Air conditioning products regulations based on Ecodesign directive (> 12 kW)

Philippe Rivière, CEP, Mines ParisTech / Armines

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Ecodesign Preparatory Study (Dir. 2009/125/EC)

ENTR Lot 6: Air-conditioning and ventilation systems

Contract No. ENTR / 2009/ 035/ LOT6/ SI2.549494

Service Contract to European Commission, DG Enterprise

Sustainable Industrial Policy –

Building on the Ecodesign Directive – Energy-Using Product Group Analysis/2

Main contractor: Armines (FR)

Consortium:

Armines (FR), Air Conditioning Systems

VHK (NL), Ventilation Systems

BRE (UK), market analysis

Ecodesign study ENTR Lot 6

- Ecodesign methodology
  - ✓ T1: Definition, T2: Economic and market analysis, T3: Consumer behavior, T4: Base cases, T5: BAT – BNAT

  Comments until October 31, 2011

  – T6: Improvement potential, T7: Policy scenarios and impacts

- Timetable

January 2010	Project launch
June / July 2010	Draft report: Tasks 1,2 & 3 (part 1)
July 2010	1st stakeholder meeting
May / September 2011	Draft report: Tasks 1 to 5
September 2011	2nd stakeholder meeting
December 2011 / January 2012	Draft final report (including Tasks 6, 7)
January 2012	3rd stakeholder meeting
March 2012	Final report

Task 1: Products in scope

1. **Air conditioners > 12 kW and air conditioning condensing units**
   - Package, split and multi split air conditioner [air-to-air > 12 kW, water-to-air, evaporatively cooled] and positive temperature air condensing units [air-cooled, water-cooled, evaporatively-cooled]
   - VRF systems (centralized air conditioning systems with refrigerant fluid as the main media to circulate and extract heat from the building) [air-to-air and water-to-air]
2. **Chillers for air conditioning applications** [air-to-water, water-to-water, evaporatively-cooled]
3. **Terminal units** to extract heat from the space to be conditioned,
   - Fan coils
4. **Heat rejection units,** i.e. from the cooling system
   - Cooling towers, Dry cooler

Task 1: Scope limits

1. Cooling generators

Air conditioners < 12 kW, process chillers and refrigeration condensing units

2. AHU and more generally ventilation function of air conditioning products

AHU are studied in ENTR Lot 6 - ventilation part, BUT cooling systems integrated in AHU included

3. Motors, fans, circulators

Circulators already covered in ENER Lot 11 study and part of them by regulation

Fans and motors partly covered by regulation

4. Heating function

Heating function of reversible chiller, ENER Lot 1

Heating function of reversible air conditioners, ENER Lot 21

Task 1: Rating standards – cooling generators

- Electric

- Full load EN 14511, Part load prEN14825, Evaporatively-cooled condenser EN 15218
- Defines rating conditions, Heating and cooling capacities, EER, COP, SEER, SCOP

Issues

- 14825 Part load of multi-split / VRF systems
- 14825 Adaptation of low power modes as for air conditioners < 12 kW ?
- 14825 Adaptation of climatic/load curve data for larger generators ?
- 14825 Part load conditions missing for evaporatively-cooled condensers and dry coolers
- Missing information for EPBD application
- No standard regarding condensing units in AHU

- Engine driven compressor: no standard
- Absorption
  - Gas fired // EN 12309: 2009 // defines cooling and heating capacity and GUE

