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Trends and Perspectives in Refrigeration Technology

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  - Global warming
- Reduction of indirect global warming contribution
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- Reduction of direct greenhouse gas emissions
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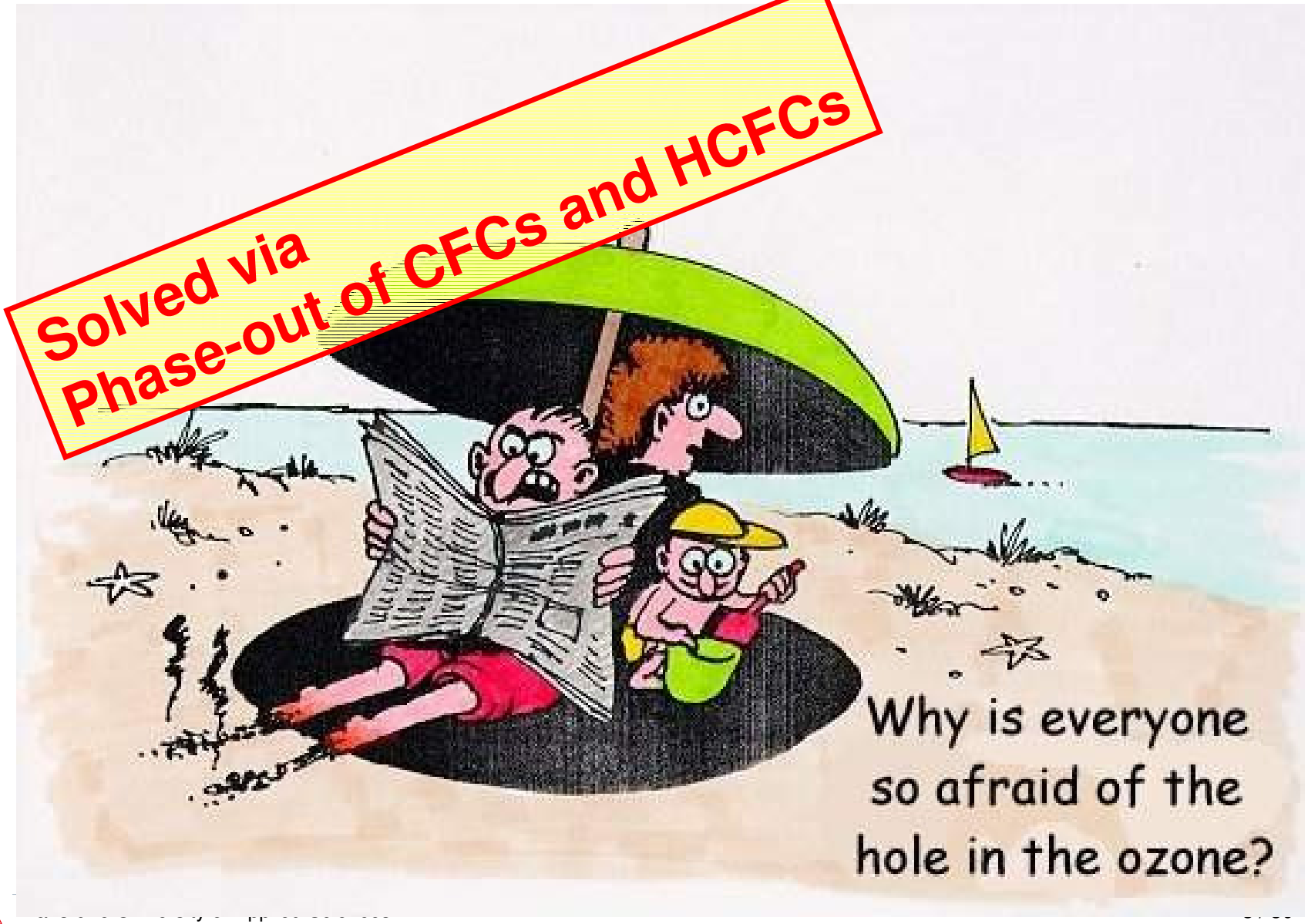
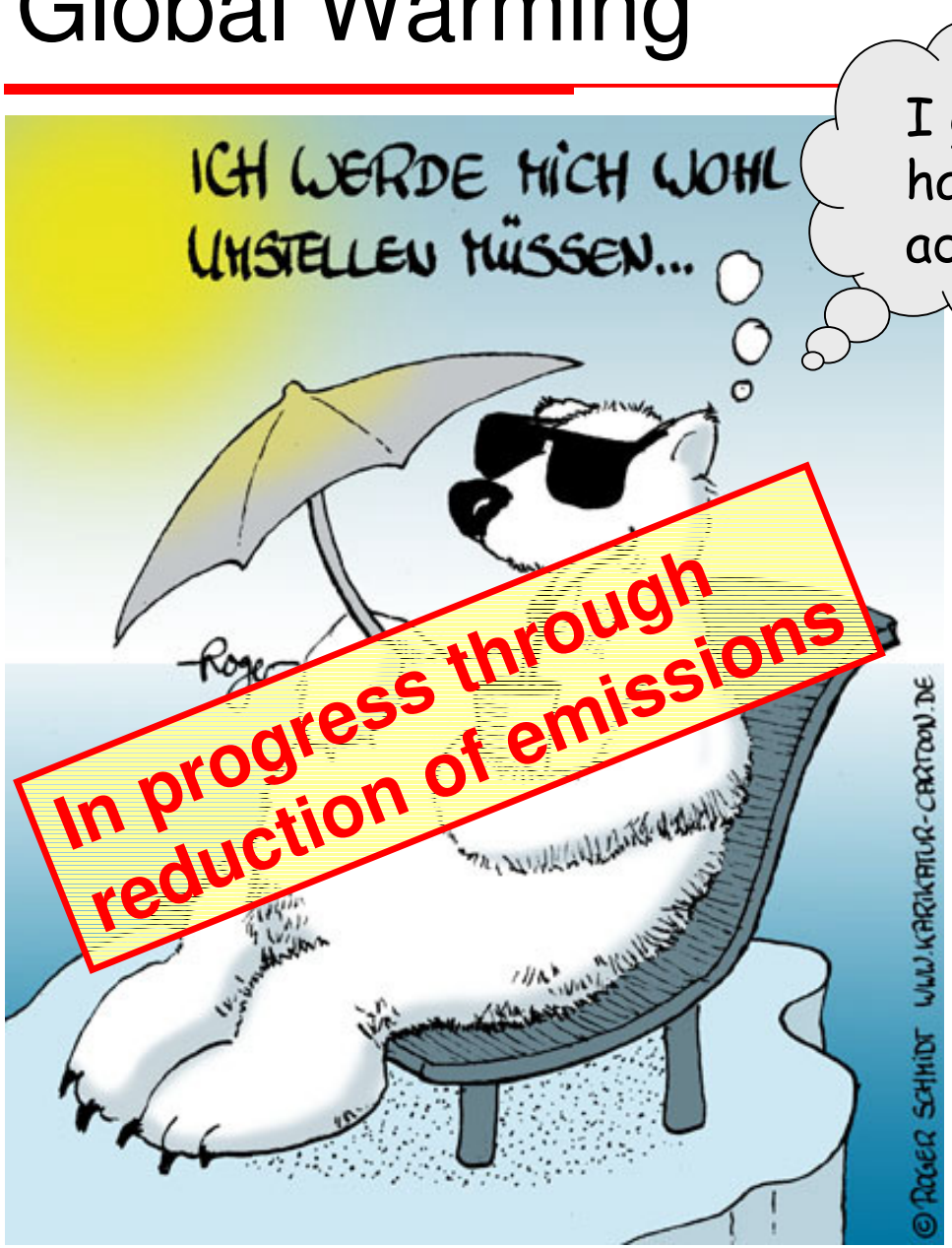
- Conclusion

Ozone Hole



Global Warming



Refrigeration's contribution :

