"Applying the Natural Refrigerant CO_2 to Improve the Energy Efficiency of AC Cooling and Water Heating in Hotels and Hospitals in the EU Plus Norway and Switzerland."

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eurammon Symposium, July 2022

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Issues

- Energy Consumption
- Global Warming Resulting From Energy Consumption
- Global Warming Resulting From HFC/HCFC Fugitive Gases
- Cooling Water Consumption
- Legionella Disease Spread from Cooling Towers
- How will CO_2 and Ammonia Help?

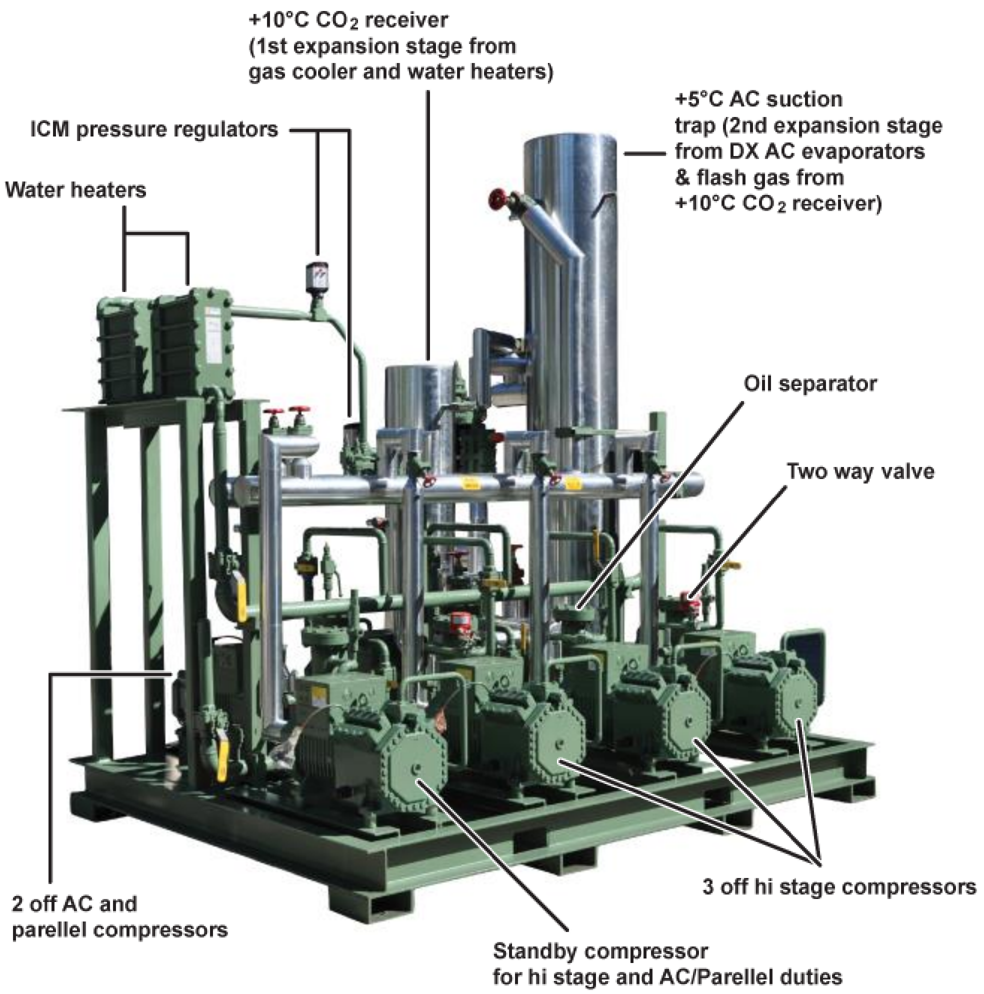
Advantages of CO_2

- CO_2 is non toxic and non flammable.
- CO_2 has good thermal transfer properties.
- No product damage should CO_2 leak into product stores.
- COP has GWP of 1 and is environmentally sustainable.
- CO_2 use in product stores and work areas restricts NH_3 and HCF in the plant room reducing NH_3 and HCF system charges to 10% or less in LR systems and thus enhances OH&S.
- At the minimum evaporating temperature of -55°C, the CO_2 suction pressure is 5.55 bar. This is higher than atmospheric pressure, no risk of air entering into the system like with NH_3 below -33.3°C at atmospheric pressure.
- CO_2 has superior heat transfer properties at low temps compared to other refrigerants.
- Pressure vessel and suction pipe diameters are about half those required for NH_3 at equal capacities.
- Pumped CO_2 may be used as a fire fighting system.

Disadvantages of CO_2

- Low temp steel is required for pressure vessels and piping below -10°C because CO_2 operating pressures are much higher than NH_3 and other refrigerants.
- At concentrations of 8% and higher CO_2 can be fatal in confined spaces. Extensive leak detection is required.
- An NH_3 cooled CO_2 cascade condenser is an expensive piece of equipment. CO_2 mixing with NH_3 creates a highly abrasive ammonium carbonate which is very destructive in compressors and pumps.
- Water in a CO_2 system is major contamination.
  Multiple evacuation is required before charging with CO_2 with not more than 5ppm water content.
- POE oil is used to enhance miscibility, but it is very expensive and highly hygroscopic requiring careful handling with minimum exposure to moisture laden air.
- Satisfactory and reliable oil recovery requires additional pressure vessels in the dry suction lines returning from the low stage evaporators as a minimum and ideally also in the dry suction line from the high stage evaporators.

