]	0	115	0	115
Transoceanic transport [km]	0	10000	0	10000
Port or Production -> preassembling or interm. storage [km]	600	880	600	800
Preassembling → installation site [km]	200	200	200	200

3.5. Impact Assessment Results

3.5.1. Introduction

The pipe materials compared are: 1) COOL-FIT (with different shares of input material from recycled plastic as well as a pipe installed in the USA), 2) chromium steel pipes, 3) low-alloy steel pipes and 4) copper pipes. All pipes are enclosed by a jacket pipe (HDPE in the case of COOL-FIT, low-alloy steel in all other cases) and have PUR insulations of identical thickness.

Although data for different pipe diameters were compiled in the previous chapter, the impact assessment concentrates exclusively on pipes with an inner diameter of 79 mm in order to have a common and an unbiased basis (as far as possible) for the comparison. The other diameters come into use later when the supermarket and cold store installations are assessed.

3.5.2. Cumulative Energy Demand

As can be seen in Figure 9 the non-renewable CED indicator bars for copper, chromium steel and COOL-FIT pipes without recycled plastic content are very close to each other, whereas for the renewables the COOL-FIT pipes perform significantly better than the copper and chromium steel pipes. This is the consequence of the COOL-FIT pipes made of plastic. Plastic is made of fossil fuels, which contributes to the non-renewable part of the cumulative energy demand, but not to the renewable one.

Considering also the lifespan of the pipes the steel pipes possibly have the lowest lifespan due to the vulnerability to corrosive effects. The lifespan was assumed to be the same for all pipes. Since pipes are often replaced together with the whole cooling system and, as a consequence, before achieving their maximum lifespan, this assumption can be considered as reasonable.

It is obvious that the share of recycled plastic in the COOL-FIT pipes has a significant impact on the result. COOL-FIT pipes with about 40% of recycled material achieve a result close to the low-alloyed steel pipes and outperform them with higher recycled material content. On the other hand the effect of the transport of the COOL-FIT pipes to the USA is of minor, but still noticeable, importance.

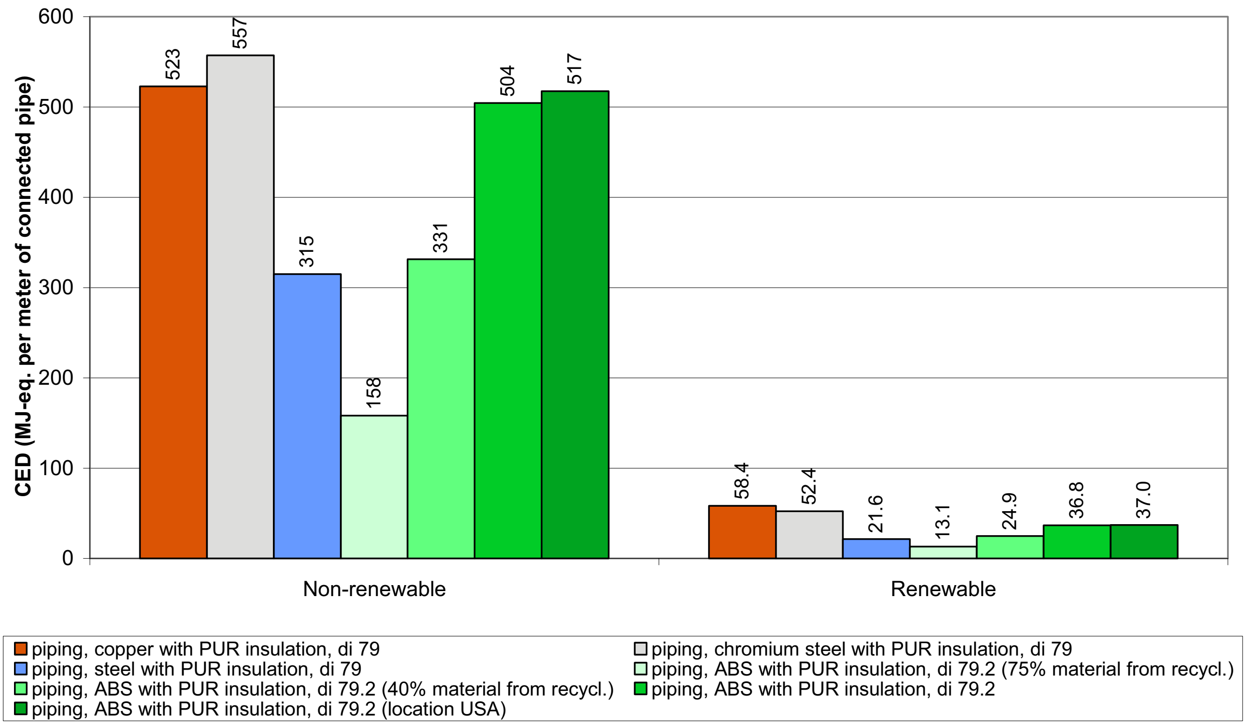

Figure 9: Absolute values of the cumulative energy demand of the four pipe materials (incl. connections, transport to the installation site, pipe hanging and end of life treatment) for renewable and non-renewable energy.

3.5.3. Environmental Impacts According to CML 2001

The picture in the CML assessment differs from the CED assessment in chapter 3.5.2. While still either copper or chromium steel pipes have the highest environmental impact in all indicators, the COOL-FIT pipes (0% recycled plastic) now perform better than the steel pipes in 4 out of 8 indicators. In the CED assessment the steel pipes are distinctly better (Figure 9) – also compared to COOL-FIT, but in the CML assessment this is only true for abiotic depletion, global warming and acidification (Figure 10).

Increasing the share of recycled plastic in the COOL-FIT pipes – as was already realised in the CED assessment (chapter 3.5.2) – results in a significant improvement in most of the indicators. The effect of transporting the COOL-FIT pipes to the USA results in a slightly higher environmental impact than the respective pipe installed in Europe.

The contrast between copper and chromium steel pipes on one hand and steel and COOL-FIT pipes on the other is most apparent in human toxicity, freshwater aquatic ecotoxicity, photochemical oxidation and eutrophication (Figure 10). This is due to the toxicity of chromium and copper and because their emission to air and water cannot be completely avoided during the extraction, beneficiation and processing to the final metal product.

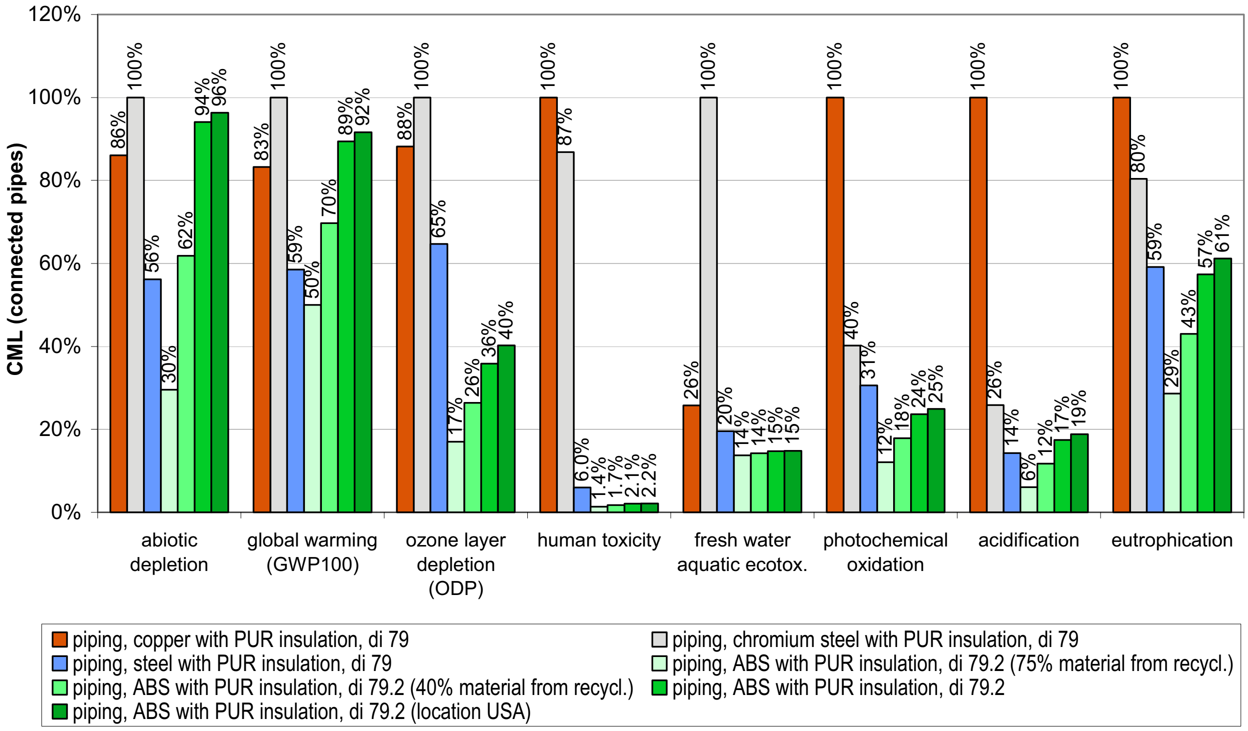

Figure 10: Percentage representation of the impact assessment of the four different pipe materials (incl. connections, transport to the installation site, pipe hanging and end of life treatment) with CML 2001.The highest value in each indicator is set to 100%

3.6. Interpretation

The direct comparison of the installed piping has to be used with care, since it does not consider the constraints each piping system entails. For example the heat exchanger between the primary and secondary circuit are compulsory for COOL-FIT piping, but not for traditional metal piping. These aspects become included when the comparison is based on supermarket (chapter 4) and cold store operation (chapter 5).

In any case it can be said that the use of input material from recycling is advantageous. COOL-FIT pipes without a share of recycled input materials have in some indicators an environmental impact as high as chromium steel or copper pipes, but with only 40% share of recycled material input COOL-FIT pipes perform in most indicators at least as good as steel pipes.

As a conclusion, it can be said that using (partly) recycled material input in the production of COOL-FIT pipes can lead to a significant improvement in the environmental performance of COOL-FIT piping.

4. Supermarket

4.1. Scope

This scope chapter only covers the aspects specific to the supermarket installation (i.e. functional unit, system boundaries, TEWI impact assessment). The remaining parts are covered in the general scope chapter (chapter 2).

4.1.1. Functional Unit

The purpose of a supermarket cooling system is to extract energy from the cooling appliances in order to keep the products cooled (or frozen). The amount of energy extracted from the cooling appliances is not easily accessible. However, the number and types of the cooling devices are often known. Frischknecht (1999a, p. 71) used correction factors (see Appendix A4) to consider the different shapes as well as the depth and height of the appliances. Since the openness of the cooling appliances is a main factor in the loss of cold, it can be assumed that such a corrected front length is directly correlated with the amount of cooling energy used at those end-user appliances. Therefore, the linear length of the appliances can be used as a feasible substitute of end-user cooling energy.

The functional unit for the supermarket is defined as **"one year operation of one corrected linear meter of cooling appliances"** with the unit m*a.

4.1.2. System Boundaries

The layout of a typical Swiss supermarket cooling system of today is an indirect circuit for fridge cooling and direct evaporation for the freezer cooling with a total average cooling capacity of 104 kW (Frischknecht 1999a). This is different from the layout for which COOL-FIT is designed. Therefore, two layouts providing the same cooling energy have to be compared. One is a typical supermarket layout with copper piping and a direct as well as an indirect cooling circuit (Figure 11):

freezer cooling: direct evaporation of the refrigerant in the end device

fridge cooling: indirect evaporation (with a secondary circuit and a cooling fluid)

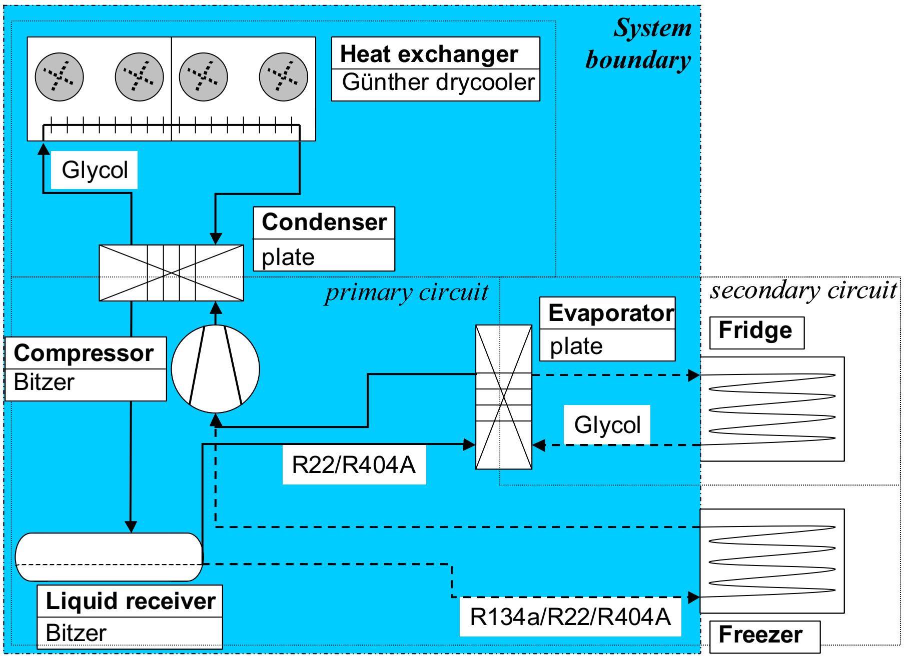

Figure 11: Layout of the copper supermarket cooling system with direct evaporation for freezers (low temperature circuit) and indirect for fridges (medium temperature circuit)

The second one is a typical COOL-FIT layout with twice an indirect cooling circuit (Figure 12):

freezer cooling: indirect evaporation (with a secondary circuit and a cooling fluid)

fridge cooling: indirect evaporation (with a secondary circuit and a cooling fluid)

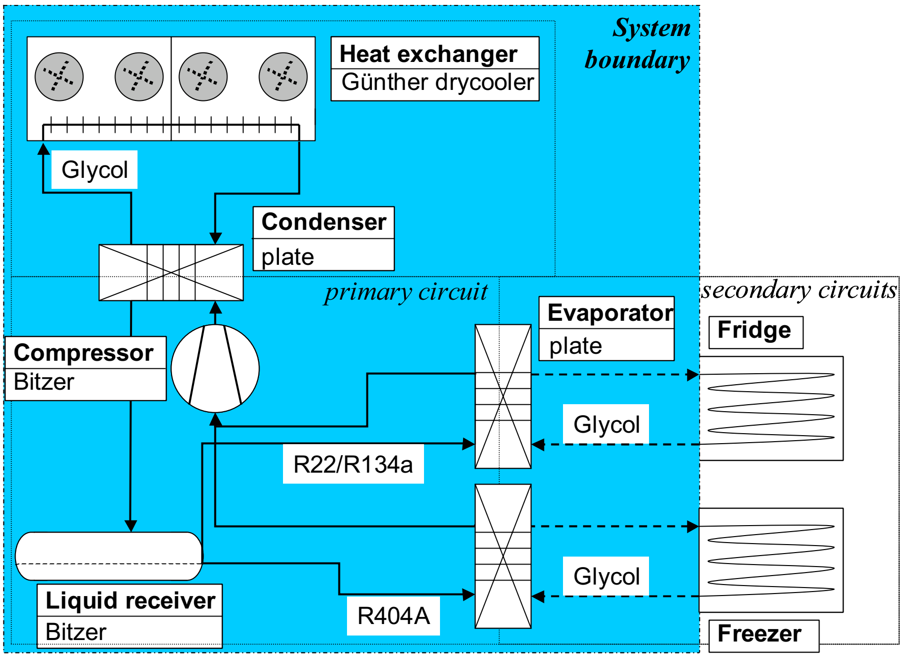

Figure 12: Layout of the COOL-FIT supermarket cooling system with indirect evaporation for freezers and for fridges

Common to both types of layout are:

- the heat exchangers
- the condenser
- the evaporator (however, the COOL-FIT layouts need one more)
- the compressor
- the liquid receiver

The differences between the supermarket installation layouts are summarised in the following Table 13. There are different kinds of refrigerants in the supermarket layouts. Since they have an influence on the efficiency of the cooling system, the electricity consumption will be individual for each layout to assure that the same amount of cooling energy is provided in all layouts. This is necessary to be in accordance with the definition of the functional unit.

Table 13: Overview of the 5 supermarket layouts analysed in this study. The first three systems are mixed with direct and indirect evaporation, the last two – the ones with COOL-FIT – are indirectly evaporating for both circuits. DX: Direct expansion (direct cooling), 2L: Secondary loop (indirect cooling)

	Layout S-1 (copper)	Layout S-2 (copper)	Layout S-3 (copper)	Layout S-4 (COOL-FIT)	Layout S-5 (COOL-FIT)
Fridge cooling					
type of circuit	2L	2L	2L	2L	2L
refrigerant	R134a	R404A	R22	R22	R134a
cooling fluid	glycol	glycol	glycol	glycol	glycol
primary circuit	copper	copper	copper	copper	copper
secondary circuit	copper	copper	copper	COOL-FIT	COOL-FIT
Freezer cooling					
type of circuit	DX	DX	DX	2L	2L
refrigerant	R404A	R404A	R22	R404A	R404A
cooling fluid	-	-	-	glycol	glycol
primary circuit	copper	copper	copper	copper	copper
secondary circuit	-	-	-	COOL-FIT	COOL-FIT
Piping insulation					
primary circuits	Armaflex	Armaflex	Armaflex	Armaflex	Armaflex
secondary circuit(s)	Armaflex	Armaflex	Armaflex	PUR with HDPE jacket	PUR with HDPE jacket

Apart from the already mentioned components the following processes are also considered:

- Installation of the cooling system (material use for the pipe supports, insulation, welding and cementing, the transport of the whole cooling system to the installation site)
- replacement and emissions of refrigerant during operation
- the final disposal of the cooling system including the refrigerants

The fridges and freezers of the supermarket are outside the system boundary. The goal of this study is to compare the different cooling system layouts where all of them provide the same amount of cooling energy to these end devices. Therefore, it is not necessary to include them.

4.1.3. System Boundaries specific to TEWI impact assessment

For the calculation of the TEWI (Total Equivalent Warming Impact) the system boundaries of the life cycle inventory need to be set differently from the main study (see also chapter 2.1.4). The TEWI concept encompasses only two aspects of greenhouse gas emissions (Fischer et al. 1991):

1) The indirect global warming effects due to electricity consumption
2) The direct effects due to refrigerant losses during the operation and disposal of the cooling system

Emissions of greenhouse gases in connection with the infrastructure of the cooling system or the power plants are not included in TEWI. Also excluded are losses of refrigerants during their production, storage or transport.

4.1.4. Data and Data Quality Requirements

The supermarket layouts represent type specific average installations in Switzerland in the year 1999. The layouts with COOL-FIT piping are for the fridge cooling basically the same installations, but with COOL-FIT instead of copper or steel pipes. The main difference in the freezer cooling is the direct vs. indirect cooling for copper and COOL-FIT pipes respectively. The operational data is assumed to be independent of the piping, but dependent on whether a direct or indirect design is used. Frischknecht (1999a) also reports data for indirect freezer cooling, which is used for the COOL-FIT layouts. The refrigerant leakage rates are updated for all layouts to the 2005 situation, since the refrigerant loss contributed largely to the overall result in Frischknecht (1999a) and a significant reduction in the last years can be expected due to awareness as well as regulations. This update will enhance the validity of the conclusions also for present-day supermarket installations.

4.2. Life Cycle Inventory (LCI)

4.2.1. Introduction

The average supermarket that was defined in Frischknecht (1999a) and which is also used in this study, has a cooling capacity of 82.3 kW for medium and 21.3 kW for low temperature cooling (fridge and freezer cooling, respectively) totalling in approximately 104 kW.

The data reported in Frischknecht (1999a; 1999b), were partly recalculated because of some minor errors in the values reported. This concerns only the electricity consumption and the refrigerant charge of some of the supermarket cooling systems.

4.2.2. Main Data Sources

The data for the supermarket stem mainly from the following sources:

Personal communications:

- Mark Bulmer, GF Piping Systems - COOL-FIT parts list for the supermarket
- Mr. Gysin, Schaller Uto AG, Bern – general information on supermarket layouts as well as estimations from practical experience of today
- Mr. Trüssel, KWT Kälte-Wärme-Technik AG, Belp – general information on supermarket layouts as well as estimations from practical experience of today
- Mr. Burger, Walter Wettstein AG, Gümligen – general information on supermarket as well as estimations from practical experience with special focus on secondary systems

Literature:

- Umweltrelevanz natürlicher Kältemittel (Frischknecht 1999a; b)

There is some overlapping in data between Frischknecht (1999a) and ecoinvent data 1.2. As mentioned in chapter 2.2 priority is given to the ecoinvent data in these cases.

4.2.3. Condensing Circuit Piping Kit

This process encompasses the piping of the condensing circuit, i.e. the additional circuit needed to cool down the refrigerant after its compression. The heat exchangers are not included but just the piping from the heat exchanger with the primary circuit to the heat exchanger (dry cooler or hybrid liquid fluid cooler) on the outside – normally the rooftop. There is no insulation on those pipes. The length of the piping can vary considerably, especially in the case of the supermarket, where often special local conditions have to be considered. The condensing circuit data is based on original data collected by Frischknecht (1999a), but was not published as such in the report. 3.5 kg of steel per kW cooling power is mentioned there.

Copper is the most frequently used piping material for average supermarket installations. With the higher density of copper (assuming the same pipe length and inner as well as outer diameter) this previously mentioned number translates to about 4 kg/kW for copper piping.

The interpolation is performed according to the cooling power. The drawing of the pipes, transports and the installation of the pipes are considered (see appendix A5.3 for the process data).

4.2.4. Supermarket Cooling System Infrastructure

The basic infrastructure outline consisting of pipes, compressor, heat exchanger and other pieces of equipment has been shown in Figure 11 (for the copper layouts) and in Figure 12 (for the COOL-FIT layouts).

To prepare the cooling system for operation it needs to be transported to the installation site. It was assumed that the transport distances in the USA are double the ones Frischknecht (1999a) reported for the Swiss supermarkets (Table 14). The transport distance for the COOL-FIT are assumed to be higher than for the copper pipes, since there is only one production site in Denmark, whereas copper pipes are produced in more than one location.

The infrastructure and installation material needed (refrigerants, coolant, lubricating oil, welding gas) is assumed to be identical independently of the location and is summarised in Table 15. The input data is shown in appendix A8.2).

Table 14: Transport distances used for the transport of the infrastructure from the production plant to an intermediate storage or preassembling site and the final transport to the installation site (Data based on Frischknecht 1999b).

	Layout S-1 (copper)	Layout S-2 (copper)	Layout S-3 (copper)	Layout S-4 (COOL-FIT)	Layout S-5 (COOL-FIT)
Transports (location CH) [km]					
Plant → preassembling site	300	300	300	440	440
Preassembling site → client	100	100	100	100	100
Transports (location USA) [km]					
Plant → preassembling site	600	600	600	880	880
Preassembling site → client	200	200	200	200	200

Table 15: The infrastructure inputs for the five supermarkets layouts, which are used for Swiss and US supermarkets equally (Data based on Frischknecht 1999b)

	Layout S-1 (copper)	Layout S-2 (copper)	Layout S-3 (copper)	Layout S-4 (COOL-FIT)	Layout S-5 (COOL-FIT)
Pipe Length [m]					
Copper	920	920	920	98	98
COOL-FIT				878	878
Total	920	920	920	975	975
Installation weight [kg]					
Pipes	1300	1300	1300	1000	1000
non-pipe installation	5300	5300	5300	5950	5950
Total	6600	6600	6600	6950	6950
Assembling the cooling system (excluding pipes)					
Propane [kg]	20	20	20	20	20
Nitrogen [kg]	17	17	17	17	17
Oxygen [kg]	70	70	70	70	70
Electricity (low voltage) [kWh]	500	500	500	500	500
Refrigerant charge [kg]					
Propylene Glycol	1640	1640	1640	2580	2580
R134a	59.9				59.9
R404A	75.2	115.7		22.4	22.4
R22			152.4	56.6	
Lubricating oil charge [kg]					
Cooling circuit	32	32	32	50	50
Compressor	26.9	26.9	26.9	26.9	26.9
Total	58.9	58.9	58.9	76.9	76.9

The data on the infrastructure was taken from Frischknecht (1999b). Concerning pipe length, installation weight[4], propylene glycol and lubricating oil charge, the two COOL-FIT layouts (S-4 and S-5) are based on the ammonia supermarket in Frischknecht (1999b). The main reason for the higher weight of the COOL-FIT layouts is that there is one more heat transfer in these configurations, which means more heat exchanger units and as a consequence more weight despite the lighter pipes.

The refrigerant charges are average values of the respective cooling systems. Systems with direct cooling need a higher charge of refrigerant, since the whole circuit – from the compressor to the end-user device – needs to be filled with refrigerant. In contrast, the indirect systems need less, since only the primary circuit contains refrigerant, which is often limited to the

[4] the installation weight of the completely secondary installation is 7900 kg according to Frischknecht (1999b). The use of COOL-FIT piping reduces the weight by about 900 kg. This was accounted for.

machine room. The extraction of the energy is realised through a second circuit filled with glycol (of which more is needed).

4.2.5. Supermarket Cooling System Operation in Switzerland (Europe)[5]

The data on the supermarket operation stem from Frischknecht (1999b). The loss of refrigerants is updated according to a literature review and personal communications (Table 34 and Table 35 in the Appendix A3). The mentioned rates vary largely, but there is a trend towards lower values in recent years. For the calculations reasonable European average values were deduced (Table 16). The low and high rates are used in the sensitivity analysis in chapter 4.4.

Table 16: Updated refrigerant loss rates used in this study for the Swiss supermarkets. The average values are used (the full tables with the complete list of literature values can be found in Table 34 and Table 35 in the Appendix A3). DX: direct cooling, 2L: indirect cooling system.

	Type	**Refrigerant**	**Leakage rate**			**Remarks**
			low	average	high	
Frischknecht 1999b	DX/2L	general	6%		13.5%	low: “near future” optimisation high: “today” condition (i.e. 1999)
This study	**DX**	**general**	4%	**7%**	10%	
Frischknecht 1999b	2L	Ammonia	2%		5%	low: “near future” optimisation, high: “today” condition (i.e. 1999)
This study	**2L**	**general**	1%	**3%**	5%	

The electricity consumption and hence the efficiency of the cooling systems depends on several factors summarised in Table 17. A leakage of propylene glycol was not assumed, since it is a liquid at normal pressure and not experiencing any changes in pressure. The data for the operation is shown in Table 18 and the input data can be found in appendix A8.3.

5 The assumptions are probably also valid for Western European supermarkets

Table 17: Factors and assumptions influencing the electricity consumption of supermarket cooling systems.

Factor Influencing Electricity Consumption	**Affected Systems and Consequences**	**Source of data or assumption**
The efficiency of the system partly depends on the type of refrigerant used and determines as such the basic electricity consumption of the chosen 104 kW supermarket. This basic consumption is possibly modified by the subsequently mentioned factors.	All systems are affected (basic assumption for electricity consumption)	Measured data of Swiss supermarkets from Frischknecht (1999a)
Indirect expansion leads to about 10% higher electricity consumption compared to direct expansion using the same refrigerant.	Assumption for low temperature circuits of COOL-FIT systems. Since the value is deduced from experience it is probably reflecting the differences correctly.	Value recommended by experts[6]
Quality, heat transfer properties, thickness and completeness of the piping system insulation affects cold loss and hence electricity consumption. Although this aspect might lead to a lower consumption for COOL-FIT systems it was assumed that there is no difference to a copper system of the same refrigerant.	Assumption for high and low temperature circuits of COOL-FIT systems. This leads to a possible overestimation of electricity consumption of the COOL-FIT systems, but can not yet be verified due to a lack of long-time experience with COOL-FIT systems.	Mark Bulmer (Georg Fischer Piping Systems)
Steady loss of refrigerant can lead to a deterioration of the cooling system's efficiency until the refrigerant is replenished.	All systems are affected. Since measured data is used, this aspect is already included. However, COOL-FIT layouts have on average lower loss rates, which could lead to a – probably small – overestimation of electricity consumption of those systems.	-

The repairs of the cooling system and the replacement of parts are considered negligible. The typical life-span of a supermarket cooling system in Switzerland is 10 to 20 years, whereas the design normally assumes 15 years. Under normal circumstances major replacements are, therefore, only to be expected if the cooling system is operated more than the assumed 15 years.[7]

6 personal communication by Mr. Gysin (Schaller Uto AG, Bern) on 31.05.2005 and Mr. Trüssel (KWT Kälte-Wärme-Technik AG, Belp) on 2.6.2005

7 personal communication by Mr. Trüssel (KWT Kälte-Wärme-Technik, Belp) on 02.06.2005 and by Mr. Gysin (Schaller Uto AG, Bern) on 31.05.2005

Table 18: The inputs for the operation of the Swiss supermarkets.

	Layout S-1 (copper)	Layout S-2 (copper)	Layout S-3 (copper)	Layout S-4 (COOL-FIT)	Layout S-5 (COOL-FIT)
Refrigerant loss					
During initial filling	1%	1%	1%	1%	1%
Annual (medium temperature circuit)	3%	3%	3%	3%	3%
Annual (low temperature circuit)	7%	7%	7%	3%	3%
During final disposal (dismantling, destroying/recycling)	10%	10%	10%	10%	10%
Electricity consumption [kWh/(a*m cooling device)]					
Medium temperature (fridges)	3'881	5'248	4'408	4'408	3'881
Low temperature (freezers)	6'115	6'115	6'536	6'727	6'727
Total (weighted average)	4'340	5'426	4'846	4'885	4'466
Life-span [a]					
Cooling system installation	15	15	15	15	15

4.2.6. Supermarket Cooling System Operation in USA

The data on the supermarket operation stem from Frischknecht (1999b). The loss of refrigerants is updated according to a literature review and personal communications (Table 34 and Table 35 in the Appendix A3). The mentioned rates vary largely, but there is a trend towards lower values in recent years. For the calculations reasonable US average values were deduced (Table 16). These are about the double of the European values. The low and high rates are the range, and are only used for the sensitivity analysis of the TEWI assessment.

The remaining inputs to the operation are of identical values to the operation in Switzerland. The only difference is the usage of the US electricity mix instead of the Swiss one, while maintaining the amount of energy consumed (Table 20).

Table 19: Updated refrigerant loss rates used in this study for the American supermarkets in the TEWI assessment. The average values are used (the full tables with the complete list of literature values can be found in Table 34 and Table 35 in the Appendix A3). DX: direct cooling, 2L: indirect cooling system.

	Type	Refrigerant	Leakage rate			Remarks
			low	average	high	
Arthur D. Little 2002	DX	R404A/R507		15%		optimum installation, p.8-4
This study	**DX**	**general**	10%	**15%**	20%	
Baxter 2003	2L	R507	2%	5%	10%	
This study	**2L**	**general**	1%	**5%**	10%	

Table 20: The inputs for the operation of the US supermarkets.

	Layout S-1 (copper)	Layout S-2 (copper)	Layout S-3 (copper)	Layout S-4 (COOL-FIT)	Layout S-5 (COOL-FIT)
Refrigerant loss					
During initial filling	1%	1%	1%	1%	1%
Annual (medium temperature circuit)	5%	5%	5%	5%	5%
Annual (low temperature circuit)	15%	15%	15%	5%	5%
During final disposal (dismantling, destroying/recycling)	10%	10%	10%	10%	10%
Electricity consumption [kWh/(a*m cooling device)]					
Medium temperature (fridges)	3'881	5'248	4'408	4'408	3'881
Low temperature (freezers)	6'115	6'115	6'536	6'727	6'727
Total (weighted average)	4'340	5'426	4'846	4'885	4'466
Life-span [a]					
Cooling system installation	15	15	15	15	15

4.2.7. Supermarket Cooling System Dismantling and Disposal

At the end-of-life the cooling system has to be dismantled and its parts disposed. The metal parts are completely recycled whereas the insulation, the plastic pipes (COOL-FIT) and the lubricating oil are incinerated.[8] The coolant (propylene glycol) is sent to a wastewater treatment plant for treatment. The refrigerants are assumed to be recycled, but a part of it is released to the air during the disposal process (Table 18, Table 20 and appendix A8.4).

The only difference between the Swiss and US disposal and dismantling is the use of double the disposal transport distance. Due to lack of information it was assumed that the non-recyclable parts of the cooling system are sent to incineration for Swiss and US supermarket disposal likewise.

The sensitivity analysis in chapter 4.4.3 investigates the effect of recycling the COOL-FIT pipes instead of incinerating it. It is assumed that all three components (ABS, HDPE and PUR) can be recycled.

8 personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

4.3. Impact Assessment Results

The impact assessment is divided into two sections:

- impact assessment of the base case (this chapter)
- sensitivity analysis (chapter 4.4)

4.3.1. Introduction

The five supermarket cooling systems - as defined in chapter 4.1.2 - are compared in this chapter. It starts with the energy based assessment of the CED (chapter 4.3.2) and then continues with the environmental assessment using CML 2001 (chapter 4.3.3). The assessment concludes with the TEWI, which has - as mentioned in chapter 4.1.3 – distinctly different system boundaries (chapter 4.3.4). The sensitivity analysis of the supermarket cooling systems can be found in chapter 4.4.

Due to the high relevance of electricity consumption and the underlying assumptions (see chapters 4.2.5 and 4.2.6) a comparison between the layouts needs special care. Only layout S-1 and S-5 are directly comparable. Since they have identical refrigerants the electricity consumption is based on the same data and the differences are truly attributable to a difference in the layout. While comparing layout S-2 and S-3 with layout S-4 the differences in electricity consumption (due to different refrigerants) blur the differences attributable to the layout.

4.3.2. Cumulative Energy Demand

Supermarket Operation in Switzerland

The differences in Figure 13 can be almost exclusively attributed to the difference in electricity consumption of the five layouts. Looking at the electricity consumption in Table 18 layout S-2 has the highest, layout S-3 and S-4 almost equal and layout S-1 the lowest consumption. This exact order can be found again in Figure 13. Additionally, it can be seen in Table 21 that the electricity consumption is clearly dominating the renewable as well as the non-renewable part of the CED.

The statistical comparison between layout S-1 and S-5 (Figure 14) shows that considering the data uncertainty layout S-1 is always better than layout S-5. The main difference between the two layouts is the 10% higher electricity consumption of layout S-5 in the low temperature cooling. Electricity is the main contributor to the CED indicators and the result of the uncertainty analysis is the direct consequence of these two aspects. However, the difference between the layouts is only 3% and can, therefore, not be considered significant according to the criteria specified in chapter 2.2.

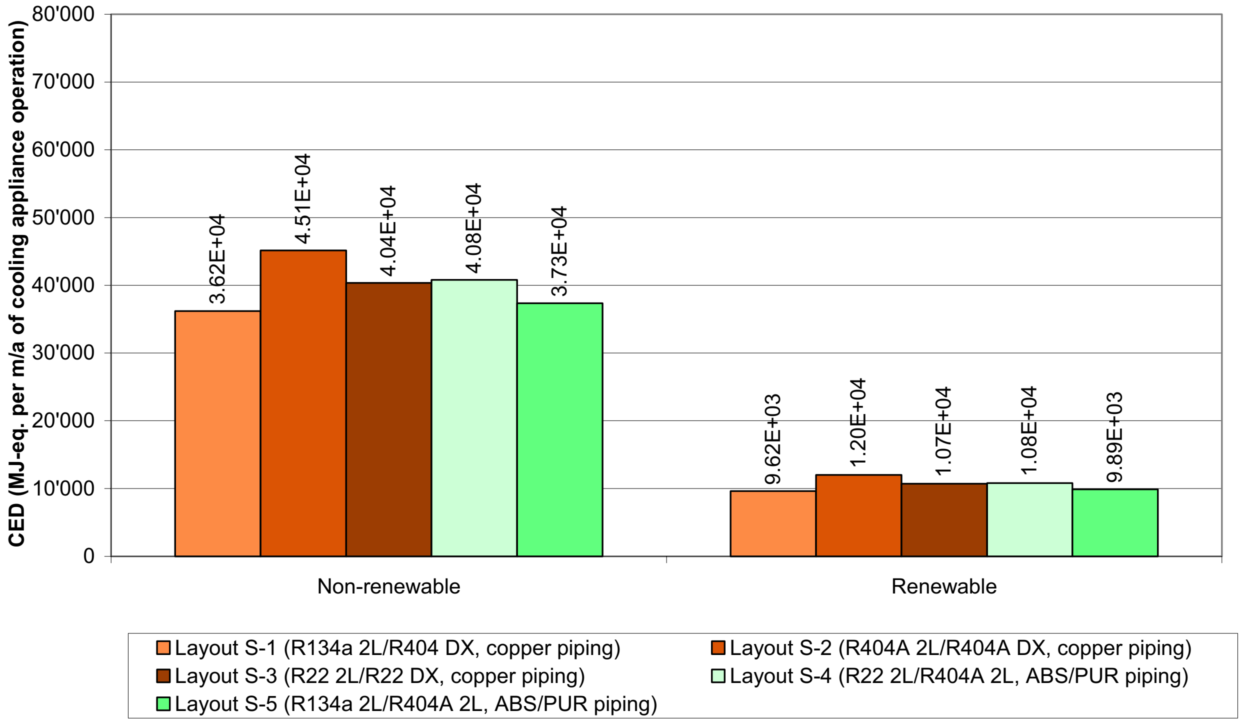

Figure 13: Absolute values of the cumulative energy demand of the five supermarket layouts operated in Switzerland for renewable and non-renewable.

Table 21: Separation of the total impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation for Cumulative Energy Demand.