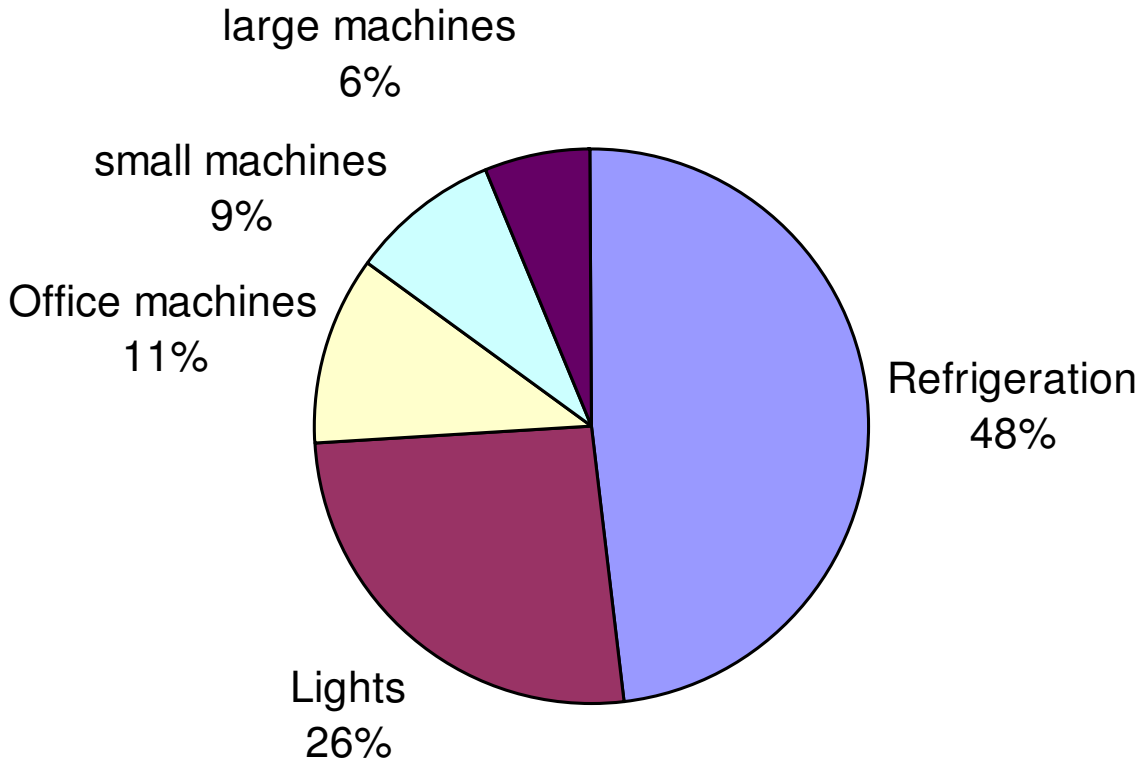
- Direct through emissions of potent greenhouse gases
- Indirect through CO_2-emissions at energy conversion

How Refrigeration can help to reduce Global Warming

- Reduce emissions of greenhouse gases
  - Hermetically tight systems with control scheme
    → EU F-Gas regulation
  - Refrigerants without or with negligible GWP
- Reduce energy consumption
- Use regenerative energy

Reduce Energy Consumption (1/4)

Consumption of Electricity in a typical Supermarket



… in addition use of fossil fuel for space heating and hot water

Reduce Energy Consumption (2/4)

During design / installation

- Glass door or lid
- Improved insulation
- Fan motor outside cabinet
- Improved evaporator fan and/or fan motor
- Improved air flow in open multidecks
- Infrared reflecting shades or baldachines
- Improved antisweat heaters / dew point control
- Siphon in defrost drain
- Hot gas defrost
- Speed control of compressors, pumps, fans
- Improved expansion valve
- Expansion machine

Reduce Energy Consumption (3/4)

During design / installation

- Improved evaporator
- Flooded evaporator
- Defrost on demand
- Improved lights
- Reduced condensation temperature
  - Outside air temperature adjusted condensing temperature
  - Evaporative cooling of condenser
  - Condenser heat to soil
- Free cooling
- Heat recovery
- Cold storage

Reduce Energy Consumption (4/4)

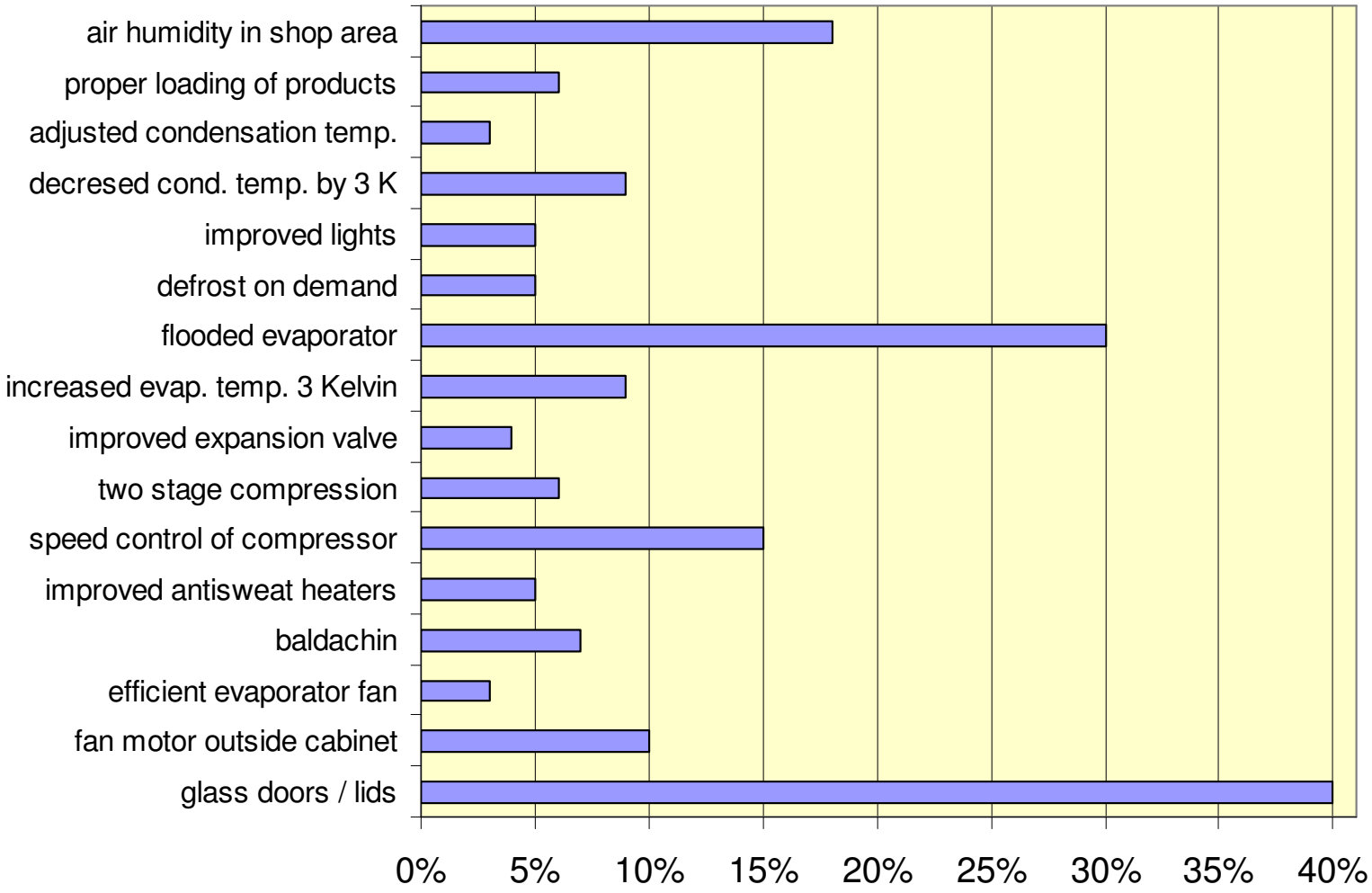
During operation

- Correct loading of products
- Air humidity in shop area
- Evaporator and condenser cleaning