Prototype Hi Stage & AC Compressor Rack For a Multifunction Two Stage Transcritical CO_2 Refrigeration System with Parallel Compression for Cooling & Heating



Refrigeration Functions

- -35°C Blast Freezing (BF)
- -20°C Cold Storage (CS)
- 0°C Chill Storage
- +4°C Chilled Water
- +10°C Packing Area Cooling
- +18°C Factory Cooling
- +22-24°C Office AC

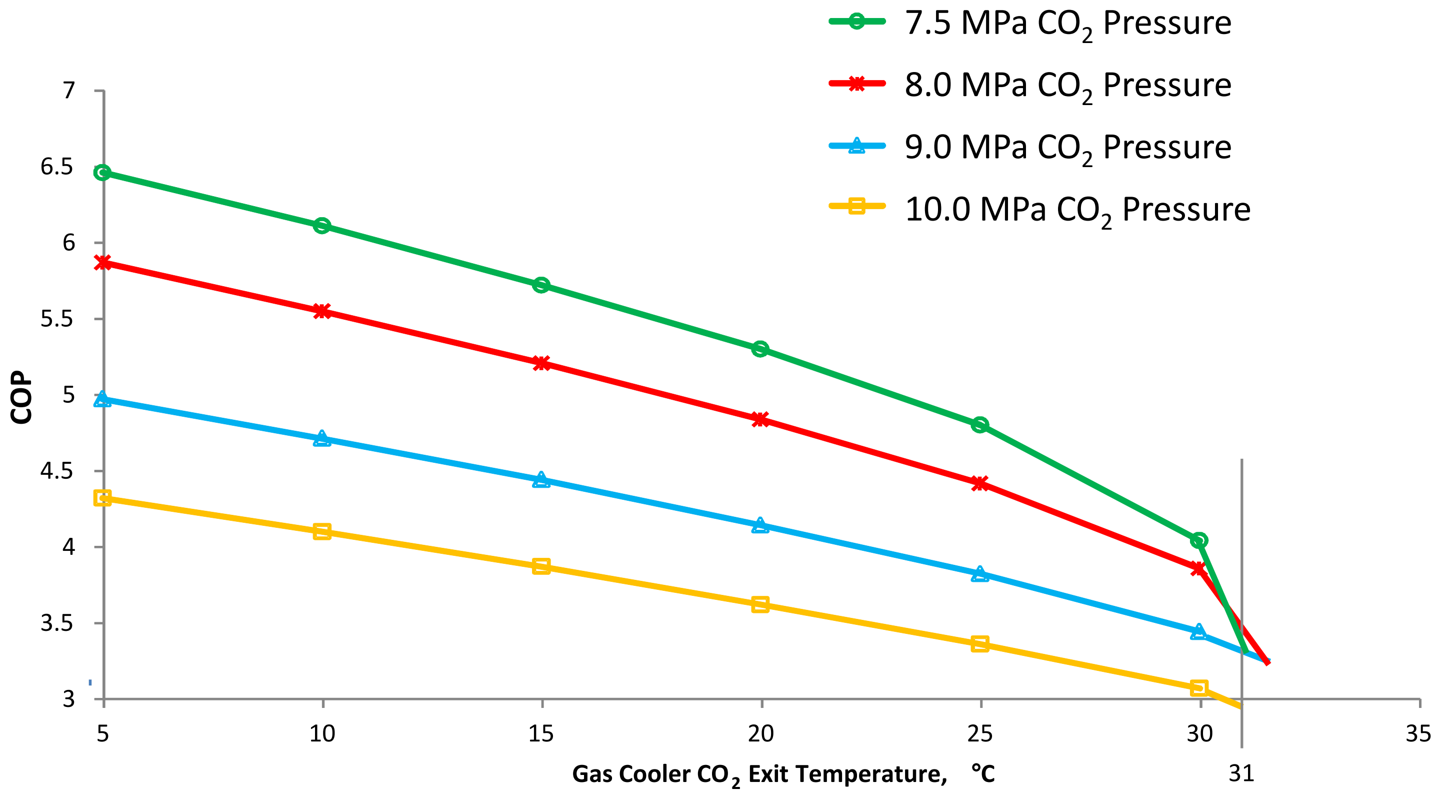
Heating Functions

- 10°C C.S. & BF glycol under floor heating
- 50°C glycol defrost
- 50°C glycol door heating
- **85°C process hot water**
- **65°C domestic hot water**
- **65°C cleaning hot water**
- **60°C office heating and AC reheat**