	Layout S-1 (R134a 2L/R404 DX, copper piping)		**Layout S-5 (R134a 2L/R404A 2L, ABS/PUR piping)**	
	non-renewable	renewable	non-renewable	renewable
Electricity consumption	98.6%	99.5%	98.4%	99.5%
Cooling System	1.39%	0.46%	1.64%	0.46%
Refrigerant Emission and Replacement	0.034%	0.006%	0.014%	0.004%

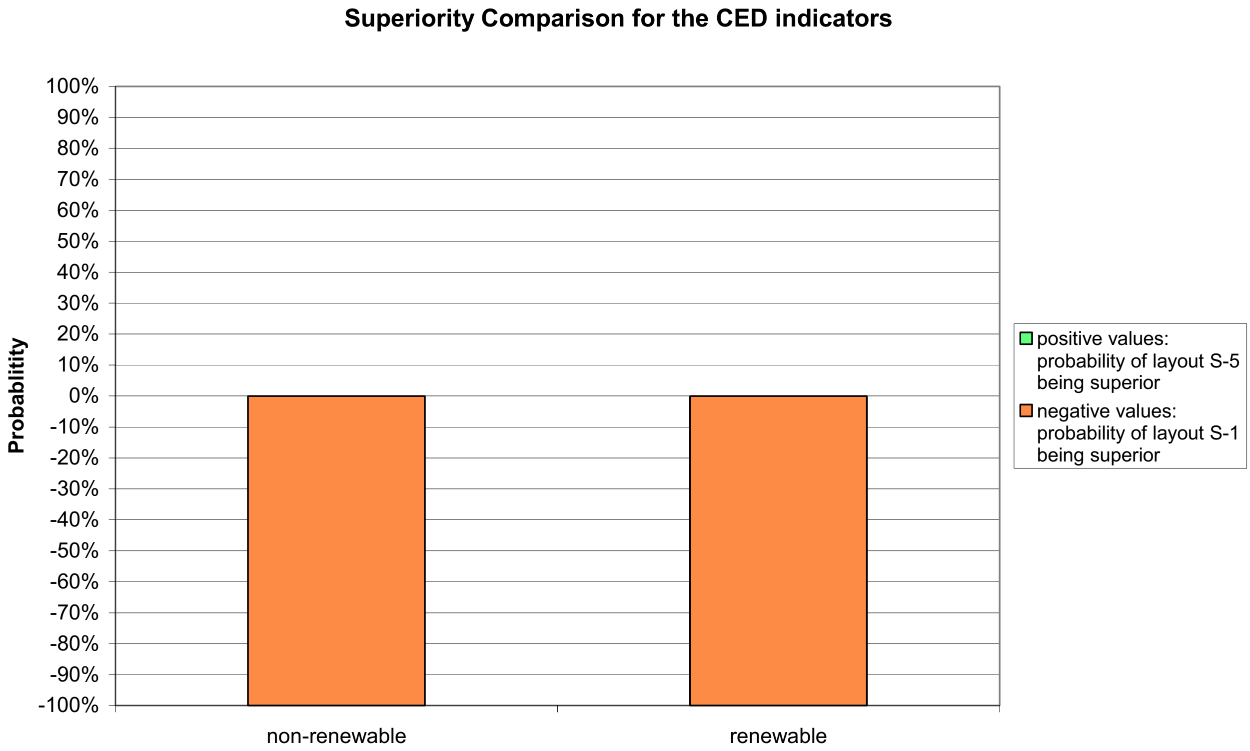

Figure 14: Uncertainty comparison of layout S-1 (R134a 2L, R404A DX, copper piping) with layout S-5 (R134a 2L, R404A 2L, ABS/PUR piping) concerning superiority towards the CED indicators. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a posiitive probability.)

Supermarket Operation in USA

Only the transport distances have been increased and the electricity mix has changed compared to the operation in Switzerland. Therefore, only little change between the layouts was expected and indeed the difference is very low (Figure 15). Again, the electricity consumption is dominating the indicators.

Comparing Figure 13 (operation in Switzerland) and Figure 15 (operation in USA) it can be noticed that first of all the non-renewable indicator is higher for USA than for Switzerland whereas it is vice-versa for the renewables. This effect can be attributed to the more fossil based energy generation in USA, while renewables like hydro have smaller shares in the electricity mix.

The uncertainty analysis (Figure 16) shows the same picture as for the supermarket operation in Switzerland: layout S-1 is superior to S-5. However, the difference is only 3% and, therefore, not significant according to the criteria specified in chapter 2.2.

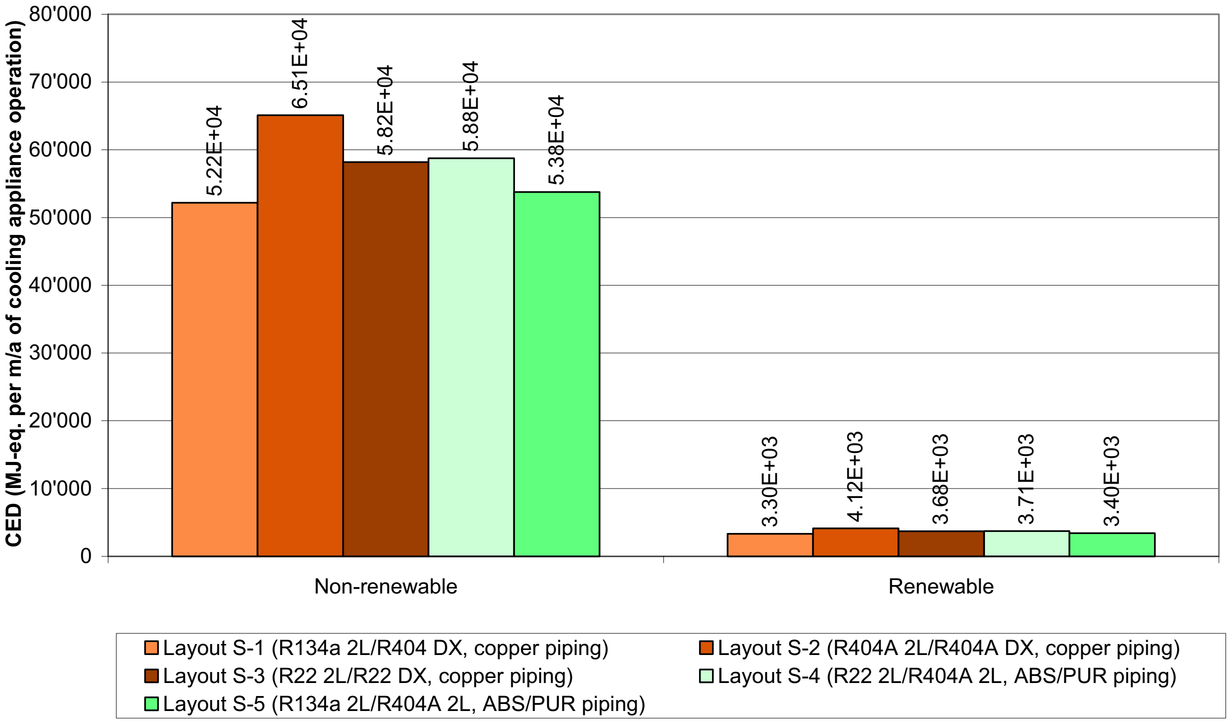

Figure 15: Relative values of the cumulative energy demand of the five supermarket layouts operated in USA for renewable and non-renewable energy.

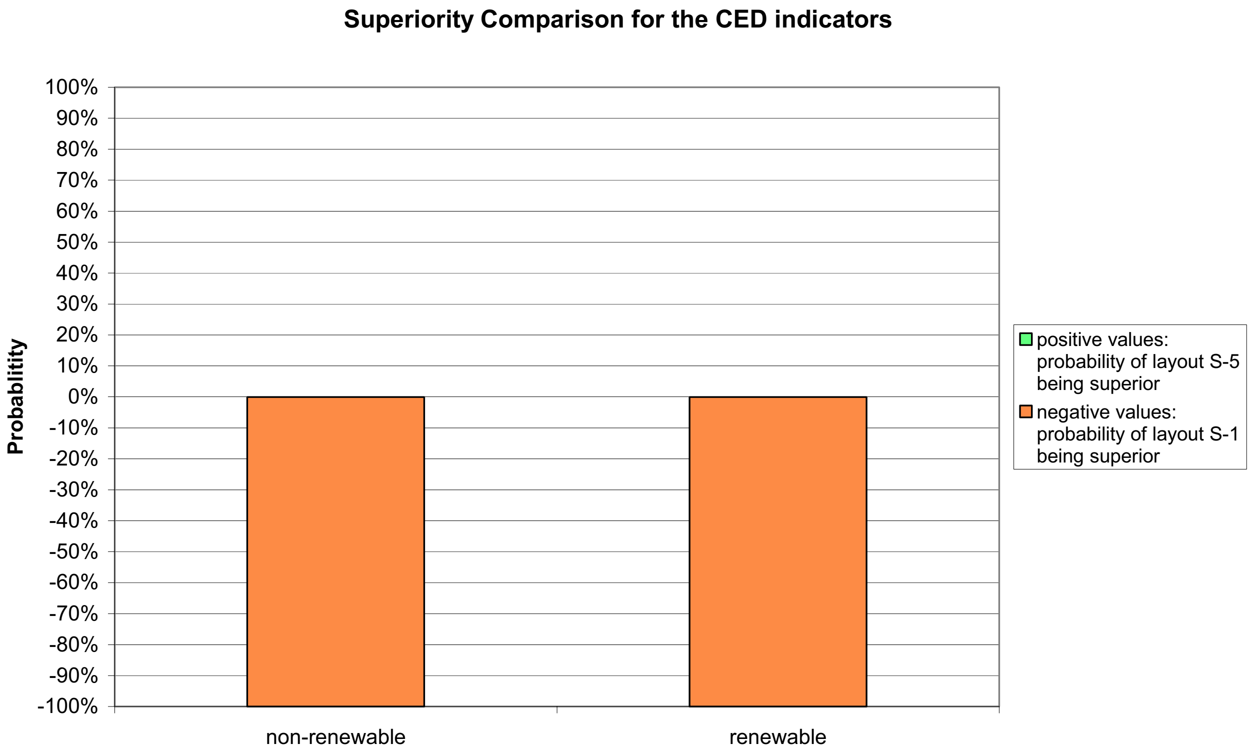

Figure 16: Uncertainty comparison of layout S-1 (R134a 2L, R404A DX, copper piping) with layout S-5 (R134a 2L, R404A 2L, ABS/PUR piping) concerning superiority towards the CED indicators for the supermarket operation in the USA. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a posiitive probability.)

4.3.3. Environmental Impacts According to CML 2001

Supermarket Operation in Switzerland

There is no apparent, well-defined pattern in the results of the CML impact assessment, when it comes to comparing the five layouts (Figure 17). However, the result of an indicator is often strongly influenced by the electricity consumption during the operation of a supermarket. This can be seen in Figure 19 for a copper and in Figure 20 for a COOL-FIT layout where the electricity consumption is always the most important source of the environmental impact except for the ozone layer depletion. This indicates that most of the difference in all but one indicator can be explained by the difference in energy consumption. The choice of refrigerant and indirectly also the piping (via expected emission rates) has, therefore, only an influence with respect to the ozone layer depletion. However, the electricity consumption is itself influenced by 1) the piping (better insulation properties lead to a lower energy demand, for instance), 2) the refrigerant (the efficiency of the cooling system depends also on the choice of the refrigerant), 3) the choice on direct or indirect cooling (one more heat transfer with indirect cooling lowers the energy efficiency).

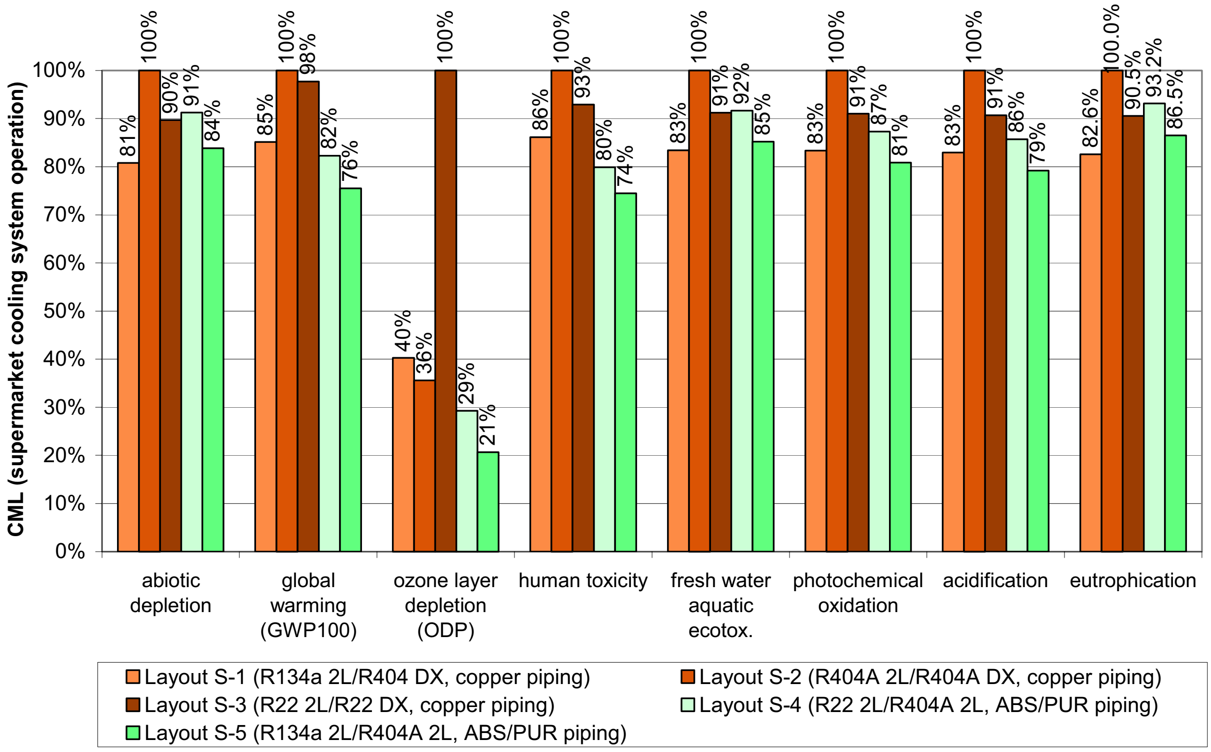

*Figure 17: Percentage representation of the impact Assessment of the operation of cooling devices (m*a) according to the five supermarket layouts operated in Switzerland with CML 2001. The highest value in each indicator is set to 100%.*

Layout S-3 is obviously an outliner in *ozone layer depletion* and has a distinctly higher impact value than the four other layouts. This is mainly due to the direct, ozone layer depleting R22 emissions during operation. The R134a- and R404A-emissions do not directly contribute to the ozone layer depletion, since they are zero ODP refrigerants (Table 22). Nevertheless, in the production process of those refrigerants some ozone layer depleting substances are released. The layouts with COOL-FIT (S-4 and S-5) perform slightly better than S-1 and S-2, which is not to be expected from the electricity consumption. This is a consequence of the indirect piping for both temperature levels, leading to a significantly lower amount of refrigerant to be replaced during operation and, hence, also less indirect releases of ozone depleting substances. The superiority of layout S-5 over S-1 (Figure 18) is significant according to criteria specified in chapter 2.2. Superiority is also likely for layout S-4, but was not calculated explicitly.

Table 22: Direct ozone depletion potential (ODP) and global warming potential (GWP100) of the refrigerants.

	R22	R134a	R404A
Ozone Depleting Potential (ODP)	0.055	0	0
Global Warming Potential (GWP100)	1700	1300	3784

The COOL-FIT layouts achieve the best (S-5) and the second best (S-4) result in the *global warming potential* indicator, *ozone layer depletion* and *human toxicity*. The indirect layout leads to less annual refrigerant loss, which results in a significant advantage (≥ 5%) of the COOL-FIT layouts over the traditional layouts in the first two indicators. This finding is supported by the statistical comparison of layout S-1 (copper) with S-5 (COOL-FIT), where COOL-FIT is superior with a probability of 95% to 100% in these three indicators (Figure 18).

The lower need for copper due to the replacement of copper with COOL-FIT pipes leads to the good performance for COOL-FIT layouts in *human toxicity*. The layout S-5 always performs better than S-4 due to direct electricity consumption, which is about 10% lower for layout S-5. The highest impact in most indicators is caused by layout S-2 due to the electricity consumption, which is the highest among all layouts (Table 18).

Concerning the remaining five indicators layout S-1 can never be called superior over S-5, since the differences between these layouts is always less than 5% (condition for superiority according to chapter 2.2)

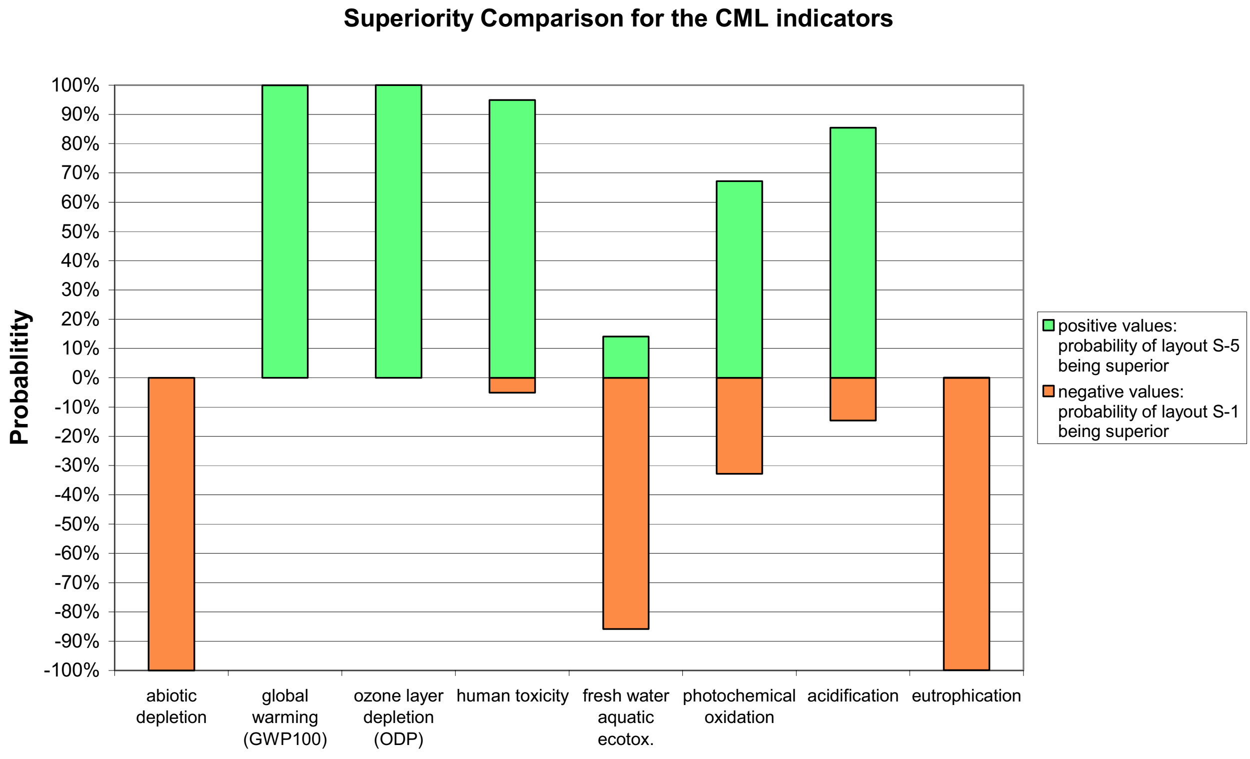

Figure 18: Uncertainty comparison of layout S-1 (R134a 2L, R404A DX, copper piping) with layout S-5 (R134a 2L, R404A 2L, ABS/PUR piping) concerning superiority towards the CML indicators. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a posiitive probability.)

Approximately 75% of the *acidification* indicator is the consequence of sulphur dioxide (SO_2) emissions into the atmosphere. The main source is the electricity production by coal power plants. Although there are no coal power plants in Switzerland, electricity imported from abroad often contains a share produced by coal power plants. This aspect is only influenced by the electricity consumption. The second most important source is the copper production, which leads to the same reasoning as in the previous paragraph on human toxicity.

Atmospheric nitrogen oxide (NO_x) emissions are the major contributors to *eutrophication*. NO_x mainly stems from blasting and from burning of diesel. The former is used in the extraction of hard coal and copper and the latter mainly in transports. The transports for the COOL-FIT pipes and fittings are higher, since the actual transport situation with production plants in Germany and Denmark and the supermarket in Switzerland results in larger and more lorry based transports than the standard distances applied for the copper piping. The fact that the distance is larger and that all transports are operated by lorries finally results in a comparatively higher environmental impact of the COOL-FIT layouts S-4 and S-5 in the eutrophication indicator (Figure 17 and Figure 18), which is, however, not significant.

As a conclusion, it can be said that the completely indirect systems with COOL-FIT need comparatively more electricity, which is an important factor in most indicators. However, this is balanced or outweighed sometimes due to 1) lower refrigerant emissions and 2) a lower need for copper in the COOL-FIT layouts. Comparing layout S-1 (copper) and S-5 (COOL-FIT) it can be said that COOL-FIT is superior in three indicators and inferior in none of the five remaining indicators.

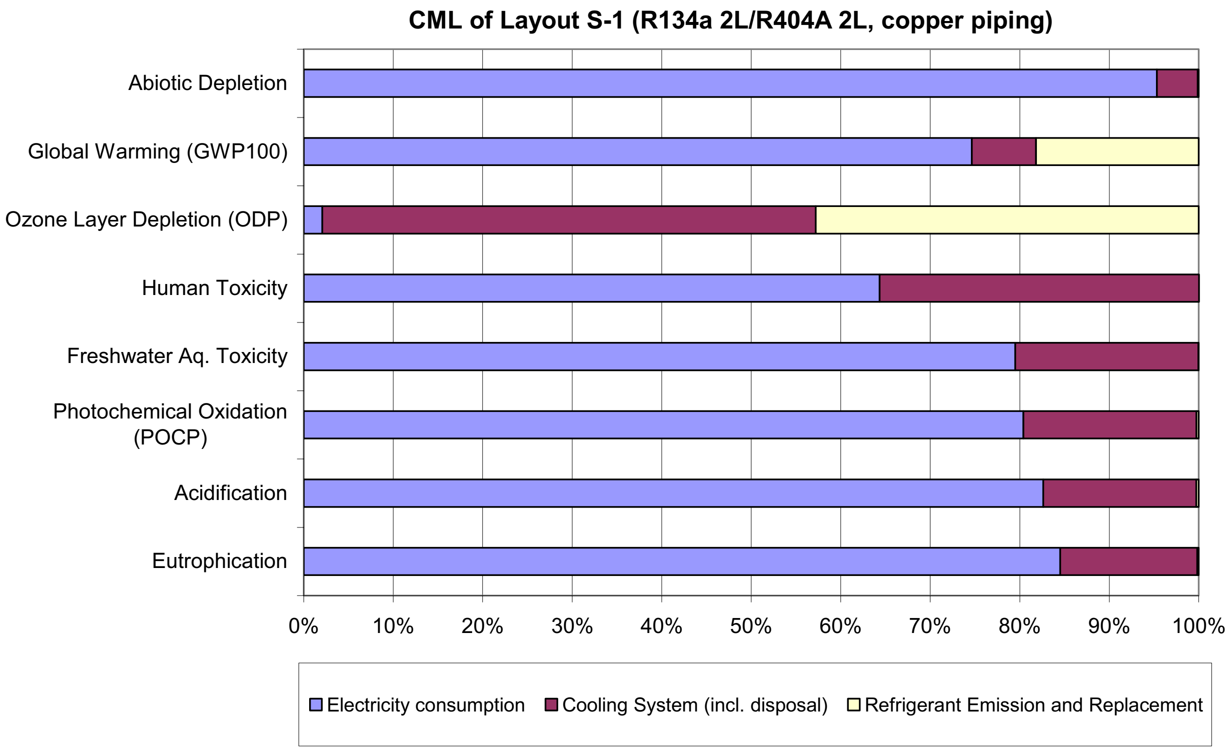

Figure 19: Share of the three main issues (electricity consumption, cooling system, refrigerant loss and replacement) of a supermarket operated in Switzerland in the example of the layout S-1 (R134a 2L/R404 DX, copper piping) for the CML 2001 indicators

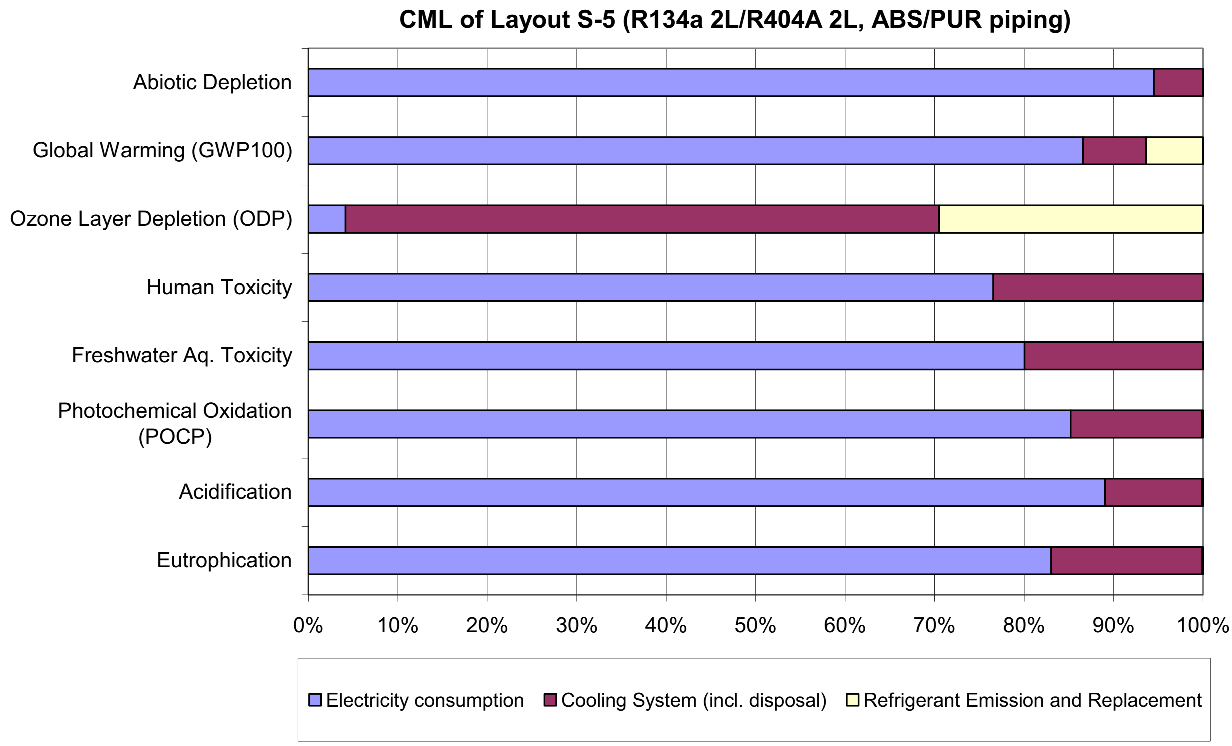

Figure 20: Share of the three main issues (electricity consumption, cooling system, refrigerant loss and replacement) of a supermarket operated in Switzerland in the example of layout S-5 (R134a 2L/R404A 2L, ABS/PUR piping) for the CML 2001 indicators

Table 23: Separation of the total environmental impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation of a supermarket operated in Switzerland in the example of the layout S-1 (R134a 2L/R404 DX, copper piping) and for the CML 2001 indicator

	Abiotic Depletion	Global Warming Potential	Ozone Layer Depletion	Human Toxicity	Freshwater Aq. Ecotox.	Photochemical Oxidation	Acidification	Eutrophication
Electricity consumption	95%	75%	2.1%	64%	79%	80%	83%	85%
Cooling System	4.6%	7.2%	55%	36%	20%	19%	17%	15%
Refrigerant Emission and Replacement	0.11%	18.2%	43%	0.04%	0.05%	0.25%	0.29%	0.17%

Table 24: Separation of the total environmental impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation of a supermarket operated in Switzerland in the example of layout S-5 (R134a 2L/R404A 2L, ABS/PUR piping) and for the CML 2001 indicators

	Abiotic Depletion	Global Warming Potential	Ozone Layer Depletion	Human Toxicity	Freshwater Aq. Ecotox.	Photochemical Oxidation	Acidification	Eutrophication
Electricity consumption	94%	87%	4.2%	77%	80%	85%	89%	83%
Cooling System	5.5%	7.1%	66%	23%	20%	15%	11%	17%
Refrigerant Emission and Replacement	0.04%	6.4%	29%	0.02%	0.02%	0.10%	0.11%	0.06%

Supermarket Operation in USA

The ranking of the layouts (Figure 21) has not changed compared to the operation in Switzerland (Figure 20). The COOL-FIT layouts still perform well in *ozone layer depletion* (due to lower refrigerant losses) and in *human toxicity*. In the remaining indicators the performance of the COOL-FIT layouts is in the order of the copper layouts S-1 and S-3. However, the probability of superiority (Figure 22) has declined and the indicator *global warming* does not show a significant difference anymore. Only *ozone layer depletion* and *human toxicity* remain significant differences between layout S-1 and S-5 according to the criteria specified in chapter 2.2. Still in the remaining seven indicators the COOL-FIT layout is not inferior compared to the copper one.

Comparing the environmental impact resulting from the operation in Switzerland with the one in USA (Figure 23) one realises that in some indicators the impact in the USA is almost six times as high as in Switzerland. This is almost exclusively the consequence of the differences in the electricity mix. The larger share of fossil energy generation is the main reason for the significantly higher environmental impact of a supermarket operated in USA. This had a direct influence on the indicators *photochemical oxidation* and *acidification*, which are more likely (but not significantly) to the advantage of layout S-1 (Figure 22) while in case of operation in Switzerland it was rather the contrary (Figure 18).

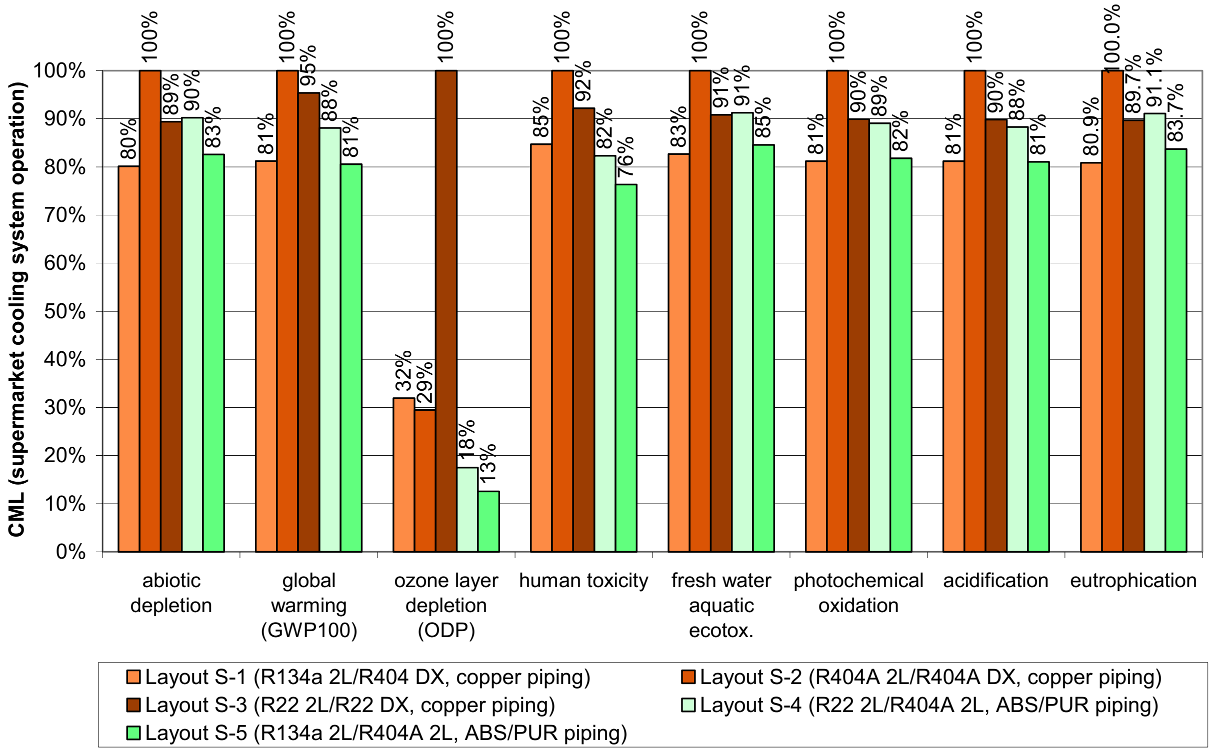

*Figure 21: Percentage representation of the impact Assessment of the operation of cooling devices (m*a) according to the five supermarket layouts operated in USA with CML 2001. The highest value in each indicator is set to 100%.*

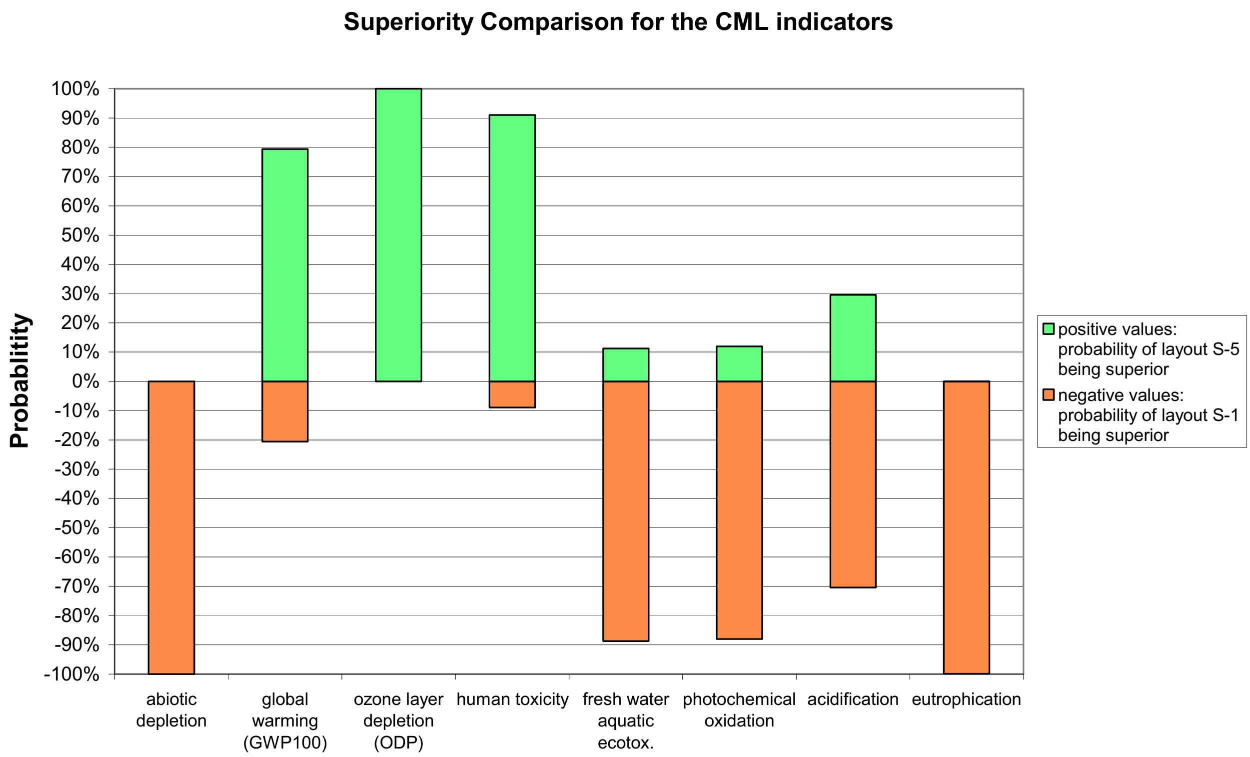

Figure 22: Uncertainty comparison of layout S-1 (R134a 2L, R404A DX, copper piping) with layout S-5 (R134a 2L, R404A 2L, ABS/PUR piping) concerning superiority towards the CML indicators for the supermarket operation in the USA. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a posiitive probability.)

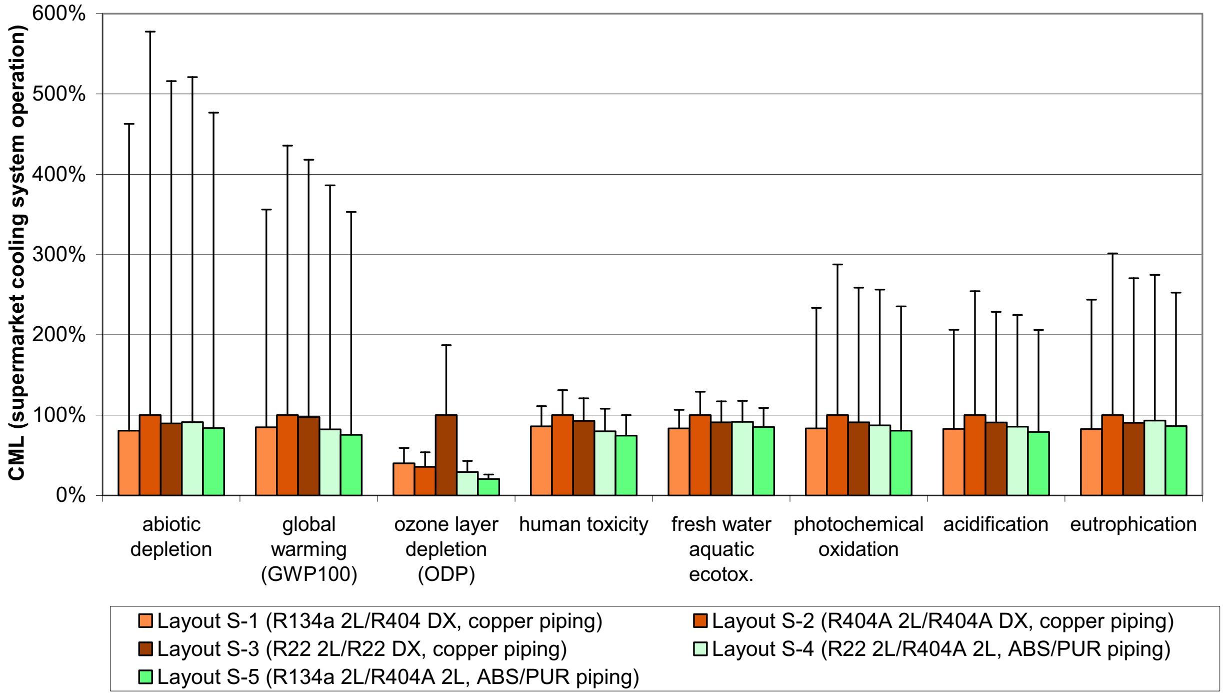

Figure 23: Representation of the differences between the supermarket operation in Switzerland (normal bars) and the operation in USA (the error bars) for each layout and indicator.