Reduction of energy consumption is important due to :

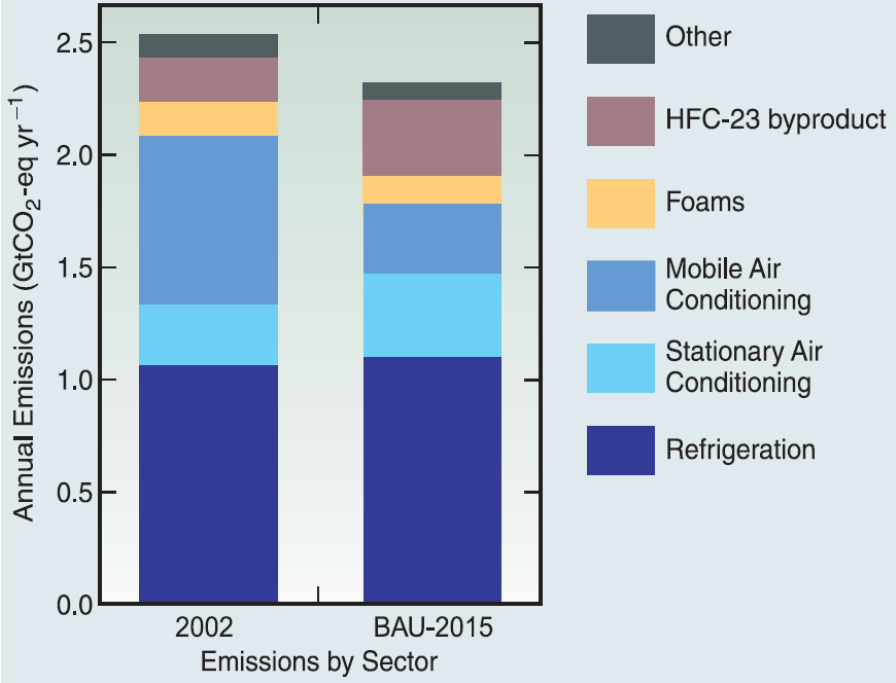
- **Reduction of global warming** through indirect emissions
  depending on refrigerant, leakage rate and refrigeration system, energy related global warming contribution varies from 50 % for a R404A multiplex system with 300 kg refrigerant charge, 10 % leakage rate and almost 100 % for a R290 plug-in freezer or a R744 central system.
- Reduction of running cost – **increase of profit**
  refrigeration accounts for 40 to 60 % of store energy consumption; energy costs some times in the same order of magnitude as profit (1 to 2 % of turnover).

Potential of selected measures



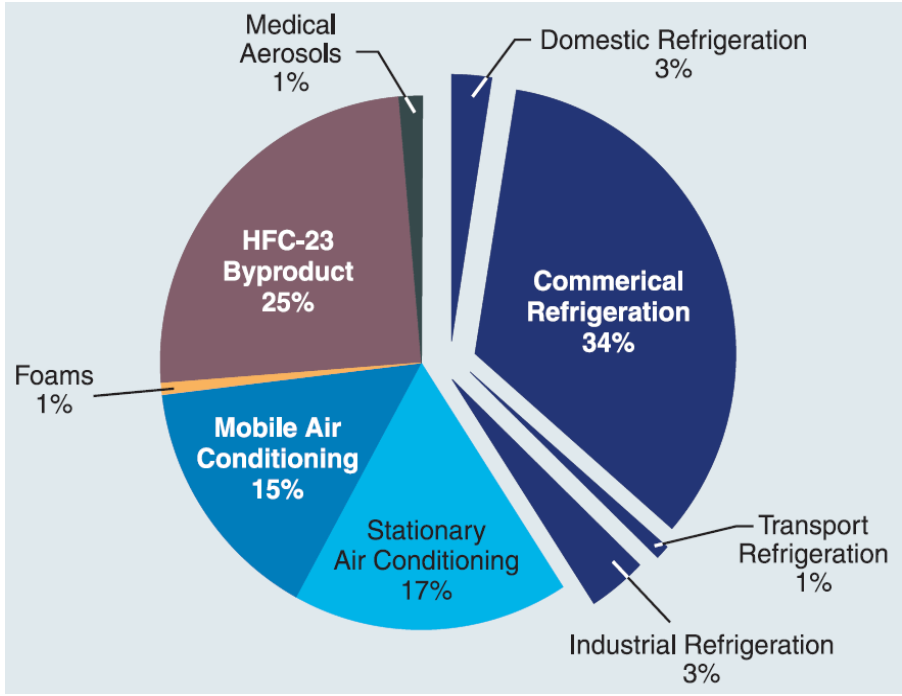
… many of them can be combined

Reduce Emissions of Greenhouse Gases



Historic data for 2002 and Business-As-Usual (BAU) projections for 2015.

IPCC/TEAP: Safeguarding the Ozone Layer and the Global Climate System. 2005



Sectoral reduction potentials for direct emissions of CFCs, HCFCs and HFCs in 2015 as compared to the BAU projections. The overall reduction potential is about half (1.2 Gt CO_2-eq per year) of the BAU direct GHG emissions.

Reduce Emissions of Greenhouse Gases

Table TS-7. Percentage contribution of direct emissions to total lifetime greenhouse gas emissions in various applications (emissions associated to functional unit) – selected indicative examples for applications using HFCs.

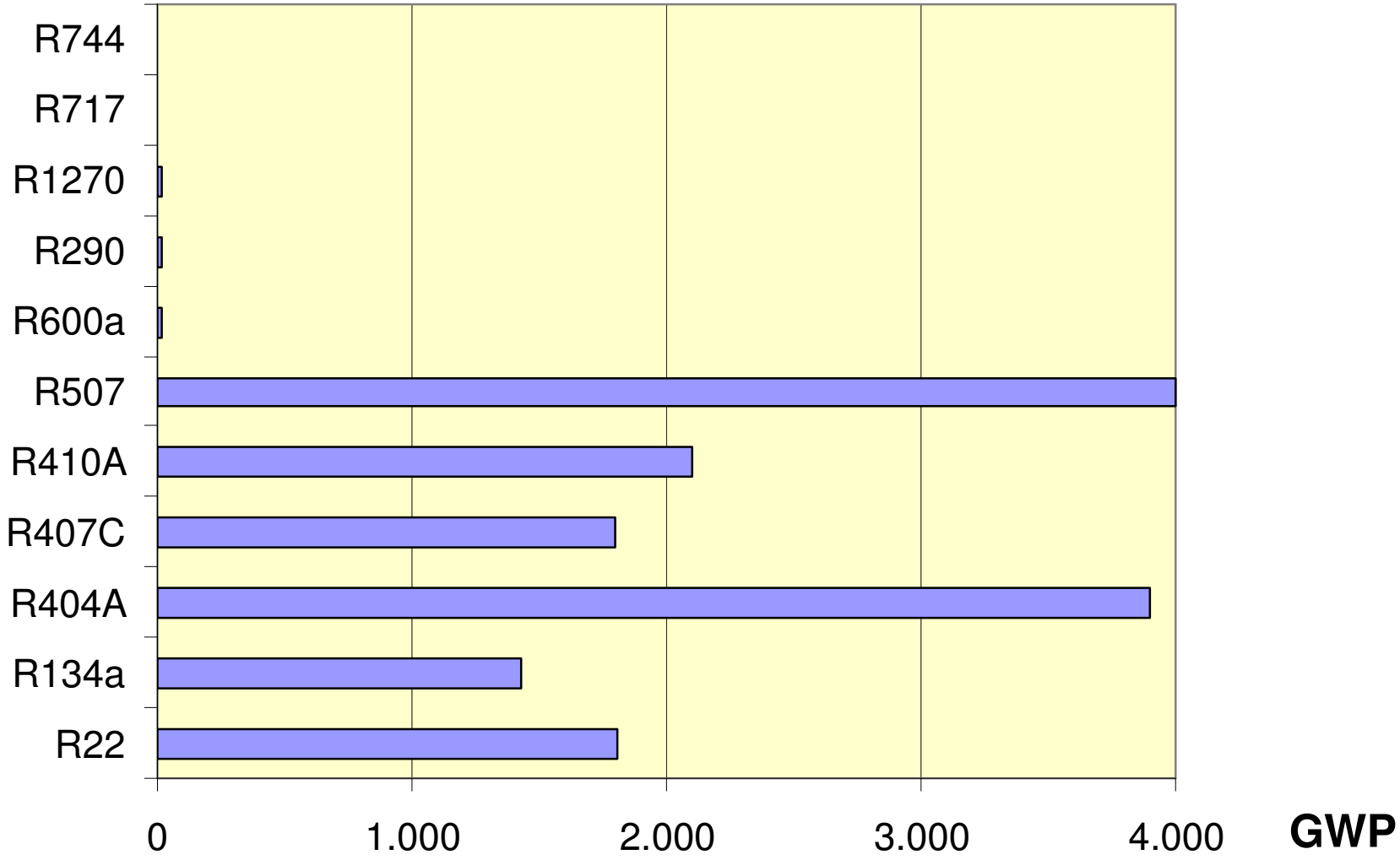
Application sector	Method applied	Percentage of HFC emissions of lifetime system greenhouse emissions (using GWP-100)	Characterization of system and key assumptions
MAC	TEWI	**40–60%** – Current systems (gasoline engine) **50–70%** – Current systems (diesel engine)	Passenger vehicle; HFC-134a Sevilla (Spain)
Commercial refrigeration	LCCP	**20–50%** – For a wide range of sensitivity tests on leakage rate, energy efficiency and energy supply	Direct expansion refrigeration unit; supermarket (1000 m^2); R-404A; Germany
Domestic refrigeration	TEWI	**2–3%** – No recovery at end-of-life	European standard domestic refrigerator; HFC-134a; world average electricity mix