Beneficial Results from Prototype

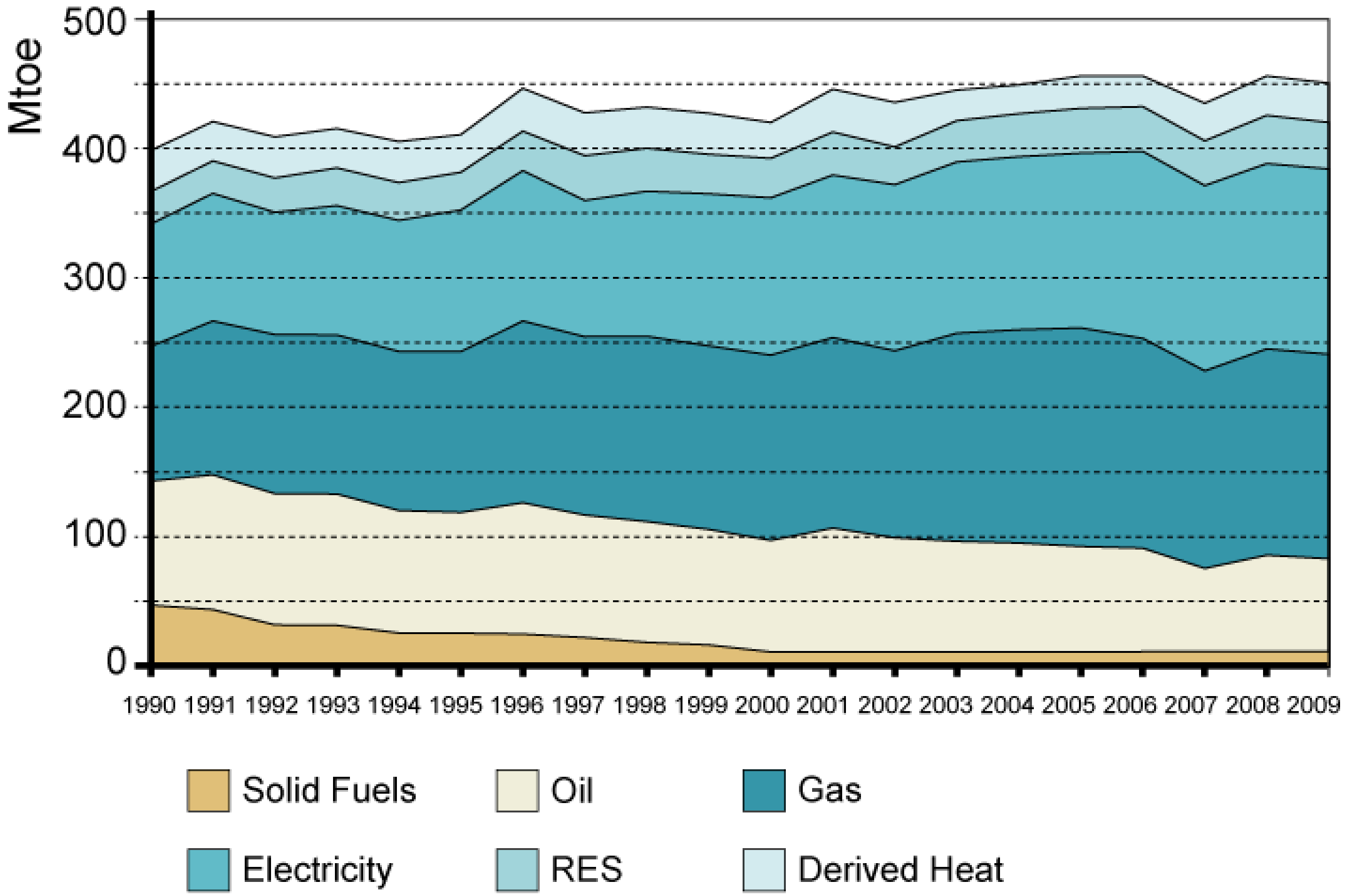
- 33% Reduction in Specific Electrical Energy Consumption. kWh/kg
- 60% Reduction in Specific Gas Consumption, MJ/kg
- 40% Reduction in Specific Emissions due to the above reductions in specific energy consumption, CO_2-e/kg
- Emissions from fugitive CFC, HCFC and HFC chemical refrigerant gases are not included in the emissions data due to unavailability of relevant information on chemical refrigerant consumption at the facility.

Transcritical CO_2 Compressor COP vs CO_2 Gas Cooler Exit Temperature at 5°C SST and 5 K Superheat



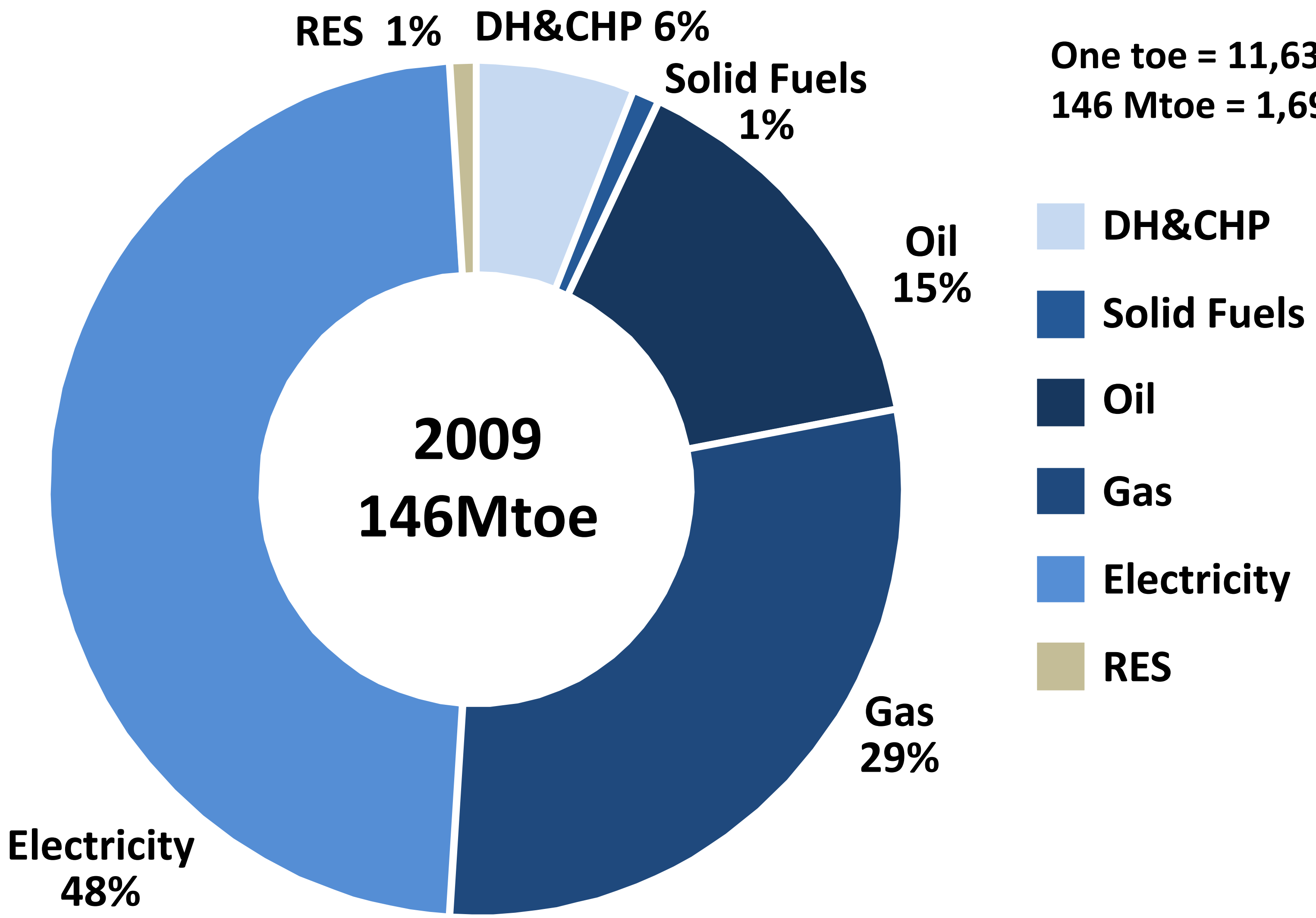
By using a hybrid CO_2 gas cooler, a CO_2 gas cooler exit temperature of 31°C is achievable in 98% of the world's climates in which the 1% incidence ambient design Web Bulb does not exceed 28°C. This provides a comfortable leaving approach of 3K between the CO_2 exit temperature of 31°C and the 28°C entering air Wet Bulb temperature.