4.3.4. TEWI (Total Equivalent Warming Impact)

The electricity consumption is the main factor in the TEWI assessment contributing about 82% (layout S-1) up to 98% (the COOL-FIT layouts S-4 and S-5) to the total amount. This is not surprising, since the COOL-FIT layouts are completely indirect and have, therefore, a considerably lower loss rate but also contain a smaller refrigerant load in the cooling system. These are two effects leading to a reduction in the release of refrigerants (in absolute amounts) and the observed difference concerning this aspect between the copper (layout S-1 to S-3) and the COOL-FIT layouts (S-4 and S-5).

One layout (S-2) has a notably higher environmental impact than the others because of lower energy efficiency (i.e. higher electricity consumption) and R404A as the refrigerant, which has a GWP about twice the one of R22 and about three times higher than R134a (Table 22). Using R22 instead of R404A in layout S-1 could considerably reduce the TEWI for this layout. However, R22 has a non-zero ozone depleting potential, whereas R134a and R404A have no direct ozone depleting potential (i.e. ODP=0).

A further reduction in the refrigerant loss rates in American supermarkets will lead to a TEWI that is even more closely linked to the direct electricity consumption also in the case of the copper layouts and the CO_2 emissions associated with the electricity production.

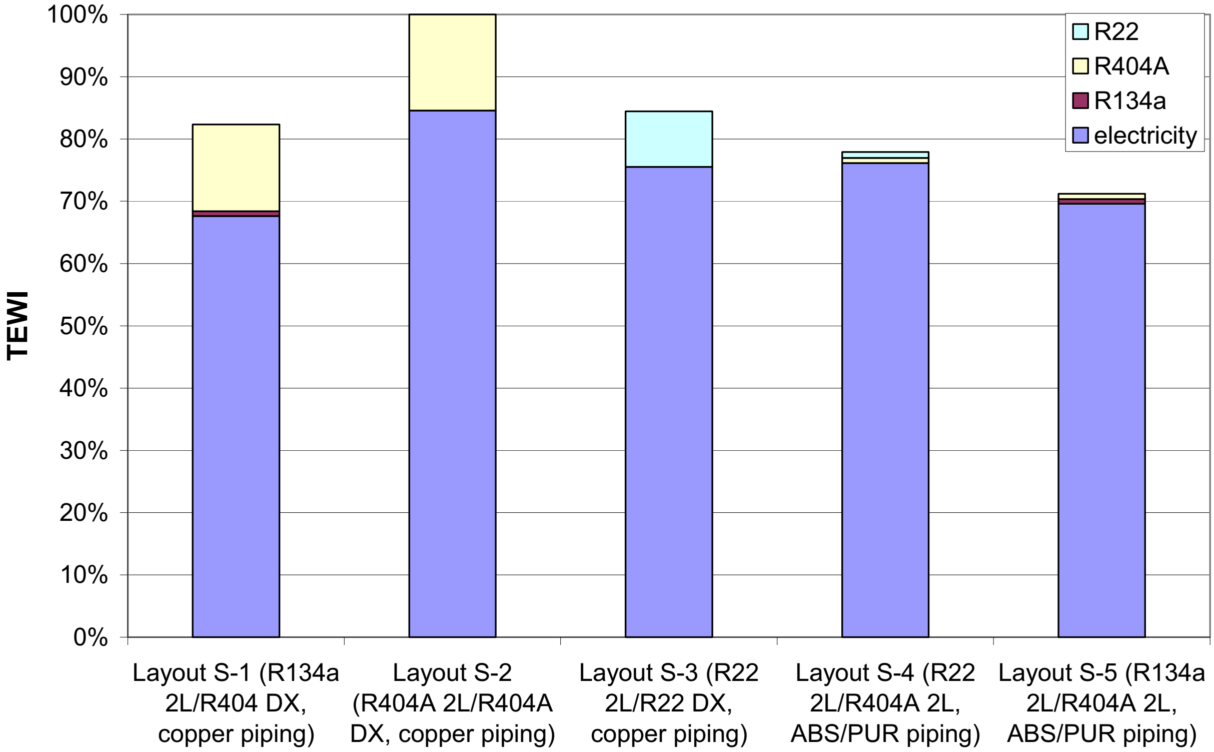

Figure 24: The results from the TEWI assessment for the five supermarket layouts operated in USA. The values represent one meter of cooling device operation over the whole lifetime.

4.4. Sensitivity Analysis

4.4.1. Direct Electricity Consumption

Introduction

The direct electricity consumption is an important factor in the assessment as was stated in the previous chapter several times. In the following the sensitivity of the indicators to a variation by +10% and -10% of the direct electricity consumption of the supermarkets is evaluated.

On one hand this sensitivity analysis reflects the importance of electricity consumption in each indicator. On the other hand the base case of the non-COOL-FIT systems can be compared with the case of the COOL-FIT systems having a 10% lower electricity consumption due to better insulation properties. Disregarding this difference was an important assumption probably to the disadvantage of the COOL-FIT systems.

Cumulative Energy Demand (CED)

The sensitivity of the cumulative energy demand is strongly correlated with the direct electricity consumption during the operation of a supermarket (Figure 25). An increase in the electricity consumption by 10% leads to an increase in the cumulative energy demand indicators of at least 9.8% (layout S-5, non-renewable).

Comparing the base case of the best copper layout (S-1) with the COOL-FIT layouts with a 10% lower electricity consumption it seems to be likely that layout S-5 performs now better than S-1 while S-4 gets into the range of S-1.

As a conclusion it can be said that both CED indicators are determined by the direct electricity consumption. The differences between the layouts are almost completely attributable to this aspect.

The sensitivity analysis of the supermarket operation in the USA showed an identical picture and is, therefore, not shown.

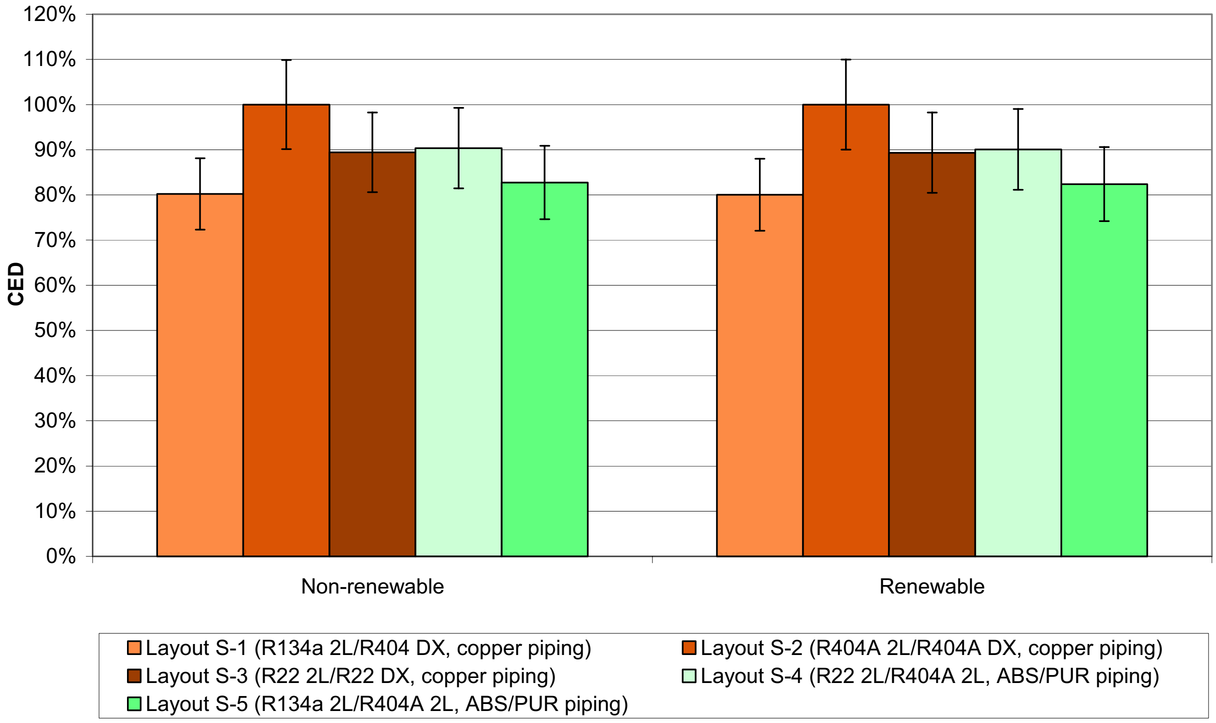

Figure 25: Sensitivity of the CED to a 10% variation of the direct electricity consumption of the supermarket operation in Switzerland

Environmental Impacts According to CML 2001

With the exception of *ozone layer depletion*, all indicators correlate with the variation of the electricity consumption. *Abiotic depletion* shows in all layouts the strongest correlation (up to 9.5%) and human toxicity the weakest (6.4%) (Figure 26).

Global warming as well as *ozone layer depletion* are both influenced by the loss of refrigerants, but show a completely different behaviour in sensitivity. The greenhouse gas emissions from electricity generation are largely dominant (75%-90% of *global warming*), while the release of ozone depleting substances is almost exclusively attributable to refrigerant production or direct losses during the supermarket operation – only 2% - 4% are due to electricity production (Table 23 and Table 24). Therefore, there is no sensitivity of *ozone layer depletion* to be expected, although *global warming* shows sensitivity with respect to the electricity consumption.

While there is no change to be expected in *ozone layer depletion* when the COOL-FIT layouts with a 10% lower electricity consumption are compared with the base case copper layouts, it will have an effect on the remaining indicators. The overall picture will shift to a relevant extent in favour of the COOL-FIT layouts.

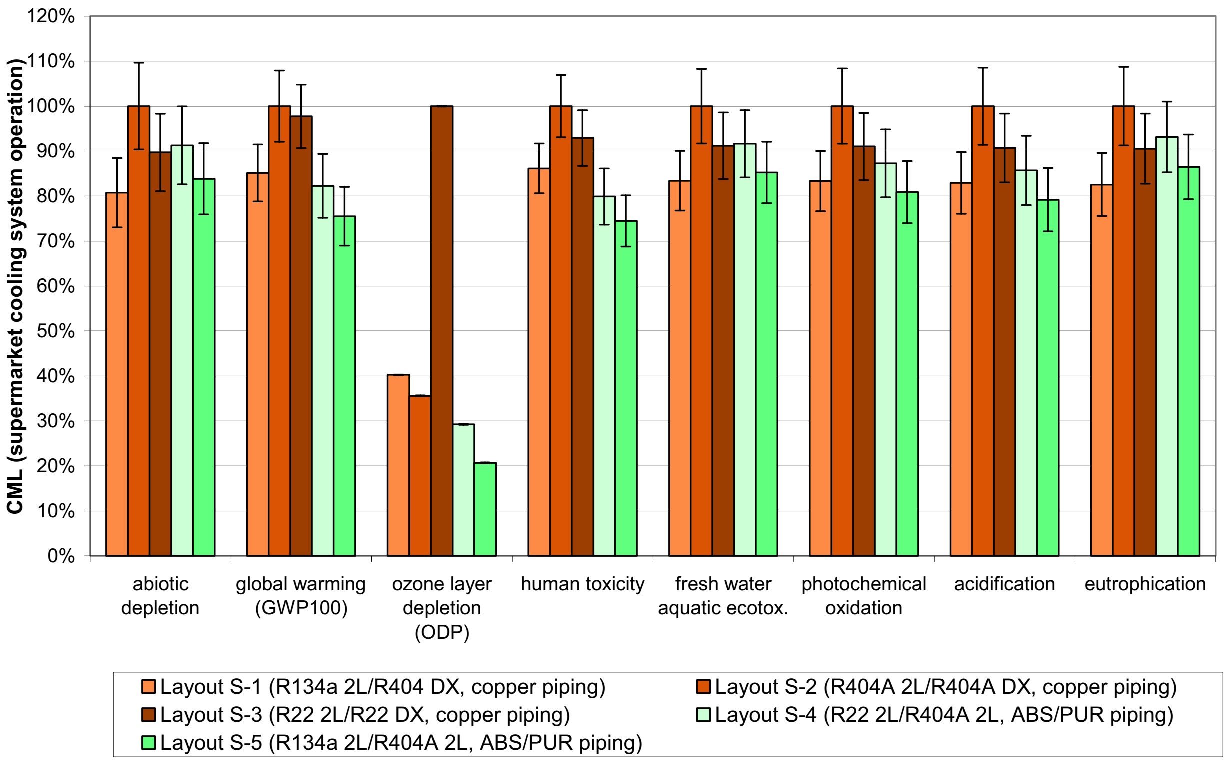

Figure 26: Sensitivity of the CML 2001 indicators to a 10% variation of the direct electricity consumption for the supermarket operation in Switzerland

The difference to the sensitivity of the supermarket operated in the USA is marginal (Figure 27), but one can notice that the electricity is slightly more dominant. The indicators change between 7.2% (human toxicity) and 9.9% (abiotic depletion) for a 10% variation with the exception of *ozone layer depletion*.

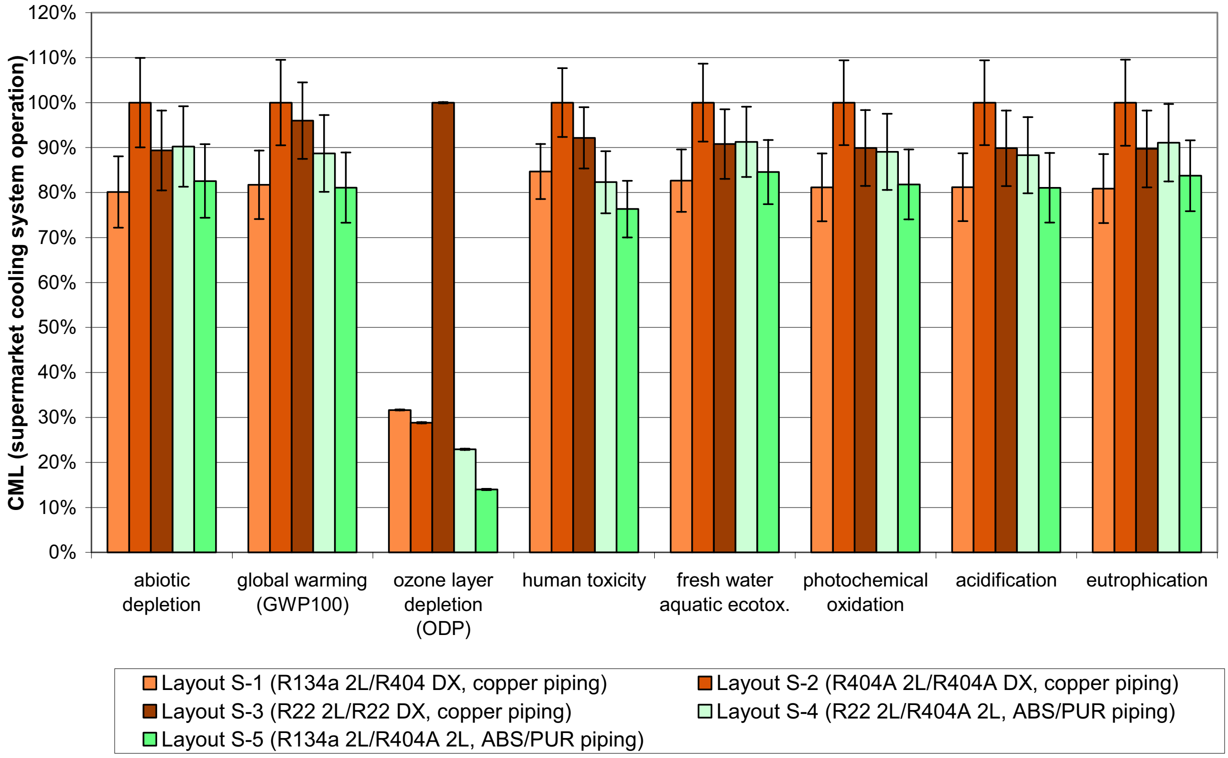

Figure 27: Sensitivity of the CML 2001 indicators to a 10% variation of the direct electricity consumption for the supermarket operation in USA

TEWI (Total Equivalent Warming Impact)

The highest sensitivity to the variation of the direct electricity consumption is encountered with the COOL-FIT layouts (S-4 and S-5). In these cases almost the whole TEWI is attributable to the direct electricity consumption and a 10% variation in electricity leads to a variation in the TEWI only little below 10%. In the other layouts, where the refrigerants contribute non-negligibly to the TEWI, the sensitivity is somewhat lower and about 8.5% as a consequence.

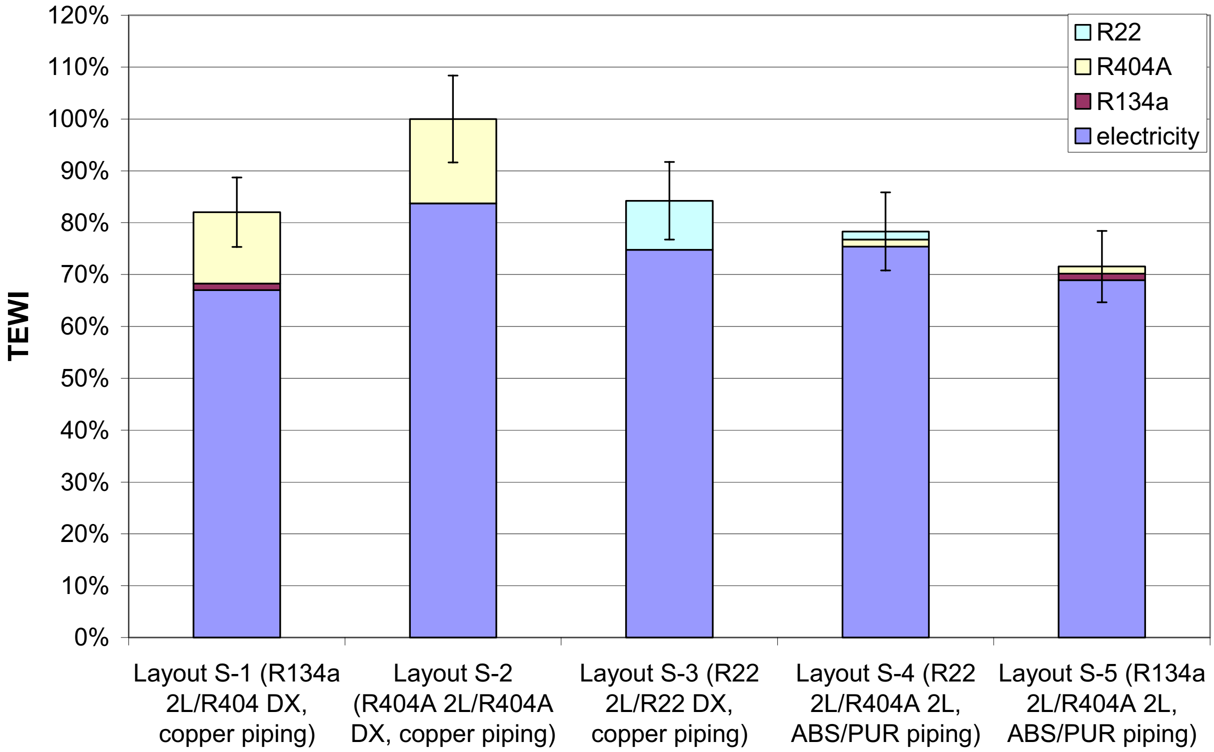

Figure 28: Sensitivity of the TEWI to a 10% variation of the direct electricity consumption

4.4.2. Direct Refrigerant Loss

Introduction

The refrigerant loss rates in supermarkets have declined in recent years. New supermarkets may perform better, older ones worse than the assumed average supermarket. Therefore, a sensitivity analysis can contribute valuable insights. The variation of refrigerant losses for the analysis with CED and CML 2001 are according to the low and high values in Table 16 (Swiss supermarket). The loss rates in an American average supermarket are higher (Table 19).

Cumulative Energy Demand (CED)

There is almost no sensitivity (<0.1%) of the CED towards variation in the refrigerant loss rates and, therefore, not noticeable in Figure 29. This is not surprising since the CED is already determined almost completely through the direct electricity consumption (chapter 4.3.2). The result for the Swiss supermarket is very much identical to the supermarket operated in the USA and, therefore, not shown.

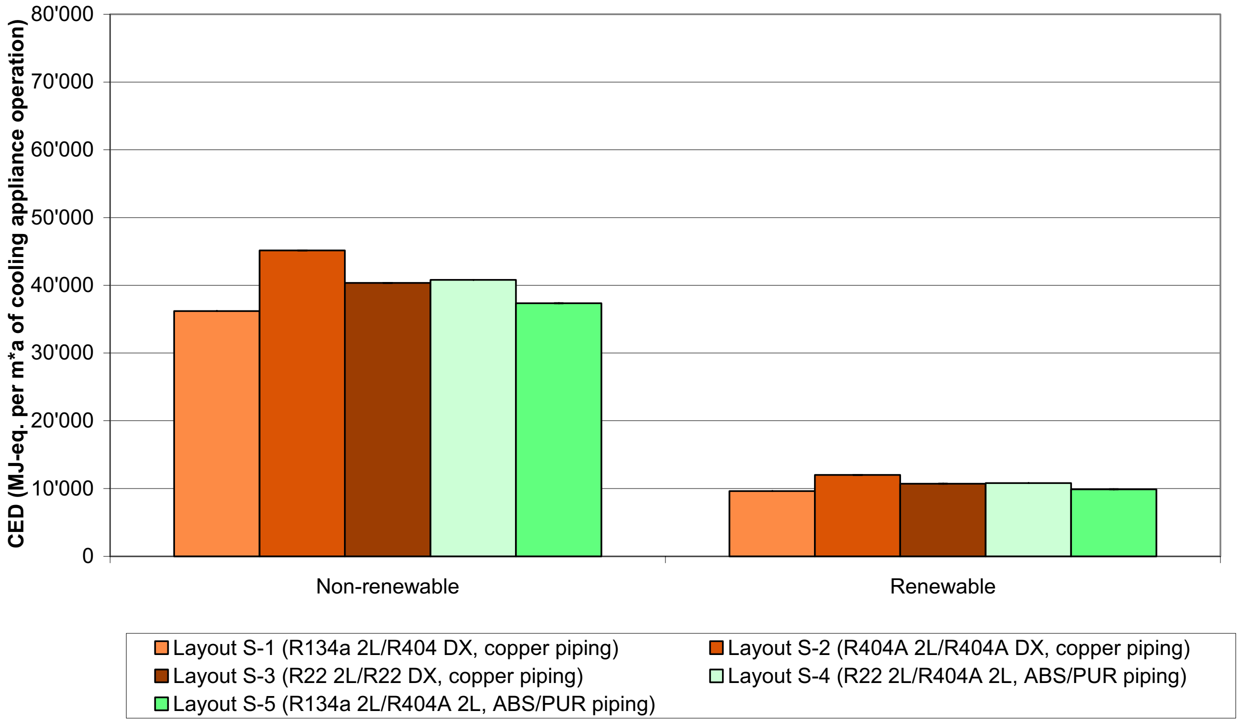

Figure 29: Sensitivity of the CED to a the variation of the refrigerant loss rates for the supermarket operation in Switzerland (the effect of the sensitivity can not be seen, since the variation is less than 0.1%).

Environmental Impacts According to CML 2001

The assumption on the refrigerant loss rates only influences the global warming and the ozone layer depletion indicators to a substantial amount. In *global warming* the variation is approximately 4.5% for the COOL-FIT layouts and 7% to 10% for the others. By reducing the refrigerant loss rates in a COOL-FIT installation from 3% to 1% (a reduction by 2/3) leads to an overall improvement of only 4% (a reduction by 1/25) in *global warming*. The non-COOL-FIT layouts have higher refrigerant charges and, therefore, higher emissions on a per kW basis, which leads to the higher sensitivity.

Ozone layer depletion shows a higher sensitivity for layouts containing R22, which is the only refrigerant with a direct effect on the ozone layer depletion. The R22-free layouts (S-1, S-2 and S-5) show, nevertheless, a considerable sensitivity due to the release of ozone depleting substances in the production chain of the refrigerants. The sensitivity is about 39% (layout S-3) and 41% (layout S-4) for the layouts containing R22. It is about 20% for the layouts without R22. All other indicators show a sensitivity often far below 0.1% for all layouts.

As can be deduced from Figure 31 the difference concerning the *ozone layer depletion* is marginal between the operation in Switzerland and the USA. However, the sensitivity of *global warming* is significantly reduced for the operation in the USA to about 2% for the COOL-FIT layouts and about 2%-4.5% for the copper ones. This is due to the fossil fuel based electricity mix in the USA, which entails a much higher amount CO_2 emissions, hence, rendering the effect from the refrigerant less important.

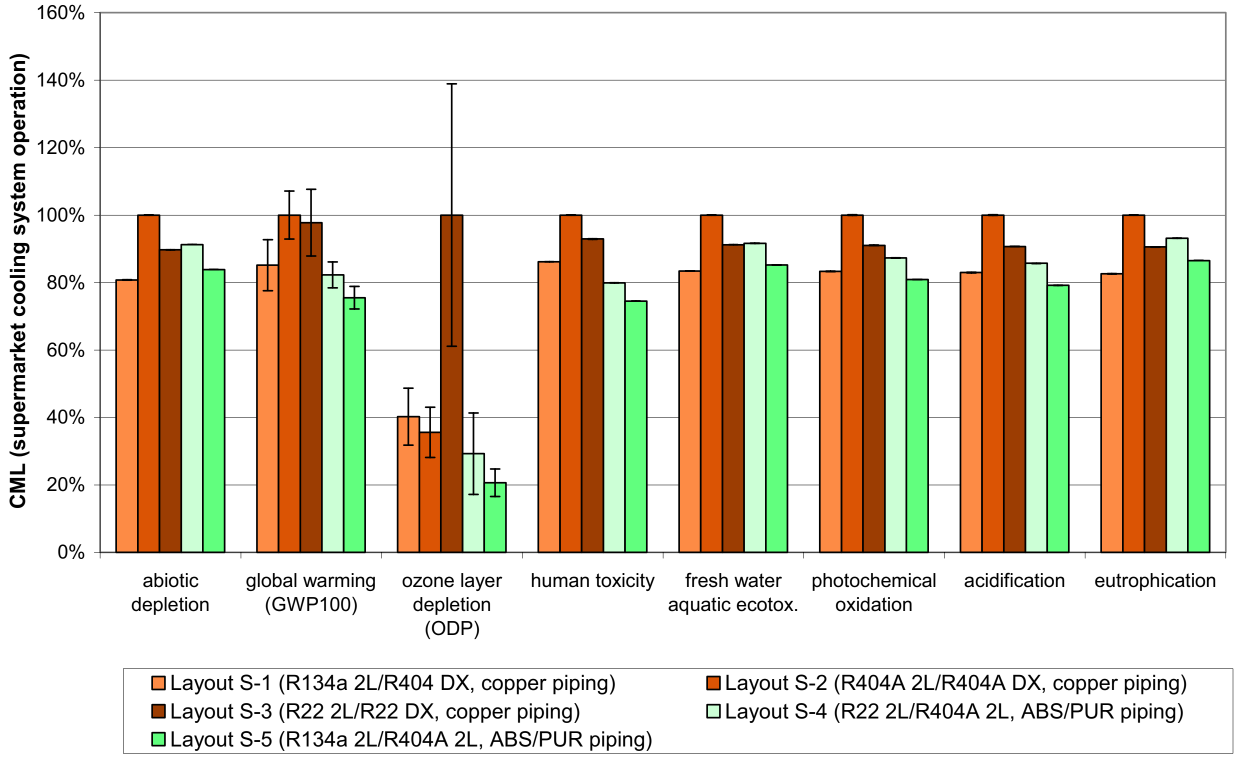

Figure 30: Sensitivity of the CML 2001 indicators to a variation of the refrigerant loss rates for the supermarket operated in Switzerland

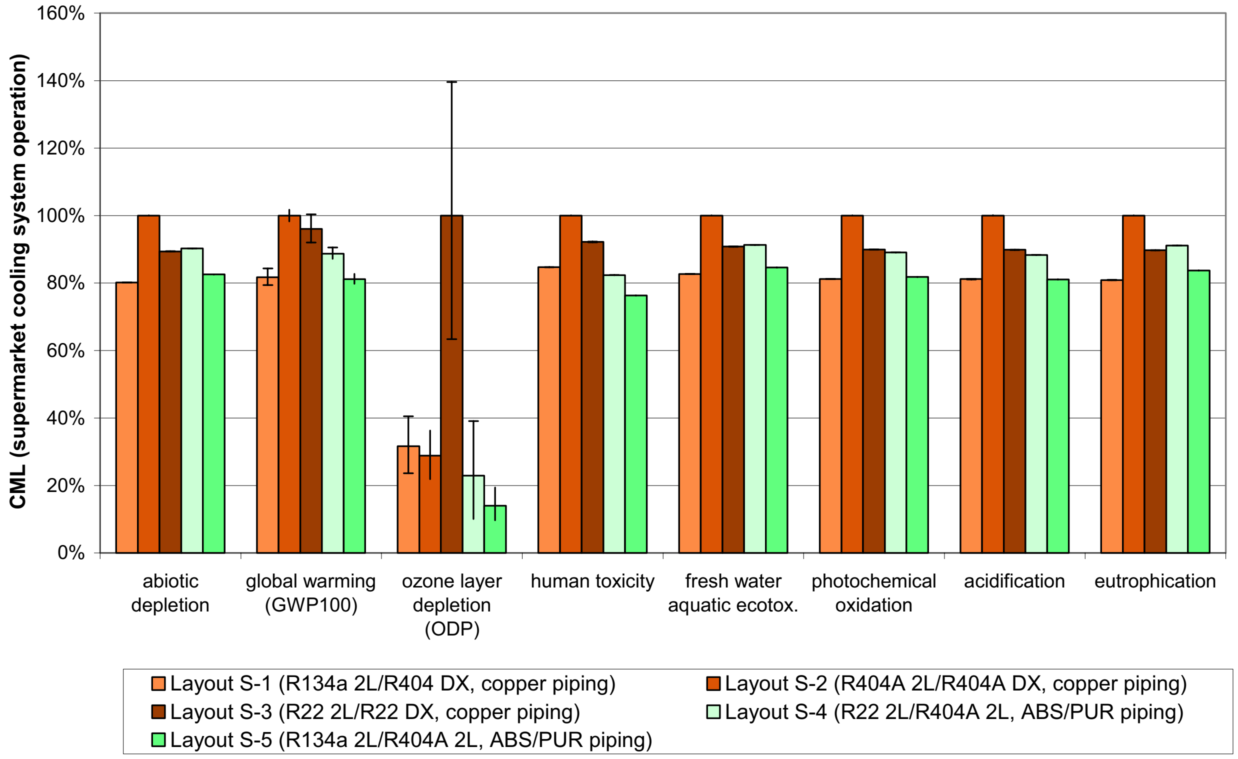

Figure 31: Sensitivity of the CML 2001 indicators to a variation of the refrigerant loss rates for the supermarket operated in USA

TEWI (Total Equivalent Warming Impact)

The layouts with a significant contribution of the refrigerants to the total TEWI show a certain sensitivity (5%-7%), whereas for the COOL-FIT layouts with its low refrigerant charges the sensitivity is lower (3.7%). Low charge cooling systems are, thus, largely independent of the loss rate, since the absolute amount of released refrigerant stays low even when compared to the release of a direct cooling system with low loss rates.

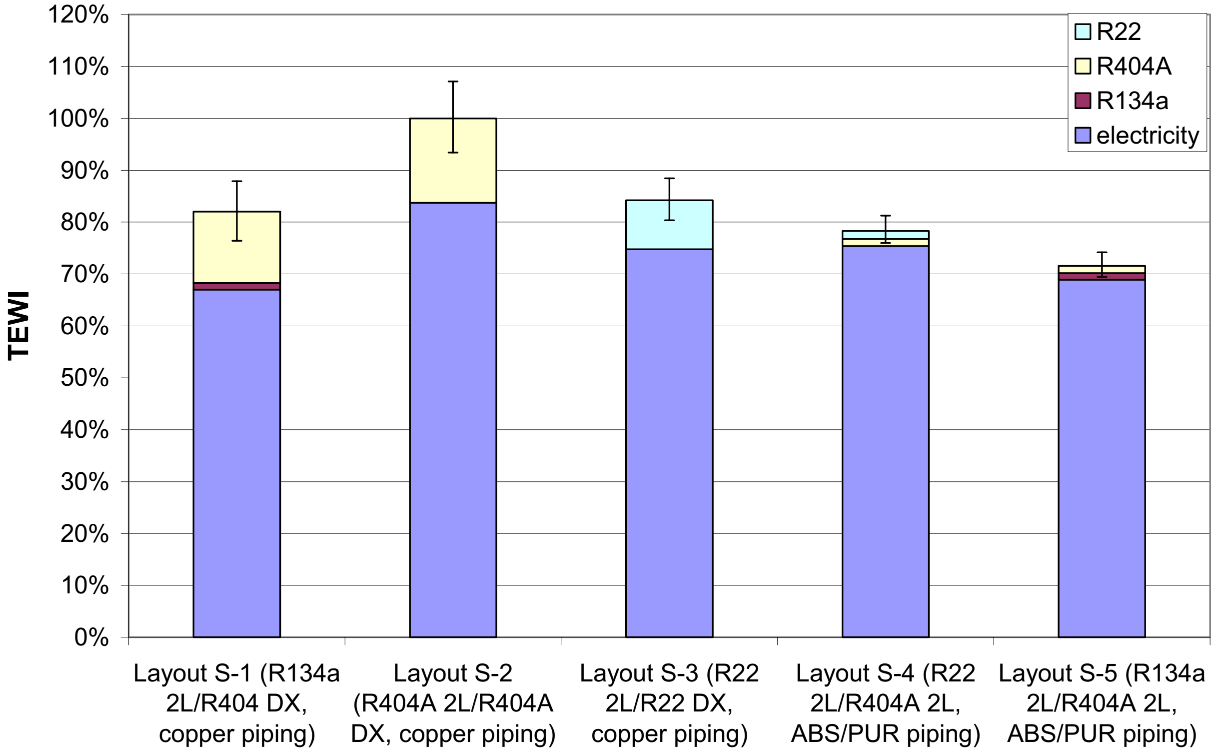

Figure 32: Sensitivity of the TEWI to a variation of the refrigerant loss rate for the operation of a supermarket located in USA

4.4.3. COOL-FIT Pipes Recycling

Introduction

In the main assessment it was assumed that the copper pipes are recycled, whereas the COOL-FIT pipes were supposed to be incinerated. This is probably the standard case at the moment. However, Løgstør, the producer of the insulation and the jacket pipe of the COOL-FIT pipe has established a recycling process where PE as well as the PUR fraction can be recovered. It is assumed that the ABS can also be recycled. To show the full potential for recycling in the sensitivity analysis, it is assumed that 100% of ABS, PE and PUR is recycled at the end-of-life. It is also assumed that these pipes were made without any share of recycled input materials.

Cumulative Energy Demand

The first three layouts (layout S-1 to S-3) must not show any sensitivity to the change of the recycling rate, since they do not contain ABS piping. However, also the remaining two COOL-FIT layouts do not show any sensitivity. This is not surprising, since the use phase (i.e. electricity consumption, refrigerant loss) of the supermarket is dominating, hence, a change in the recycling rate (disposal phase) has no noticeable effect at all, irrespective of the location the supermarket is operated.

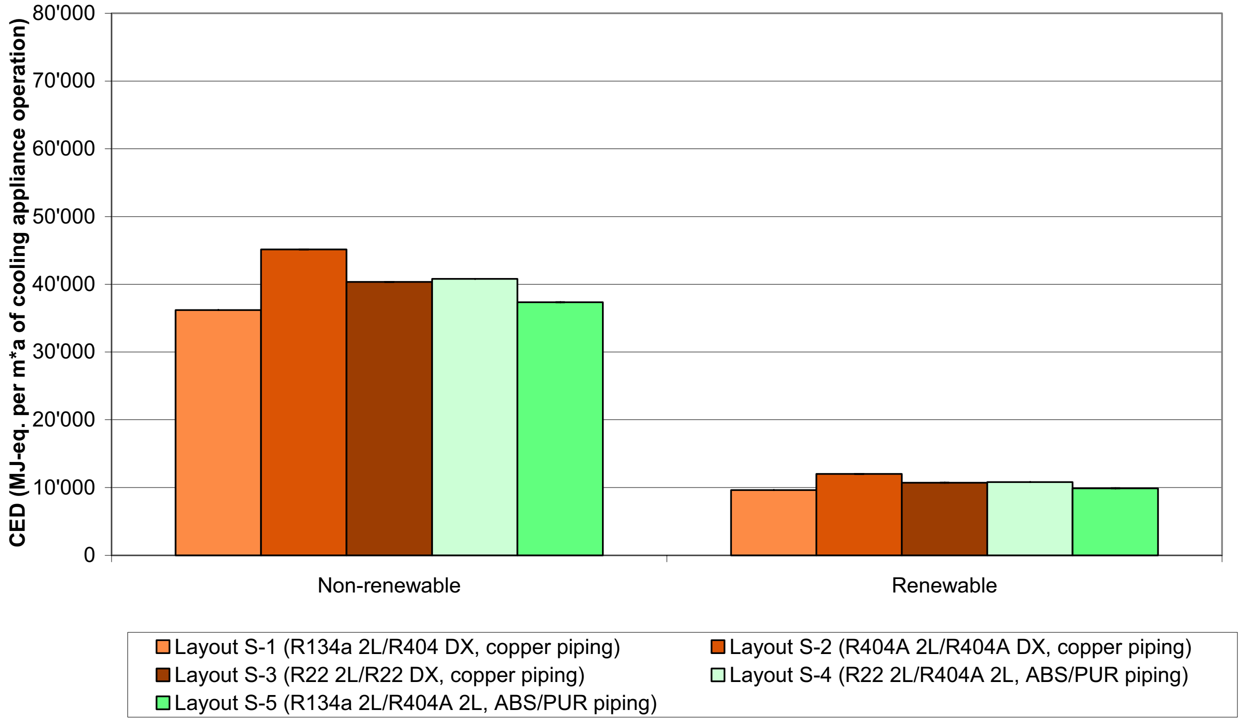

Figure 33: Sensitivity of the CED to the recycling of the ABS pipes (the sensitivity can not be noticed, since the variation is less than 0.001%)

Environmental Impacts According to CML 2001

All but one of the CML indicators show almost no sensitivity (<0.3%) towards the recycling of the COOL-FIT pipes. The same argument as in the previous paragraph on CED that the cooling systems are dominated by the environmental impact through energy consumption and refrigerant losses, is also valid here. *Freshwater aquatic toxicology* is the single indicator showing a noticeable improvement (2.6%) for a complete recycling of the COOL-FIT pipes.