Commercial Refrigeration

Central Refrigeration System: between 20 and 50 % are direct greenhouse gas emissions

IPCC/TEAP: Safeguarding the Ozone Layer and the Global Climate System. 2005

GWP of Selected Commercial Refrigerants

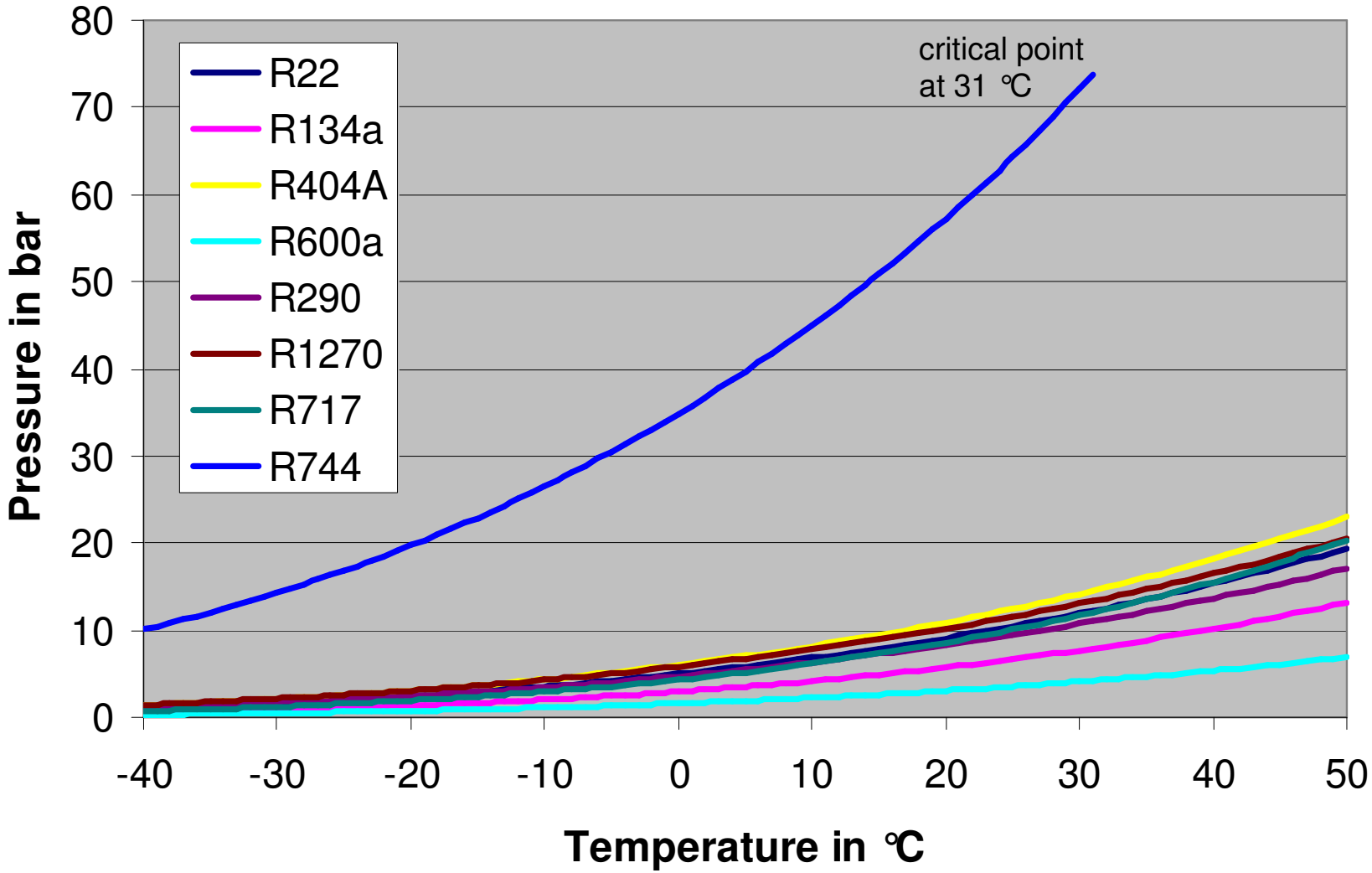


Low GWP is not the only Requirement

- Zero ODP
- Non-toxic
- Non-flammable
- Good thermodynamic properties, among others
  - Good heat transfer
  - Low pressure ratio
  - High volumetric refrigeration capacity
- Non-corrosive
- Oil compatibility
- Stable
- Available
- Cheap

… no refrigerant fulfills all requirements

Vapor Pressure of Refrigerants



Refrigerants for Supermarket Refrigeration

	GWP	Flam-mability	Toxicity	Price of Refrigerant	Price of System	Theoretical system efficiency
HFCs	high	no	no	moderate	low	good
Hydrocarbons	low	yes	no	low	medium	good
Carbon Dioxide	low	no	only at high concentr.	low	medium	medium
Ammonia	low	can be ignited	yes	low	high	good