  Issues

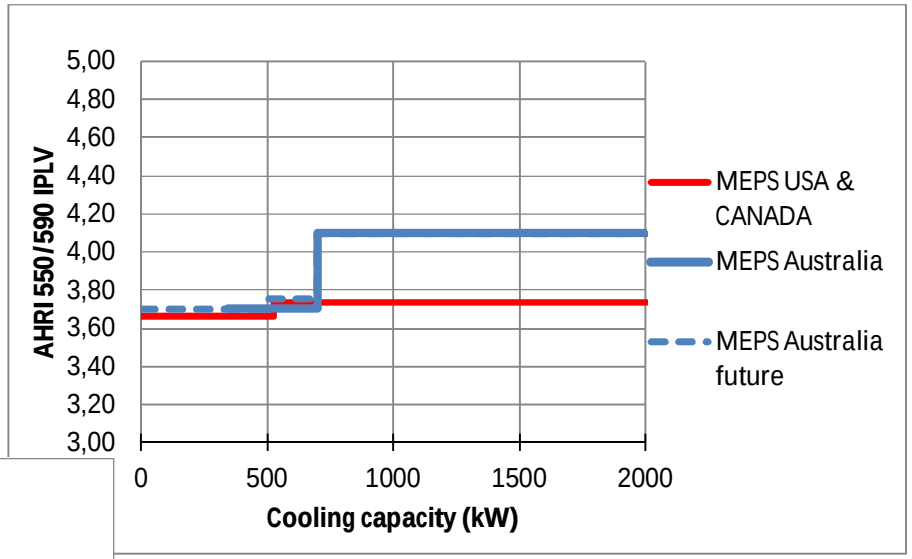
  missing water temperature levels, part load testing and conditions, electric auxiliaries (incl head losses for heat exchangers as in EN14511), sound power
  - Steam fired : no standard

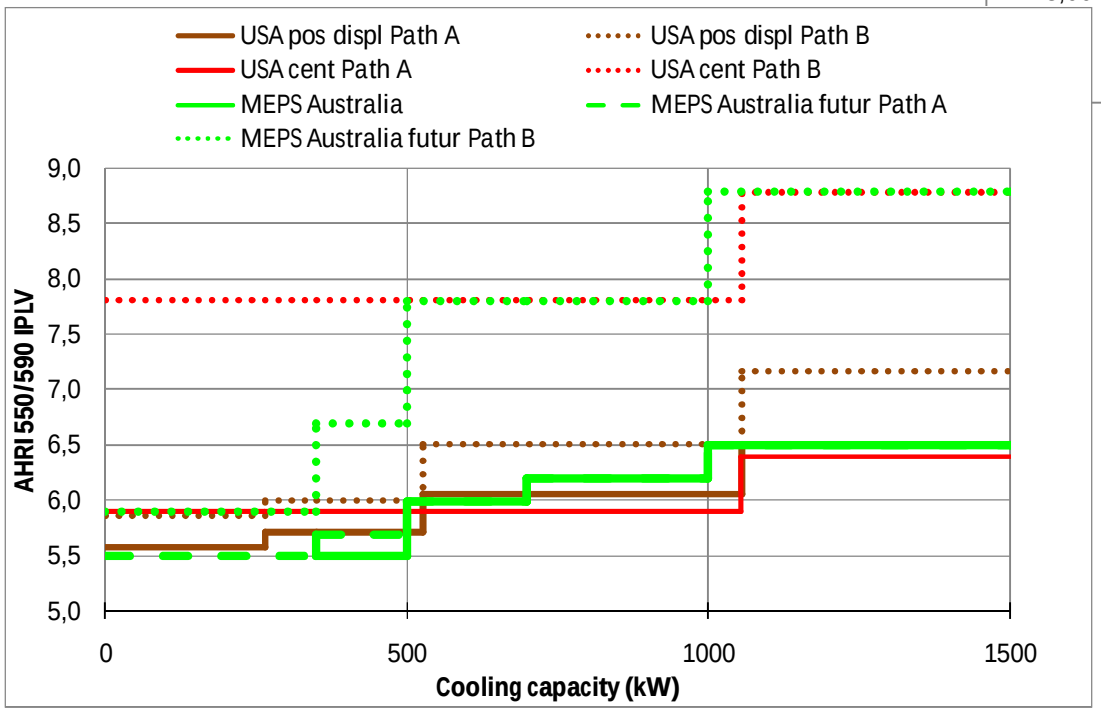
Task 1: Existing legislation – cooling generators

- Most requirements for electric cooling generators
  - Both full load and part load requirements
  - Air cooled and water cooled (separated requirements)
  - Australia included low power modes for AC up to 65 kW
  - All EERs over the world not always the same definition
- Requirements also for
  - Absorption (gas or steam) / lower levels than for electric ones
  - Engine air conditioners (UK)
- US and Japan use different seasonal performance indicators
  - US IPLV for chillers
  - US SEER and IEER for air conditioners
  - Japan APF for air conditioners (weighted Japan SEER and HSPF)