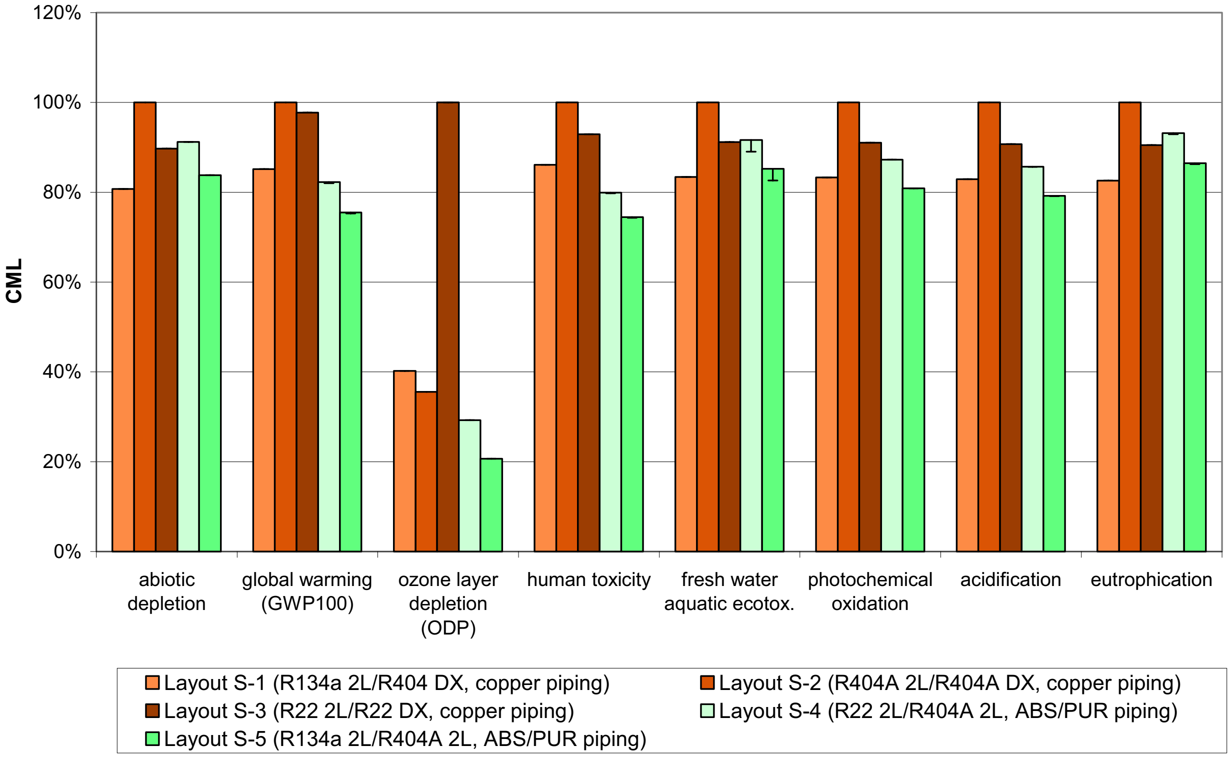

Figure 34: Sensitivity of the CML 2001 indicators to the recycling of the ABS pipes

TEWI (Total Equivalent Warming Impact)

Since the TEWI only encompasses the global warming potential from direct refrigerant losses and the direct electricity consumption, the recycling rate of the COOL-FIT pipe has no influence on the result. The TEWI can - by definition - not be dependent on the recycling rate.

4.5. Interpretation

In the life cycle impact assessment (LCIA) as well as in the following sensitivity analysis the direct electricity consumption was the determining factor for most indicators. Therefore, the assumption concerning the electricity consumption are an important aspect influencing the results. These assumptions were taken rather to the disadvantage of the COOL-FIT layouts. The discovered superiorities of COOL-FIT layouts can, therefore, assumed to be valid despite the uncertainties in the assumptions.

The extent of the domination of the results by the electricity consumption depends on the environmental impact of a country's electricity mix compared to the Swiss mix. However, the Swiss electricity mix (high share of hydropower) used in this study has a lower environmental impact than the mix of many other countries. This is especially true for countries with a particular share of the production from fossil power plants (e.g. USA (EIA 2003), but also countries like Germany (Frischknecht & Faist Emmenegger 2003)). As was shown in the case of supermarket operation in USA, an operation in such countries tend to have indicators dominated even more by the direct electricity consumption and further reducing the differences found because of the toxicity of copper, the transportation and the refrigerant losses.

One important aspect that turned up in several LCIA indicators was the use of copper. The COOL-FIT layouts replace copper pipes resulting in a lower need thereof. Since the toxicity of copper and its related processes have a noticeable influence, this effect is to the favour of COOL-FIT when compared with copper layouts.

The transportation is to the favour of the copper piping, since here (shorter) standard distances are used, whereas for the COOL-FIT pipes the actual transport distances are inventoried. Since there is only one COOL-FIT producer, but several locations producing copper pipes, it is reasonable that COOL-FIT has on average a greater total transport distance. This is the more true for the supermarket operation in USA, where the COOL-FIT pipes are assumed to be produced in Denmark as well. Only in the eutrophication indicator do the transports have a noticeable effect, however.

Frischknecht (1999a) stated the importance of the refrigerant losses and the direct electricity consumption. With the updated (and therefore lower) refrigerant loss rates, the loss rates became less important and only have a noticeable effect concerning global warming and ozone layer depletion. The TEWI assessment also shows noticeable sensitivity to refrigerant loss rates when the layout makes use of direct expansion. For the secondary systems (COOL-FIT) the loss is so little that it influences the TEWI only marginally.

An improvement in efficiency of cold generation in the meantime, could have led to lower electricity consumption than reported in Frischknecht (1999a), i.e. overestimating it in this study. The expected improvement in efficiency would be in the order of a few percent, since the technology has not changed. Therefore, it is reasonable that the results in this study still stress the importance of direct electricity consumption over other aspects of cooling systems.

The operation data of the COOL-FIT layouts is actually based on data coming from supermarkets with traditional copper or chromium steel piping. There is still too little experience with COOL-FIT in supermarkets to obtain accurate data for this study. It is supposed that 1 m COOL-FIT piping has a lower cold loss compared to traditional piping.[9] This is achieved by pre-insulating the pipes as well as the fittings in the factory resulting in a constantly high quality of the insulation. Fittings are hard to properly insulate on-site leading to spots of high cold loss. Pre-insulated COOL-FIT fittings minimise this kind of gaps in the insulation. It can, therefore, be assumed that the loss of cold is lower compared to traditional ways of insulation.

[9] Personal Communications on COOL-FIT and the Cold Store by Mark Bulmer (Georg Fischer Piping Systems, Schaffhausen), several dates 2005

5. Cold Store

5.1. Scope

This scope chapter only covers the aspects specific to the cold store installation (i.e. functional unit, system boundaries). The remaining parts are covered in the general scope chapter (chapter 2).

5.1.1. System Boundaries

In contrast to the supermarket all cold store layouts are based on indirect cooling. The basis for the layout is a cold store in the UK, which was built with COOL-FIT piping in the secondary circuit and has a total cooling capacity of 2430 kW (3*810 kW) and a volume of 333'290 m^3 at a temperature of 7°C (Figure 35). The piping of the secondary circuit is the only part altered between the different cold store layouts. There are the following three layouts to be compared:

Table 25: Overview of the three cold store layouts used in this study
**) The pipe material and insulation of the primary circuit is actually defined through the packaged chiller unit, whereof it is an internal component.*

	Layout CS-1	**Layout CS-2**	**Layout CS-3**
type of circuit	indirect	indirect	indirect
refrigerant	Ammonia	Ammonia	Ammonia
cooling fluid	glycol	glycol	glycol
primary circuit)*	chromium steel	chromium steel	chromium steel
secondary circuit	low-alloy steel	chromium steel	COOL-FIT
piping insulation	PUR with steel jacket	PUR with steel jacket	PUR with HDPE jacket

The insulation thickness of the steel and the chromium steel pipes are chosen such that the loss of cooling energy in the secondary circuit is the same for all three piping layouts. As a consequence, the electricity consumption of the compressor can be assumed to be equal for all three layouts. As the loss is identical in that case, the cooling energy delivered to the cold rooms as well as the cold to be produced at the compressor will be the same for all layouts.[10]

The boundaries of the considered system encompass the following elements (identical to all three piping layouts):

- Evaporative condenser
- Packaged chiller (i.e. a single unit containing compressor, heat exchangers, the refrigerant ammonia and a liquid receiver)
- Copper piping for the condenser circuit
- Glycol as 1) the cooling fluid in the secondary circuit, 2) the heat-transfer medium in the condenser circuit

Apart from the already mentioned components the following processes are also considered:

- Installation of the cooling system (material use for the pipe supports, insulation, welding and cementing, the transport of the whole cooling system to the installation site)
- replacement and emissions of the refrigerant during operation

[10] This was decided on the meeting on 3. May 2005 by Mark Bulmer, since there was too little experience to make an estimation on the difference in energy consumption.

- the final disposal of the cooling system including the refrigerants

The roof where the cooling water stems from is outside of the system boundary, since it is completely assigned to the building. The water used for cooling is actually “grey” water and, therefore, assumed to be free of any environmental burden.

The air coolers and similar devices used for cooling rooms are outside the system boundary. The goal of this study is to compare the different cooling system layouts with all of them providing the same amount of cooling energy to these end devices. Therefore, it is not necessary to include them.

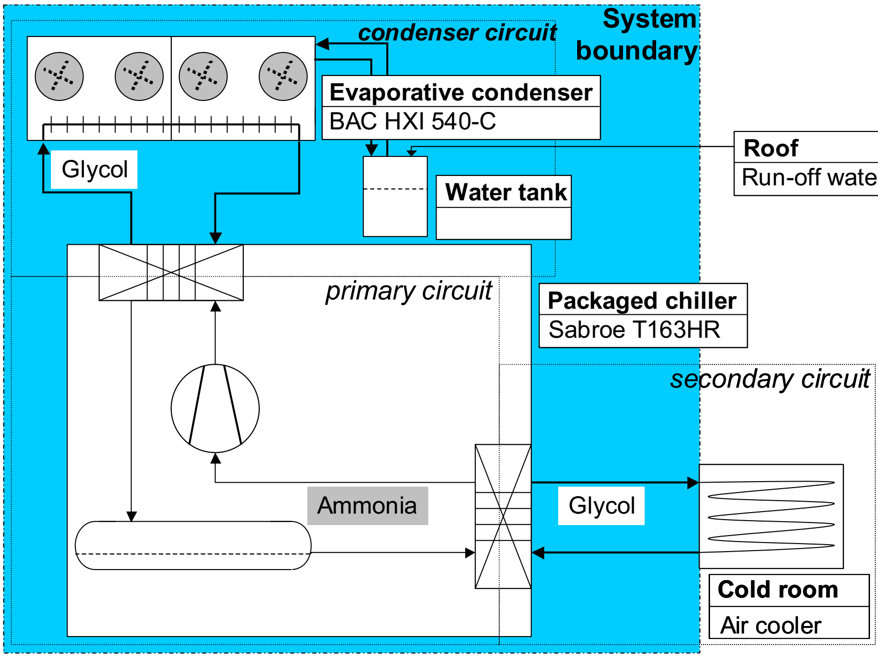

Figure 35: Layout of the cold store with its main components the packaged chiller for ammonia, the evaporative condenser and the piping. The system boundary is highlighted.

5.1.2. Functional Unit

The purpose of a cold store cooling system is to keep the products at a certain temperature level. In the considered cold store this is 7°C. To keep this temperature constant the cooling system has to extract energy equal to the gains[11] plus the cooling energy to cool newly stored products to the mentioned temperature. For large, medium temperature cold stores, like the one considered in this study, the amount of products stored is the most important and the energy gain by air exchange the second most important factor in the planning of the cooling capacity (Breidert 2003). The amount of products stored in the cold store can not easily be used as the functional unit, because of varying amounts of products stored throughout the year and this amount had to be corrected for the specific heat capacity of the different products. From that evaluation, it can be assumed that for an annual average the volume of the cold store is at least equally accurate and is, therefore, used as the reference for the functional unit.

The functional unit for the cold store is defined as “**cooling of one cubic meter of a cold store at 7°C for one year**” with the unit m^3*a.

[11] Gains not only includes heat transfer through walls and by air exchanges, but also the heat resulting from lighting as well as from persons and machines working in the cooled area (Breidert 2003)

5.2. Life Cycle Inventory (LCI)

5.2.1. Introduction

The cold story layout used in this study is a current installation in England, which was assumed to be located and operated in Switzerland and USA without changes to the layout. The cooling capacity of 2'420 kW is provided by three packaged chillers run with ammonia as refrigerant.

5.2.2. Main Data Sources

The data stem mainly from the following sources:

Personal communications:

- Mark Bulmer, GF Piping Systems – layout of the cold store in the UK
- Mr. Gysin, Schaller Uto AG, Bern – general information on cold store layouts as well as estimations from practical experience of today
- Mr. Trüssel, KWT Kälte-Wärme-Technik AG, Belp – general information on cold store layouts as well as estimations from practical experience of today
- Mr. Burger, Walter Wettstein AG, Gümligen – general information on cold store layouts as well as estimations from practical experience with special focus on secondary systems

5.2.3. Packaged Chiller for Cold Store

The packaged chiller used in the cold store was custom made for the investigated cold store. Therefore, there is no data publicly available. The amount of material and the relative composition was estimated from the ammonia compressor inventoried by Frischknecht (1999b). The total weight was determined by using a packaged ammonia chiller from the normal product range. According to these assumptions, one unit weights 5900 kg and consists of 30% cast iron, 51% chromium steel, 13% copper and 6% aluminium.

The manufacturing process of cooling system devices, documented in chapter 3.3.3, is used as a proxy due to the lack of more precise data on the production (see appendix A5.3 for the full details of the process data).

5.2.4. Hybrid Liquid Fluid Cooler

The inventory of the cooler refers to a BAC HXI 540 (manufactured by Baltimore Aircoil), which can be operated in dry and wet mode. Wet mode means that water is sprayed over the coils to achieve an additional cooling effect through the evaporating water. It was not possible to obtain precise data on the design of the cooler from the producer, neither data on manufacturing. However, the main materials it consists of are mentioned in the operating and maintenance manual (BAC 2001):

- galvanised steel
- copper (assumingly only for the coils and its fins)

To get an estimation for the share of those two metals in the 5'700 kg weighting unit, it was assumed that the share of the copper coils is the same as for the dry cooler in Frischknecht (1999b), i.e. 15%. The manufacturing process of cooling system devices, documented in chapter 3.3.3, is used as a proxy due to the lack of more precise data on the production (see appendix A5.3 for the full details of the process data).

5.2.5. Condensing Circuit Piping Kit

In contrast to the condensing circuit piping kit of the supermarket (chapter 4.2.3) where copper is used, the commonly used material in larger installations is steel.

The 3.5 kg/kW steel reported by Frischknecht (1999a) is interpolated to the 2'420 kW cooling power of the cold store. Manufacturing the pipes from the steel, the transport to the site and the installation of the pipes are all considered (see appendix A5.3 for the process data).

5.2.6. Cold Store Cooling System Infrastructure

The basic layout of the cold store was already presented in Figure 35. The following data was adapted from the supermarket using the cooling capacity ratio:

- non-pipe installation weight
- assembling and welding the cooling system

Since the data on the cold store infrastructure was only partly available, the remaining data were mainly estimated from the supermarket data. The propylene glycol charge was estimated from the pipe volume. The infrastructure data and the methods of estimation (if used) are indicated in Table 26. The piping, storage and collection devices related to providing water to the hybrid liquid cooler, were assumed to be of minor importance and, hence, negligible.

Table 26: The infrastructure inputs for the three cold store layouts. They are assumed to be independent of the operation site. The source of data estimation is indicated.

	Layout CS-1 (steel)	Layout CS-2 (chromium steel)	Layout CS-3 (COOL-FIT)	Estimated from
Pipe length [m]				
- di44	100	100	100	-
- di55	100	100	100	-
- di79	1’200	1’200	1’200	-
Total	1’400	1’400	1’400	
Installation weight [kg]				
Pipes	6'900	6'900	4'900	-
non-pipe installation	55'600	55'600	55'600	Supermarket
Total	62'500	62'500	60'500	
Assembling the cooling system (without the pipes)				
Propane [kg]	141	141	141	Supermarket
Nitrogen [kg]	120	120	120	″
Oxygen [kg]	493	493	493	″
Electricity (low voltage) [kWh]	3'521	3'521	3'521	″
Refrigerant Charge [kg]				
Propylene Glycol	5’590	5’590	5’590	pipe volume
Ammonia	321	321	321	similar ammonia chiller
Lubricating oil charge [kg]				
Total	236	236	236	Supermarket

5.2.7. Cold Store Cooling System Operation in Switzerland (Europe)[12]

The data on the cold store operation stem mainly from personal communication[13]. The loss of refrigerants is derived from the data in Frischknecht (1999b) on the ammonia supermarket and from a personal communication[14]. For the calculations the average values were applied (Table 27). The low and high rates are used in the sensitivity analysis in chapter 5.4.

[12] the assumptions are probably also valid for other European cold stores

[13] by Mark Bulmer (Georg Fischer Piping Systems, Schaffhausen), several dates 2005

[14] by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

Table 27: Refrigerant loss rates used for the cold stores operated in Switzerland. The average values are used (the full tables with more literature values can be found in Table 34 and Table 35 in the Appendix).

	Type	Refrigerant	Leakage rate low	Leakage rate average	Leakage rate high	Remarks
Personal Communication[15]	2L	Ammonia		~0%		without incidents
Frischknecht 1999b	2L	Ammonia	2%		5%	low: "near future" optimisation, high: "today" condition (i.e. 1999)
This study	**2L**	**Ammonia**	1%	**3%**	5%	

Due to the absence of long-time experience with COOL-FIT piping it was assumed that the operation of the cold store would be equal for all three layouts. This leads to:

- equal refrigerant loss for all three layouts - since also the steel and chromium steel layouts are welded nowadays and all layouts make use of indirect cooling, this assumption is realistic
- equal electricity consumption – since the configuration of the pipes assumes the same insulation material and thickness for the metal pipes as for the COOL-FIT ones only a small variation is to be expected due to the higher heat conductivity of the metal over the plastic and different qualities of the insulations

The typical life-span of a cold store in Switzerland is 20 to 30 years.[16] Ammonia systems may also be in service for 35 years or longer but need a major overhaul including replacements of major parts.[17] The typical life-span is 25 years, which means that the repairs of the cooling system and the replacement of parts can be considered negligible. However, 25 years of life-span might be an overestimation in the case of the steel layout, where corrosion leads to a more frequent need for replacement than for pipes in chromium steel or COOL-FIT.

The annual electricity consumption of the cold store (Table 28) was estimated using the full load hours of the supermarket, which are 2630 h/a (30% of one year) and the power consumption of the compressors at full load (243 kW per chiller unit).

[15] personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

[16] personal communication by Mr. Trüssel (KWT Kälte-Wärme-Technik, Belp) on 02.06.2005 and by Mr. Gysin (Schaller Uto AG, Bern) on 31.05.2005

[17] personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

Table 28: The inputs for the operation of the three cold store layouts in Switzerland.

	Layout CS-1 (steel)	Layout CS-2 (chromium steel)	Layout CS-3 (COOL-FIT)
Refrigerant loss			
During initial filling	1%	1%	1%
Annual (average)	3%	3%	3%
During final disposal	2%	2%	2%
Electricity [kWh/(m^3*a)]			
Cold Store	5.76	5.76	5.76
Life-span [a]			
Cooling system installation	25	25	25

5.2.8. Cold Store Cooling System Operation in USA

The operation of the cold store in the USA is assumed to be similar to the one operated in Switzerland (chapter 5.2.7). The differences are:

- the refrigerant loss rates, which are assumed to be higher in the USA (Table 29)
- the electricity mix is changed to the USA mix, which has a higher share of fossil fuels and less renewables

For the calculations the average refrigerant loss rates were applied (Table 29). The low and high rates are used in the sensitivity analysis in chapter 5.4.

Table 29: Refrigerant loss rates used for the cold stores operated in USA. The average values are used (the full tables with more literature values can be found in Table 34 and Table 35 in the Appendix).

	Type	Refrigerant	Leakage rate			Remarks
			low	average	high	
Bivens 1999	2L	general	2%		4%	high: "today", low: near future for US-supermarket, p.5
Baxter 2003	2L	R507	2%	5%	10%	R507 is a blend of 50% R125 and 50% R143a (per mass)
This study	**2L**	**general**	1%	**5%**	10%	

5.2.9. Cold Store Cooling System Dismantling and Disposal

At the end-of-life the cooling system has to be dismantled and its parts disposed. The metal parts are completely recycled, whereas the insulation, the plastic pipes (COOL-FIT) and the lubricating oil are incinerated.[18] The coolant (propylene glycol) is sent to a wastewater treatment plant for treatment. The ammonia refrigerant is assumed to be recycled, but a part of it is released to the air during the disposal process (extraction from the cooling system, transport to recycling site, recycling process. In this study 2% loss during disposal is assumed (Table 28).

It is assumed that in the case of the USA supermarket the same assumptions remain valid.

[18] personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

5.3. Impact Assessment Results

The impact assessment is divided into two parts:

- impact assessment of the base case (this chapter)
- sensitivity analysis (chapter 5.4)

5.3.1. Introduction

There are three cold store layouts to be compared as defined in chapter 5.1.1. However, there was not so detailed data available as for the supermarkets. The results in the following chapters are based on assumptions important for the outcome – e.g. on the electricity consumption. However, since these assumptions are the same for all layouts the comparison is not biased by them. The assessment starts with the CED (chapter 5.3.2) and is continued with CML 2001 (chapter 5.3.3). There is no assessment with the TEWI method, since in the case of the cold store the value only depends on the electricity consumption, which is chosen identical to all three layouts but also contains a high degree of uncertainty. Ammonia does not contribute to the TEWI.

The cold store piping is less complex and the whole installation has a higher lifespan compared to the supermarket assessed in the previous chapter. Therefore, it is to be expected that the electricity becomes even more dominant in the following assessments.

5.3.2. Cumulative Energy Demand

Cold Store Operation in Switzerland

The difference between the layouts is less than 0.1% and actually not noticeable in Figure 36 and shows an equal probability in the uncertainty comparison between layout CS-2 and CS-3 (Figure 37). Such an undifferentiated outcome was not expected, but shows that the electricity consumption is even more important in the case of the cold store (Table 30) as it was already the case for the supermarkets (Table 21).

Table 30: Separation of the total impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation of the cold store cooling systems assessed with Cumulative Energy Demand.

	Layout CS-1 (Ammonia 2L, steel piping)		**Layout CS-2 (Ammonia 2L, chromium steel piping)**		**Layout CS-3 (Ammonia 2L, ABS piping)**	
	non-renewable	renewable	non-renewable	renewable	non-renewable	renewable
Electricity Consumption	97.1%	99.5%	97.0%	99.5%	97.0%	99.5%
Cooling System	2.93%	0.49%	3.01%	0.53%	2.99%	0.51%
Refrigerant Replacement	0.005%	0.003%	0.005%	0.003%	0.005%	0.003%

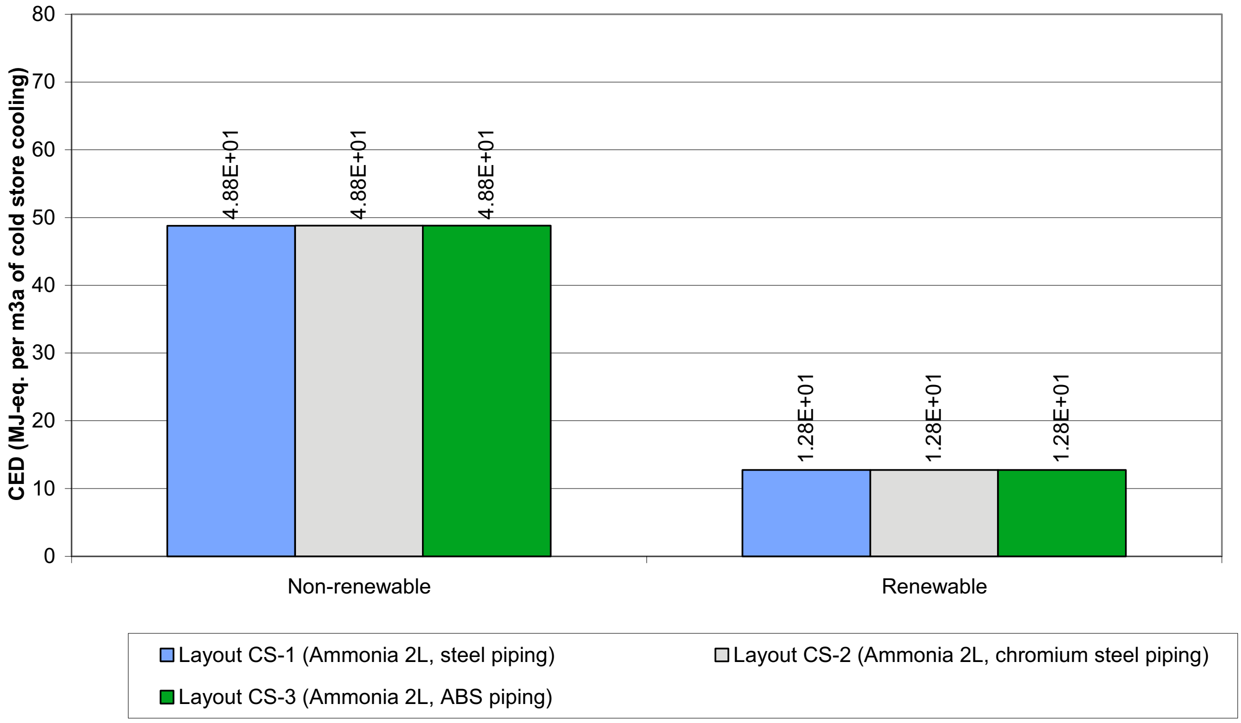

Figure 36: Absolute values of the cumulative energy demand of the three cold store layouts operated in Switzerland.

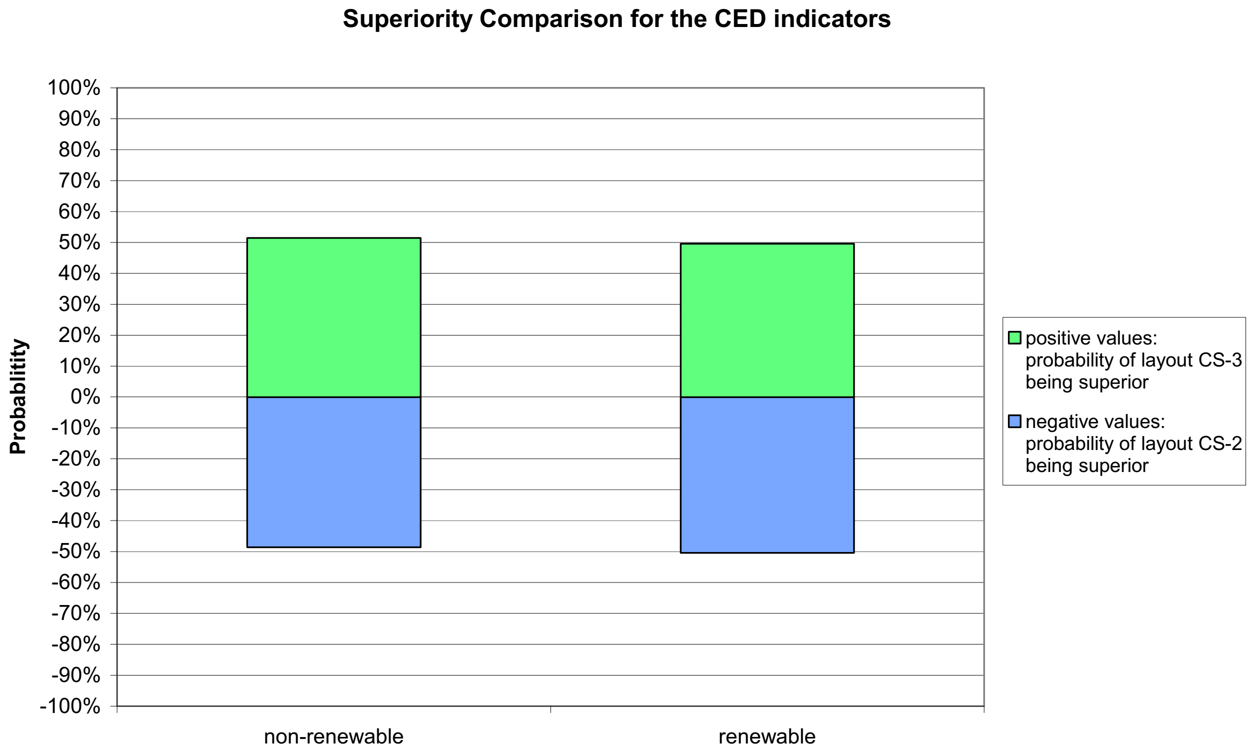

Figure 37: Uncertainty comparison of layout CS-2 (Ammonia 2L, chromium steel piping) with layout CS-3 (Ammonia 2L, ABS/PUR piping) concerning superiority towards the CED indicators for cold store operation in Switzerland. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a positive probability.)

Cold Store Operation in USA

Figure 38 shows the identical picture as was already encountered for the operation in Switzerland (Figure 36). There is a difference of less than 0.1% between the three layouts, which is also reflected in the 50% probability of superiority for layout CS-2 as well as CS-3 (Figure 39). However, the absolute values are, when compared to the result from the Swiss supermarket, higher for the non-renewable and lower for the renewable part, which is mainly due to the differences in the electricity mix.

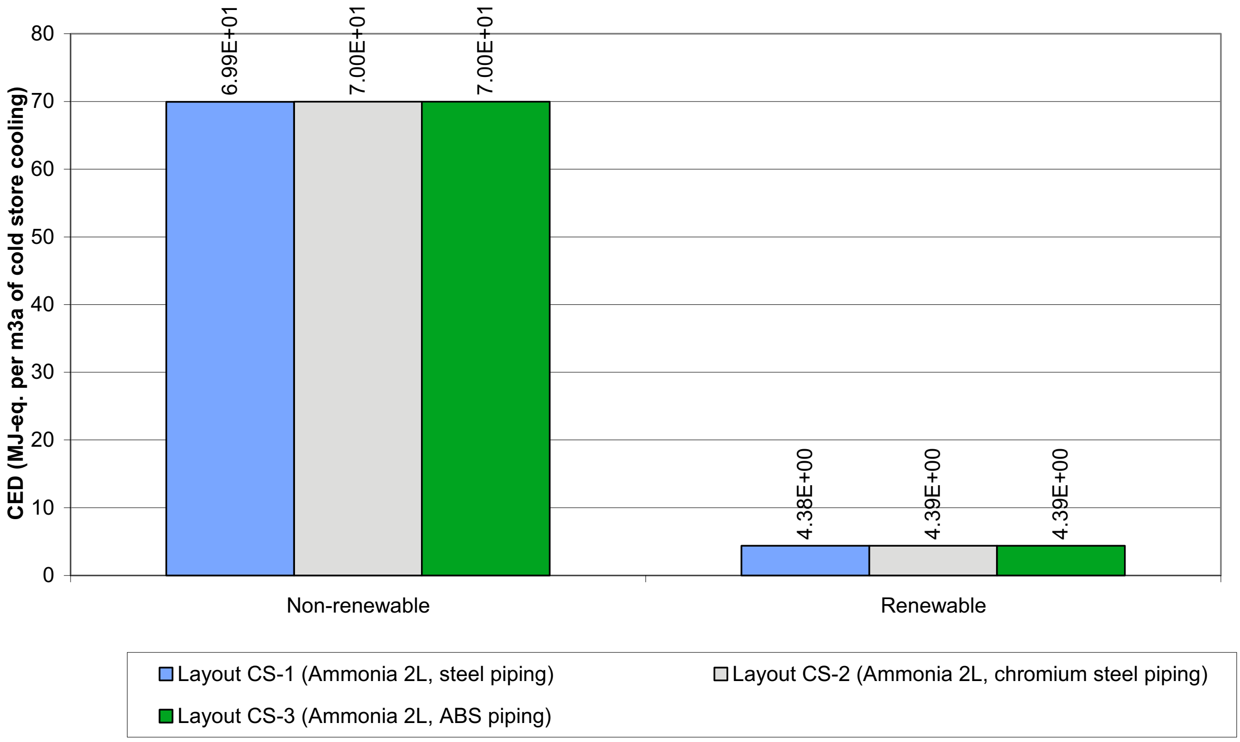

Figure 38: Absolute values of the cumulative energy demand of the three cold store layouts operated in USA.

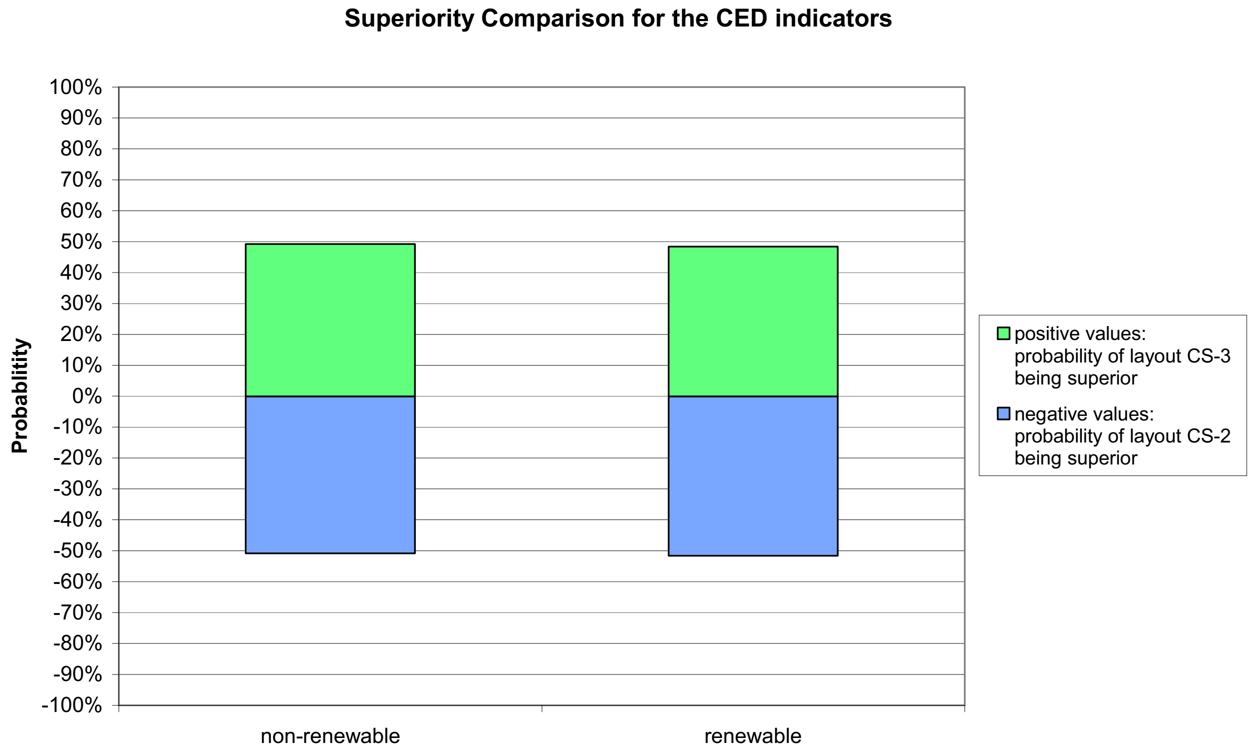

Figure 39: Uncertainty comparison of layout CS-2 (Ammonia 2L, chromium steel piping) with layout CS-3 (Ammonia 2L, ABS/PUR piping) concerning superiority towards the CED indicators for cold store operation in USA. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a positive probability.)

5.3.3. Environmental Impacts According to CML 2001

Cold Store Operation in Switzerland

It was already realised in the cumulative energy demand assessment that the electricity consumption is dominating the results (Table 30). Using the CML 2001 impact assessment the result is very much the same (Figure 40, Table 31, Table 32 and Table 33). The share of the environmental impact due to the electricity consumption is often greater than 90%. However, the cooling system installation achieves a share of 12% to 20% in human toxicity and 16% to 25% in freshwater aquatic ecotoxicity, which are the second highest values after electricity. This effect can also be noticed in Figure 41 where a differentiation between the three layouts can be found for these two indicators, but not for the other ones. This finding is also supported by the uncertainty analysis (Figure 42), where only the mentioned two indicators show a higher probability towards the superiority of layout CS-3 over CS-2. However, the probability is too low to be considered as a significant difference according to the criteria specified in chapter 2.2.

It seems that the cooling system installation has a relatively high impact concerning toxicity. The source of the toxicity is the chromium steel of the packaged chillers and the copper used in the hybrid liquid coolers. Chromium and copper are released in certain quantities to the environment in the whole production chain from mining until the final product. Since both elements are toxic, these emissions contribute to indicators assessing toxicity. The cold store with chromium piping entails the highest amount of chromium steel and, therefore, also shows the highest shares in the toxicity indicators (Figure 41 and Table 32).