… but many other aspects to be considered,
e.g. real system efficiency

Refrigerants for Supermarket Refrigeration

	Normal-siedepunkt in °C	kritische Temperatur in °C	Druck in bar bei Siedetemperatur von			brenn-bar	giftig	ODP	GWP[1)]	vol. Verdam-pfungs-wärme bei 0 °C kJ/m³
			-30 °C	0 °C	40 °C					
R22	-40,8	96,1	1,6	5,0	15,3	nein	nein	0,04	1.810	4.360
R134a	-26,1	101,1	0,8	2,9	10,2	nein	nein	0	1.430	2.870
R404A	-46,5	72,1	2,1	6,1	18,2	nein	nein	0	3.900	5.070
R407C[2)]	-43,6	86,0	1,9	5,6	17,5	nein	nein	0	1.800	4.230
R410A	-51,4	72,5	2,7	8	24,3	nein	nein	0	2.100	6.780
R507	-46,7	70,9	2,1	6,2	18,7	nein	nein	0	4.000	5.230
R600a **Isobutan**	-11,7	134,7	0,5	1,6	5,3	ja	nein	0	~20	1.510
R290 **Propan**	-42,2	96,7	1,7	4,7	13,7	ja	nein	0	~20	3.880
R1270 **Propen**	-47,7	92,4	2,1	5,9	16,5	ja	nein	0	~20	4.670
R717 **Ammoniak**	-33,3	132,3	1,2	4,3	15,5	(ja)	ja	0	< 1	4.360
R744 **Kohlendioxid**	(-78,4) [3)]	31,0	14,3	34,8	90 - 120	nein	< 10 % nein	0	1	22.550