Total Energy Consumption in the EU27+2 - Data



Source: O. Rapf. "Europe's buildings under the microscope", International Expert Workshop "Energy assessment of National Housing Stocks – Building Typologies", 29 February 2012.

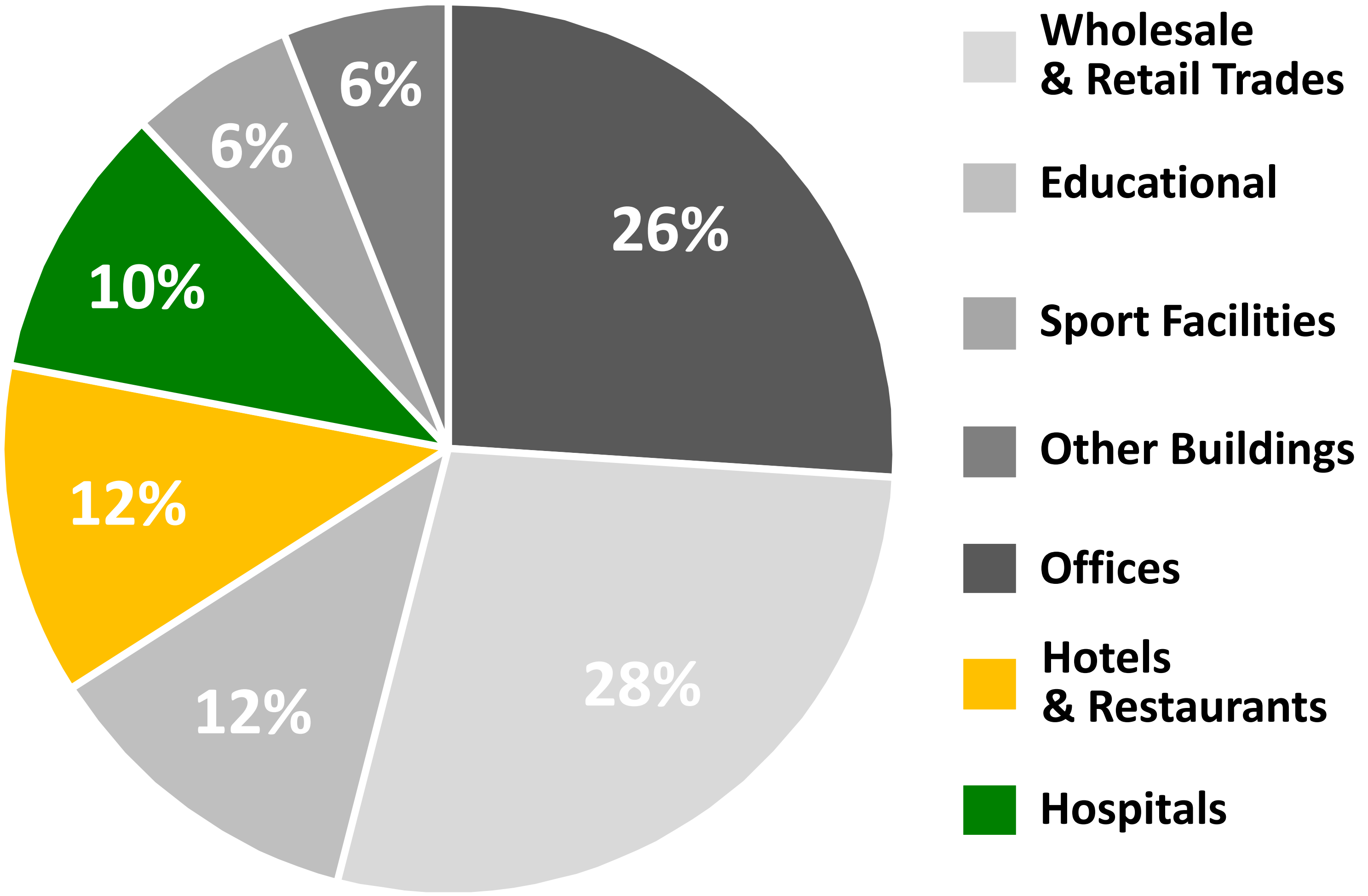
Energy Mix in the Non-Residential Sector in the EU 2009 - Data