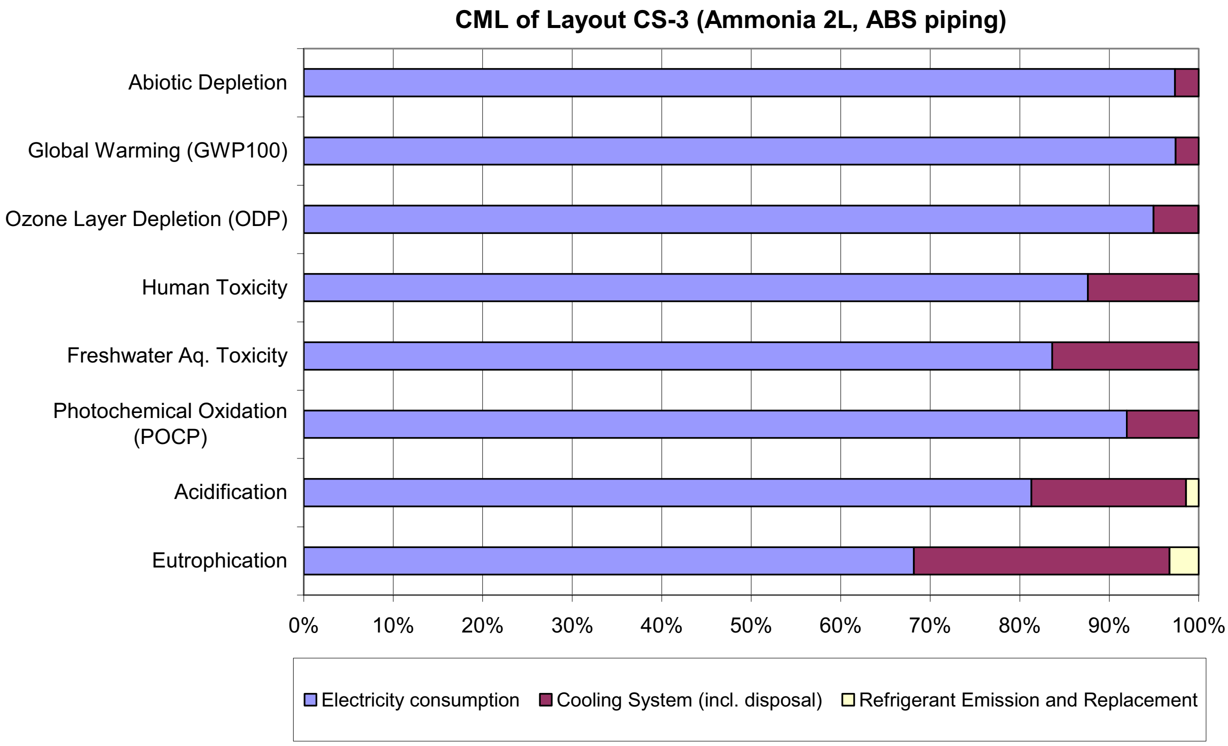

Figure 40: Share of the three main issues (electricity consumption, cooling system, refrigerant loss and replacement) of a cold store cooling system in the example of the layout CS-3 (Ammonia 2L, ABS piping) for the CML 2001 indicators.

Table 31: Separation of the total environmental impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation for the layout CS-1 (Ammonia 2L, steel) and the CML 2001 indicators (graphical representation of the numbers in Figure 40)

	Abiotic Depletion	Global Warming Potential	Ozone Layer Depletion	Human Toxicity	Freshwater Aq. Ecotox.	Photo-chemical Oxidation	Acidifica-tion	Eutrophi-cation
Electricity consumption	97.6%	97.6%	94.8%	87.3%	83.1%	91.7%	81.4%	68.1%
Cooling System	2.4%	2.4%	5.2%	12.7%	16.9%	8.3%	17.2%	28.6%
Refrigerant Emission and Replacement	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	1.41%	3.25%

Table 32: Separation of the total environmental impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation for the layout CS-2 (Ammonia 2L, chromium steel) and the CML 2001 indicators

	Abiotic Depletion	Global Warming Potential	Ozone Layer Depletion	Human Toxicity	Freshwa-ter Aq. Ecotox.	Photo-chemical Oxidation	Acidifica-tion	Eutrophi-cation
Electricity consumption	97.3%	97.3%	94.6%	80.7%	74.7%	91.3%	81.1%	67.9%
Cooling System	2.7%	2.7%	5.4%	19.2%	25.3%	8.7%	17.5%	28.9%
Refrigerant Emission and Replacement	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	1.41%	3.24%

Table 33: Separation of the total environmental impact into electricity consumption during operation, cooling system (manufacturing, installation and disposal of the system incl. initial refrigerant charge) as well as refrigerant emission and replacement during the operation for the layout CS-3 (Ammonia 2L, ABS) and the CML 2001 indicators

	Abiotic Depletion	Global Warming Potential	Ozone Layer Depletion	Human Toxicity	Freshwater Aq. Ecotox.	Photo-chemical Oxidation	Acidification	Eutrophication
Electricity consumption	97.4%	97.4%	94.9%	87.6%	83.6%	92.0%	81.3%	68.2%
Cooling System	2.6%	2.6%	5.0%	12.4%	16.4%	8.0%	17.3%	28.6%
Refrigerant Emission and Replacement	0.01%	0.01%	0.02%	0.01%	0.01%	0.01%	1.41%	3.26%

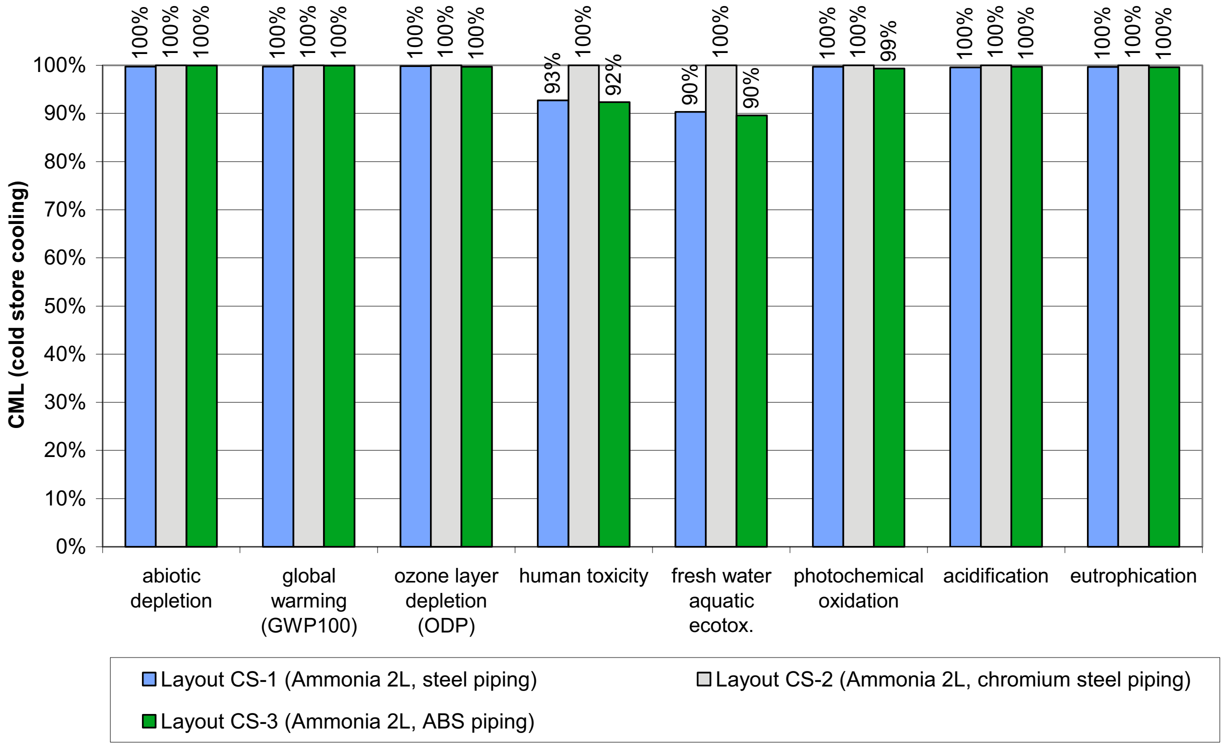

Figure 41: Percentage representation of the impact Assessment of the cold store cooling systems operated in Switzerland assessed with CML 2001.The highest value in each indicator is set to 100%

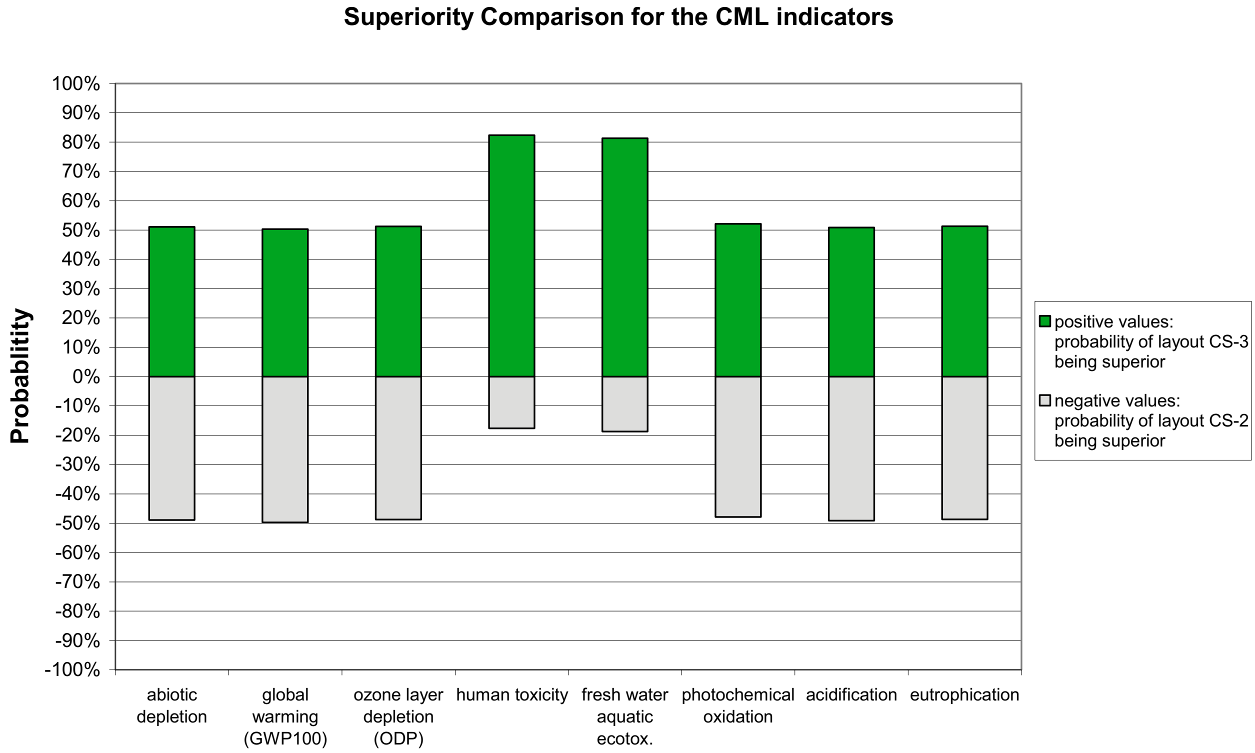

Figure 42: Uncertainty comparison of layout CS-2 (Ammonia 2L, chromium steel piping) with layout CS-3 (Ammonia 2L, ABS/PUR piping) concerning superiority towards the CML indicators for cold store operation in Switzerland. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a positive probability.)

Cold Store Operation in USA

Not only are the CED assessments for the cold stores operated in Switzerland and USA very similar, but also when it comes to the CML assessment (see Figure 43 and compare it to Figure 41). The minor differences concern *human toxicity* and *fresh water aquatic ecotoxicity* where the steel and ABS layouts are now closer to the chromium steel layout. This is a result of the higher environmental impact of the USA electricity mix, which reduces the relative importance of the piping towards the whole result. The (non-significant) difference in the mentioned two indicators can also be noticed in the uncertainty comparison in Figure 44.

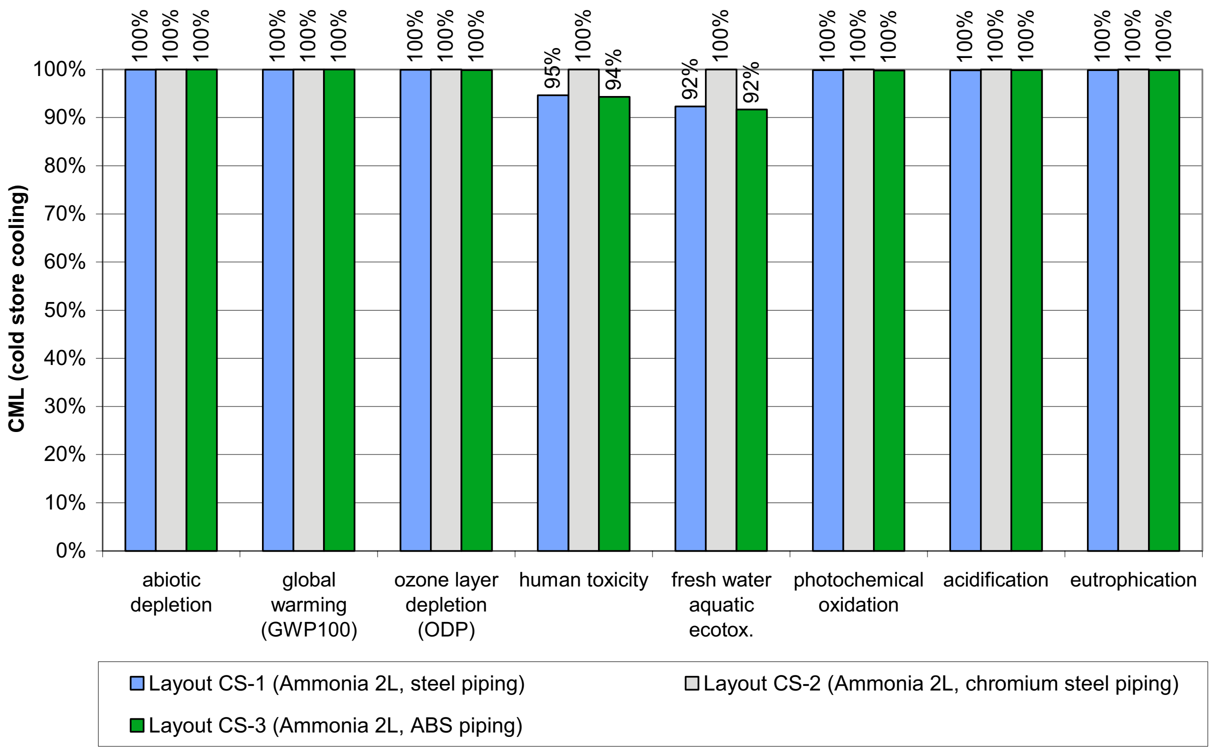

Figure 43: Percentage representation of the impact Assessment of the cold store cooling systems operated in USA assessed with CML 2001.The highest value in each indicator is set to 100%

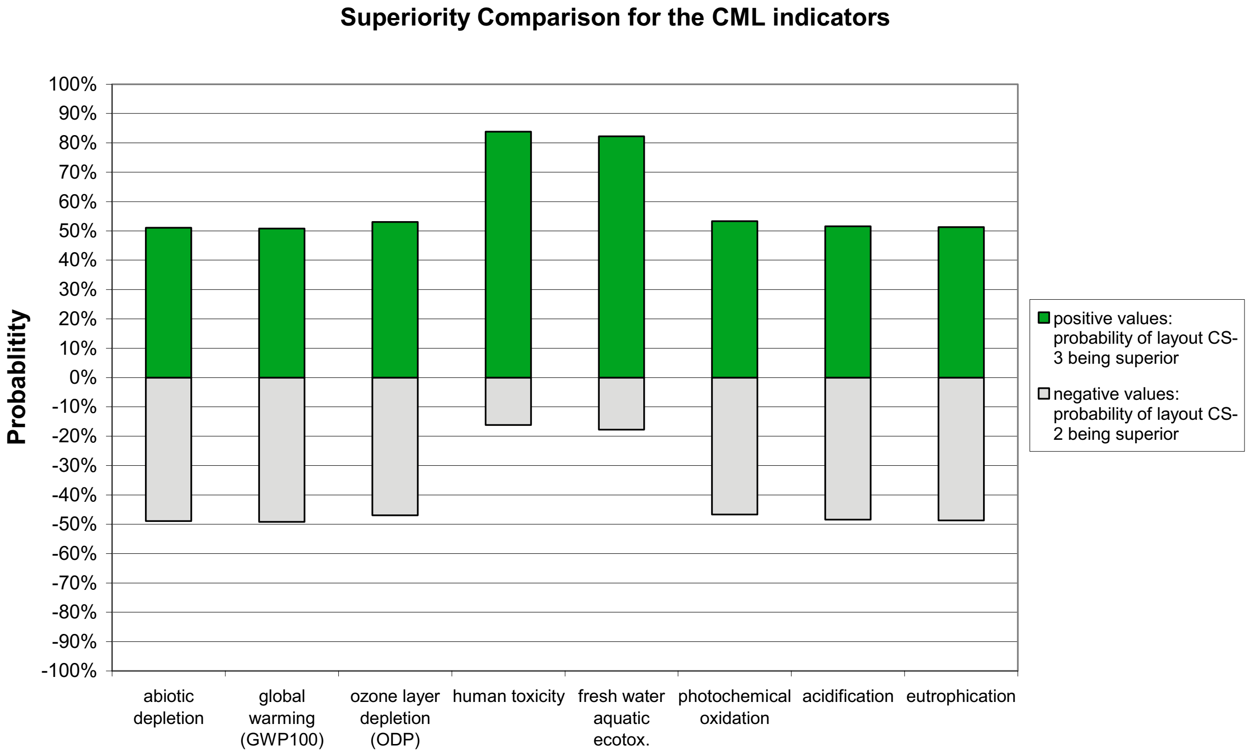

Figure 44: Uncertainty comparison of layout CS-2 (Ammonia 2L, chromium steel piping) with layout CS-3 (Ammonia 2L, ABS/PUR piping) concerning superiority towards the CML indicators for cold store operation in USA. (Remark: due to graphical reasons the scale contains negative percentage values. However, they should be interpreted as positive values, i.e. they do not represent negative, but a positive probability.)

5.4. Sensitivity Analysis

5.4.1. Direct Electricity Consumption

Introduction

The direct electricity consumption is the dominating factor in the environmental impact assessment as was confirmed in the previous chapter. In the following the sensitivity of the indicators to a variation by +10% and -10% of the direct electricity consumption of the cold stores is evaluated.

On one hand this sensitivity analysis reflects the importance of electricity consumption in each indicator. On the other hand the base case of the non-COOL-FIT systems can be compared with the case of the COOL-FIT systems having a 10% lower electricity consumption due to better insulation properties. Disregarding this difference was an important assumption probably to the disadvantage of the COOL-FIT systems.

Cumulative Energy Demand

The sensitivity of the cumulative energy demand ought to be strongly correlated with the direct electricity consumption due to the results of the impact assessment (chapter 5.3.2). As can be seen in Figure 45 for the operation in Switzerland a 10% variation of the electricity leads directly to a 9.7% variation in the CED non-renewable and 9.95% in the CED renewable. There is virtually no sensitivity left for other aspects of the cooling systems. Therefore, no further sensitivity analysis concerning refrigerant loss or recycling of the pipes is needed. Although, the sensitivity values have been calculated (see following chapter), it can be already deduced from this outcome that the sensitivity must be smaller than 0.3% in any case.

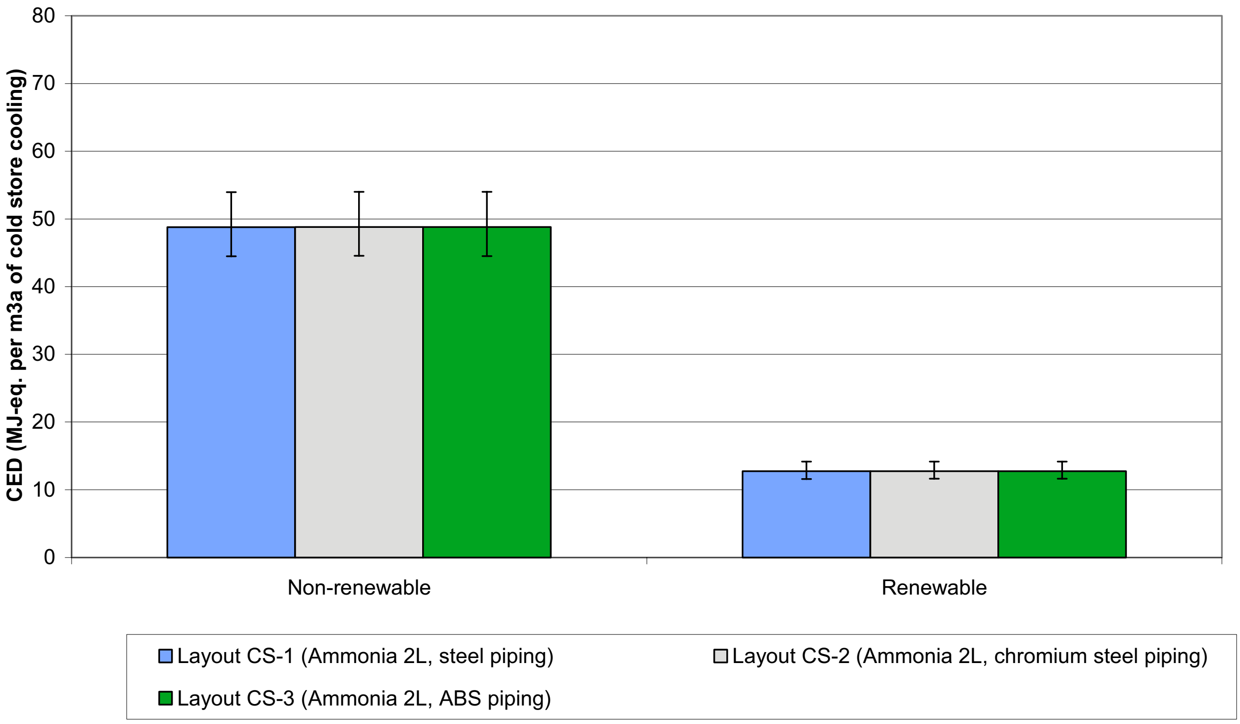

Figure 45: Sensitivity of the CED to a 10% variation of the direct electricity consumption, when the cold store is operated in Switzerland

The result for the cold store operated in USA instead of Switzerland is almost identical to Figure 45 and, therefore, not shown separately. The resulting variation is 9.8% for the non-renewable and 9.85% for the renewables.

Environmental Impacts According to CML 2001

The sensitivity always follows the change of electricity consumption very closely. For the operation in Switzerland (Figure 46) the variation is between 7% (eutrophication) and 9% (global warming). The dependence is slightly more pronounced for the cold store operation in USA (figure not shown), where it varies between 8% (freshwater aquatic ecotoxicity) and almost 10% (abiotic depletion). This result had also to be expected from the impact assessment (chapter 5.3.3).

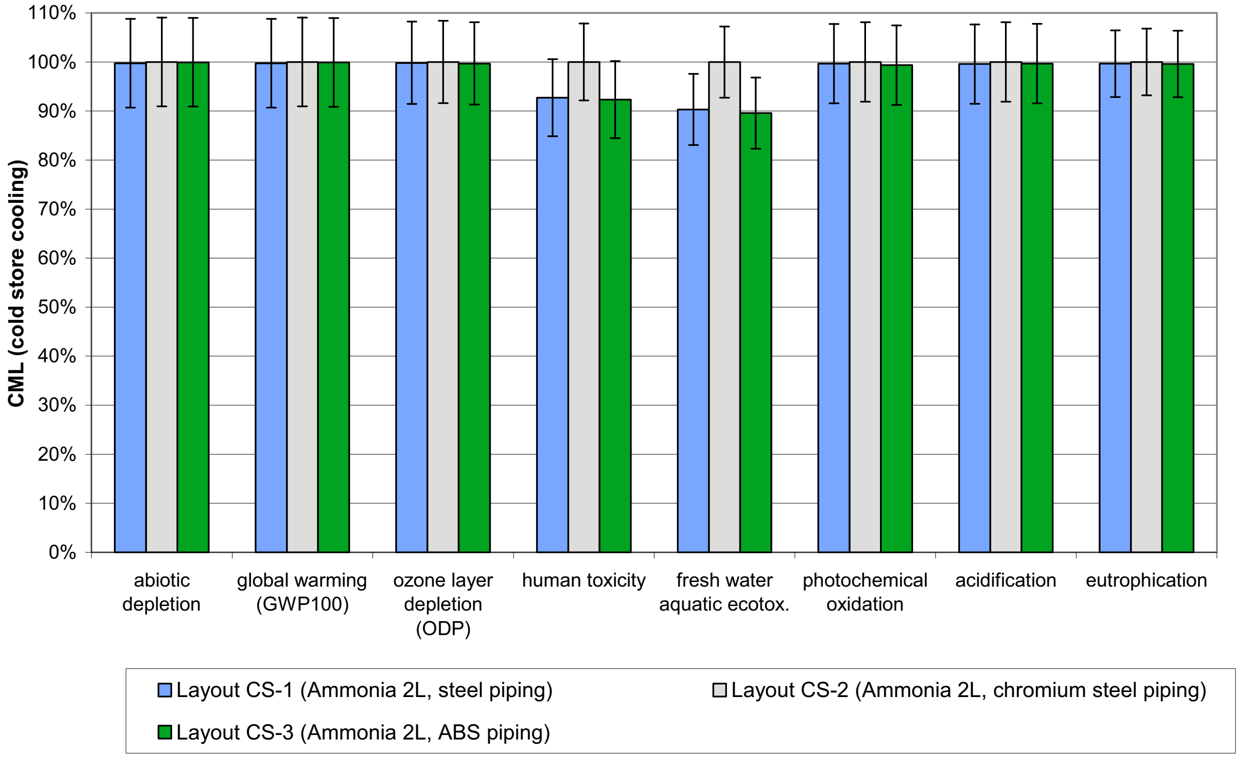

Figure 46: Sensitivity of the CML 2001 indicators to a 10% variation of the direct electricity consumption (cold store operation in Switzerland)

5.4.2. Direct Refrigerant Loss

Introduction

The refrigerant loss rates in the considered indirect cooling systems are already quite low. The lower value of the sensitivity range (1%, see Table 28) can probably be achieved with today's technology. The upper refrigerant loss rate (5% and 10% for Swiss and American location respectively) rather represents an older and not so well maintained cooling system.

CED

The sensitivity of cumulative energy demand with respect to the refrigerant loss is extremely low (<0.002%). Although the variation of the refrigerant loss was assumed to span a wider range in the case of the supermarket located in the USA, it remains very low (<0.003%).

Environmental Impacts According to CML 2001

There is a very low sensitivity in acidification and eutrophication with respect to the refrigerant loss. This is in the order of 1% (acidification) and 2% (eutrophication) for Swiss (Figure 47) as well as American location (not shown since virtually identical) of the cold store. Ammonia, which is used as the refrigerant in all three layouts has through its chemical properties a direct influence on these two indicators, hence, this effect is not surprising. The remaining indicators show a very low sensitivity not noticeable in Figure 47.

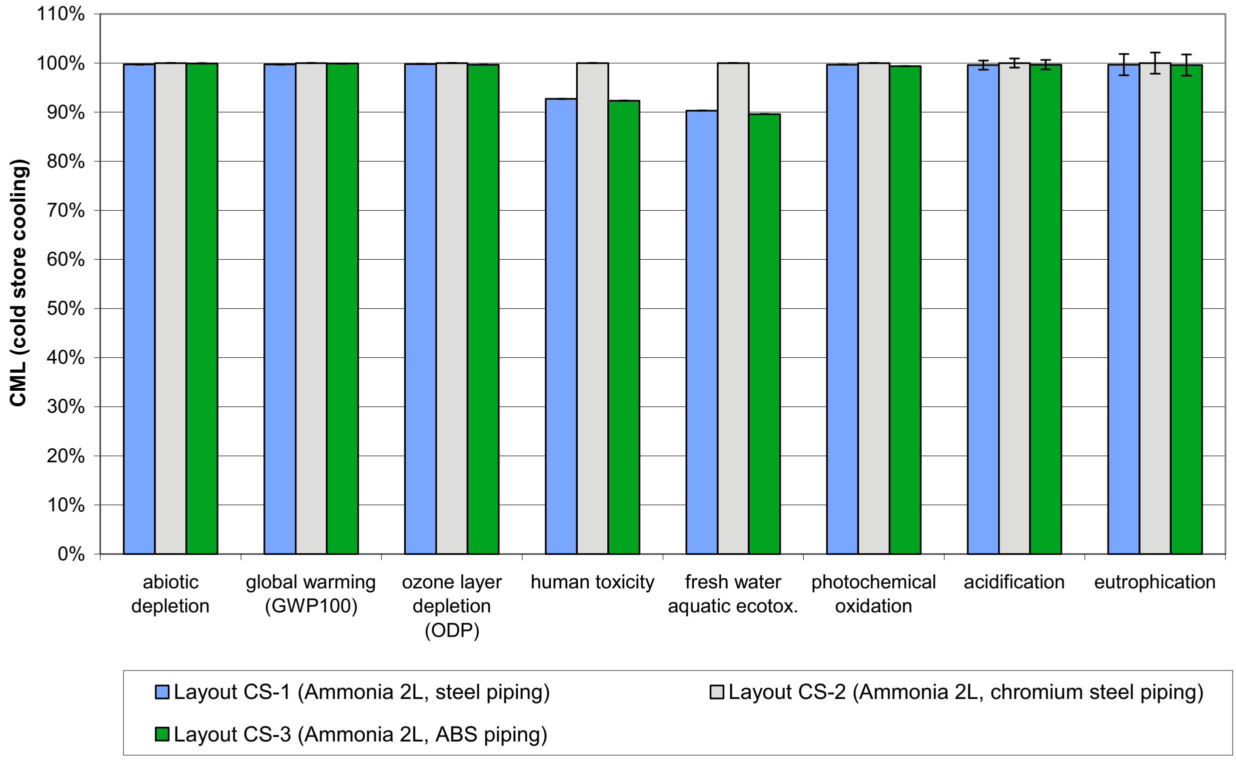

Figure 47: Sensitivity of the CML 2001 indicators to a variation of the refrigerant loss rates

5.4.3. COOL-FIT Pipes Recycling

The result of the impact assessment is – as discussed in the previous chapter - completely dominated by the use phase, i.e. electricity consumption, refrigerant emissions and replacement (Table 30 up to Table 33). The share of the cooling system infrastructure is very low, except in toxicity indicators where the higher shares are attributable to chromium steel and copper use. The share of the environmental impact of the piping is, therefore, already very small and recycling can only have a marginal effect (figures not shown).

5.5. Interpretation

In the case of the cold store the environmental impact attributable to the electricity consumption is even more dominating than it was for the supermarket. A longer lifespan of the installation (25 instead of 15 years) and a less complex piping installation leads to a significantly lower relative material need, i.e. kg material per kWh cold is lower. Therefore, the result is almost exclusively dependent on the electricity consumption. This can be clearly seen in the sensitivity chapter on electricity (chapter 5.4.1). The electricity consumption was assumed to be the same for all layouts leading to very small and not significant differences between the layouts caused by the slightly different infrastructure needed in each case.

The sensitivity towards the refrigerant loss is very low (Figure 47) illustrating the low importance of the ammonia refrigerant in the impact assessment of the cold stores. There is only one noticeable difference between the three layouts. The chromium steel layout CS-2 has a higher impact in the CML toxicity indicators than the layouts with the steel and the COOL-FIT piping. The higher toxicity of chromium steel and its related production processes become evident here. The packaged chiller needs to be made of chromium steel in the case of ammonia as the refrigerant. Using a refrigerant that does not need a chiller made of chromium steel would lead to a higher difference in the toxicity indicators between the chromium steel piping and the other two piping materials, but probably a noticeable effect in global warming and ozone layer depletion as well (depending on the characteristics of the refrigerant).

It was assumed that all three layouts have the same electricity consumption, since the insulation thickness was chosen such that the loss of cold is the same in all layouts. However, it is thought by Georg Fischer Piping that its COOL-FIT piping is performing better compared to conventional piping technology concerning the loss of cold. If it can be shown in the future – after some more years of experience - that this is going to be the case, this will have a direct influence on the environmental performance of the COOL-FIT layouts. To result in a significant superiority (according to the definition in this study) a reduction in electricity consumption of at least 5% must be achieved.

6. Conclusions

The direct influence from the cooling system infrastructure is in general small for all layouts, except for the human toxicity and freshwater aquatic toxicity indicators, where the toxic properties of copper and chromium steel show a certain relevance. The main driver in most indicators is the electricity consumption, while the refrigerant loss shows some importance in *global warming, ozone layer depletion* and *TEWI*.

Although the choice of piping system does not influence the electricity consumption or the refrigerant emissions directly, it does so indirectly. COOL-FIT can only be used in indirect configurations and comes as preinsulated pipes. This entails the following effects, which are relevant to the environmental assessment:

1. indirect cooling systems have a lower energy efficiency due to the additional heat transfer step
→ increased environmental impact for COOL-FIT systems (based on experience by experts a 10% higher electricity consumption in the low temperature section compared to the equivalent with direct cooling is assumed)
2. indirect cooling systems have lower refrigerant emissions due to lower loss rates, and also significantly reduced charges
→ decreased environmental impact for COOL-FIT systems (data based on a literature review)
3. better insulation of the pipes would lead to less cold loss and, finally, to a lower electricity consumption
→ decreased environmental impact for COOL-FIT systems (this reduction was not considered due to lack of data, but the effect can be deduced from the sensitivity analysis on the electricity consumption)

If it can be proven in the future that the electricity consumption of a cooling system with COOL-FIT is lower than with a comparable traditional layout, this would directly reduce the environmental impact of most indicators.

At the moment the results of the environmental assessment of the cooling systems, be it a supermarket or a cold store, show little difference in most indicators and layouts. In some indicators the traditional layouts seem to perform better in others the COOL-FIT ones. According to the criteria of superiority (at least 5% difference and a probability of superiority greater than 90%) the COOL-FIT layouts are not inferior in any of the indicators compared to traditional layouts. Furthermore, COOL-FIT is superior in the indicators *global warming, ozone layer depletion and human toxicity* in the case of supermarket operation in Switzerland. Supermarket operation in the USA leads to *ozone layer* and *human toxicity* as indicators with a significant superiority of COOL-FIT layouts.

The cold store cooling systems are even more dominated by the electricity consumption. Consequently, the differences between the layouts are even smaller and none of the indicators showed a significant difference.

As outlined above, the comparison of the COOL-FIT with the copper layouts (supermarket) and steel and chromium steel layouts (cold store) is not a clear and straightforward task. The aspects influencing the results – or the ones thought to at the beginning of the project - are summarised in the following (stated in order of importance):

- **electricity consumption** is highly relevant in all indicators, except *ozone layer depletion* in the supermarket assessment. Indirect systems have higher electricity consumptions, while improved insulation of the piping leads to a reduction. Both aspects play an important role when it comes to the COOL-FIT systems. While the first aspect to the disadvantage of COOL-FIT was considered, the second one – probably being to the benefit of COOL-FIT layouts – was not. The location of the supermarket is insofar of importance as the environmental impact per kWh depends on the country's electricity mix. The higher the environmental impact per kWh of electricity the less importance other aspects become (assessments for Switzerland – low impact – and USA – comparatively higher impact – were conducted).

- **refrigerant emissions** become relevant in the indicators *global warming, ozone layer depletion* and *TEWI* and particularly when HFC refrigerants are used. Indirect layouts have an advantage towards this aspect since the loss rates as well as the refrigerant charges are lower compared to direct cooling. However, this is at the cost of a higher electricity consumption as mentioned before.
- **life cycle toxicity of used materials** is of some relevance in *human toxicity* and *freshwater aquatic toxicity*. The material used for the COOL-FIT pipes causes lower environmental impacts compared to copper and chromium steel in this respect.
- **transport distance of the pipes** is of minor importance. Even a transport from Europe to USA has only a small influence on the environmental impact of the installation and an even smaller one when also operation is considered.
- **recycling** of the COOL-FIT pipes at the end of life does almost not improve the environmental performance. Instead the use of recycled materials in the production of the pipes would lead to a certain environmental improvement of the cooling system installation.

It has been realised that the environmental impacts from the electricity consumption are dominating the results. When it comes to the cold store, no significant difference was identified between the layouts since the environmental impact of the piping material and the refrigerant loss is of too little importance compared to electricity consumption. In the case of the supermarket in Switzerland a superiority of COOL-FIT in three out of ten indicators and equality in the remaining seven has been shown. The somewhat higher importance of the material mainly due to a shorter life-span compared to the cold store and environmentally more important refrigerant losses lead to the discovered differences between traditional and COOL-FIT supermarket layouts.

The share of the environmental impact from non-electricity related aspects will rise as cooling systems become more energy efficient. Therefore, a cooperation of GF with the best refrigeration engineers is crucial to combine the benefits of the piping system with those of the most efficient cooling equipment.

A Appendix

A1 Life Cycle Assessment (LCA) Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[19]. The LCA is based on a perspective encompassing the whole life cycle. Hence, the environmental impacts of a product are evaluated from cradle to grave, which means from the resource extraction up to the disposal of the product and also the production wastes.

The International Organization for Standardization (ISO) has standardised the general procedure of conducting an LCA in ISO 14040 (International Organization for Standardization (ISO) 1997). The definition of goal and scope as well as the life cycle inventory are specified in ISO 14041 (International Organization for Standardization (ISO) 1998). The standards to further phases of a LCA were published in 2000 (International Organization for Standardization (ISO) 2000a; b).