[1)] bezogen auf CO_2 bei einem Zeithorizont von 100 Jahren

[2)] Temperaturgleit von 6 bis 7 K

[3)] Tripelpunkt von CO_2 bei 5,18 bar und –56 °C

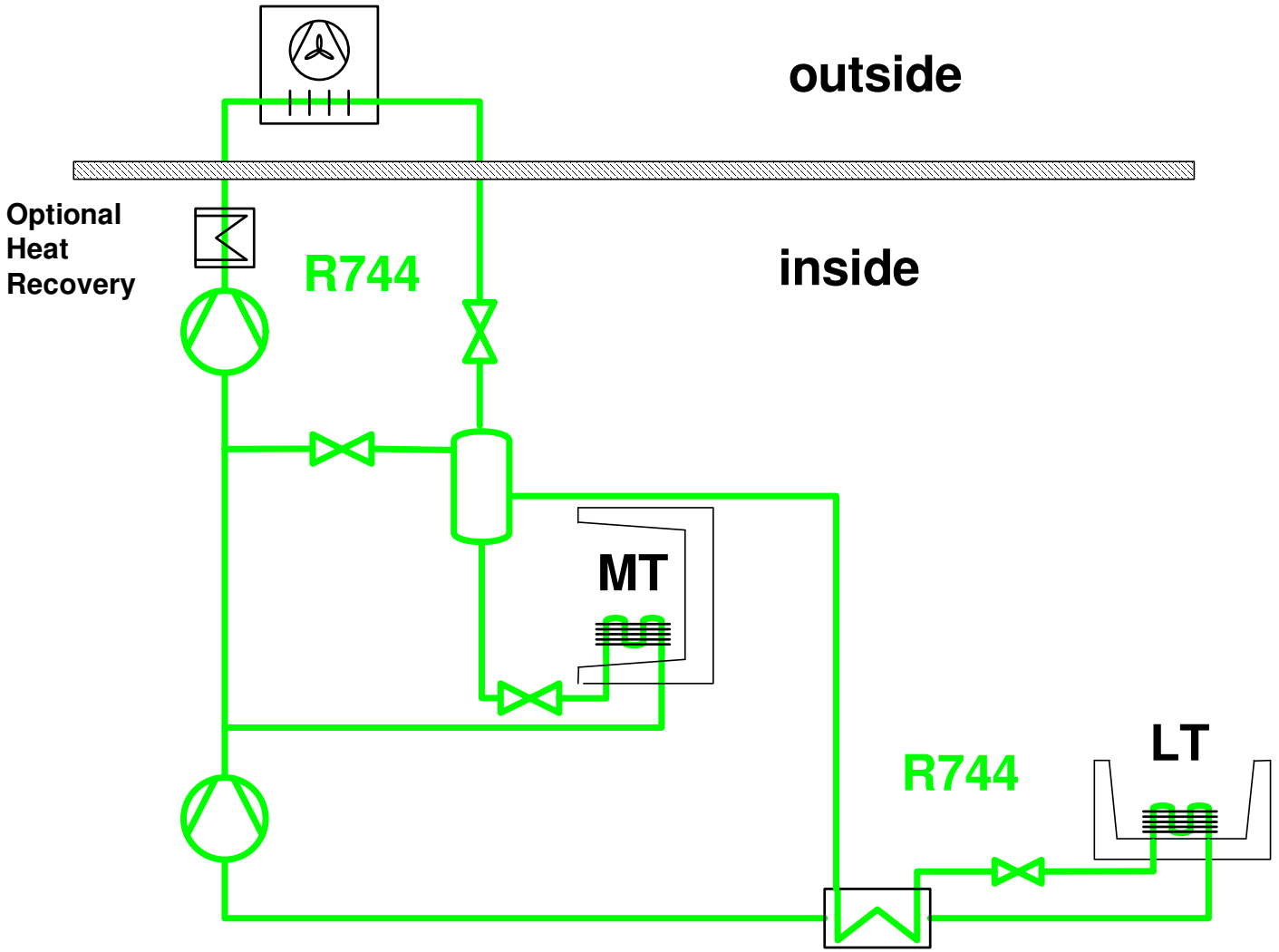
”Natürliche” Kältemittel

nicht oder nur sehr selten verwendet

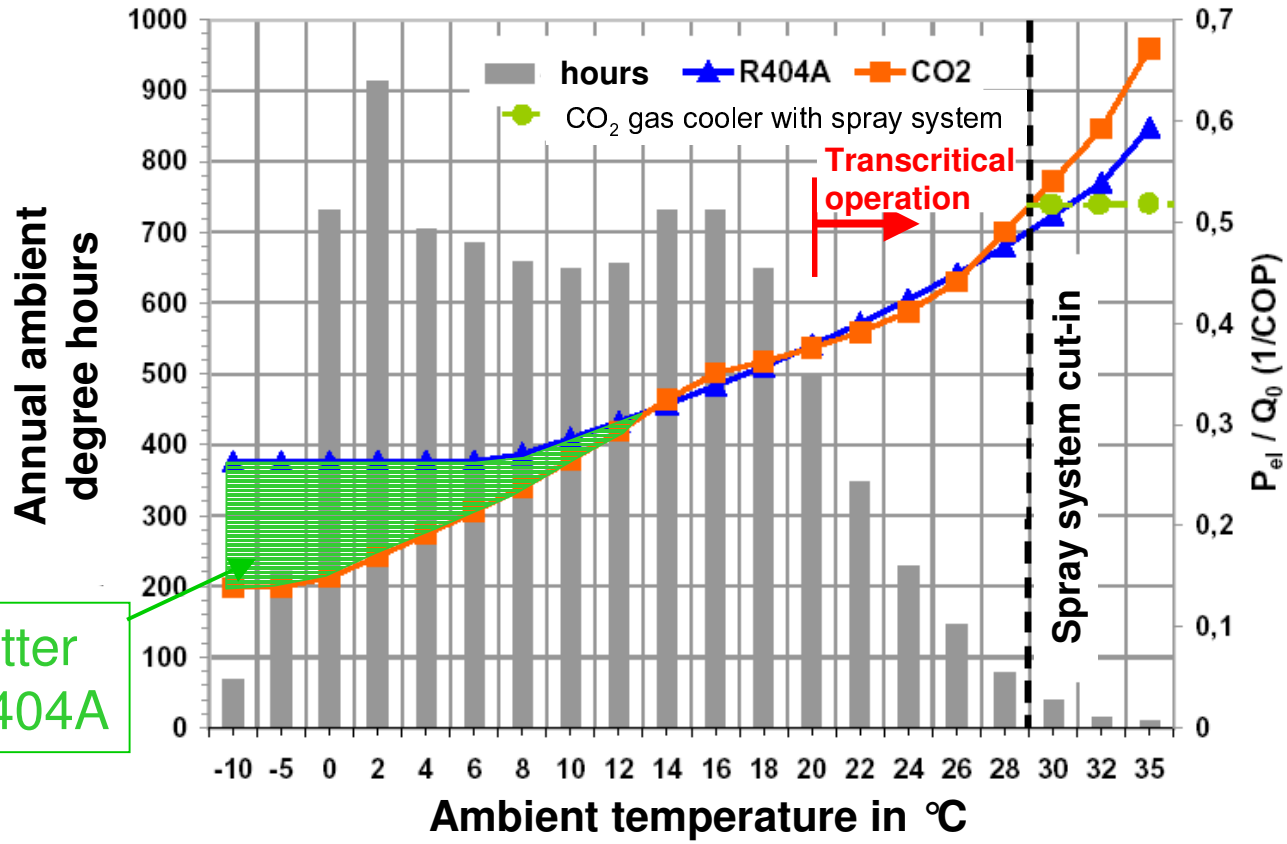
Central Multiplex Systems

Condenser	air cooled; ambient	air cooled; heating store air (heat recovery)	water cooled; heating tab water or store (heat recovery)	water cooled; water cooling in ambient air cooled heat exchanger
Refrigerant MT	HFC (R134a, R404A, R410A or R507)	Hydrocarbon (R290 or R1270)	R717	R744
Cold Distribution MT	Direct expansion (only HFC and R744)	Liquid secondary refrigerant, single phase	Evaporating secondary refrigerant	Melting secondary refrigerant
Refrigerant LT	HFC (R404A, R507)	Hydrocarbon (R290 or R1270)	R717	R744
Cold Distribution LT	Direct expansion (only HFC and R744)	Liquid secondary refrigerant, single phase	Evaporating secondary refrigerant	Melting secondary refrigerant

Example 1: Central Multiplex System with CO_2



Example 1: Transcritical CO_2-System



CO_2 better than R404A

Energy consumption in North and Central Europe approx. 5 to 10 % lower than comparable R404A-System (R744 annual mean COP = 3,4)

Investment cost (objective) approx. 10 to 20 % higher depending on size

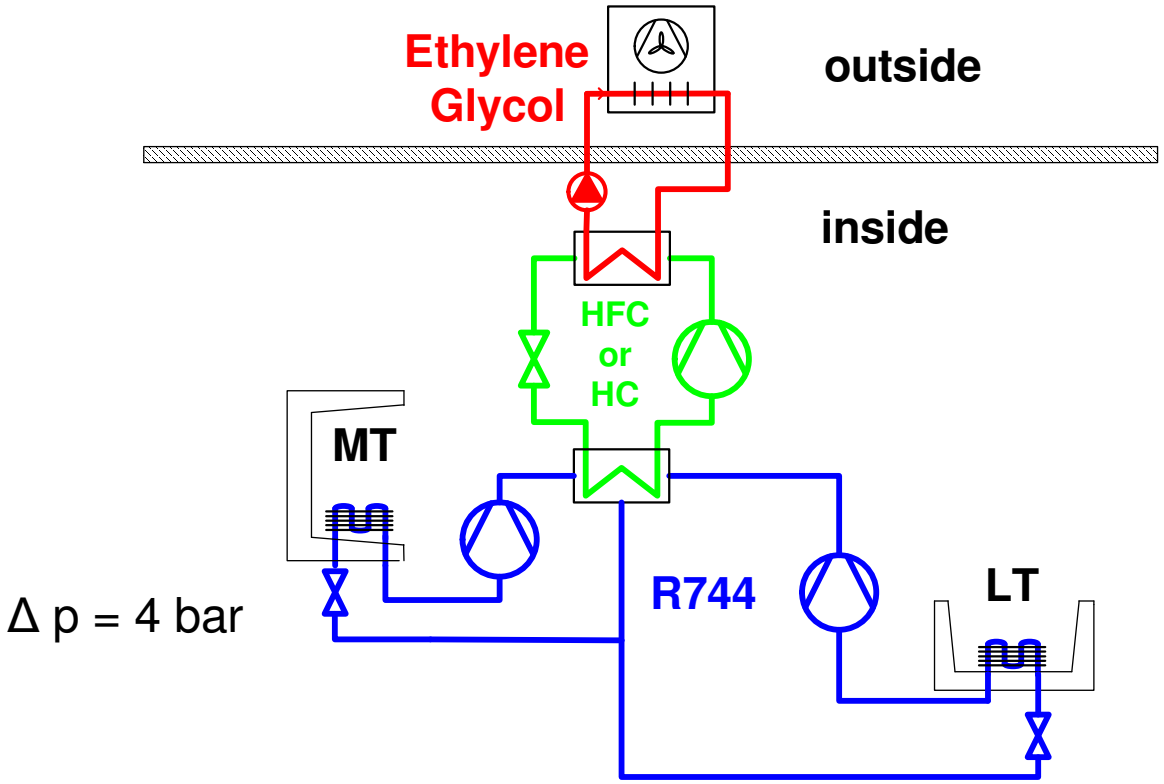
/Heinbokel, B.; Gernemann, A.: Eine neuentwickelte CO2-Kälteanlage für den Normal- und Tiefkühlbereich in einem Schweizer Hypermarkt. DKV 2005, Würzburg /

Example 1: Additional Energy Savings

… in a transcritical CO_2-system :

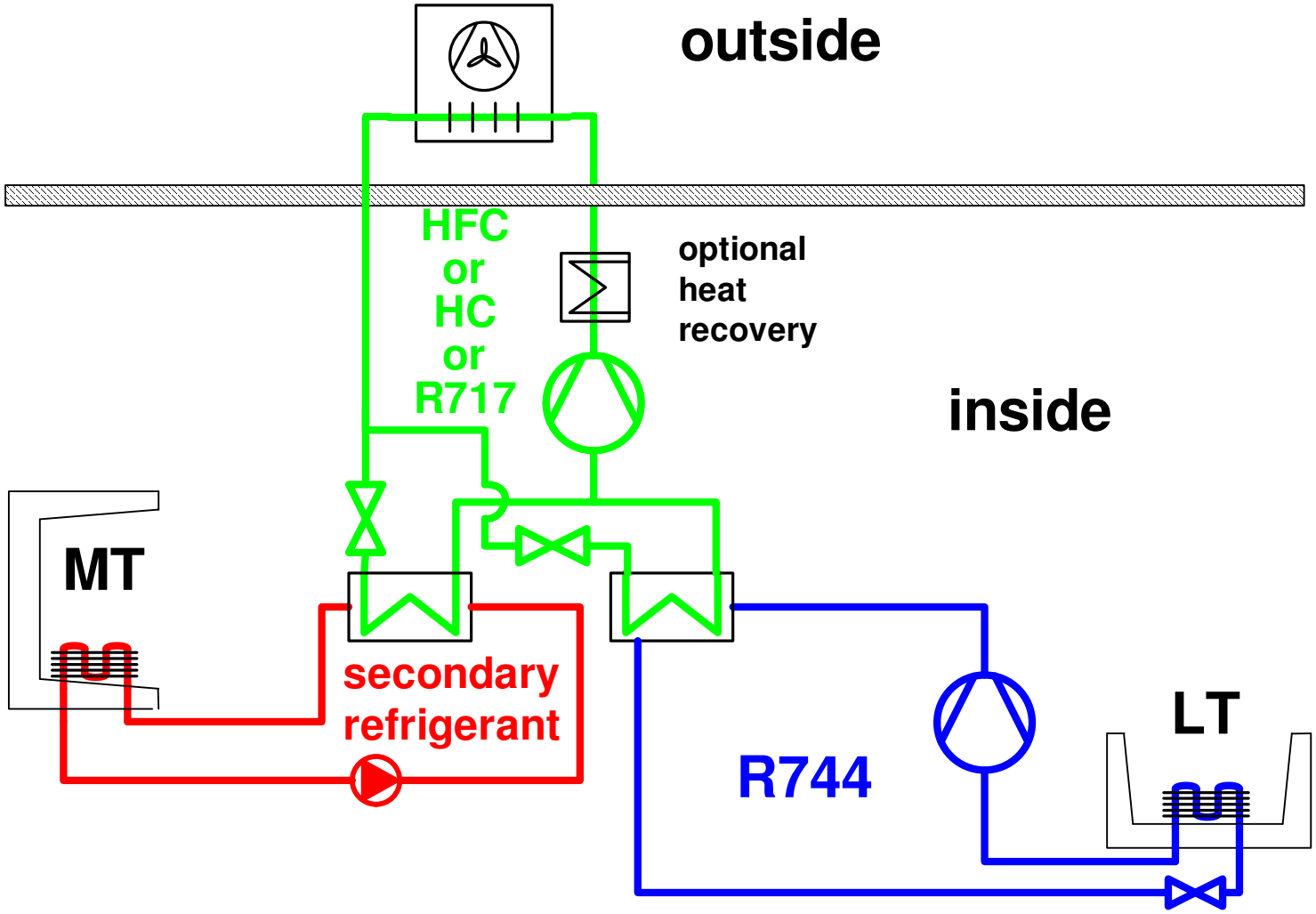
- Water spray on condenser
- Expansion machine instead of valve
- Ejector as expansion device