One toe = 11,630kWh
146 Mtoe = 1,698 x 10^9kWh

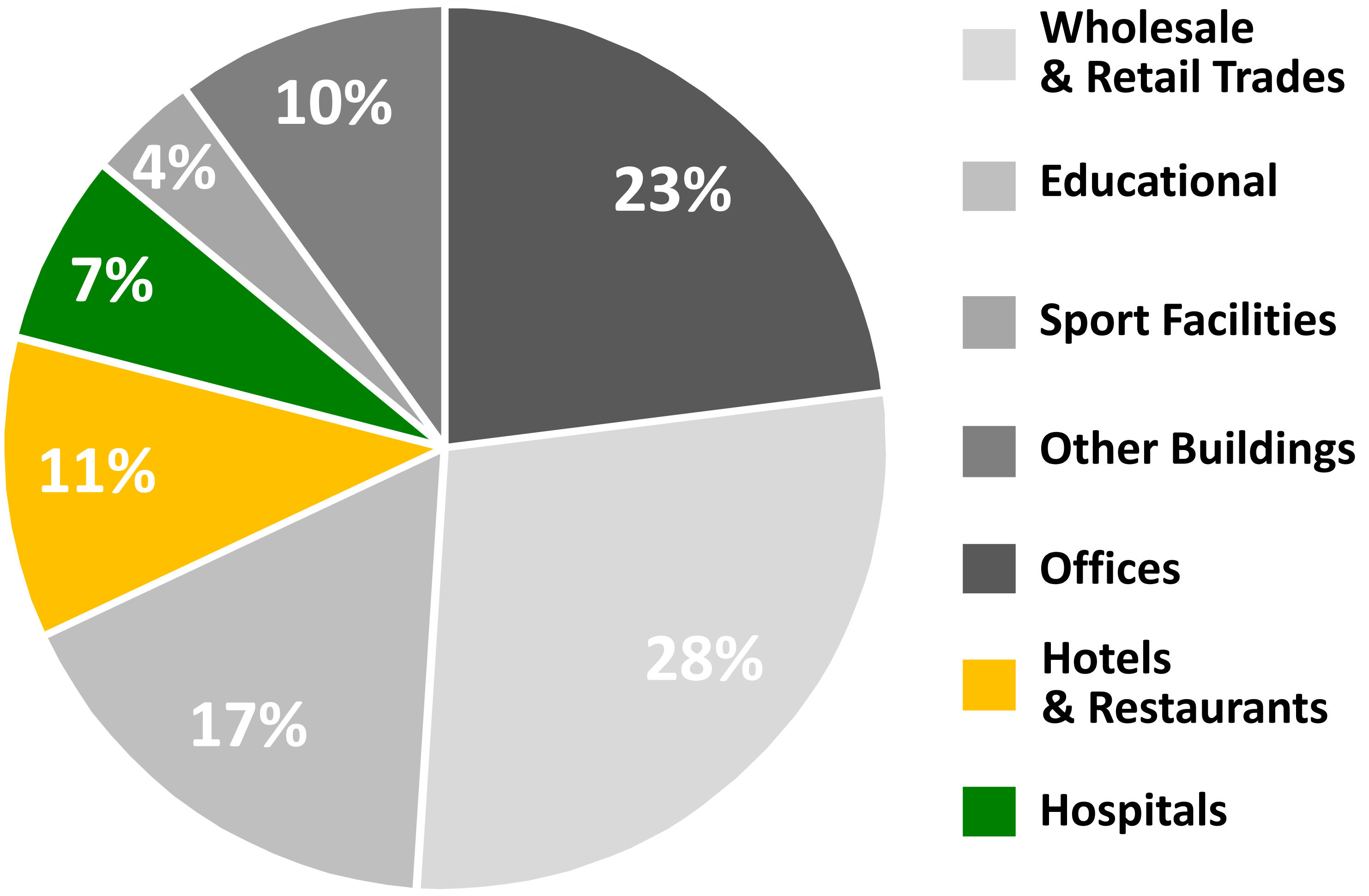
Source: O. Rapf. "Europe's buildings under the microscope", International Expert Workshop "Energy assessment of National Housing Stocks – Building Typologies", 29 February 2012.

Proportion of Energy Use by Sector in Non-Residential Building Types Across Europe - Data