A LCA consists according to ISO 14040 of four phases (Figure 48):

1) Goal and Scope Definition
2) Inventory Analysis
3) Impact Assessment
4) Interpretation

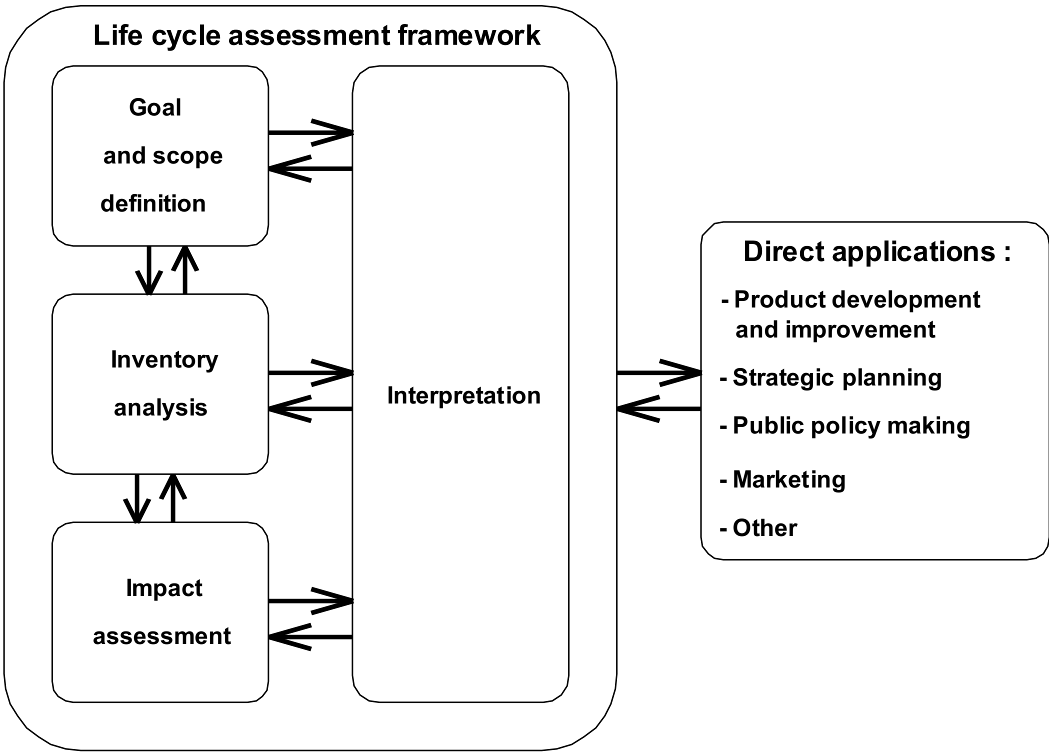

Figure 48: Components of a life cycle assessment (LCA) according to International Organization for Standardization (1997)

[19] The term product also encompasses services

The *Goal Definition* (phase 1) covers the description of the object of investigation. The environmental aspects to be considered in the interpretation are also defined here. The *Scope Definition* includes the way of modelling the object of investigation, the identification as well as the description of the processes of importance towards the object of investigation. The functional unit, which determines the base for the comparison, is defined here.

The direct environmental impacts[20], the amount of semi-finished products, auxiliary materials and energy of the processes involved in the life cycle are determined and inventoried in the *Inventory Analysis* (phase 2). This data is set in relation to the object of investigation, i.e. the functional unit. The final outcome consists of the cumulative resource demands and emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3) (International Organization for Standardization (ISO) 2000a). Applying current valuation methods, e.g. eco-indicator, ecological scarcity or CML, to the inventory results in indicator values that are used and referred to in the interpretation.

The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA (International Organization for Standardization (ISO) 2000b). Final conclusions are drawn and recommendations stated.

[20] Resource extraction and emission of pollutants

A2 Main Data Sources

Source	Type	Information provided
ecoinvent database V1.2 (incl. corrections until 23 Jan. 2006)		background LCI data
Umweltrelevanz natürlicher Kältemittel (Frischknecht 1999a; b)	L	Supermarket electricity consumption, average supermarket layout, several cooling system devices
The Georg Fischer brochure "Technical Information and Product Range COOL-FIT ABS" (Georg Fischer 2004)	L	detailed information on the specification of the COOL-FIT pipes, i.e. diameters, material use
Safety datasheets by Henkel on the cement and cleaner (Henkel 2005a; b)	L	data on composition of the ABS cement and cleanser (more detailed data were available through the questionnaire)
+GF+ Deka, 35232 Dautphetal, Germany	Q	data on the production of the ABS pipes for COOL-FIT
Løgstør Rør A/S, 9670 Løgstør, Denmark	Q	data on applying the PUR insulation and HDPE jacket pipe to the ABS pipes
Henkel, Düsseldorf, Germany	Q	data on producing the ABS cement and cleaner
Mark Bulmer, GF Piping Systems	P	COOL-FIT parts list for the supermarket, definition of the type of cold store to be evaluated and detailed specification thereof
Mr. Gysin, Schaller Uto AG, Bern	P	general information on supermarket and cold store layouts as well as estimations from practical experience of today
Mr. Trüssel, KWT Kälte-Wärme-Technik AG, Belp	P	general information on supermarket and cold store layouts as well as estimations from practical experience of today
Mr. Burger, Walter Wettstein AG, Gümligen	P	general information on supermarket and cold store layouts as well as estimations from practical experience with special focus on secondary systems

Q: Questionnaire
L: Literature or other publications
P: Personal Communication

A3 Refrigerant Loss Rates

Table 34: Literature overview on refrigerant loss rates of direct expansion (DX) systems for supermarkets. The values with a grey shadow represent American figures, whereas those without shadow are valid for a Swiss or European installation.

	Type	Refrigerant	Leakage rate			Remarks
			low	average	high	
Fischer et al. 1994	DX	general	20%	33.3%	50%	average supermarket, p.126
Sand et al. 1997	DX	general	4%	6%	8%	near future (2005-2010) for DX US-supermarket, p.77
Sand et al. 1997	DX	general	10%	13.5%	15%	"today" for US-supermarket, p.77
Birndt 1999	DX/2L	general	2.3%	4.1%	9.3%	measurements on 60 German supermarkets (1990 or newer); low: without incidents, average: with existing incidents, high: with incidents occurring in the near future
Bivens 1999	DX	general	4%		8%	near future for US-supermarket, p.5
Bivens 1999	DX	general	7%		17%	"today" for US-supermarket, p.5
Frischknecht 1999b	DX/2L	general	6%		13.5%	low: "near future" optimisation, high: "today" condition (i.e. 1999)
Walker & Baxter 2002	DX	R22/R404A	15%		30%	based on actual experience, p.12
Arthur D. Little 2002	DX	R404A/R507		15%		optimum installation, p.8-4
Baxter 2003	DX	R404A/R22		30%		p. 39. Data for a large US supermarket
Farmarazi & Walker 2004	DX	R22/R404A		12.4%		based on measurements in one supermarket, p.61
Godwin 2005	DX/(2L)	CFC/HCFC	10%	18%	25%	low, average and high value for US supermarkets, which are probably some years old due to the types of refrigerant. Value includes some 2L cooling systems
Godwin 2005	DX/(2L)	HFC		9%		US supermarkets, probably modern ones due to type of refrigerant. Value includes some 2L cooling systems
Godwin 2005	DX/2L	general		10%		Swedish supermarkets
Personal Communication[21]	DX	general	5%		10%	average Swiss supermarket
Personal Communication[22]	DX	general	1.5%		2%	optimum conditions, Swiss supermarket
Personal Communication[23]	DX	Ammonia		~ 0%		without incidents, Swiss conditions
This study (European situation)			**4%**	**7%**	**10%**	
This study (American situation)			**10%**	**15%**	**20%**	

[21] personal communication by Mr. Gysin (Schaller Uto AG, Bern) on 31.05.2005

[22] personal communication by Mr. Trüssel (KWT Kälte-Wärme-Technik, Belp) on 02.06.2005

[23] personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

Table 35: Literature overview on refrigerant loss rates of secondary loop (2L) systems for supermarkets, i.e. indirect cooling. The values with a grey shadow represent American figures, whereas those without shadow are valid for a Swiss or European installation.

	Type	Refrigerant	Leakage rate low	Leakage rate average	Leakage rate high	
Sand et al. 1997	2L	general	2%		4%	high: "today", low: near future (2005-2010) for 2L US-supermarket, p.78
Birndt 1999	DX/2L	general	2.3%	4.1%	9.3%	measurements on 60 German supermarkets (1990 or newer); low: without incidents, average: with existing incidents, high: with incidents occurring in the near future
Bivens 1999	2L	general	2%		4%	high: "today", low: near future for US-supermarket, p.5
Frischknecht 1999b	DX/2L	general	6%		13.5%	low: "near future" optimisation, high: "today" condition (i.e. 1999)
Frischknecht 1999b	2L	Ammonia	2%		5%	low: "near future" optimisation, high: "today" condition (i.e. 1999)
Walker & Baxter 2002	2L	R507	5%		10%	based on actual experience, p.12
Arthur D. Little 2002	2L	R404A/R507		2%		"today", p.8-4
Baxter 2003	2L	R507	2%	5%	10%	4 different temperature loops, p. 39. Data for a large US supermarket
Farmarazi & Walker 2004	2L	R507		<8.6%		based on measurements in one supermarket, loss mainly due to a fitting break, p.61
Godwin 2005	DX/2L	general		10%		Swedish supermarkets
Personal Communication[24]	2L	general	5%		10%	Swiss supermarket
Personal Communication[25]	2L	general	1.5%		2%	Swiss supermarket
Personal Communication[26]	2L	Ammonia		~ 0%		without incidents, Swiss conditions
This study (European situation)			**1%**	**3%**	**5%**	
This study (American situation)			**1%**	**5%**	**10%**	

24 personal communication by Mr. Gysin (Schaller Uto AG, Bern) on 31.05.2005

25 personal communication by Mr. Trüssel (KWT Kälte-Wärme-Technik, Belp) on 02.06.2005

26 personal communication by Mr. Burger (Walter Wettstein AG, Gümligen) on 09.06.2005

A4 Correction Factors for Supermarket Fridge and Freezer appliances

	Correction-Factor
Medium Temperature	
Refrigerated display (h = 2 m)	1
Refrigerated display (h = 2.2 m)	1.1
Top access fridge (depth < 1.5 m)	0.5
Top access fridge (depth > 1.5 m)	1
Cooled sales counter	0.5
Sub cabinet top access fridge	0.25
Low Temperature	
Display cabinet with open sub cabinet freezer (h = 2 m)	1
Display cabinet with open sub cabinet freezer (h = 2.2 m)	1.1
Display cabinet (h = 2.2 m)	1
Display cabinet (h = 2.2 m)	1.1
Top access freezer (depth < 1.5 m)	0.5
Top access freezer (depth > 1.5 m)	1

A5 Background Processes

How to read the tables:

The **light green fields** describe the name of the product/process, its region (e.g. RER stands for Europe) and the unit data it refers to. It is the output product (the reference output) of the process and always equal to '1'. The **yellow fields** show the inputs and outputs of the respective processes. The **grey fields** specify whether it is an input from or an output to nature or technosphere and the compartment to which a pollutant is emitted. For each product, additional descriptive information is given in separate tables.

The location codes (an extended ISO alpha-2 code-set) have the following meaning:

CH Switzerland
DE Germany
DK Denmark
GLO Global
NL Netherlands
RER Europe
UCTE Union for the Co-ordination of Transmission of Electricity

A5.1 Steel and Copper Pipes

product	pipe, copper with Armaflex insulation, for supermarket, at plan	RER	1	m	**1**	
technosphere	copper, at regional storage	RER	0	kg	1.56E+0	Frischknecht, 1999 and own calculations
	wire drawing, copper	RER	0	kg	1.72E+0	assumption for drawing of pipes from Literature
	tube insulation, elastomere, at plant	DE	0	kg	1.48E-1	Frischknecht, 1999 and own calculations
	transport, freight, rail	RER	0	tkm	1.02E+0	standard distance
	transport, lorry 32t	RER	0	tkm	8.54E-2	standard distance

product	pipe, chromium steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m	**1**				
product	pipe, chromium steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m		**1**			
product	pipe, chromium steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m			**1**		
product	pipe, copper with PUR insulation and steel jacket, 83x79, at plant	RER	1	m				**1**	
technosphere	chromium steel 18/8, at plant	RER	0	kg	1.85E+0	3.09E+0	4.39E+0		pipe, assumption from company data and Literature
	drawing of pipes, steel	RER	0	kg	1.85E+0	3.09E+0	4.39E+0		pipe, assumption from company data and Literature
	copper, at regional storage	RER	0	kg				4.53E+0	pipe, assumption from company data and Literature
	wire drawing, copper	RER	0	kg				4.53E+0	pipe, assumption from company data and Literature
	reinforcing steel, at plant	RER	0	kg	3.81E-1	4.45E-1	5.68E-1	5.68E-1	jacket, assumption from company data and Literature
	sheet rolling, steel	RER	0	kg	3.81E-1	4.45E-1	5.68E-1	5.68E-1	jacket, assumption from company data and Literature
	zinc coating, pieces	RER	0	m2	2.42E-1	2.83E-1	3.61E-1	3.61E-1	jacket, assumption from company data and Literature
	tube insulation, elastomere, at plant	DE	0	kg					Frischknecht, 1999
	polyurethane, rigid foam, for on-site foaming, at plant	RER	0	kg	5.08E-1	6.14E-1	8.09E-1	8.09E-1	assumption from company data
	transport, freight, rail	RER	0	tkm	1.64E+0	2.49E+0	3.46E+0	3.54E+0	standard distance
	transport, lorry 32t	RER	0	tkm	1.37E-1	2.08E-1	2.89E-1	2.95E-1	standard distance

product	pipe, steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m	1			
product	pipe, steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m		1		
product	pipe, steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m			1	
technosphere	steel, low-alloyed, at plant	RER	0	kg	1.85E+0	3.09E+0	4.39E+0	pipe, assumption from company data and Literature
	drawing of pipes, steel	RER	0	kg	1.85E+0	3.09E+0	4.39E+0	pipe, assumption from company data and Literature
	reinforcing steel, at plant	RER	0	kg	3.81E-1	4.45E-1	5.68E-1	jacket, assumption from company data and Literature
	sheet rolling, steel	RER	0	kg	3.81E-1	4.45E-1	5.68E-1	jacket, assumption from company data and Literature
	zinc coating, pieces	RER	0	m2	2.42E-1	2.83E-1	3.61E-1	jacket, assumption from company data and Literature
	tube insulation, elastomere, at plant	DE	0	kg				Frischknecht, 1999
	polyurethane, rigid foam, for on-site foaming, at plant	RER	0	kg	5.08E-1	6.14E-1	8.09E-1	assumption from company data
	transport, freight, rail	RER	0	tkm	1.64E+0	2.49E+0	3.46E+0	standard distance
	transport, lorry 32t	RER	0	tkm	1.37E-1	2.08E-1	2.89E-1	standard distance

A5.2 Condensing Circuit Piping

product	condensing circuit piping kit, copper, for supermarket, at plant	RER	1	unit	1	
technosphere	copper, at regional storage	RER	0	kg	4.13E+2	own calc. from Frischknecht 1999
	wire drawing, copper	RER	0	kg	4.54E+2	from Literature
	installation, distribution pipes, welded pipes, in supermarket	CH	0	m	5.00E+1	Frischknecht 1999
	transport, freight, rail	RER	0	tkm	9.25E+1	standard distance
	transport, lorry 32t	RER	0	tkm	4.13E+1	standard distance

product	condensing circuit piping kit, low-alloy steel, for cold store, at plant	RER	1	unit	1	
	steel, low-alloyed, at plant	RER	0	kg	2.83E+3	own calc. from Frischknecht 1999
	drawing of pipes, steel	RER	0	kg	2.83E+3	from Literature
	installation, distribution pipes, welded pipes, in cold store	CH	0	m	5.00E+1	Frischknecht 1999
	transport, freight, rail	RER	0	tkm	5.77E+2	standard distance
	transport, lorry 32t	RER	0	tkm	2.88E+2	standard distance

A5.3 Cooling System Devices

product	plate heat exchanger, corrosion resistant, at plant	RER	1	unit	1	
technosphere	chromium steel 18/8, at plant	RER	0	kg	1.08E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	sheet rolling, chromium steel	RER	0	kg	1.08E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	reinforcing steel, at plant	RER	0	kg	2.88E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	sheet rolling, steel	RER	0	kg	2.88E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	argon, liquid, at plant	RER	0	kg	1.08E+1	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	heat, natural gas, at industrial furnace >100kW	RER	0	MJ	6.48E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	transport, freight, rail	RER	0	tkm	2.38E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	transport, lorry 32t	RER	0	tkm	1.98E+1	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)

product	tube heat exchanger, at plant	RER	1	unit	1	
technosphere	copper, at regional storage	RER	0	kg	2.32E+2	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	wire drawing, copper	RER	0	kg	2.55E+2	Frischknecht, 1999 (1 unit = 104kW)
	reinforcing steel, at plant	RER	0	kg	2.68E+2	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	sheet rolling, steel	RER	0	kg	2.68E+2	Frischknecht, 1999 Tab 2.8 (1 unit = 360 kg)
	acetylene, at regional storehouse	CH	0	kg	5.46E+0	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	nitrogen, liquid, at plant	RER	0	kg	6.37E+0	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	oxygen, liquid, at plant	RER	0	kg	9.10E+0	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	heat, natural gas, at industrial furnace >100kW	RER	0	MJ	8.19E+2	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	transport, freight, rail	RER	0	tkm	3.00E+2	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)
	transport, lorry 32t	RER	0	tkm	2.50E+1	Frischknecht, 1999, Tab 2.9 (1 unit = 455 kg)

product	refrigerant receiver, at plant	RER	1	unit	1	
technosphere	reinforcing steel, at plant	RER	0	kg	7.26E+1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	sheet rolling, steel	RER	0	kg	7.26E+1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	8.32E+1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	heat, natural gas, at industrial furnace >100kW	RER	0	MJ	6.42E+2	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	tetrachloroethylene, at regional storage	CH	0	kg	2.15E-2	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	9.50E-1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	disposal, packaging cardboard, 19.6% water, to municipal incineration	CH	0	kg	9.50E-1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	transport, freight, rail	RER	0	tkm	4.36E+1	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
	transport, lorry 32t	RER	0	tkm	3.63E+0	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)
emission air, high population density	Ethene, tetrachloro-	-	-	kg	2.15E-2	Frischknecht, 1999 Tab 2.12 (1 unit = 66 kg)

product	dry liquid cooler, supermarket, at plant	RER	1	unit	**1**	
technosphere	fan, for dry liquid cooler, at plant	RER	1	unit	1.00E+0	Frischknecht, 1999 (1 unit = 104kW)
	copper, at regional storage	RER	0	kg	1.66E+2	Frischknecht, 1999 (1 unit = 104kW)
	wire drawing, copper	RER	0	kg	1.83E+2	Frischknecht, 1999 (1 unit = 104kW)
	aluminium, production mix, at plant	RER	0	kg	2.70E+2	Frischknecht, 1999 (1 unit = 104kW)
	sheet rolling, aluminium	RER	0	kg	2.70E+2	Frischknecht, 1999 (1 unit = 104kW)
	reinforcing steel, at plant	RER	0	kg	6.03E+2	Frischknecht, 1999 (1 unit = 104kW)
	sheet rolling, steel	RER	0	kg	6.03E+2	Frischknecht, 1999 (1 unit = 104kW)
	zinc coating, pieces	RER	0	m2	3.07E+1	assumption from Literature
	light fuel oil, burned in industrial furnace 1MW, non-modulating	CH	0	MJ	1.54E+4	Frischknecht, 1999 (1 unit = 104kW)
	heat, natural gas, at industrial furnace >100kW	RER	0	MJ	1.92E+4	Frischknecht, 1999 (1 unit = 104kW)
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	3.58E+2	Frischknecht, 1999 (1 unit = 104kW)
	transport, freight, rail	RER	0	tkm	7.28E+2	Frischknecht, 1999 (1 unit = 104kW)
	transport, lorry 32t	RER	0	tkm	6.24E+1	Frischknecht, 1999 (1 unit = 104kW)

product	fan, for dry liquid cooler, at plant	RER	-	-	1	unit	**1**	
technosphere	cast iron, at plant	RER	-	-	0	kg	8.63E+1	Frischknecht, 1999 (1 unit =104kW)
	aluminium, production mix, at plant	RER	-	-	0	kg	1.56E+1	Frischknecht, 1999 (1 unit =104kW)
	copper, at regional storage	RER	-	-	0	kg	1.25E+1	Frischknecht, 1999 (1 unit =104kW)
	wire drawing, copper	RER	-	-	0	kg	1.37E+1	assumption for drawing of pipes from Literature
	heat, natural gas, at industrial furnace >100kW	RER	-	-	0	MJ	2.60E+1	Frischknecht, 1999 (1 unit =104kW)
	electricity, medium voltage, production UCTE, at grid	UCTE	-	-	0	kWh	1.44E+1	Frischknecht, 1999 (1 unit =104kW)
	transport, lorry 32t	RER	-	-	0	tkm	5.72E+1	Frischknecht, 1999 (1 unit =104kW)

product	hybrid liquid fluid cooler, at plant	RER	-	-	1	unit	**1**	
technosphere	reinforcing steel, at plant	RER	-	-	0	kg	4.83E+3	assumption from Frischkı
	copper, at regional storage	RER	-	-	0	kg	8.66E+2	assumption from Frischkı
	sheet rolling, steel	RER	-	-	0	kg	4.83E+3	Literature
	zinc coating, pieces	RER	-	-	0	m2	2.05E+2	Literature
	wire drawing, copper	RER	-	-	0	kg	9.53E+2	Literature
	manufacturing process, cooling system devices	RER	-	-	0	kg	5.70E+3	
	transport, freight, rail	RER	-	-	0	tkm	1.14E+3	standard distance
	transport, lorry 32t	RER	-	-	0	tkm	5.70E+2	standard distance

product	packaged chiller, ammonia, 810kW cooling capacity, at plant	RER	1	unit	**1**	
technosphere	cast iron, at plant	RER	0	kg	1.79E+3	interpolated from Frischknecht, 1999
	reinforcing steel, at plant	RER	0	kg	2.99E+3	interpolated from Frischknecht, 1999
	chromium steel 18/8, at plant	RER	0	kg	7.64E+2	interpolated from Frischknecht, 1999
	aluminium, production mix, at plant	RER	0	kg	3.65E+2	interpolated from Frischknecht, 1999
	manufacturing process, cooling system devices	RER	0	kg	5.70E+3	own calculation
	transport, lorry 32t	RER	0	tkm	3.25E+3	interpolated from Frischknecht, 1999

product	compressor Bitzer, at plant	RER	1	unit	**1**	
technosphere	cast iron, at plant	RER	0	kg	2.64E+2	Frischknecht, 1999, Tab 2.2 (1 unit = 840kg)
	reinforcing steel, at plant	RER	0	kg	4.40E+2	Frischknecht, 1999, Tab 2.2 (1 unit = 840kg)
	copper, at regional storage	RER	0	kg	1.13E+2	Frischknecht, 1999, Tab 2.2 (1 unit = 840kg)
	aluminium, production mix, at plant	RER	0	kg	5.38E+1	Frischknecht, 1999, Tab 2.2 (1 unit = 840kg)
	manufacturing process, cooling system devices	RER	0	kg	8.40E+2	own calculation
	transport, lorry 32t	RER	0	tkm	4.79E+2	Frischknecht, 1999, Tab 2.2 (1 unit = 840kg)

A5.4 Butyl Acetate

product	butyl acetate, at plant	RER	0	kg	**1**	
technosphere	acetic acid, 98% in H2O, at plant	RER	0	kg	5.71E-1	Literature
	butanol, 1-, at plant	RER	0	kg	7.05E-1	Literature
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	3.30E-1	Literature (EI)
	heat, unspecific, in chemical plant	RER	0	MJ	2.00E+0	Literature (EI)
	chemical plant, organics	RER	1	unit	4.00E-10	Literature (EI)
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	1.71E-4	assumption for disposal of the Water from reaction
	transport, freight, rail	RER	0	tkm	7.66E-1	standard distance
	transport, lorry 32t	RER	0	tkm	1.28E-1	standard distance
resource, in water	Water, cooling, unspecified natural origin	-	-	m3	2.40E-2	Literature (EI)
	Water, unspecified natural origin	-	-	m3	1.20E-2	Literature (EI)
emission air, high population density	Acetic acid	-	-	kg	2.72E-3	Literature (EI), assumption on loss in production
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	7.76E-2	Literature (EI), assumption on loss in production
emission water, river	Acetic acid	-	-	kg	2.45E-2	Literature (EI), assumption on loss in production
	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg	8.62E-3	Literature (EI), assumption on loss in production

A5.5 Manufacturing Process Cooling System Devices

product	manufacturing process, cooling system devices	RER	0	kg	1	
technosphere	heat, light fuel oil, at industrial furnace 1MW	RER	0	MJ	1.65E+00	environmental report Bitzer 2004
	heat, natural gas, at industrial furnace >100kW	RER	0	MJ	1.65E+00	environmental report Bitzer 2004
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	8.83E-01	environmental report Bitzer 2004
	alkyd paint, white, 60% in H2O, at plant	RER	0	kg	8.33E-03	environmental report Bitzer 2004
	epoxy resin, liquid, at plant	RER	0	kg	1.01E-04	environmental report Bitzer 2004
	lubricating oil, at plant	RER	0	kg	1.05E-02	environmental report Bitzer 2004
	glued laminated timber, indoor use, at plant	RER	0	m3	9.39E-06	environmental report Bitzer 2004
	paper, woodfree, uncoated, at regional storage	RER	0	kg	1.25E-02	environmental report Bitzer 2004
	packaging film, LDPE, at plant	RER	0	kg	1.90E-03	environmental report Bitzer 2004
	water, decarbonised, at plant	RER	0	kg	1.85E+00	environmental report Bitzer 2004
	treatment, sewage, to wastewater treatment, class 2	CH	0	m3	1.85E-03	environmental report Bitzer 2004
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.24E-03	environmental report Bitzer 2004
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.08E-02	environmental report Bitzer 2004
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	2.15E-02	environmental report Bitzer 2004
	building, hall	CH	1	m2	2.60E-03	environmental report Bitzer 2004
resource, land	Occupation, industrial area, vegetation	-	-	m2a	5.57E-03	environmental report Bitzer 2004
	Transformation, from unknown	-	-	m2	6.96E-05	environmental report Bitzer 2004
	Transformation, to industrial area, vegetation	-	-	m2	6.96E-05	environmental report Bitzer 2004

A5.6 Process Descriptions

Name	pipe, copper with Armaflex insulation, for supermarket, at plant	pipe, steel with Armaflex insulation, for supermarket, at plant	pipe, steel with PUR insulation and steel jacket, 47x44, at plant	pipe, steel with PUR insulation and steel jacket, 59x55, at plant	pipe, steel with PUR insulation and steel jacket, 83x79, at plant	plate heat exchanger, corrosion resistant, at plant
Location	RER	RER	RER	RER	RER	RER
InfrastructureProcess	1	1	1	1	1	1
Unit	m	m	m	m	m	unit
IncludedProcesses	This data set includes the material use for an average pipe size used in a supermarket of 104kW. It includes the metal needed for the pipe, the production process as well as the elastomere insulation.	This data set includes the material use for an average pipe size used in a supermarket of 104kW. It includes the metal needed for the pipe, the production process as well as the elastomere insulation.	This data set includes the metal needed for the pipe, the production process as well as the insulation and a steel jacket.	This data set includes the metal needed for the pipe, the production process as well as the insulation and a steel jacket.	This data set includes the metal needed for the pipe, the production process as well as the insulation and a steel jacket.	This data set includes the material use for the plate heat exchanger, the welding and the transports.
GeneralComment	For 100kW cooling power about 950m of pipes are needed	For 100kW cooling power about 950m of pipes are needed	foaming on site	foaming on site	foaming on site	1 unit (360 kg) is needed for a 104 kW cooling system.
StartDate	1996	1996	1996	1996	1996	1998
EndDate	2000	2005	2005	2005	2005	2000
Text	Data was obtained from the cooling systems in two Swiss supermarkets	Data was obtained from the cooling systems in two Swiss supermarkets	Production in Europe	Production in Europe	Production in Europe	Data is from a cooling system in a Swiss supermarket
Text	It is an average of the pipe sizes in two installations of 100 and 145kW.	It is an average of the pipe sizes in two installations of 100 and 145kW.	Average european technology assumed	Average european technology assumed	Average european technology assumed	Based on a device for a NH3-cooling system

Name	tube heat exchanger, at plant	refrigerant receiver, at plant	dry liquid cooler, supermarket, at plant	fan, for dry liquid cooler, at plant	compressor Bitzer, at plant	condensing circuit piping kit, copper, for supermarket, at plant
Location	RER	RER	RER	RER	RER	RER
InfrastructureProcess	1	1	1	1	1	1
Unit	unit	unit	unit	unit	unit	unit
IncludedProcesses	This data set includes the material use for the tube heat exchanger, the welding and the transports.	This data set includes the material use for the tube heat exchanger, the degreasing of the metal and the transports.	This data set includes the material use and the energy consumption in the production process. Transports are considered as well.	This data set includes the material use and the energy consumption in the production process. Transports are considered as well.	This data set includes the material use for the production. The production process is considered accurately. Transports are considered as well.	This data set contains the piping of the condensing circuit. It includes the installation work. One unit is needed for a 104kW supermarket.
GeneralComment	1 unit (455 kg) is needed for a 104 kW cooling system.	1 unit (66 kg) is needed for a 104 kW cooling system.	1 unit has the necessary cooling power for a 104 kW supermarket cooling systems and a total weight of 1155 kg	1 unit (115 kg) is needed in a dry liquid cooler for a 104kW supermarket.	1 unit has a cooling power output of 104 kW and a total weight of 840 kg	1 unit corresponds to 1 kit for a 104kW supermarket
StartDate	1998	1998	1998	1998	1997	2004
EndDate	2000	2000	2000	2000	1997	2005
Text	Data is from a cooling system in a Swiss supermarket	Data is from a cooling system in a Swiss supermarket	Data is from a cooling system in a Swiss supermarket	Data is from a cooling system in a Swiss supermarket	Data is from a cooling system in a Swiss supermarket	Data is based on information from Swiss supermarkets
Text			average dry liquid cooler			Average Swiss supermarket outline

Name	condensing circuit piping kit, copper, for supermarket, at plant	pipe, chromium steel with PUR insulation and steel jacket, 47x44, at plant	pipe, chromium steel with PUR insulation and steel jacket, 59x55, at plant	pipe, chromium steel with PUR insulation and steel jacket, 83x79, at plant	hybrid liquid fluid cooler, at plant	pipe, copper with PUR insulation and steel jacket, 83x79, at plant	packaged chiller, ammonia, 810kW cooling capacity, at plant
Location	RER	RER	RER	RER	RER	RER	RER
InfrastructureProcess	1	1	1	1	1	1	1
Unit	unit	m	m	m	unit	m	unit
IncludedProcesses	This data set contains the piping of the condensing circuit. It includes the installation work. One unit is needed for a 104kW supermarket.	This data set includes the material use for the production an insulated pipe. It includes the metal needed for the pipe and the jacket, the galvanisation of the jacket pipe as well as the PUR insulation and transports.	This data set includes the material use for the production an insulated pipe. It includes the metal needed for the pipe and the jacket, the galvanisation of the jacket pipe as well as the PUR insulation and transports.	This data set includes the material use for the production an insulated pipe. It includes the metal needed for the pipe and the jacket, the galvanisation of the jacket pipe as well as the PUR insulation and transports.	This data set includes the material use for the production of a large evaporative hybrid cooler. Production process and transports are considered as well.	This data set includes the metal needed for the pipe, the production process as well as the insulation and a steel jacket.	This data set is an estimation on the material, transports and manufacturing needed to produce one unit.
GeneralComment	1 unit corresponds to 1 kit for a 104kW supermarket				The cooling power depends on the configuration. The maximum water throughput is 60l/s. The device weights about 5.7t.	foaming on site	
StartDate	2004	1996	1996	1996	1996	1996	1996
EndDate	2005	2005	2005	2005	2005	2005	2005
Text	Data is based on information from Swiss	Data is valid for Europe	Data is valid for Europe	Data is valid for Europe	Data is valid for Europe	Data is valid for Europe	Data is valid for Europe
Text	Average Swiss supermarket outline	Average european technology is assumed.	Average european technology is assumed.	Average european technology is assumed.	Average european technology is assumed.	Average european technology is assumed.	Average european technology is assumed.

Name	manufacturing process, cooling system devices	butyl acetate, at plant
Location	RER	RER
InfrastructureProcess	0	0
Unit	kg	kg
IncludedProcesses	This dataset is based on three factories producing cooling system equipment. It includes auxiliary inputs like water, energy and waste for the production of an appliance consisting mainly of metals. Service and development divisions are also included. Buildings and land occupation is considered as well. The material needed for the product to be produced is not included neither is the metal scrap.	This data set includes the inputs, the emissions, and the transports as well as the facilities to produce the chemical.
GeneralComment	This dataset can be used as an approximation when no specific production data is available.1 kg of this process is needed per 1 kg weight of the end-product.	The process is based on data for vinyl acetate, which is produced by the same type of reaction.
StartDate	2003	2000
EndDate	2005	2005
Text	Data is from three factories in Germany	Average european production
Text	2 factories producing mainly compressors and closely related equipment, 1 factory does only auxiliary cooling system equipment.	production from butanol and acetic acid, based on stoechiometric relation. Assuming 5% loss during production.

A6 COOL-FIT components

A6.1 Pipes

product	pipe, ABS without insulation, for supermarket, at plant	DE	1	m	**1**				average pipe size for supermarket
	pipe, ABS without insulation, 50x44, at plant	DE	1	m		**1**			
	pipe, ABS without insulation, 63x55.4, at plant	DE	1	m			**1**		
	pipe, ABS without insulation, 90x79.2, at plant	DE	1	m				**1**	
technosphere	acrylonitrile-butadiene-styrene copolymer, ABS, at plant	RER	0	kg	2.85E-1	4.56E-1	7.28E-1	1.48E+0	own calculation from company data
	manufacturing process, ABS pipe production	DE	0	kg	2.85E-1	4.56E-1	7.28E-1	1.48E+0	company data
	manufacturing process, ABS pipe production	US	0	kg					company data
	packaging film, LDPE, at plant	RER	0	kg	6.41E-3	1.00E-2	1.67E-2	5.00E-2	pipe transport packaging, company data
	transport, lorry 32t	RER	0	tkm	3.89E-1	6.23E-1	9.94E-1	2.02E+0	distance ABS resin producer in GB to factory

product	pipe, ABS with PUR insulation, for supermarket, at plant	RER	1	m	**1**				average pipe size for supermarket
	pipe, ABS with PUR insulation, 110x44, at plant	RER	1	m		**1**			
	pipe, ABS with PUR insulation, 125x55.4, at plant	RER	1	m			**1**		
	pipe, ABS with PUR insulation, 160x79.2, at plant	RER	1	m				**1**	
technosphere	pipe, ABS without insulation, for supermarket, at plant	DE	1	m	1				
	pipe, ABS without insulation, 50x44, at plant	DE	1	m		1			
	pipe, ABS without insulation, 63x55.4, at plant	DE	1	m			1		
	pipe, ABS without insulation, 90x79.2, at plant	DE	1	m				1	
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	6.41E-3	1.00E-2	1.67E-2	5.00E-2	packaging waste,own calculation from company data
	disposal, polyethylene, 0.4% water, to sanitary landfill	CH	0	kg					packaging waste,own calculation from company data
	polyurethane, rigid foam, for pipe insulation, at plant	DK	0	kg	2.76E-1	4.64E-1	5.60E-1	8.59E-1	company data
	polyurethane, rigid foam, for pipe insulation, at plant	US	0	kg					company data
	jacket pipe, HDPE, at plant	DK	0	kg	4.75E-1	8.56E-1	1.08E+0	1.39E+0	company data
	jacket pipe, HDPE, at plant	US	0	kg					company data
	packaging film, LDPE, at plant	RER	0	kg	1.44E-2	5.00E-2	5.00E-2	5.00E-2	pipe packaging, own calculation from company data
	transport, lorry 32t	RER	0	tkm	2.65E-1	4.23E-1	6.76E-1	1.39E+0	company data, added 5% to account for pallet weight

product	manufacturing process, ABS pipe production	DE	0	unit	1.00E+0	
technosphere	building, hall	CH	1	m2	2.45E-3	data from company, production hall
	building, multi-storey	RER	1	m3	3.54E-4	data from company, office building
	electricity, low voltage, at grid	DE	0	kWh	6.38E-1	data from company
	light fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	3.48E-1	data from company
	tap water, at user	RER	0	kg	1.38E-1	data from company
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	8.52E-5	data from company
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	8.35E-3	data from company
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	3.16E-4	data from company
emission air, high population density	water	-	-	kg	5.28E-5	data from company
resource, land	Occupation, industrial area, vegetation	-	-	m2a	5.21E-3	data from company
	Transformation, to industrial area, vegetation	-	-	m2	5.21E-3	data from company
	Transformation, from unknown	-	-	m2	5.21E-3	data from company

A6.2 Fittings

product	fitting, ABS with PUR insulation, for cold store, at plant	RER	1	unit	1				
	nipple, ABS, for cold store, at plant	RER	1	unit		1			
	fitting, ABS with PUR insulation, for supermarket, at plant	RER	1	unit			1		
	nipple, ABS, for supermarket, at plant	RER	1	unit				1	
technosphere	pipe, ABS with PUR insulation, 160x79.2, at plant	RER	1	m	3.63E-1				calculated equivalent pipe length
	pipe, ABS without insulation, 90x79.2, at plant	DE	1	m		1.04E-1			calculated equivalent pipe length
	pipe, ABS with PUR insulation, for supermarket, at plant	RER	1	m			1.81E-1		calculated equivalent pipe length
	pipe, ABS without insulation, for supermarket, at plant	DE	1	m				6.60E-2	calculated equivalent pipe length
	packaging, corrugated board, mixed fibre, single wall, at plant	RER	0	kg	8.00E-2	2.00E-2	6.50E-2	4.00E-3	own calculation from company data
	transport, lorry 32t	RER	0	tkm	1.80E+0	7.91E-2	2.50E-1	9.66E-4	company data, added 5% to account for pallet weight

A6.3 Tangit ABS Cement and Cleaner

product	adhesive, for ABS, at plant	DE	0	kg	1		
product	cleaner, for ABS and PVC-U/C, at plant	DE	0	kg		1	
technosphere	methyl ethyl ketone, at plant	RER	0	kg	5.54E-1	5.00E-1	company data
	butyl acetate, at plant	RER	0	kg	2.00E-1		company data
	phenolic resin, at plant	RER	0	kg	2.46E-1		assumption for organic solids, company data
	acetone, liquid, at plant	RER	0	kg		5.00E-1	company data
	steel, low-alloyed, at plant	RER	0	kg	1.32E-1	1.41E-1	company data
	sheet rolling, steel	RER	0	kg	1.32E-1	1.41E-1	company data
	packaging, corrugated board, mixed fibre, single wall, at plant	RER	0	kg	5.08E-2	3.63E-2	company data
	electricity, low voltage, at grid	DE	0	kWh	1.00E-2	2.25E-3	company data
	chemical plant, organics	RER	1	unit	4.00E-10	4.00E-10	Literature (EI)
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	6.15E-4	3.75E-4	company data
	disposal, solvents mixture, 16.5% water, to hazardous waste incineration	CH	0	kg	2.46E-3	1.25E-3	company data
	transport, lorry 32t	RER	0	tkm	1.00E-1	1.00E-1	company data
emission air, high population density	Carbon dioxide, fossil	-	-	kg	1.54E-3	1.25E-3	company data