Example 2: Central Multiplex System with CO_2



- Energy efficient application of CO_2-system for MT and LT – both work sub-critical
- All components available; pressure below 40 bar
- Factory built HFC or HC system as upper stage with reduced charge, e.g. 10 kg for 24 kW MT and 10 kW LT
- Easy heat recovery in water cooled condenser

Example 3: Secondary Refrigerant



Example 3: Secondary Refrigerant

- High energy efficiency sub-critical carbon dioxide LT system
- Liquid secondary refrigerant for MT results in better product quality due to higher air humidity and hence lower fresh food shrinkage
- Very low charge, factory assembled HFC or HC system → low leak potential
- Reduced oil charge for HFC / HC system
- Inexpensive plastic piping system for secondary refrigerant
- Easy and flexible heat recovery when using water cooled condenser

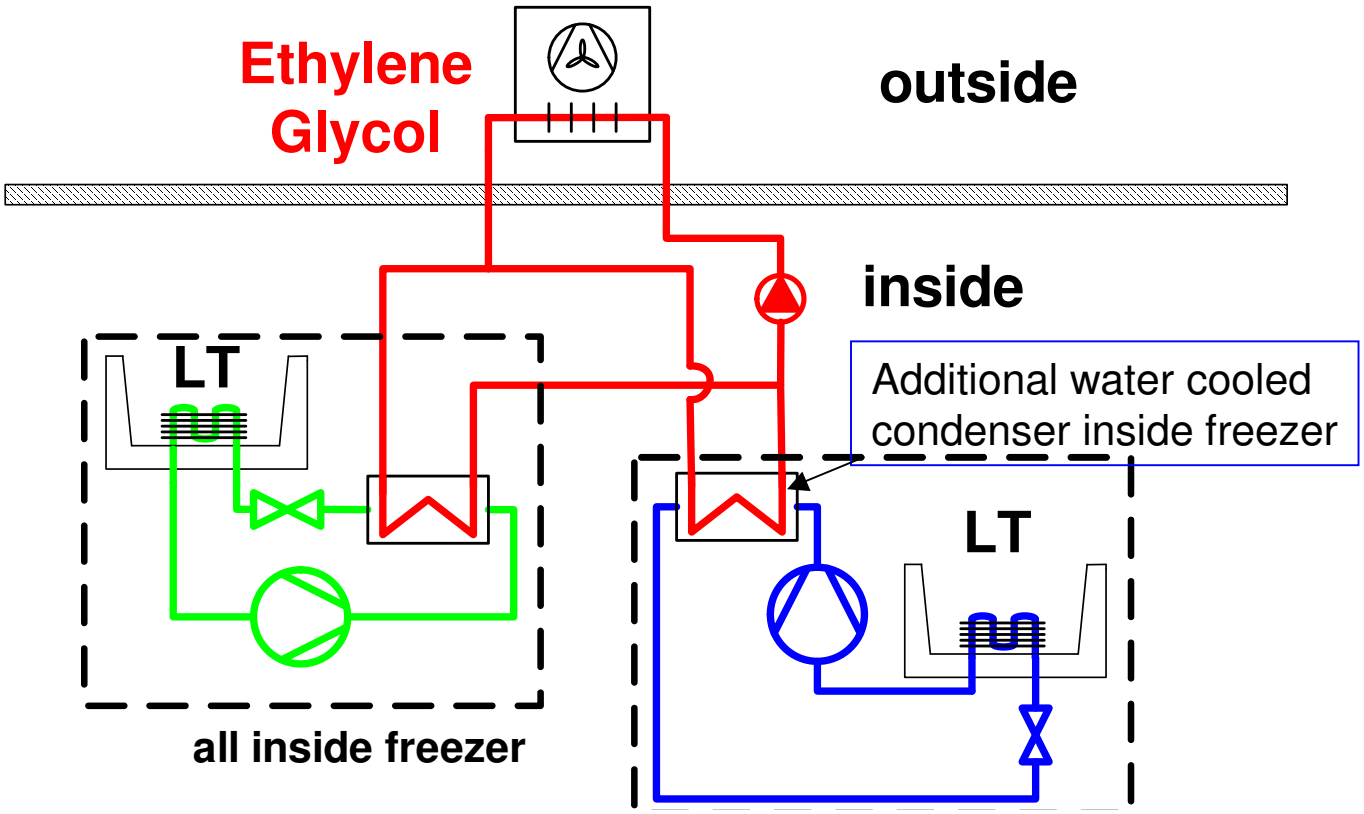
Example 4: Plug-in Chest Freezers

- Change from R404A to R290
  → GWP reduced from 3.900 to approximately 20
  → 10 to 15 % energy savings
- Speed controlled compressor
  → 10 to 15 % energy savings

→ In total approx. 25 % lower energy consumption while at the same time reducing the direct greenhouse gas emissions to almost Zero

- Investment cost currently approx. 15 % higher
- Charge limit at 150 g for HC
  → 1 kW maximum refrigeration capacity
  entire range could be covered with 500 g HC charge

Example 4: Additional Energy Savings

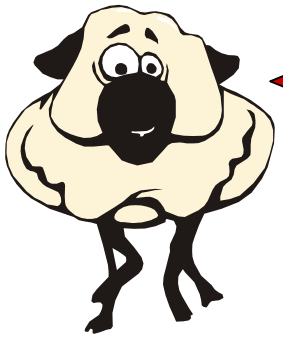


Water cooling loop for removal of condenser heat during non-heating periods

Other trends

In future **customers** will set the trend **!**

Producers will have to listen more to the “trendsetters”.



old-fashioned customer

modern customer

/Paul Spoonley: Technological and social changes into the third millennium. 20th International Congress of Refrigeration, IIR, Sydney, 1999/

Customers as Trendsetters

- McDonald's goes for natural refrigerants
- The Coca-Cola Company will only use HFC-free technology from 2004
- Unilever wants to use HFC-free technology
- Nestlé wants to use natural refrigerants wherever possible
- Danish Coop and Danish Supermarket value natural refrigerant supermarkets higher than conventional
- British insurance companies are said to reduce investments in greenhouse warming industry
- Aldi Süd buys only low energy consumption plug-in freezer and develops new lighting system for refrigerated shelves

But these are only spear heads! Governmental laws and enforcements needed for wide application, e.g. Denmark, Norway, Sweden

Summary

- HFC can be replaced at acceptable cost in all applications
- Energy savings potential in supermarket refrigeration systems up to 50 % and more at moderate costs
- In countries with adequate laws, e.g. Denmark, Norway and Sweden, many HFC-free or HFC-reduced systems are built with good energy efficiency
- HFC-free plug-in units with better energy efficiency are available up to approximately 1 kW capacity

Comments, Questions ?