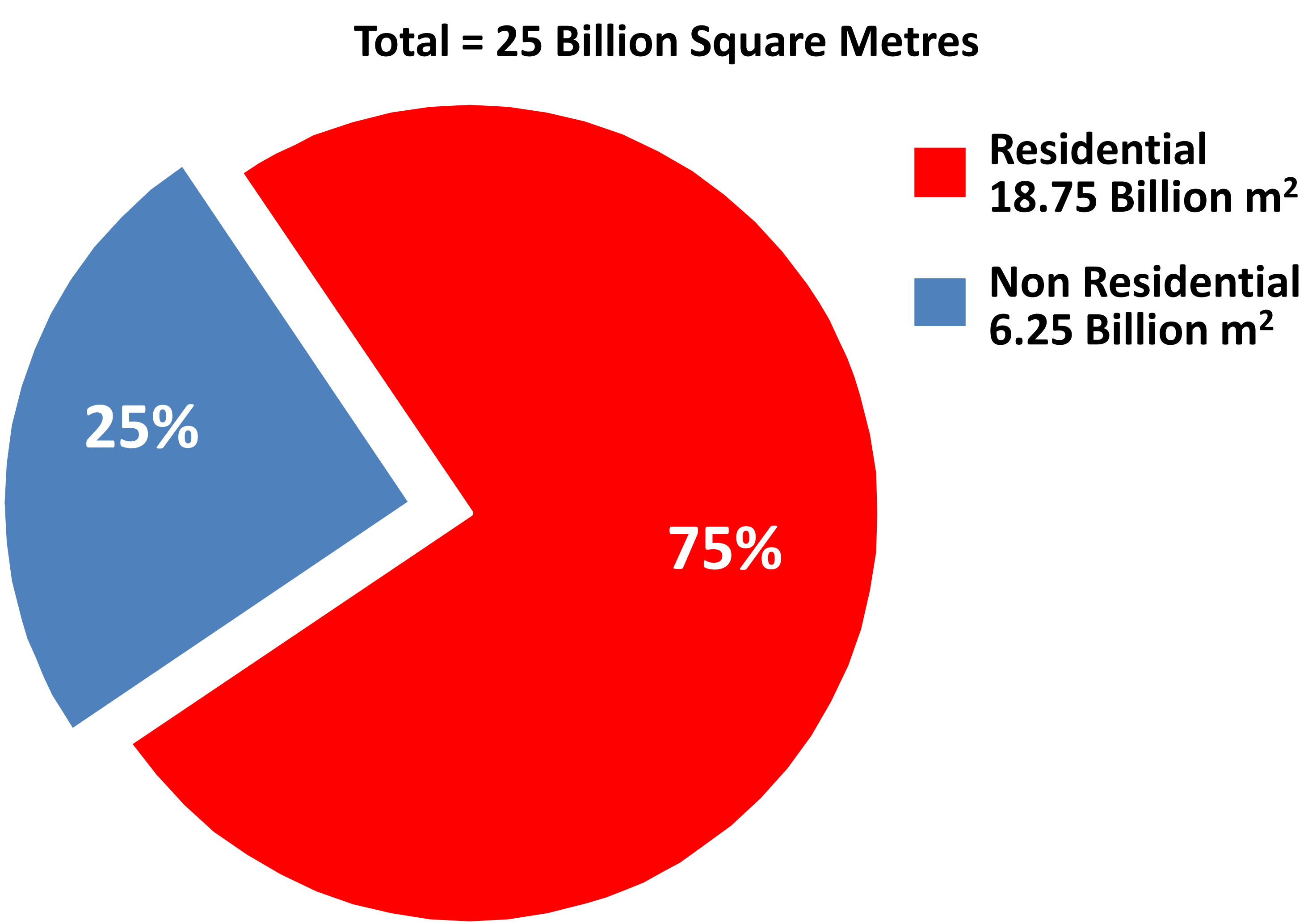
Source: O. Rapf. "Europe's buildings under the microscope", International Expert Workshop "Energy assessment of National Housing Stocks – Building Typologies", 29 February 2012.

Percentage Share of Floor Area by Use in Non-Residential Building Sector in EU27+2



Source: O. Rapf. "Europe's buildings under the microscope", International Expert Workshop "Energy assessment of National Housing Stocks – Building Typologies", 29 February 2012.