A6.4 PUR Insulation and Jacket Pipe

product	polyurethane, rigid foam, for pipe insulation, at plant	DK	0	kg	1		
product	polyurethane, rigid foam, for on-site foaming, at plant	RER	0	kg		1	
technosphere	polyols, at plant	RER	0	kg	3.51E-1	3.58E-1	company data
	methylene diphenyl diisocyanate, at plant	RER	0	kg	6.25E-1	6.38E-1	company data
	pentane, at plant	RER	0	kg	3.87E-2	3.94E-2	company data
	tap water, at user	RER	0	kg	2.07E+1	2.07E+1	company data
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	2.07E-2	2.07E-2	assumption
	heat, at cogen 1MWe lean burn, allocation exergy	RER	0	MJ	6.91E+0	6.91E+0	company data
	electricity, low voltage, at grid	DK	0	kWh	3.54E+0		company data
	electricity, low voltage, production UCTE, at grid	UCTE	0	kWh		3.54E+0	assumption
	building, hall	CH	1	m2	1.37E-3	1.37E-3	company data
	transport, freight, rail	RER	0	tkm	2.03E-1	2.03E-1	standard distance
	transport, lorry 32t	RER	0	tkm	1.02E-1	1.02E-1	standard distance
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	0	kg	1.12E-2	3.14E-2	production waste and scrap
emission air, high population density	Carbon dioxide, fossil	-	-	kg	1.90E-4	1.94E-4	in production waste
	Pentane	-	-	kg	3.87E-3	3.94E-3	company data
resource, land	Occupation, industrial area, vegetation	-	-	m2a	2.24E-1	2.24E-1	company data
	Transformation, to industrial area, vegetation	-	-	m2	4.49E-3	4.49E-3	company data
	Transformation, from unknown	-	-	m2	4.49E-3	4.49E-3	company data

product	jacket pipe, HDPE, at plant	DK	0	kg	1.00E+0	
technosphere	polyethylene, HDPE, granulate, at plant	RER	0	kg	1.02E+0	company data
	tap water, at user	RER	0	kg	2.07E-2	company data
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	2.07E-2	assumption from water usage
	heat, at cogen 1MWe lean burn, allocation exergy	RER	0	MJ	6.91E+0	company data
	electricity, low voltage, at grid	DK	0	kWh	3.54E+0	company data
	building, hall	CH	1	m2	1.37E-3	company data
	transport, freight, rail	RER	0	tkm	2.03E-1	standard distance
	transport, lorry 32t	RER	0	tkm	1.02E-1	standard distance
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	1.50E-2	company data
resource, land	Occupation, industrial area, vegetation	-	-	m2a	2.24E-1	company data
	Transformation, to industrial area, vegetation	-	-	m2	4.49E-3	company data
	Transformation, from unknown	-	-	m2	4.49E-3	company data

A6.5 Process Descriptions

Name	pipe, ABS without insulation, for supermarket, at plant	pipe, ABS without insulation, 50x44, at plant	pipe, ABS without insulation, 63x55.4, at plant	pipe, ABS without insulation, 90x79.2, at plant	polyurethane, rigid foam, for pipe insulation, at plant	polyurethane, rigid foam, for on-site foaming, at plant
Location	DE	DE	DE	DE	DK	RER
InfrastructureProcess	1	1	1	1	0	0
Unit	m	m	m	m	kg	kg
IncludedProcesses	This data set includes the material use for the pipes and the manufacturing process at the plant in Germany. Transport of the material to the site is considered, as is the final packaging.	This data set includes the material use for the pipes and the manufacturing process at the plant in Germany. Transport of the material to the site is considered, as is the final packaging.	This data set includes the material use for the pipes and the manufacturing process at the plant in Germany. Transport of the material to the site is considered, as is the final packaging.	This data set includes the material use for the pipes and the manufacturing process at the plant in Germany. Transport of the material to the site is considered, as is the final packaging.	This data set includes the raw materials to produce rigid foam PUR, the auxiliary manufacturing inputs and the emissions as well as transports.	This data set includes the raw materials to produce rigid foam PUR, the auxiliary manufacturing inputs and the emissions at the factory as well as on site.
GeneralComment	The module reflects an average pipe size for a supermarket cooling system. For 100kW about 950m pipes are needed.				The foaming of the considered process is performed by automated injection in a factory. The general production data, like electricity, water or heat, was calculated from data for the whole factory according to the weight share.	The foaming of the considered process is manually performed.
CASNumber						
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text	production data from a German plant, pipe data from a Swiss supermarket	Data from a German plant	Data from a German plant	Data from a German plant	Data from a Danish plant	Data from a Danish plant
Text	endless pipe extrusion	endless pipe extrusion	endless pipe extrusion	endless pipe extrusion	foaming is done with cyclopentane, therefore zero GWP emissions	foaming is done with cyclopentane

Name	jacket pipe, HDPE, at plant	pipe, ABS with PUR insulation, for supermarket, at plant	pipe, ABS with PUR insulation, 110x44, at plant	pipe, ABS with PUR insulation, 125x55.4, at plant	pipe, ABS with PUR insulation, 160x79.2, at plant	fitting, ABS with PUR insulation, for cold store, at plant
Location	DK	RER	RER	RER	RER	RER
InfrastructureProcess	0	1	1	1	1	1
Unit	kg	m	m	m	m	unit
IncludedProcesses	This data set includes the raw materials to produce a HDPE jacket pipe and the auxiliary manufacturing inputs as well as transports.	This data set includes the manufacturing process to produce an insulated pipe and the needed input goods. Final packaging is considered.	This data set includes the manufacturing process to produce an insulated pipe and the needed input goods. Final packaging is considered.	This data set includes the manufacturing process to produce an insulated pipe and the needed input goods. Final packaging is considered.	This data set includes the manufacturing process to produce an insulated pipe and the needed input goods. Final packaging is considered.	This data set relies on the process of the respective insulated ABS pipe, which has only been corrected in length.
GeneralComment	The general production data, like electricity, water or heat, was calculated from data for the whole factory according to the weight share.	The module reflects an average pipe size for a supermarket cooling system. For 100kW about 950m pipes are needed.				one fitting (1 unit) corresponds to about 0.36m of a pipe
CASNumber						
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text	Data from a Danish plant	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe
Text	extrusion of pipe	extrusion of jacket pipe and injection of PUR are taking place at the same modern factory	extrusion of jacket pipe and injection of PUR are taking place at the same modern factory	extrusion of jacket pipe and injection of PUR are taking place at the same modern factory	extrusion of jacket pipe and injection of PUR are taking place at the same modern factory	

Name	nipple, ABS, for cold store, at plant	fitting, ABS with PUR insulation, for supermarket, at plant	nipple, ABS, for supermarket, at plant	manufacturing process, ABS pipe production	adhesive, for ABS, at plant	cleaner, for ABS and PVC-U/C, at plant
Location	RER	RER	RER	DE	DE	DE
InfrastructureProcess	1	1	1	0	0	0
Unit	unit	unit	unit	unit	kg	kg
IncludedProcesses	This data set relies on the process of the respective non-insulated ABS pipe, which has only been corrected in length.	This data set relies on the process of the respective insulated ABS pipe, which has only been corrected in length.	This data set relies on the process of the respective non-insulated ABS pipe, which has only been corrected in length.	This data set includes the land and material use as well as the energy consumption and the direct process emissions from manufacturing the pipes.	This data set includes the inputs, the emissions during production, the waste and the transports as well as the facilities to produce the adhesive.	This data set includes the inputs, the emissions during production, the waste and the transports as well as the facilities to produce the adhesive.
GeneralComment	one nipple (1 unit) corresponds to about 0.10m of a pipe	one fitting (1 unit) corresponds to about 0.18m of a pipe	one nipple (1 unit) corresponds to about 0.07m of a pipe	1 unit of the manufacturing process is needed to produce 1 kg of an ABS pipe. (This process is an artificial separtion of the pipe production process based on data availability and evaluation considerations.)	This dataset is based on company data except for the chemical plant, where the assumptions from ecoinvent are used.	This dataset is based on company data except for the chemical plant, where the assumptions from ecoinvent are used.
CASNumber						
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe	input goods and raw materials are from different locations in Europe	Data from a German plant	German producer, inputs from Europe	German producer, inputs from Europe
Text				endless pipe extrusion	This process only mixes the two main components. 0% loss of the main components during transporting and mixing is assumed.	This process only mixes the two main components. 0% loss of the main components during transporting and mixing is assumed.

A7 Piping Comparison

product	piping, ABS with PUR insulation, di 79.2, connected, at cold store	RER	1	m	1							
product	piping, Cr-steel with PUR insulation,di 79, connected, at cold store	RER	1	m		1						
product	piping, steel with PUR insulation, di 79, connected, at cold store	RER	1	m			1					
product	piping, copper with PUR insulation, di 79, connected, at cold store	RER	1	m				1				
product	piping, ABS with PUR insulation, di 79.2, connected, at cold store	US	1	m					1			
product	piping, ABS with PUR insulation, 40% recy., di 79.2, connected, at cold store	RER	1	m						1		
product	piping, ABS with PUR insulation, 75% recy., di 79.2, connected, at cold store	RER	1	m							1	
technosphere	pipe, steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m			1.00E+0					pipe incl. insulation
	pipe, chromium steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m		1.00E+0						pipe incl. insulation
	pipe, ABS with PUR insulation, 160x79.2, at plant	RER	1	m	1.00E+0				1.00E+0	1.00E+0	1.00E+0	pipe incl. insulation
	pipe, ABS without insulation, 90x79.2, at plant	DE	1	m						-5.00E-1	-1.00E+0	correction for amount of recycled plastic used
	jacket pipe, HDPE, at plant	DK	0	kg						-6.95E-1	-1.39E+0	correction for amount of recycled plastic used
	pipe, copper with PUR insulation and steel jacket, 83x79, at plant	RER	1	m				1.00E+0				pipe incl. insulation
	installation, distribution pipes, welded pipes, in cold store	CH	0	m			1.00E+0	1.00E+0				
	installation, distribution pipes, chromium steel pipes, in cold store	CH	0	m		1.00E+0						
	installation, distribution pipes, cemented ABS pipes, in cold store	CH	0	m	1.00E+0					1.00E+0	1.00E+0	
	installation, distribution pipes, cemented ABS pipes, in cold store	US	0	m					1.00E+0			
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.48E+0				1.48E+0	1.48E+0	1.48E+0	Coolfit inner pipe (ABS)
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	0	kg	8.59E-1	8.09E-1	8.09E-1	8.09E-1	8.59E-1	8.59E-1	8.59E-1	
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	0	kg	1.39E+0				1.39E+0	1.39E+0	1.39E+0	Coolfit jacket pipe
	transport, lorry 28t	CH	0	tkm	3.73E-2	8.09E-3	8.09E-3	8.09E-3	3.73E-2	3.73E-2	3.73E-2	standard disposal distance

Name	piping, ABS with PUR insulation, di 79.2, connected, at cold store	piping, Cr-steel with PUR insulation,di 79, connected, at cold store	piping, steel with PUR insulation, di 79, connected, at cold store	piping, copper with PUR insulation, di 79, connected, at cold store	piping, ABS with PUR insulation, di 79.2, connected, at cold store	piping, ABS with PUR insulation, 40% recy., di 79.2, connected, at cold store	piping, ABS with PUR insulation, 75% recy., di 79.2, connected, at cold store
Location	RER	RER	RER	RER	US	RER	RER
InfrastructureProcess	1	1	1	1	1	1	1
Unit	m	m	m	m	m	m	m
IncludedProcesses	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).	This data reflects a connected piping system. It includes the pipe, fittings and the materials directly related to connecting the pipes (i.e. adhesive, welding, transport to site, pipe supports).
GeneralComment				Estimated from data for chromium steel pipes.	included are also transports from the European production site to USA	included are also transports from the European production site to USA. 50% of the PE and ABS is from recycled plastic, which leads to an overall recycling share of 40%	included are also transports from the European production site to USA. 100% of the PE and ABS is from recycled plastic, which leads to an overall recycling share of 75%
StartDate	2005	2005	2005	2005	2005	2005	2005
EndDate	2005	2005	2005	2005	2005	2005	2005
Text							
Text	Average technology	Average technology	Average technology	Average technology	Average technology	Average technology	Average technology

A8 Supermarket

A8.1 Pipe installation

product	installation, distribution pipes, welded pipes, in supermarket	CH	0	m	**1**				
	installation, distribution pipes, cemented ABS pipes, in supermarket	CH	0	m		**1**			
	installation, distribution pipes, welded pipes, in supermarket	US	0	m			**1**		
	installation, distribution pipes, cemented ABS pipes, in supermarket	US	0	m				**1**	
technosphere	welding, gas, steel	RER	0	m	1.54E+0		1.54E+0		welding pipes; calc. from Frischknecht,
	adhesive, for ABS, at plant	DE	0	kg		4.90E-2		4.90E-2	company data
	cleaner, for ABS and PVC-U/C, at plant	DE	0	kg		1.12E-2		1.12E-2	company data
	polyethylene, HDPE, granulate, at plant	RER	0	kg		2.26E-1		2.26E-1	company data, shrink sleeve
	polyurethane, flexible foam, at plant	RER	0	kg		6.36E-3		6.36E-3	company data, gap insulator
	extrusion, plastic film	RER	0	kg		2.31E-1		2.31E-1	company data, shrink sleeve
	reinforcing steel, at plant	RER	0	kg	5.63E-1	3.75E-1	5.63E-1	3.75E-1	pipe support; Frischknecht, 1999 and
	section bar rolling, steel	RER	0	kg	5.63E-1	3.75E-1	5.63E-1	3.75E-1	pipe support
	transport, lorry 28t	CH	0	tkm	5.22E-1	4.92E-1			own calc. based on Frischknecht, 1999
	transport, lorry 16t	CH	0	tkm	1.74E-1	1.13E-1			own calc. based on Frischknecht, 1999
	transport, transoceanic freight ship	OCE	0	tkm				1.04E+1	estimation
	transport, lorry 32t	RER	0	tkm			1.02E+0	1.11E+0	estimation based on Frischknecht, 1999
	transport, lorry 16t	RER	0	tkm			3.48E-1	2.26E-1	estimation based on Frischknecht, 1999
emission air, high population density	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg		4.81E-2		4.81E-2	solvent emissions from adhesive and cleaner

A8.2 Supermarket Infrastructure

					Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5	
product	cooling system, 104kW, copper, R134a	CH	1	unit	**1**					
	cooling system, 104kW, copper, R404A	CH	1	unit		**1**				
	cooling system, 104kW, copper, R22 2L/R22	CH	1	unit			**1**			
	cooling system, ABS/PUR, R22 2L/R404A 2L,	CH	1	unit				**1**		
	cooling system, ABS/PUR, R134a 2L/R404A	CH	1	unit					**1**	
technosphere	installation, distribution pipes, welded pipes,	CH	0	m	9.20E+2	9.20E+2	9.20E+2	9.75E+1	9.75E+1	Frischknecht, 1999, Tab 2.33f
	installation, distribution pipes, cemented ABS	CH	0	m				8.78E+2	8.78E+2	Frischknecht, 1999, Tab 2.33f
	pipe, copper with Armaflex insulation, for	RER	1	m	9.20E+2	9.20E+2	9.20E+2	9.75E+1	9.75E+1	Frischknecht, 1999, Tab 2.33f
	pipe, ABS with PUR insulation, for	RER	1	m				8.78E+2	8.78E+2	Frischknecht, 1999, Tab 2.33f
	fitting, ABS with PUR insulation, for	RER	1	unit				3.40E+2	3.40E+2	company data
	nipple, ABS, for supermarket, at plant	RER	1	unit				8.05E+2	8.05E+2	company data
	condensing circuit piping kit, copper, for	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	based on Frischknecht, 1999
	compressor Bitzer, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	Frischknecht, 1999, Tab 2.33f
	dry liquid cooler, supermarket, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	Frischknecht, 1999, Tab 2.33f
	plate heat exchanger, corrosion resistant, at	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	2.11E+0	2.11E+0	Frischknecht, 1999, Tab 2.33f
	tube heat exchanger, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0			Frischknecht, 1999, Tab 2.33f
	refrigerant receiver, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	2.61E+0	2.61E+0	Frischknecht, 1999, Tab 2.33f
	propane/ butane, at refinery	CH	0	kg	2.00E+1	2.00E+1	2.00E+1	2.00E+1	2.00E+1	Frischknecht, 1999, Tab 2.33f
	oxygen, liquid, at plant	RER	0	kg	1.70E+1	1.70E+1	1.70E+1	1.70E+1	1.70E+1	Frischknecht, 1999, Tab 2.33f
	nitrogen, liquid, at plant	RER	0	kg	7.00E+1	7.00E+1	7.00E+1	7.00E+1	7.00E+1	Frischknecht, 1999, Tab 2.33f
	electricity, low voltage, at grid	CH	0	kWh	5.00E+2	5.00E+2	5.00E+2	5.00E+2	5.00E+2	Frischknecht, 1999, Tab 2.33f
	propylene glycol, liquid, at plant	RER	0	kg	1.64E+3	1.64E+3	1.64E+3	2.58E+3	2.58E+3	Frischknecht, 1999, Tab 2.33f
	refrigerant R134a, at plant	RER	0	kg	5.99E+1				5.99E+1	Frischknecht, 1999, Tab 2.33f (korrigiert)
	R404A, 52% R143a, 44% R125, 4% R134a, at plant	RER	0	kg	7.52E+1	1.16E+2		2.24E+1	2.24E+1	Frischknecht, 1999, Tab 2.33f (korrigiert)
	chlorodifluoromethane, at plant	NL	0	kg			1.52E+2	5.66E+1		Frischknecht, 1999, Tab 2.33f (korrigiert)
	lubricating oil, at plant	RER	0	kg	3.20E+1	3.20E+1	3.20E+1	5.00E+1	5.00E+1	Frischknecht, 1999, Tab 2.33f
	tube insulation, elastomere, at plant	DE	0	kg	5.00E+1	5.00E+1	5.00E+1			Frischknecht, 1999, Tab 2.33f
	transport, lorry 28t	CH	0	tkm	1.50E+3	1.50E+3	1.50E+3	2.62E+3	2.62E+3	Frischknecht, 1999, Tab 2.33f and standard distances
	transport, lorry 16t	CH	0	tkm	5.00E+2	5.00E+2	5.00E+2	5.95E+2	5.95E+2	Frischknecht, 1999, Tab 2.33f
emission air, high	Propane	-	-	kg	2.00E-1	2.00E-1	2.00E-1	2.00E-1	2.00E-1	propane loss, assumption from Literature (EI)
	Methane, chlorodifluoro-, HCFC-22	-	-	kg			1.52E+0	5.66E-1		Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	6.29E-1	4.63E-2		8.98E-3	6.08E-1	Frischknecht, 1999, Tab 2.33f
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.31E-1	5.09E-1		9.88E-2	9.88E-2	Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.91E-1	6.02E-1		1.17E-1	1.17E-1	Frischknecht, 1999, Tab 2.33f

product	cooling system, 104kW, copper, R134a	US	1	unit	**1**					
	cooling system, 104kW, copper, R404A	US	1	unit		**1**				
	cooling system, 104kW, copper, R22 2L/R22	US	1	unit			**1**			
	cooling system, ABS/PUR, R22 2L/R404A 2L,	US	1	unit				**1**		
	cooling system, ABS/PUR, R134a 2L/R404A	US	1	unit					**1**	
technosphere	installation, distribution pipes, welded pipes,	US	0	m	9.20E+2	9.20E+2	9.20E+2	9.75E+1	9.75E+1	Frischknecht, 1999, Tab 2.33f
	installation, distribution pipes, cemented ABS	US	0	m				8.78E+2	8.78E+2	Frischknecht, 1999, Tab 2.33f
	pipe, copper with Armaflex insulation, for	RER	1	m	9.20E+2	9.20E+2	9.20E+2	9.75E+1	9.75E+1	Frischknecht, 1999, Tab 2.33f
	pipe, ABS with PUR insulation, for	RER	1	m				8.78E+2	8.78E+2	Frischknecht, 1999, Tab 2.33f
	fitting, ABS with PUR insulation, for	RER	1	unit				3.40E+2	3.40E+2	company data
	nipple, ABS, for supermarket, at plant	RER	1	unit				8.05E+2	8.05E+2	company data
	condensing circuit piping kit, copper, for	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	based on Frischknecht, 1999
	compressor Bitzer, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	Frischknecht, 1999, Tab 2.33f
	dry liquid cooler, supermarket, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	1.00E+0	1.00E+0	Frischknecht, 1999, Tab 2.33f
	plate heat exchanger, corrosion resistant, at	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	2.11E+0	2.11E+0	Frischknecht, 1999, Tab 2.33f
	tube heat exchanger, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0			Frischknecht, 1999, Tab 2.33f
	refrigerant receiver, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	2.61E+0	2.61E+0	Frischknecht, 1999, Tab 2.33f
	propane/ butane, at refinery	CH	0	kg	2.00E+1	2.00E+1	2.00E+1	2.00E+1	2.00E+1	Frischknecht, 1999, Tab 2.33f
	oxygen, liquid, at plant	RER	0	kg	1.70E+1	1.70E+1	1.70E+1	1.70E+1	1.70E+1	Frischknecht, 1999, Tab 2.33f
	nitrogen, liquid, at plant	RER	0	kg	7.00E+1	7.00E+1	7.00E+1	7.00E+1	7.00E+1	Frischknecht, 1999, Tab 2.33f
	electricity, low voltage, at grid	US	0	kWh	5.00E+2	5.00E+2	5.00E+2	5.00E+2	5.00E+2	Frischknecht, 1999, Tab 2.33f
	propylene glycol, liquid, at plant	RER	0	kg	1.64E+3	1.64E+3	1.64E+3	2.58E+3	2.58E+3	Frischknecht, 1999, Tab 2.33f
	refrigerant R134a, at plant	RER	0	kg	5.99E+1				5.99E+1	Frischknecht, 1999, Tab 2.33f (korrigiert)
	R404A, 52% R143a, 44% R125, 4% R134a, at plant	RER	0	kg	7.52E+1	1.16E+2		2.24E+1	2.24E+1	Frischknecht, 1999, Tab 2.33f (korrigiert)
	chlorodifluoromethane, at plant	NL	0	kg			1.52E+2	5.66E+1		Frischknecht, 1999, Tab 2.33f (korrigiert)
	lubricating oil, at plant	RER	0	kg	3.20E+1	3.20E+1	3.20E+1	5.00E+1	5.00E+1	Frischknecht, 1999, Tab 2.33f
	tube insulation, elastomere, at plant	DE	0	kg	5.00E+1	5.00E+1	5.00E+1			Frischknecht, 1999, Tab 2.33f
	transport, lorry 32t	RER	0	tkm	3.00E+3	3.00E+3	3.00E+3	5.24E+3	5.24E+3	estimation from Frischknecht, 1999, Tab 2.33f and standard distances
	transport, lorry 16t	RER	0	tkm	1.00E+3	1.00E+3	1.00E+3	1.19E+3	1.19E+3	estimation from Frischknecht, 1999, Tab 2.33f
emission air, high	Propane	-	-	kg	2.00E-1	2.00E-1	2.00E-1	2.00E-1	2.00E-1	propane loss, assumption from Literature (EI)
	Methane, chlorodifluoro-, HCFC-22	-	-	kg			1.52E+0	5.66E-1		Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	6.29E-1	4.63E-2		8.98E-3	6.08E-1	Frischknecht, 1999, Tab 2.33f
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.31E-1	5.09E-1		9.88E-2	9.88E-2	Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.91E-1	6.02E-1		1.17E-1	1.17E-1	Frischknecht, 1999, Tab 2.33f
					Layout S-1	**Layout S-2**	**Layout S-3**	**Layout S-4**	**Layout S-5**	

A8.3 Supermarket Operation

product	operation, cooling devices (0), R134a 2L/R404 DX,	CH	0	ma	**1**					
	operation, cooling devices (0), R404A 2L/R404A DX,	CH	0	ma		**1**				
	operation, cooling devices (0), R22 2L/R22 DX,	CH	0	ma			**1**			
	operation, cooling devices (0), R22 2L/R404A 2L,	CH	0	ma				**1**		
	operation, cooling devices (0), R134a 2L/R404A 2L,	CH	0	ma					**1**	
technosphere	cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket, at client	CH	1	unit	9.07E-4					Frischknecht, 1999, Tab 3.18f
	cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket, at client	CH	1	unit		9.07E-4				Frischknecht, 1999, Tab 3.18f
	cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket, at client	CH	1	unit			9.07E-4			Frischknecht, 1999, Tab 3.18f
	cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket, at client	CH	1	unit				9.07E-4		based on Frischknecht, 1999
	cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket, at client	CH	1	unit					9.07E-4	based on Frischknecht, 1999,
	refrigerant R134a, at plant	RER	0	kg	2.45E-2				2.45E-2	own calc. based on Frischknecht, 1999
	R404A, 52% R143a, 44% R125, 4% R134a, at plant	RER	0	kg	7.16E-2	8.82E-2		9.16E-3	9.16E-3	own calc. based on Frischknecht, 1999
	chlorodifluoromethane, at plant	NL	0	kg			1.14E-1	2.31E-2		own calc. based on Frischknecht, 1999
	transport, lorry 28t	CH	0	tkm	4.80E-3	4.41E-3	5.72E-3	1.61E-3	1.68E-3	standard distance
	transport, freight, rail	CH	0	tkm	5.77E-2	5.29E-2	6.87E-2	1.94E-2	2.02E-2	standard distance
	electricity, low voltage, at grid	CH	0	kWh	4.34E+3	5.43E+3	4.85E+3	4.88E+3	4.47E+3	Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket	CH	1	unit	9.07E-4					Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket	CH	1	unit		9.07E-4				Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket	CH	1	unit			9.07E-4			Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket	CH	1	unit				9.07E-4		based on Frischknecht, 1999
	disposal, cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket	CH	1	unit					9.07E-4	based on Frischknecht, 1999
emission air, high population density	Methane, chlorodifluoro-, HCFC-22	-	-	kg			1.14E-1	2.31E-2		own calc. based on Frischknecht, 1999
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	2.73E-2	3.53E-3		3.67E-4	2.48E-2	own calc. based on Frischknecht, 1999
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.15E-2	3.88E-2		4.03E-3	4.03E-3	own calc. based on Frischknecht, 1999
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.73E-2	4.59E-2		4.77E-3	4.77E-3	own calc. based on Frischknecht, 1999
					Layout S-1	**Layout S-2**	**Layout S-3**	**Layout S-4**	**Layout S-5**	

product	operation, cooling devices (0), R134a 2L/R404 DX,	US	0	ma	1					
	operation, cooling devices (0), R404A 2L/R404A DX,	US	0	ma		1				
	operation, cooling devices (0), R22 2L/R22 DX,	US	0	ma			1			
	operation, cooling devices (0), R22 2L/R404A 2L,	US	0	ma				1		
	operation, cooling devices (0), R134a 2L/R404A 2L,	US	0	ma					1	
technosphere	cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket, at client	US	1	unit	9.07E-4					Frischknecht, 1999, Tab 3.18f
	cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket, at client	US	1	unit		9.07E-4				Frischknecht, 1999, Tab 3.18f
	cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket, at client	US	1	unit			9.07E-4			Frischknecht, 1999, Tab 3.18f
	cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket, at client	US	1	unit				9.07E-4		based on Frischknecht, 1999
	cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket, at client	US	1	unit					9.07E-4	based on Frischknecht, 1999,
	refrigerant R134a, at plant	RER	0	kg	4.08E-2				4.08E-2	own calc. based on Frischknecht, 1999
	R404A, 52% R143a, 44% R125, 4% R134a, at plant	RER	0	kg	1.54E-1	1.81E-1		1.53E-2	1.53E-2	own calc. based on Frischknecht, 1999
	chlorodifluoromethane, at plant	NL	0	kg			2.34E-1	3.85E-2		own calc. based on Frischknecht, 1999
	transport, lorry 32t	RER	0	tkm	9.71E-3	9.05E-3	1.17E-2	2.69E-3	2.80E-3	standard distance
	transport, freight, rail	RER	0	tkm	1.17E-1	1.09E-1	1.41E-1	3.23E-2	3.36E-2	standard distance
	electricity, low voltage, at grid	US	0	kWh	4.34E+3	5.43E+3	4.85E+3	4.88E+3	4.47E+3	Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket	US	1	unit	9.07E-4					Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket	US	1	unit		9.07E-4				Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket	US	1	unit			9.07E-4			Frischknecht, 1999, Tab 3.18f
	disposal, cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket	US	1	unit				9.07E-4		based on Frischknecht, 1999
	disposal, cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket	US	1	unit					9.07E-4	based on Frischknecht, 1999
emission air, high population density	Methane, chlorodifluoro-, HCFC-22	-	-	kg			2.34E-1	3.85E-2		own calc. based on Frischknecht, 1999
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	4.36E-2	3.53E-3		3.67E-4	4.11E-2	own calc. based on Frischknecht, 1999
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.15E-2	3.88E-2		4.03E-3	4.03E-3	own calc. based on Frischknecht, 1999
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.73E-2	4.59E-2		4.77E-3	4.77E-3	own calc. based on Frischknecht, 1999
					Layout S-1	**Layout S-2**	**Layout S-3**	**Layout S-4**	**Layout S-5**	

A8.4 Supermarket Disposal

product	disposal, cooling system, 104kW, copper,	CH	1	unit	1					
	disposal, cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket	CH	1	unit		1				
	disposal, cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket	CH	1	unit			1			
	disposal, cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket	CH	1	unit				1		
	disposal, cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket	CH	1	unit					1	
technosphere	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	5.89E+1	5.89E+1	5.89E+1	7.69E+1	7.69E+1	Frischknecht, 1999, Tab 2.33f
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	0	kg	1.86E+2	1.86E+2	1.86E+2	1.45E+1	1.45E+1	Frischknecht, 1999, Tab 2.33f
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg				2.50E+2	2.50E+2	company data, assumption for ABS-pipe
	disposal, polyurethane, 0.2% water, to	CH	0	kg				2.42E+2	2.42E+2	company data
	disposal, polyethylene, 0.4% water, to	CH	0	kg				4.17E+2	4.17E+2	company data
	treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2	CH	0	m3	1.80E+0	1.80E+0	1.80E+0	2.84E+0	2.84E+0	Frischknecht, 1999, Tab 2.33f
	transport, lorry 28t	CH	0	tkm	2.05E+1	2.05E+1	2.05E+1	3.84E+1	3.84E+1	standard distance
emission air, high population density	Methane, chlorodifluoro-, HCFC-22	-	-	kg			1.51E+1	5.60E+0		Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	6.23E+0	4.58E-1		8.89E-2	6.02E+0	Frischknecht, 1999, Tab 2.33f
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.28E+0	5.04E+0		9.78E-1	9.78E-1	Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.87E+0	5.96E+0		1.16E+0	1.16E+0	Frischknecht, 1999, Tab 2.33f
					Layout S-1	**Layout S-2**	**Layout S-3**	**Layout S-4**	**Layout S-5**	

product	disposal, cooling system, 104kW, copper,	US	1	unit	1					
	disposal, cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket	US	1	unit		1				
	disposal, cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket	US	1	unit			1			
	disposal, cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket	US	1	unit				1		
	disposal, cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket	US	1	unit					1	
technosphere	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	5.89E+1	5.89E+1	5.89E+1	7.69E+1	7.69E+1	Frischknecht, 1999, Tab 2.33f
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	0	kg	1.86E+2	1.86E+2	1.86E+2	1.45E+1	1.45E+1	Frischknecht, 1999, Tab 2.33f
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg				2.50E+2	2.50E+2	company data, assumption for ABS-pipe
	disposal, polyurethane, 0.2% water, to	CH	0	kg				2.42E+2	2.42E+2	company data
	disposal, polyethylene, 0.4% water, to	CH	0	kg				4.17E+2	4.17E+2	company data
	treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2	CH	0	m3	1.80E+0	1.80E+0	1.80E+0	2.84E+0	2.84E+0	Frischknecht, 1999, Tab 2.33f
	transport, lorry 32t	RER	0	tkm	4.09E+1	4.09E+1	4.09E+1	7.67E+1	7.67E+1	double the standard distance
emission air, high population density	Methane, chlorodifluoro-, HCFC-22	-	-	kg			1.51E+1	5.60E+0		Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	-	-	kg	6.23E+0	4.58E-1		8.89E-2	6.02E+0	Frischknecht, 1999, Tab 2.33f
	Ethane, pentafluoro-, HFC-125	-	-	kg	3.28E+0	5.04E+0		9.78E-1	9.78E-1	Frischknecht, 1999, Tab 2.33f
	Ethane, 1,1,1-trifluoro-, CFC-143a	-	-	kg	3.87E+0	5.96E+0		1.16E+0	1.16E+0	Frischknecht, 1999, Tab 2.33f
					Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5	

A8.5 Process Descriptions

Name	installation, distribution pipes, welded pipes, in	installation, distribution pipes, cemented ABS pipes,	installation, distribution pipes, welded pipes, in	installation, distribution pipes, cemented ABS pipes,
Location	CH	CH	US	US
InfrastructureProcess	0	0	0	0
Unit	m	m	m	m
IncludedProcesses	This data set includes the transport of all the necessary material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a supermarket are considered as well.	This data set includes the transport of all the necessary material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a supermarket are considered as well.	This data set includes the transport of all the necessary material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a supermarket are considered as well.	This data set includes the transport of all the necessary material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a supermarket are considered as well.
GeneralComment		It is assumed that 100% of the solvents in the cleaner and the adhesive are released to the air.		It is assumed that 100% of the solvents in the cleaner and the adhesive are released to the air. It is furthermore assumed that the pipes are transported from Denmark to USA.
StartDate	1998	2004	1998	2004
EndDate	2005	2005	2005	2005
Text	data is based on a Swiss supermarket installation	data is based on a Swiss supermarket installation	data is based on a Swiss supermarket installation	data is based on a Swiss supermarket installation
Text	normal supermarket installation	normal supermarket installation	normal supermarket installation	normal supermarket installation

Name	cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket, at client	cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket, at client	cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket, at client	cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket, at client	cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket, at client
Location	CH	CH	CH	CH	CH
InfrastructureProcess	1	1	1	1	1
Unit	unit	unit	unit	unit	unit
IncludedProcesses	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (welding) and material (pipe supports, insulation) as well as the initial set of	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (welding) and material (pipe supports, insulation) as well as the initial set of	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (welding) and material (pipe supports, insulation) as well as the initial set of	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.
GeneralComment	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems.1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.
StartDate	1996	1996	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	The cooling systems are located in Switzerland; the components are mostly from a European location.	The cooling systems are located in Switzerland; the components are mostly from a European location.	The cooling systems are located in Switzerland; the components are mostly from a European location.	The cooling systems are located in Switzerland; the components are mostly from a European location.	The cooling systems are located in Switzerland; the components are mostly from a European location.
Text	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing.
	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5

Name	cooling system, 104kW, copper, R134a 2L/R404 DX,	cooling system, 104kW, copper, R404A 2L/R404A	cooling system, 104kW, copper, R22 2L/R22 DX, for	cooling system, ABS/PUR, R22 2L/R404A 2L, for	cooling system, ABS/PUR, R134a 2L/R404A 2L, for
Location	US	US	US	US	US
InfrastructureProcess	1	1	1	1	1
Unit	unit	unit	unit	unit	unit
IncludedProcesses	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.	This data set includes the material needed to set up a cooling system in a supermarket, which provides cooling energy to refrigerators and freezers. This is a compressor, pipes and heat exchangers. The data also includes the installation work (gluing) and material (pipe supports) as well as the initial set of refrigerant.
GeneralComment	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.	The data for the installations stems from three different cooling systems in Swiss supermarkets. The data is extrapolated to reflect an average cooling system installation. Some components are based on similar types of cooling systems. 1 unit corresponds to 1 cooling system installation of 104kW.
StartDate	1998	1998	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	A swiss cooling system is adapted to reflect a cooling system in the USA	A swiss cooling system is adapted to reflect a cooling system in the USA	A swiss cooling system is adapted to reflect a cooling system in the USA	A swiss cooling system is adapted to reflect a cooling system in the USA	A swiss cooling system is adapted to reflect a cooling system in the USA
Text	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing. Data is adapted to reflect the US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing. Data is adapted to reflect the US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing. Data is adapted to reflect the US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing. Data is adapted to reflect the US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating and 21.3 kW for freezing. Data is adapted to reflect the US-situation.
	Layout S-5	Layout S-5	Layout S-5	Layout S-5	Layout S-5

Name	operation, cooling devices, R134a 2L/R404 DX, copper piping, for supermarket	operation, cooling devices, R404A 2L/R404A DX, copper piping, for supermarket	operation, cooling devices, R22 2L/R22 DX, copper piping, for supermarket	operation, cooling devices, R22 2L/R404A 2L, ABS/PUR piping, for supermarket	operation, cooling devices, R134a 2L/R404A 2L, ABS/PUR piping, for supermarket
Location	CH	CH	CH	CH	CH
InfrastructureProcess	0	0	0	0	0
Unit	m/a	m/a	m/a	m/a	m/a
IncludedProcesses	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.
GeneralComment	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 1%. Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 1%. Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 1%. Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 1%. Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 1%. Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland
StartDate	1998	1998	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	Operation of a supermarket cooling system in Switzerland	Operation of a supermarket cooling system in Switzerland	Operation of a supermarket cooling system in Switzerland	Operation of a supermarket cooling system in Switzerland	Operation of a supermarket cooling system in Switzerland
Text	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation).	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation).	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation).	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (indirect evaporation).	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (indirect evaporation).
	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5