Task 1: Legislation ex - chillers

Air cooled chillers IPLV





Water cooled chillers IPLV

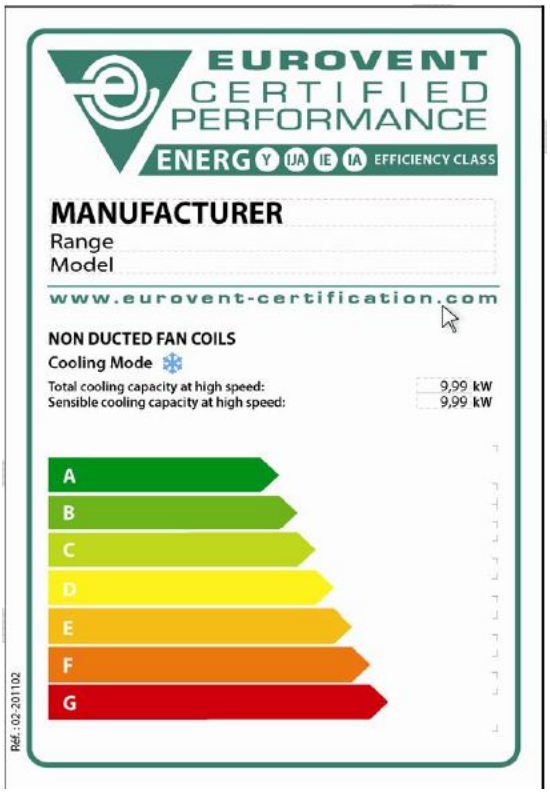
Task 1: terminal units - standards and legislation

- Standards
  - Define cooling capacity, electricity power (if any), water pressure losses
  - Fan coils Testing and rating EN 1397:1998 (could be refreshed)
  - Chilled ceilings Testing and rating EN 14240:2004
  - Chilled beams Testing and rating EN 14518:2005
  - Active chilled beams Testing and rating EN 15116:2008
  - Floor cooling Testing and rating EN 1264:2009

- No legislation
  - Fan coils // Eurovent proposal

$$FCEER = \frac{5\% \cdot Pc_{high} + 30\% \cdot Pc_{med} + 65\% \cdot Pc_{low}}{5\% \cdot Pe(c)_{high} + 30\% \cdot Pe(c)_{med} + 65\% \cdot Pe(c)_{low}}$$

$$FCCOP = \frac{5\% \cdot Ph_{high} + 25\% \cdot Ph_{med} + 70\% \cdot Ph_{low}}{5\% \cdot Pe(h)_{high} + 25\% \cdot Pe(h)_{med} + 70\% \cdot Pe(h)_{low}}$$



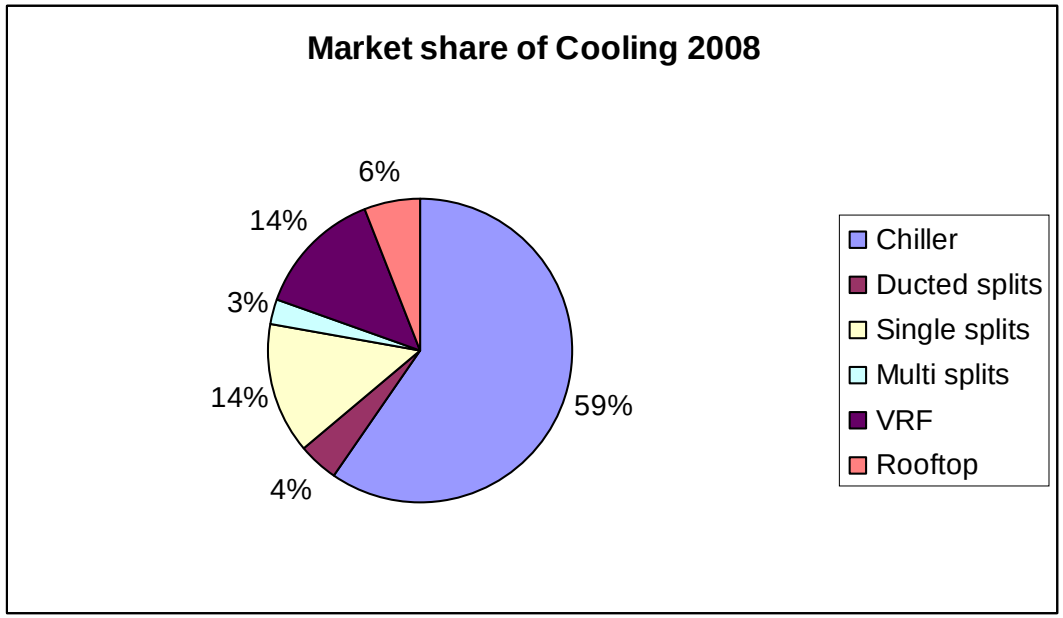
Task 1: Heat rejection - standards and legislation