Floor Areas Share in the EU27+2 - Data

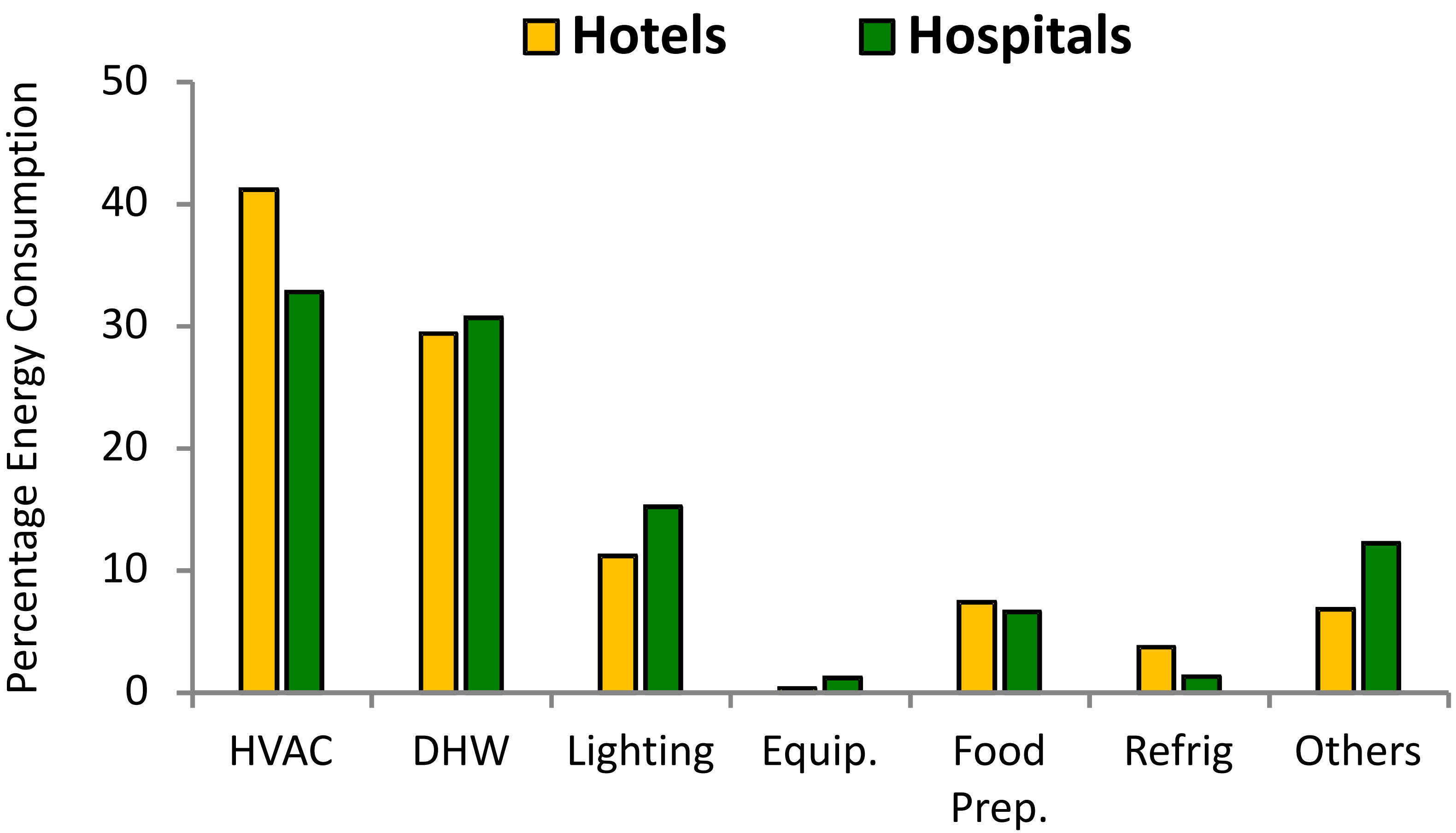


Source: O. Rapf. "Europe's buildings under the microscope", International Expert Workshop "Energy assessment of National Housing Stocks – Building Typologies", 29 February 2012.

Data Summary of 2009 Specific Energy Consumption Per m² Building Area in the Tertiary Sector in the EU27+2

Tertiary Building Sector		Floor Area		Energy Consumption/annum			
		% Slide 12	$m^2 x 10^9$	% Slide 11	Mtoe	$kWh x 10^9$	$kWh/m^2.a$
1	Offices	23	1.4375	26	37.96	441.5	307.1
2	W'sale & retail	28	1.75	28	40.88	475.4	271.7
3	Educational	17	1.0625	12	17.52	203.8	191.8
4	**Hotels & restaurants**	**11**	**0.6875**	**12**	**17.52**	**203.8**	**296.0**
5	**Hospitals**	**7**	**0.4375**	**10**	**14.6**	**169.8**	**388.1**
6	Sports facilities	4	0.25	6	8.76	101.9	407.5
7	Other types	10	0.625	6	8.76	101.9	163.0
8	**Total**	**100**	**6.25**	**100**	**146.0**	**1,698.0**	**271.7**
146 Mtoe = 32.4% of total EU energy consumption of 450 Mtoe							

Energy Consumption Share Percentage by Function



Annual Energy Consumption by End Use In Hotels and Hospitals

Energy Consumer		Quantity & % of Energy Consumed in			
		Hotels		Hospitals	
No	Description	kWh/m^2.a	%	kWh/m^2.a	%
1	HVAC	122.0	41.2	127.3	32.8
2	DHW	87.0	29.4	119.1	30.7
3	Lighting	33.2	11.2	59.0	15.2
4	Equipment	0.9	0.3	4.7	1.2
5	Kitchen	21.9	7.4	25.6	6.6
6	Refrig.	11.0	3.7	5.0	1.3
7	Others	20.0	6.8	47.3	12.2
Totals		296.0	100	388.0	100

Analysis of Energy Consumption by Consumer and Type

Energy consumer to be considered		kWh/ m².a	Energy use by consumer & type, kWh/m².a			
			Hotels		Hospitals	
			Elec.	Gas	Elec.	Gas
1	HVAC					
	.2 Hotels	122.0	41	81		
	.3 Hospitals	127.3			43.3	84
2	DHW					
	.2 Hotels	87.0	43	44		
	.3 Hospitals	119.1			59.1	60
3	REF		11	-	5.0	-
4	Totals		95	125	107.4	144
5	Combined Total		220.0 (74%)		251.4 (65%)	
6	Lighting, Equip., Kitchens, Other		76.0		136.6	
7	Grand Total		296.0		388.0	

Separation of Electrical & Gas Energy in HVAC & Reduction in AC & Compressor Energy Consumption (CEC)

Parameter		Energy consumption & cooling capacity	
		Building category, kWh/m².a	
No	Description	Hotels	Hospitals
1	HVAC		
.1	Total – (Slide 18, Item 1)	41	43.3
.2	Parasitic 45%	18.5	19.5
.3	HFC CEC	22.5	23.8
.4	COP	3.69	3.69
.5	Cooling Capacity	83.0	87.8
.6	Total heat rejection (THR) to cooling water	105.5	111.6
.7	CO_2 COP to heat water. (Slide 15)	4.29	4.29
.8	CO_2 CEC	19.3	20.5
.9	Δ CEC with CO_2 1.3 - 1.8	3.2	3.3
.10	CEC energy saved, %	13.8	13.8
.11	CO_2 comp. THR 1.5 + 1.8	102.3	108.3

Separation of Electrical & Gas Energy in HVAC & Reduction in AC & Compressor Energy Consumption (CEC)

Parameter		Energy consumption & cooling capacity	
		Building category, kWh/m^2.a	
No	Description	**Hotels**	**Hospitals**
2	MT Refrigeration		
.1	Total CEC MT + LT (Slide 17, Item 6)	11.0	5.0
.2	MT Refrig. %	60	60
.3	HFC CEC MT Refrig.	6.6	3.0
.4	HFC CEC LT Refrig.	4.4	2.0
.5	COP MT compressor	3.0	3.0
.6	Q MT 1.3 x 1.5	19.8	9.0
.7	CO_2 COP – (Slide 15)	4.29	4.29
.8	MTCO_2 CEC	4.6	2.1
.9	Saving MT CEC 1.3 - 1.8	2.2	0.9
.10	THR to gas cooler 1.6+1.8	24.4	11.1