Name	operation, cooling devices (0), R134a 2L/R404 DX,	operation, cooling devices (0), R404A 2L/R404A DX,	operation, cooling devices (0), R22 2L/R22 DX, copper	operation, cooling devices (0), R22 2L/R404A 2L,	operation, cooling devices (0), R134a 2L/R404A 2L,
Location	US	US	US	US	US
InfrastructureProcess	0	0	0	0	0
Unit	ma	ma	ma	ma	ma
IncludedProcesses	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.	This process encompasses the elements to operate a cooling system in a supermarket for one year. It includes the installation of the system, the electricity consumption and refrigerant replacement during operation as well as the final disposal of the installation.
GeneralComment	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 5% (medium temperature) and 15% (low temperature circuit). Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 5% (medium temperature) and 15% (low temperature circuit). Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 5% (medium temperature) and 15% (low temperature circuit). Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 5% (medium temperature) and 5% (low temperature circuit). Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland	The lifespan of the supermarket is considered to be 15 years. The yearly refrigerant loss is assumed to amount to 5% (medium temperature) and 5% (low temperature circuit). Data on electricity consumption, and refrigerant charge is compiled from 31 supermarkets in Switzerland
StartDate	1998	1998	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	Assumption for the operation of a supermarket in the USA.	Assumption for the operation of a supermarket in the USA.	Assumption for the operation of a supermarket in the USA.	Assumption for the operation of a supermarket in the USA.	Assumption for the operation of a supermarket in the USA.
Text	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation). Data adapted to US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation). Data adapted to US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation). Data adapted to US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation). Data adapted to US-situation.	Average cooling system of a Swiss supermarket. The refrigerating capacity is 82.3 kW for refrigerating (indirect evaporation) and 21.3 kW for freezing (direct evaporation). Data adapted to US-situation.
	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5

Name	disposal, cooling system, 104kW, copper, R134a 2L/R404 DX, for supermarket	disposal, cooling system, 104kW, copper, R404A 2L/R404A DX, for supermarket	disposal, cooling system, 104kW, copper, R22 2L/R22 DX, for supermarket	disposal, cooling system, ABS/PUR, R22 2L/R404A 2L, for supermarket	disposal, cooling system, ABS/PUR, R134a 2L/R404A 2L, for supermarket
Location	CH	CH	CH	CH	CH
InfrastructureProcess	0	0	0	0	0
Unit	unit	unit	unit	unit	unit
IncludedProcesses	The disposal considers the plastics and oils to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics and oils to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics and oils to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics and oils to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics and oils to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.
GeneralComment	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.
StartDate	1998	1998	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	Disposal of all components in Switzerland	Disposal of all components in Switzerland	Disposal of all components in Switzerland	Disposal of all components in Switzerland	Disposal of all components in Switzerland
Text	Disposal in Switzerland assuming average technology	Disposal in Switzerland assuming average technology	Disposal in Switzerland assuming average technology	Disposal in Switzerland assuming average technology	Disposal in Switzerland assuming average technology
	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5

Name	disposal, cooling system, 104kW, copper, R134a	disposal, cooling system, 104kW, copper, R404A	disposal, cooling system, 104kW, copper, R22 2L/R22	disposal, cooling system, ABS/PUR, R22 2L/R404A	disposal, cooling system, ABS/PUR, R134a 2L/R404A
Location	US	US	US	US	US
InfrastructureProcess	1	1	1	1	1
Unit	unit	unit	unit	unit	unit
IncludedProcesses	The disposal considers the plastics to be landfilled, whereas the oils is to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics to be landfilled, whereas the oils is to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics to be landfilled, whereas the oils is to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics to be landfilled, whereas the oils is to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.	The disposal considers the plastics to be landfilled, whereas the oils is to be incinerated. The steel and copper is recycled. 90% of the refrigerant is recovered, the remaining 10% is aussumed to be emitted to the air.
GeneralComment	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.	The amount of material to be disposed of is derived from the corresponding infrastructure data set of the cooling system. 1 unit corresponds to the disposal of 1 cooling system installation of 104kW.
StartDate	1998	1998	1998	1998	1998
EndDate	2005	2005	2005	2005	2005
Text	Typical disposal situation for the USA	Typical disposal situation for the USA	Typical disposal situation for the USA	Typical disposal situation for the USA	Typical disposal situation for the USA
Text	Incineration and landfilling is based on swiss technology.	Incineration and landfilling is based on swiss technology.	Incineration and landfilling is based on swiss technology.	Incineration and landfilling is based on swiss technology.	Incineration and landfilling is based on swiss technology.
	Layout S-1	Layout S-2	Layout S-3	Layout S-4	Layout S-5

A9 Cold Store

A9.1 Pipe installation

product	installation, distribution pipes, welded pipes, in cold store	CH	0	m	1						
	installation, distribution pipes, chromium steel pipes, in cold store	CH	0	m		1					
	installation, distribution pipes, cemented ABS pipes, in cold store	CH	0	m			1				
	installation, distribution pipes, welded pipes, in cold store	US	0	m				1			
	installation, distribution pipes, chromium steel pipes, in cold store	US	0	m					1		
	installation, distribution pipes, cemented ABS pipes, in cold store	US	0	m						1	
technosphere	welding, gas, steel	RER	0	m	4.88E-1			4.88E-1			welding pipes; Frischknecht, 1999 and company data
	welding, arc, steel	RER	0	m		4.88E-1			4.88E-1		welding pipes; Frischknecht, 1999 and company data
	adhesive, for ABS, at plant	DE	0	kg			1.55E-2			1.55E-2	company data
	cleaner, for ABS and PVC-U/C, at plant	DE	0	kg			3.88E-3			3.88E-3	company data
	polyethylene, HDPE, granulate, at plant	RER	0	kg			7.17E-2			7.17E-2	shrink sleeve, company data
	polyurethane, flexible foam, at plant	RER	0	kg			2.02E-3			2.02E-3	shrink sleeve, company data
	extrusion, plastic film	RER	0	kg			7.17E-2			7.17E-2	gap insulator, company data
	reinforcing steel, at plant	RER	0	kg	1.60E+0	1.60E+0	1.16E+0	1.60E+0	1.60E+0	1.16E+0	pipe support; Frischknecht, 1999 and company data
	section bar rolling, steel	RER	0	kg	1.60E+0	1.60E+0	1.16E+0	1.60E+0	1.60E+0	1.16E+0	pipe support; Frischknecht, 1999 and company data
	transport, lorry 28t	CH	0	tkm	1.48E+0	1.48E+0	1.40E+0				transport of pipes to preassembly
	transport, lorry 16t	CH	0	tkm	4.93E-1	4.93E-1	3.50E-1				transport to installation site
	transport, transoceanic freight ship	OCE	0	tkm				0	0	3.50E+1	transport to installation site
	transport, lorry 32t	RER	0	tkm				2.96E+0	2.96E+0	3.61E+0	transport to installation site
	transport, lorry 16t	RER	0	tkm				9.86E-1	9.86E-1	7.00E-1	transport to installation site
emission air, high population density	Hydrocarbons, aliphatic, alkanes, unspecified	-	-	kg			1.94E-2			1.94E-2	solvent emissions from adhesive and cleaner

A9.2 Cold Store Infrastructure

product	cooling system, steel piping, Ammonia, for cold store, at client	CH	1	unit	1			
	cooling system, chromium steel piping, Ammonia, for cold store, at	CH	1	unit		1		
	cooling system, ABS piping, Ammonia, for cold store, at client	CH	1	unit			1	
technosphere	pipe, steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m	1.00E+2			data from company
	pipe, steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m	1.00E+2			data from company
	pipe, steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m	1.20E+3			data from company
	installation, distribution pipes, welded pipes, in cold store	CH	0	m	1.40E+3			data from company
	pipe, chromium steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m		1.00E+2		data from company
	pipe, chromium steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m		1.00E+2		data from company
	pipe, chromium steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m		1.20E+3		data from company
	installation, distribution pipes, chromium steel pipes, in cold store	CH	0	m		1.40E+3		data from company
	pipe, ABS with PUR insulation, 110x44, at plant	RER	1	m			1.00E+2	data from company
	pipe, ABS with PUR insulation, 125x55.4, at plant	RER	1	m			1.00E+2	data from company
	pipe, ABS with PUR insulation, 160x79.2, at plant	RER	1	m			1.20E+3	data from company
	fitting, ABS with PUR insulation, for cold store, at plant	RER	1	unit			1.42E+2	data from company
	nipple, ABS, for cold store, at plant	RER	1	unit			3.14E+2	data from company
	installation, distribution pipes, cemented ABS pipes, in cold store	CH	0	m			1.36E+2	data from company
	packaged chiller, ammonia, 810kW cooling capacity, at plant	RER	1	unit	3.00E+0	3.00E+0	3.00E+0	data from company
	condensing circuit piping kit, low-alloy steel, for cold store, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	
	hybrid liquid fluid cooler, at plant	RER	1	unit	4.00E+0	4.00E+0	4.00E+0	
	propane/ butane, at refinery	CH	0	kg	1.41E+2	1.41E+2	1.41E+2	adapted from Frischknecht, 1999
	oxygen, liquid, at plant	RER	0	kg	1.20E+2	1.20E+2	1.20E+2	adapted from Frischknecht, 1999
	nitrogen, liquid, at plant	RER	0	kg	4.93E+2	4.93E+2	4.93E+2	adapted from Frischknecht, 1999
	electricity, low voltage, at grid	CH	0	kWh	3.52E+3	3.52E+3	3.52E+3	adapted from Frischknecht, 1999
	propylene glycol, liquid, at plant	RER	0	kg	5.59E+3	5.59E+3	5.59E+3	calc. from pipes
	ammonia, liquid, at regional storehouse	CH	0	kg	3.21E+2	3.21E+2	3.21E+2	extrapolation from similar chiller
	lubricating oil, at plant	RER	0	kg	2.36E+2	2.36E+2	2.36E+2	extrapolation from similar chiller
	transport, lorry 28t	CH	0	tkm	1.26E+4	1.26E+4	1.68E+4	transport to preassembling
	transport, lorry 16t	CH	0	tkm	4.19E+3	4.19E+3	4.19E+3	transport to installation site
emission air, high population density	Ammonia	-	-	kg	3.21E+0	3.21E+0	3.21E+0	
					layout CS-1	layout CS-2	layout CS-3	

product	cooling system, steel piping, Ammonia, for cold store, at client	US	1	unit	1			
	cooling system, chromium steel piping, Ammonia, for cold store, at	US	1	unit		1		
	cooling system, ABS piping, Ammonia, for cold store, at client	US	1	unit			1	
technosphere	pipe, steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m	1.00E+2			data from company
	pipe, steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m	1.00E+2			data from company
	pipe, steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m	1.20E+3			data from company
	installation, distribution pipes, welded pipes, in cold store	US	0	m	1.40E+3			data from company
	pipe, chromium steel with PUR insulation and steel jacket, 47x44, at plant	RER	1	m		1.00E+2		data from company
	pipe, chromium steel with PUR insulation and steel jacket, 59x55, at plant	RER	1	m		1.00E+2		data from company
	pipe, chromium steel with PUR insulation and steel jacket, 83x79, at plant	RER	1	m		1.20E+3		data from company
	installation, distribution pipes, chromium steel pipes, in cold store	US	0	m		1.40E+3		data from company
	pipe, ABS with PUR insulation, 110x44, at plant	RER	1	m			1.00E+2	data from company
	pipe, ABS with PUR insulation, 125x55.4, at plant	RER	1	m			1.00E+2	data from company
	pipe, ABS with PUR insulation, 160x79.2, at plant	RER	1	m			1.20E+3	data from company
	fitting, ABS with PUR insulation, for cold store, at plant	RER	1	unit			1.42E+2	data from company
	nipple, ABS, for cold store, at plant	RER	1	unit			3.14E+2	data from company
	installation, distribution pipes, cemented ABS pipes, in cold store	US	0	m			1.36E+2	data from company
	packaged chiller, ammonia, 810kW cooling capacity, at plant	RER	1	unit	3.00E+0	3.00E+0	3.00E+0	data from company
	condensing circuit piping kit, low-alloy steel, for cold store, at plant	RER	1	unit	1.00E+0	1.00E+0	1.00E+0	
	hybrid liquid fluid cooler, at plant	RER	1	unit	4.00E+0	4.00E+0	4.00E+0	
	propane/ butane, at refinery	CH	0	kg	1.41E+2	1.41E+2	1.41E+2	adapted from Frischknecht, 1999
	oxygen, liquid, at plant	RER	0	kg	1.20E+2	1.20E+2	1.20E+2	adapted from Frischknecht, 1999
	nitrogen, liquid, at plant	RER	0	kg	4.93E+2	4.93E+2	4.93E+2	adapted from Frischknecht, 1999
	electricity, low voltage, at grid	US	0	kWh	3.52E+3	3.52E+3	3.52E+3	adapted from Frischknecht, 1999
	propylene glycol, liquid, at plant	RER	0	kg	5.59E+3	5.59E+3	5.59E+3	calc. from pipes
	ammonia, liquid, at regional storehouse	CH	0	kg	3.21E+2	3.21E+2	3.21E+2	extrapolation from similar chiller
	lubricating oil, at plant	RER	0	kg	2.36E+2	2.36E+2	2.36E+2	extrapolation from similar chiller
	transport, lorry 32t	RER	0	tkm	2.51E+4	2.51E+4	3.35E+4	transport to preassembling
	transport, lorry 16t	RER	0	tkm	8.38E+3	8.38E+3	8.38E+3	transport to installation site
emission air, high population density	Ammonia	-	-	kg	3.21E+0	3.21E+0	3.21E+0	
					layout CS-1	layout CS-2	layout CS-3	

A9.3 Cold Store Operation

product	operation, cooling system (0), steel piping, Ammonia, for cold store	CH	-	-	0	m3a	1			
product	operation, cooling system (0), chromium steel piping, Ammonia, for cold store	CH	-	-	0	m3a		1		
product	operation, cooling system (0), ABS piping, Ammonia, for cold store	CH	-	-	0	m3a			1	
technosphere	cooling system, steel piping, Ammonia, for cold store, at client	CH	-	-	1	unit	1.20E-7			the infrastructure
	cooling system, chromium steel piping, Ammonia, for cold store, at client	CH	-	-	1	unit		1.20E-7		the infrastructure
	cooling system, ABS piping, Ammonia, for cold store, at client	CH	-	-	1	unit			1.20E-7	the infrastructure
	ammonia, liquid, at regional storehouse	CH	-	-	0	kg	2.89E-5	2.89E-5	2.89E-5	replacement of the annual loss
	electricity, low voltage, at grid	CH	-	-	0	kWh	5.76E+0	5.76E+0	5.76E+0	electricity for operation
	disposal, cooling system, steel piping, Ammonia, for cold store	CH	-	-	1	unit	1.20E-7			
	disposal, cooling system, chromium steel piping, Ammonia, for cold store	CH	-	-	1	unit		1.20E-7		
	disposal, cooling system, ABS piping, Ammonia, for cold store	CH	-	-	1	unit			1.20E-7	
emission air, high population density	Ammonia	-	air	high	-	kg	2.89E-5	2.89E-5	2.89E-5	annual loss of refrigerant
							layout CS-1	layout CS-2	layout CS-3	

product	operation, cooling system (0), steel piping, Ammonia, for cold store	US	-	-	0	m3a	1			
product	operation, cooling system (0), chromium steel piping, Ammonia, for cold store	US	-	-	0	m3a		1		
product	operation, cooling system (0), ABS piping, Ammonia, for cold store	US	-	-	0	m3a			1	
technosphere	cooling system, steel piping, Ammonia, for cold store, at client	US	-	-	1	unit	1.20E-7			the infrastructure
	cooling system, chromium steel piping, Ammonia, for cold store, at client	US	-	-	1	unit		1.20E-7		the infrastructure
	cooling system, ABS piping, Ammonia, for cold store, at client	US	-	-	1	unit			1.20E-7	the infrastructure
	ammonia, liquid, at regional storehouse	CH	-	-	0	kg	4.82E-5	4.82E-5	4.82E-5	replacement of the annual loss
	electricity, low voltage, at grid	US	-	-	0	kWh	5.76E+0	5.76E+0	5.76E+0	electricity for operation
	disposal, cooling system, steel piping, Ammonia, for cold store	US	-	-	1	unit	1.20E-7			
	disposal, cooling system, chromium steel piping, Ammonia, for cold store	US	-	-	1	unit		1.20E-7		
	disposal, cooling system, ABS piping, Ammonia, for cold store	US	-	-	1	unit			1.20E-7	
emission air, high population density	Ammonia	-	air	high	-	kg	4.82E-5	4.82E-5	4.82E-5	annual loss of refrigerant
							layout CS-1	layout CS-2	layout CS-3	

A9.4 Cold Store Disposal

product	disposal, cooling system, steel piping, Ammonia, for cold store	CH	-	-	1	unit	1			
product	disposal, cooling system, chromium steel piping, Ammonia, for cold store	CH	-	-	1	unit		1		
product	disposal, cooling system, ABS piping, Ammonia, for cold store	CH	-	-	1	unit			1	
technosphere	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	-	-	0	kg	2.36E+2	2.36E+2	2.36E+2	
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	-	-	0	kg			1.89E+3	disposal of ABS
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	-	-	0	kg	1.07E+3	1.07E+3	1.13E+3	disposal of PUR
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	-	-	0	kg			1.86E+3	disposal of jacket pipe
	treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2	CH	-	-	0	m3	6.14E+0	6.14E+0	6.14E+0	
	transport, lorry 28t	CH	-	-	0	tkm	7.77E+1	7.77E+1	1.16E+2	standard disposal distance
emission air, high population density	Ammonia	-	air	high	-	kg	6.43E+0	6.43E+0	6.43E+0	emission during decomissioning and disposal/recycling
							layout CS-1	layout CS-2	layout CS-3	

product	disposal, cooling system, steel piping, Ammonia, for cold store	US	-	-	1	unit	1			
product	disposal, cooling system, chromium steel piping, Ammonia, for cold store	US	-	-	1	unit		1		
product	disposal, cooling system, ABS piping, Ammonia, for cold store	US	-	-	1	unit			1	
technosphere	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	-	-	0	kg	2.36E+2	2.36E+2	2.36E+2	
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	-	-	0	kg			1.89E+3	disposal of ABS
	disposal, polyurethane, 0.2% water, to municipal incineration	CH	-	-	0	kg	1.07E+3	1.07E+3	1.13E+3	disposal of PUR
	disposal, polyethylene, 0.4% water, to municipal incineration	CH	-	-	0	kg			1.86E+3	disposal of jacket pipe
	treatment, heat carrier liquid, 40% C3H8O2, to wastewater treatment, class 2	CH	-	-	0	m3	6.14E+0	6.14E+0	6.14E+0	
	transport, lorry 32t	RER	-	-	0	tkm	1.55E+2	1.55E+2	2.32E+2	double the standard disposal distance - estimation for USA
emission air, high population density	Ammonia	-	air	high	-	kg	6.43E+0	6.43E+0	6.43E+0	emission during decomissioning and disposal/recycling
							layout CS-1	layout CS-2	layout CS-3	

A9.5 Process Descriptions

Name	installation, distribution pipes, welded pipes, in cold store	installation, distribution pipes, chromium steel pipes, in cold store	installation, distribution pipes, cemented ABS pipes, in cold store	installation, distribution pipes, welded pipes, in cold store	installation, distribution pipes, chromium steel pipes, in cold store	installation, distribution pipes, cemented ABS pipes, in cold store
Location	CH	CH	CH	US	US	US
InfrastructureProcess	0	0	0	0	0	0
Unit	m	m	m	m	m	m
IncludedProcesses	This data set includes the transport of all material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store are considered as well.	This data set includes the transport of all material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store are considered as well.	This data set includes pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store	This data set includes the transport of all material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store are considered as well.	This data set includes the transport of all material to the installation site. The pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store are considered as well.	This data set includes pipe supports and the auxiliary inputs to assemble and install the pipes in a cold store
GeneralComment	The pipes are not included. For 1m of pipe 1m of this process is needed.	The pipes are not included. For 1m of pipe 1m of this process is needed.	The pipes are not included. For 1m of pipe 1m of this process is needed.	The pipes are not included. For 1m of pipe 1m of this process is needed.	The pipes are not included. For 1m of pipe 1m of this process is needed.	The pipes are not included. For 1m of pipe 1m of this process is needed.
StartDate	1996	1996	2004	1996	1996	2004
EndDate	2005	2005	2005	2005	2005	2005
Text						
Text	data is based on a supermarket installation	data is based on a supermarket installation	data is based on a supermarket installation	data is based on a supermarket installation	data is based on a supermarket installation	data is based on a supermarket installation
	layout CS-1	layout CS-2	layout CS-3	layout CS-1	layout CS-2	layout CS-3

Name	cooling system, steel piping, Ammonia, for cold store, at client	cooling system, chromium steel piping, Ammonia, for cold store, at client	cooling system, ABS piping, Ammonia, for cold store, at client	cooling system, steel piping, Ammonia, for cold store, at client	cooling system, chromium steel piping, Ammonia, for cold store, at client	cooling system, ABS piping, Ammonia, for cold store, at client
Location	CH	CH	CH	US	US	US
InfrastructureProcess	1	1	1	1	1	1
Unit	unit	unit	unit	unit	unit	unit
IncludedProcesses	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.	This data set includes materials, goods and auxilliary inputs to build the cooling system in a cold store. It also includes an initial set of refrigerant and cooling agent.
GeneralComment	The cooling capacity is 810kW.	The cooling capacity is 810kW.	The cooling capacity is 810kW.	The cooling capacity is 810kW.	The cooling capacity is 810kW.	The cooling capacity is 810kW. The pipes are assumed to be transported from Denmark to USA
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in USA	The data is from a UK cold store assumed to be installed and operated in USA	The data is from a UK cold store assumed to be installed and operated in USA
Text	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.
	layout CS-1	layout CS-2	layout CS-3	layout CS-1	layout CS-2	layout CS-3

Name	operation, cooling system (0), steel piping, Ammonia, for cold store	operation, cooling system (0), chromium steel piping, Ammonia, for cold store	operation, cooling system (0), ABS piping, Ammonia, for cold store	operation, cooling system (0), steel piping, Ammonia, for cold store	operation, cooling system (0), chromium steel piping, Ammonia, for cold store	operation, cooling system (0), ABS piping, Ammonia, for cold store
Location	CH	CH	CH	US	US	US
InfrastructureProcess	0	0	0	0	0	0
Unit	m3a	m3a	m3a	m3a	m3a	m3a
IncludedProcesses	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.	This data set includes the infrastructure, the disposal at the end of life, the refrigerant replacements, the energy consumption and the emissions during the operation.
GeneralComment	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 3%. The cooling capacity is 810kW.	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 3%. The cooling capacity is 810kW.	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 3%. The cooling capacity is 810kW.	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 5%. The cooling capacity is 810kW.	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 5%. The cooling capacity is 810kW.	The lifespan of the supermarket is considered to be 25 years. The yearly refrigerant loss is assumed to amount to 5%. The cooling capacity is 810kW.
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland	The data is from a UK cold store assumed to be installed and operated in Switzerland
Text	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.	The installation is optimised for a low GWP and a high energy efficiency as well as resource conservation.
	layout CS-1	layout CS-2	layout CS-3	layout CS-1	layout CS-2	layout CS-3

Name	disposal, cooling system, steel piping, Ammonia, for cold store	disposal, cooling system, chromium steel piping, Ammonia, for cold store	disposal, cooling system, ABS piping, Ammonia, for cold store	disposal, cooling system, steel piping, Ammonia, for cold store	disposal, cooling system, chromium steel piping, Ammonia, for cold store	disposal, cooling system, ABS piping, Ammonia, for cold store
Location	CH	CH	CH	US	US	US
InfrastructureProcess	1	1	1	1	1	1
Unit	unit	unit	unit	unit	unit	unit
IncludedProcesses	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.	This data set includes the transports to disposal as well as emissions of the refrigerant during recycling.
GeneralComment	The non-recyclable part of the cooling system is incinerated.	The non-recyclable part of the cooling system is incinerated.	The non-recyclable part of the cooling system is incinerated.	The non-recyclable part of the cooling system is incinerated.	The non-recyclable part of the cooling system is incinerated.	The non-recyclable part of the cooling system is incinerated.
StartDate	2004	2004	2004	2004	2004	2004
EndDate	2005	2005	2005	2005	2005	2005
Text						
Text	Disposal in Swiss incinerators	Disposal in Swiss incinerators	Disposal in Swiss incinerators	Disposal in Swiss incinerators	Disposal in Swiss incinerators	Disposal in Swiss incinerators
	layout CS-1	layout CS-2	layout CS-3	layout CS-1	layout CS-2	layout CS-3

A10 Impact Assessment Result Tables

A10.1 Piping Material

A10.1.1 Cumulative Energy Demand

Impact category		piping, copper with PUR insulation, di 79	piping, chromium steel with PUR insulation, di 79	piping, steel with PUR insulation, di 79	
Non-renewable	MJ-eq	523	557	315	
Renewable	MJ-eq	58.4	52.4	21.6	

Impact category		piping, ABS with PUR insulation, di 79.2 (75% material from recycl.)	piping, ABS with PUR insulation, di 79.2 (40% material from recycl.)	piping, ABS with PUR insulation, di 79.2	piping, ABS with PUR insulation, di 79.2 (location USA)
Non-renewable	MJ-eq	158	331	504	517
Renewable	MJ-eq	13.1	24.9	36.8	37.0

A10.1.2 Environmental Impact Indicators According to CML 2001 (characterised values)

Impact category		piping, copper with PUR insulation, di 79	piping, chromium steel with PUR insulation, di 79	piping, steel with PUR insulation, di 79	
abiotic depletion	kg Sb eq	2.13E-01	2.47E-01	1.39E-01	
global warming (GWP100)	kg CO_2 eq	3.01E+01	3.62E+01	2.12E+01	
ozone layer depletion (ODP)	kg CFC-11 eq	1.82E-06	2.06E-06	1.34E-06	
human toxicity	kg 1,4-DB eq	4.24E+02	3.68E+02	2.53E+01	
fresh water aquatic ecotox.	kg 1,4-DB eq	1.63E+01	6.31E+01	1.23E+01	
photochemical oxidation	kg C_2H_4	3.15E-02	1.27E-02	9.64E-03	
acidification	kg SO_2 eq	7.64E-01	1.97E-01	1.09E-01	
eutrophication	kg PO_4^{2-}- eq	3.12E-02	2.51E-02	1.85E-02	

Impact category		piping, ABS with PUR insulation, di 79.2 (75% material from recycl.)	piping, ABS with PUR insulation, di 79.2 (40% material from recycl.)	piping, ABS with PUR insulation, di 79.2	piping, ABS with PUR insulation, di 79.2 (location USA)
abiotic depletion	kg Sb eq	7.32E-02	1.53E-01	2.33E-01	2.38E-01
global warming (GWP100)	kg CO_2 eq	1.81E+01	2.52E+01	3.24E+01	3.32E+01
ozone layer depletion (ODP)	kg CFC-11 eq	3.51E-07	5.45E-07	7.40E-07	8.31E-07
human toxicity	kg 1,4-DB eq	5.96E+00	7.38E+00	8.80E+00	9.16E+00
fresh water aquatic ecotox.	kg 1,4-DB eq	8.66E+00	8.98E+00	9.30E+00	9.33E+00
photochemical oxidation	kg C_2H_4	3.81E-03	5.63E-03	7.44E-03	7.84E-03
acidification	kg SO_2 eq	4.63E-02	8.98E-02	1.33E-01	1.44E-01
eutrophication	kg PO_4^{2-}- eq	8.95E-03	1.34E-02	1.79E-02	1.91E-02

A10.2 Supermarket

A10.2.1 Cumulative Energy Demand (CED)

Supermarket CH *Impact category*		**Layout S-1** R134a 2L/R404 DX, copper piping	**Layout S-2** R404A 2L/R404A DX, copper piping	**Layout S-3** R22 2L/R22 DX, copper piping	**Layout S-4** R22 2L/R404A 2L, ABS/PUR piping	**Layout S-5** R134a 2L/R404A 2L, ABS/PUR piping
Non-renewable	MJ-eq	3.62E+04	4.51E+04	4.04E+04	4.08E+04	3.73E+04
Renewable	MJ-eq	9.62E+03	1.20E+04	1.07E+04	1.08E+04	9.89E+03

Supermarket USA *Impact category*		**Layout S-1** R134a 2L/R404 DX, copper piping	**Layout S-2** R404A 2L/R404A DX, copper piping	**Layout S-3** R22 2L/R22 DX, copper piping	**Layout S-4** R22 2L/R404A 2L, ABS/PUR piping	**Layout S-5** R134a 2L/R404A 2L, ABS/PUR piping
Non-renewable	MJ-eq	5.22E+04	6.51E+04	5.82E+04	5.87E+04	5.38E+04
Renewable	MJ-eq	3.30E+03	4.12E+03	3.68E+03	3.71E+03	3.40E+03

A10.2.2 Environmental Impact Indicators According to CML 2001 (characterised values)

Supermarket CH *Impact category*		**Layout S-1** R134a 2L/R404 DX, copper piping	**Layout S-2** R404A 2L/R404A DX, copper piping	**Layout S-3** R22 2L/R22 DX, copper piping	**Layout S-4** R22 2L/R404A 2L, ABS/PUR piping	**Layout S-5** R134a 2L/R404A 2L, ABS/PUR piping
abiotic depletion	kg Sb eq	4.53E+00	5.61E+00	5.03E+00	5.12E+00	4.71E+00
global warming (GWP100)	kg CO_2 eq	8.29E+02	9.74E+02	9.52E+02	8.01E+02	7.35E+02
ozone layer depletion (ODP)	kg CFC-11 eq	2.07E-03	1.83E-03	5.15E-03	1.51E-03	1.06E-03
human toxicity	kg 1,4-DB eq	6.83E+02	7.93E+02	7.37E+02	6.34E+02	5.90E+02
fresh water aquatic eco-tox.	kg 1,4-DB eq	5.69E+01	6.82E+01	6.22E+01	6.25E+01	5.81E+01
photochemical oxidation	kg C_2H_4	1.11E-01	1.33E-01	1.21E-01	1.16E-01	1.08E-01
acidification	kg SO_2 eq	2.44E+00	2.95E+00	2.67E+00	2.53E+00	2.33E+00
eutrophication	kg PO_4^{2-}- eq	1.90E-01	2.30E-01	2.08E-01	2.14E-01	1.99E-01

Supermarket USA *Impact category*		**Layout S-1** R134a 2L/R404 DX, copper piping	**Layout S-2** R404A 2L/R404A DX, copper piping	**Layout S-3** R22 2L/R22 DX, copper piping	**Layout S-4** R22 2L/R404A 2L, ABS/PUR piping	**Layout S-5** R134a 2L/R404A 2L, ABS/PUR piping
abiotic depletion	kg Sb eq	2.60E+01	3.24E+01	2.90E+01	2.92E+01	2.68E+01
global warming (GWP100)	kg CO_2 eq	3.44E+03	4.24E+03	4.04E+03	3.73E+03	3.42E+03
ozone layer depletion (ODP)	kg CFC-11 eq	2.90E-03	2.67E-03	9.07E-03	1.59E-03	1.14E-03
human toxicity	kg 1,4-DB eq	8.81E+02	1.04E+03	9.58E+02	8.56E+02	7.93E+02
fresh water aquatic eco-tox.	kg 1,4-DB eq	7.27E+01	8.79E+01	7.98E+01	8.02E+01	7.43E+01
photochemical oxidation	kg C_2H_4	3.11E-01	3.83E-01	3.44E-01	3.41E-01	3.13E-01
acidification	kg SO_2 eq	6.09E+00	7.50E+00	6.74E+00	6.62E+00	6.08E+00
eutrophication	kg PO_4^{2-}- eq	5.60E-01	6.92E-01	6.21E-01	6.31E-01	5.80E-01

A10.2.3 TEWI (Total Equivalent Warming Impact)

Supermarket USA		**Layout S-1** R134a 2L/R404 DX, copper piping	**Layout S-2** R404A 2L/R404A DX, copper piping	**Layout S-3** R22 2L/R22 DX, copper piping	**Layout S-4** R22 2L/R404A 2L, ABS/PUR piping	**Layout S-5** R134a 2L/R404A 2L, ABS/PUR piping
Electricity	kg CO_2-eq./m	42'316	52'904	47'247	47'629	43'541
R134a	kg CO_2-eq./m	795				795
R404A	kg CO_2-eq./m	8'713	10'278		867	867
R22	kg CO_2-eq./m			5'973	981	
Total	**kg CO_2-eq./m**	**51'824**	**63'182**	**53'220**	**49'477**	**45'203**

A10.3 Cold Store

A10.3.1 Cumulative Energy Demand (CED)

Cold Store CH *Impact category*		**Layout CS-1** Ammonia 2L, ABS piping	**Layout CS-2** Ammonia 2L, chromium steel piping	**Layout CS-3** Ammonia 2L, steel piping
Non-renewable	MJ-eq	4.88E+01	4.88E+01	4.88E+01
Renewable	MJ-eq	1.28E+01	1.28E+01	1.28E+01

Cold Store USA *Impact category*		**Layout CS-1** Ammonia 2L, ABS piping	**Layout CS-2** Ammonia 2L, chromium steel piping	**Layout CS-3** Ammonia 2L, steel piping
Non-renewable	MJ-eq	6.99E+01	7.00E+01	7.00E+01
Renewable	MJ-eq	4.38E+00	4.39E+00	4.39E+00

A10.3.2 Environmental Impact Indicators According to CML 2001 (characterised values)

Cold Store CH *Impact category*		**Layout CS-1** Ammonia 2L, ABS piping	**Layout CS-2** Ammonia 2L, chromium steel piping	**Layout CS-3** Ammonia 2L, steel piping
abiotic depletion	kg Sb eq	6.32E-03	6.34E-03	6.34E-03
global warming (GWP100)	kg CO_2 eq	9.01E-01	9.03E-01	9.02E-01
ozone layer depletion (ODP)	kg CFC-11 eq	6.80E-08	6.81E-08	6.79E-08
human toxicity	kg 1,4-DB eq	6.88E-01	7.42E-01	6.85E-01
fresh water aquatic eco-tox.	kg 1,4-DB eq	7.46E-02	8.26E-02	7.40E-02
photochemical oxidation	kg C_2H_4	1.46E-04	1.46E-04	1.45E-04
acidification	kg SO_2 eq	3.29E-03	3.30E-03	3.29E-03
eutrophication	kg PO_4^{2-}- eq	3.12E-04	3.13E-04	3.12E-04

Cold Store USA *Impact category*		**Layout CS-1** Ammonia 2L, ABS piping	**Layout CS-2** Ammonia 2L, chromium steel piping	**Layout CS-3** Ammonia 2L, steel piping
abiotic depletion	kg Sb eq	3.47E-02	3.48E-02	3.48E-02
global warming (GWP100)	kg CO_2 eq	4.36E+00	4.36E+00	4.36E+00
ozone layer depletion (ODP)	kg CFC-11 eq	1.64E-07	1.64E-07	1.64E-07
human toxicity	kg 1,4-DB eq	9.50E-01	1.00E+00	9.47E-01
fresh water aquatic eco-tox.	kg 1,4-DB eq	9.56E-02	1.04E-01	9.49E-02
photochemical oxidation	kg C_2H_4	4.10E-04	4.11E-04	4.10E-04
acidification	kg SO_2 eq	8.14E-03	8.16E-03	8.15E-03
eutrophication	kg PO_4^{2-}- eq	8.09E-04	8.10E-04	8.09E-04

A11 Review Report

Critical Review of the Comparative Study "Cool-Fit Cooling Systems LCA", dated July 2006

by Arthur Braunschweig, E2 Management Consulting Inc. (CH-Zürich)

1 The Review

This is the second review comment, based on the final report dated July 2006. It is a review by an external expert according to ISO 14040 (7.3.2). The tasks of a reviewer are described in section 7.1 of ISO 14040:1997. This review may and shall be used and published together with this report.

A first review took place based on a draft study layout in early 2005. This second review was originally based on a final draft. After amendments to the final draft, this review was finalised accordingly.

In order for a report to be in accordance with ISO 14040:1997, a number of elements have to be fulfilled and included in the report. These will be commented with reference to the ISO standard in the comments below. To differentiate between Cool-Fit report sections and the ISO 14040 standard, the latter will be cited as "ISO §".

2 General Comment

The study was commissioned in order to understand the environmental pro and con's of Georg Fischer's "Cool Fit" piping system compared to other existing piping systems. The questions asked in the study are useful. It turned out that the operation of all cooling systems is environmentally much more important than the production of its materials and its final disposal. However, no data on the new Cool Fit system's operation have been available yet. Therefore assumptions on the key factors had to be made. Based on these assumptions, the study generally supports application of Cool Fit systems for the purposes analysed, and it gives guidance on how to ensure optimal application of Cool Fit piping systems. It seems advisable to recalculate the data as soon as actual electricity consumption and refrigerants emission data will be available for a certain number of Cool Fit installations.

3 Comments on the LCA study

The **goals of the study** are clearly formulated.

The **functions**, the **product systems** and the **technical system boundaries** are well described (ISO § 5.1.2). The system boundaries of the specific piping systems are clearly explained (e.g. section 4.1.2), those of the background processes are understandable for LCA specialists. However, the **time** period of the study and the date of the report is not clearly mentioned, neither in the summary nor in the full report.

The **functional units** are chosen well (ISO § 5.1.2.1).

Inventory data collection and treatment seems to have been done in an appropriate way. The study describes well the importance of the assumption concerning the electricity consumption of a Cool-Fit system. While the questionnaires to and data from Georg Fischer plants and direct suppliers was not made available to the reviewer, there is no reason to assume relevant problems there.

The **impact assessment** is based on a useful selection of methods and widely used approaches (CED, CML, plus TEWI for communication in the US). A coarse check of the results by the reviewer, based on plausibility considerations, supported the study's findings.

The **environmental analysis and interpretation** of the Cool-Fit piping system as well as the comparison between the new Cool-Fit and the traditional piping systems have been done impartially and with due care.

The study accepts a difference of 5 % in an impact category as **significant**. Even though background data (which are equal for all systems analysed) are very important, this is a small threshold. By using a Monte-Carlo analysis and demanding a 90 % probability, the robustness of such a difference improves to some extent. Still, it has to be borne in mind – and the report does say so – that in many aspects the differences between the various piping systems are very small. It should be born in mind that in practice operational differences will easily outweigh the differences described by the LCA study.

4 Executive Summary & Conclusions

The conclusions represent well the findings of the study.

Given the key relevance of electricity consumption, it would be advisable for any external communication to explicitely mention that no data is available yet on the electricity consumption of the new Cool-Fit systems, creating the need for an assumption based on experts' views.

Zürich, 26 July 2006

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