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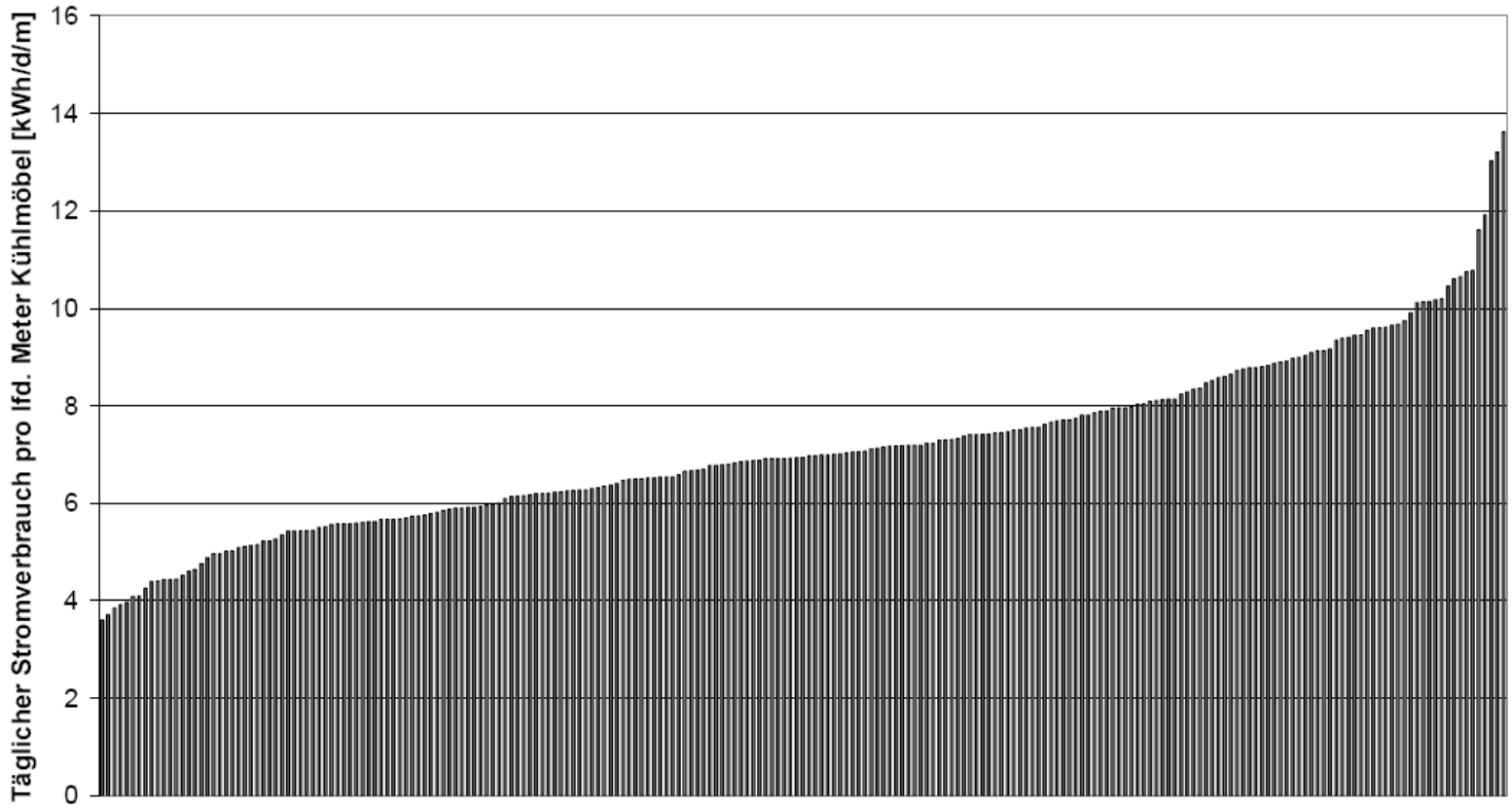
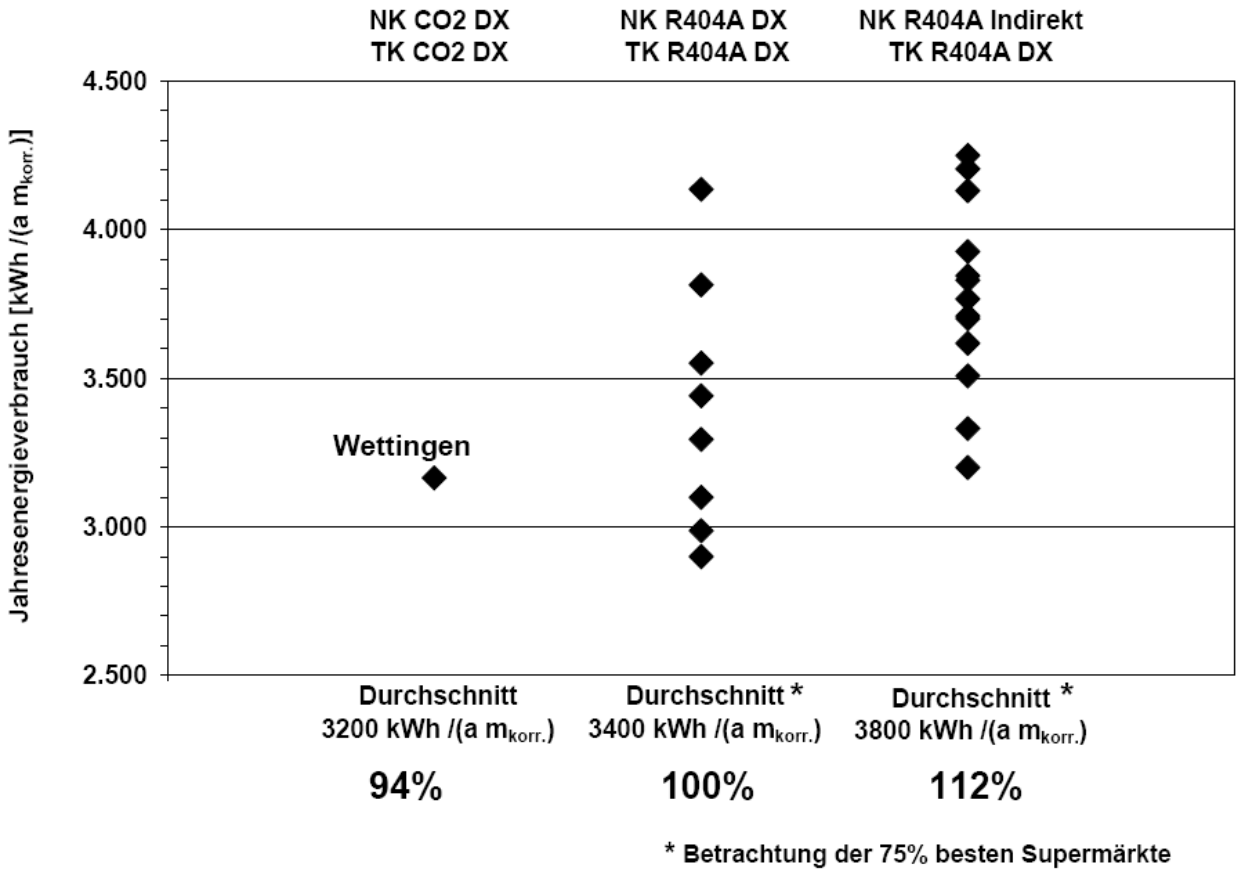
Scatter in Energy Consumption



Auf laufende Meter Kühlmöbel normierte tägliche Stromverbräuche für die Kälteerzeugung in 226 Penny-Märkten im Jahre 2001 [Ecofys2003]

Scatter in Energy Consumption



Energiebedarf pro Laufmeter Kühlmöbel in Schweizer Supermärkten.
Messwerte: COOP Basel, LKS Schweiz AG [Hei2006]