Separation of Electrical & Gas Energy in HVAC & Reduction in AC & Compressor Energy Consumption (CEC)

Parameter		Energy consumption & cooling capacity	
		Building category, kWh/m^2.a	
No	Description	**Hotels**	**Hospitals**
3	LT Refrigeration		
.1	LT CEC – 2.4 above	4.4	2.0
.2	COP HFC comp.	1.2	1.2
.3	Q – 3.1 x 3.2	5.3	2.4
.4	CO_2 COP	2.5	2.5
.5	3.3 ÷ 3.4	2.1	1.0
.6	Saving 3.1 - 3.5	2.3	1.0
.7	THR to gas cooler 1.3+1.5	7.4	3.4

Summary of AC & Refrigeration Compressors Electrical Energy Reductions & Available Heat Rejection for Water Heating

Parameter / Variable			Energy consumer kWh/m².a			
			Hotels		Hospitals	
1	AC & refrigeration compressor details & variable	Item No.	Delta Elec. Cal	THR to gas cooler	Delta Elec. Cal	THR to gas cooler
.1	AC Compressor (Slide 19)	1.9	3.2		3.3	
.2	AC compressor THR (Slide 19)	1.11		102.3		108.3
.3	MT Refrigeration (Slide 20)	2.9	2.2		0.9	
.4	MT refrigeration THR (Slide 20)	2.10		24.4		11.1
.5	LT Refrigeration (Slide 21)	3.6	2.3		1.0	
.6	LT refrigeration THR (Slide 21)	3.7		7.4		3.4
.7	Total electrical savings		7.8		5.2	
.8	THR to gas cooler			134.1		122.8

Summary of AC & Refrigeration Compressors Electrical Energy Reductions & Available Heat Rejection for Water Heating

Parameter / Variable			Energy consumer kWh/m²			
			Hotels		Hospitals	
2	Electrical Energy	Item No.	Delta Elec. Cal	THR to gas cooler	Delta Elec. Cal	THR to gas cooler
.1	HVAC (Slide 19)	1.3	22.5		23.8	
.2	MT refrigeration (Slide 20)	2.3	6.6		3.0	
.3	LT Refrigeration (Slide 21)	3.3	5.3		2.4	
.4	Total CEC		34.4		29.2	
.5	CEC with CO_2		26.6		24.0	
.6	CEC Reduction with CO_2 (Slide 22)	1.7	7.8		5.2	
.7	Reduction in CEC	%	22.7		17.8	
3	DHW – reduction in gas consumption					
.1	Heat available for DHW (Slide 22)	1.8		134.1		122.8
.2	DHW heat required – (Slide 17)	2.2		87.0		119.1
.3	Surplus heat to gas cooler			47.1		3.7
.4	% surplus			35.1		3.0

Reduction in Annual Cooling Water Consumption

Parameter			Building Category	
No	Description	Unit	Hotels	Hospitals
1	THR (Slide 22, Item 8)	$kWh/m^2.a$	134.1	122.8
2	Cooling water temp.	°C	20	20
3	Latent Heat	kJ/kg	2,454	2,454
4	Specific H_2O cons.	$kg/m^2.a$	0.055	0.05
5	Specific H_2O cons. with 20% bleed	$kg/m^2.a$	0.066	0.06
6	Building area	$m^2/10^9$	0.6875	0.4375
7	Current annual cooling tower H_2O consumption	Ml/a	37.8	21.9
8	Annual savings	Ml/a	36-41	25-26
9	Annual H_2O savings with AEC	%	80-90	96-99
10	Savings to sewer @ 20% bleed	Ml/a	6.0-7.0	4.1-4.3

Conclusions

- CO_2 application completely bypasses the HFC phase down requirements of the Kigali Amendment to the Montreal Protocol and thus avoids the use of HFO chemical refrigerants (HFOs) which are the proposed HFC replacements. HFOs are harmful to the environment according to recent reports.
- CO_2 is a low cost refrigerant which is non-toxic, non-flammable, has no ozone depletion potential (ODP) and a Global Warming Potential (GWP) = 1
- No phase out regulations and thus a future proof solution, but larger compressors are needed.
- No regulations due to hazard, which reduces capital costs. Liquid Recirculation Pumped CO_2 may be used for fire extinguishing in hotels, hospitals, office buildings, etc.
- Good thermodynamic properties.
- 65% - 95% heat recovery for water heating from the transcritical CO_2 compressor discharge is possible depending on compressor operating conditions, mains water entry and hot water exit temperature.

Conclusions *(Continued)*

- High suction vapour densities and low ΔT/ΔP ratios result in efficient evaporators with high CO_2 mass velocities in fewer circuits and small suction piping, about half the diameter of ammonia suction piping.
- No product damage in case of CO_2 leaks in refrigerated food storage facilities like cold stores.
- CO_2 does not go into vacuum at the minimum possible evaporating temperature of -55°C and therefore there is no risk of air entering the system.
- The fact that CO_2 is an all purpose refrigerant plus the possible high heat recovery rates allow simultaneous heating and cooling requirements in many food processing operations like meat, poultry and milk processing, as well as the cooling and heating of the built environment.
- Reduced energy and cooling water consumption when using hybrid evaporative gas cooler/condensers.
- Highly energy efficient when used for simultaneous cooling and heating.
- Due to a reduction in energy consumption, there is an attendant reduction in direct energy emissions, and reduced indirect emissions, as CO_2 has a GWP = 1.
- Ammonia is a very viable alternative refrigerant to CO_2, but its use is severely restricted in many jurisdictions.
- Suction heat exchangers in the high stage compressor and booster suction lines generally have a positive impact.

Thank you very much for your attention.

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eurammon e. V. is always available as a sparring partner for questions on refrigeration with natural refrigerants.

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