- Heat rejection units
  - Dry cooler - Testing and rating EN 1048:1998 – Defines rated capacity conditions, cooling capacity and electric power absorbed // only full load (inverter gain not shown) // no sound power measurement
  - Cooling towers - EN 14705:2005 - Measurement and evaluation of thermal performances of wet cooling towers – Defines performance map for cooling capacity // Fan power not included // No standard testing conditions defined // only full load // no sound power measurement
- Existing requirements in the USA (with CTI standards)

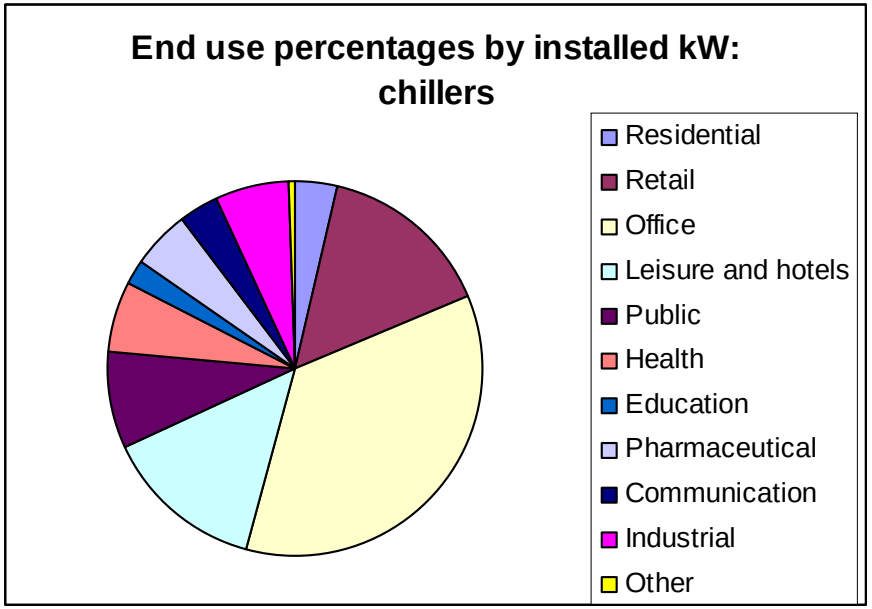
ASHRAE 90.1:2010 Cooling towers MEPS	**gpm/hp min**	**kWcool/kWelec min**
Open-circuit cooling towers		
35 °C entering water, 29.4 °C leaving water, 23.9 °C entering wet bulb		
Propeller or axial fan open-circuit cooling tower	38,2	75,0
Centrifugal fan open-circuit cooling towers	20	39,3
Closed-circuit cooling towers		
38.9 °C entering water, 32.2 °C leaving water, 23.9 °C entering wet bulb		
Propeller or axial fan closed-circuit cooling tower	14	33,0
Centrifugal fan closed-circuit cooling towers	7	16,5

Task 2: Sales of cooling generators

- Chillers account for 60% of the cooling capacity sold. About 18.9 GW
- VRF systems and non-ducted single-split systems > 12kW are also significant. About 2.6 GW each
- Rooftop units : 1.1 GW
- Ducted split systems : 0.8 GW
- Multisplit systems : 0.6 GW



Task 2: Sales of cooling generators - destination



	Chillers	FCU	VAV	Other terminal
New build	39%	48%	48%	60%
Refurbishment	32%	49%	52%	40%
Replacement	29%	3%	0%	0%

	Rooftops	Ducted splits	Single splits	Multisplits	VRF
New	38%	24%	36%	38%	55%
Refurbishment	38%	59%	49%	50%	41%
Replacement	24%	17%	15%	12%	4%

The main market sectors (65%) for central air conditioning are offices, retails, and hotels and leisure

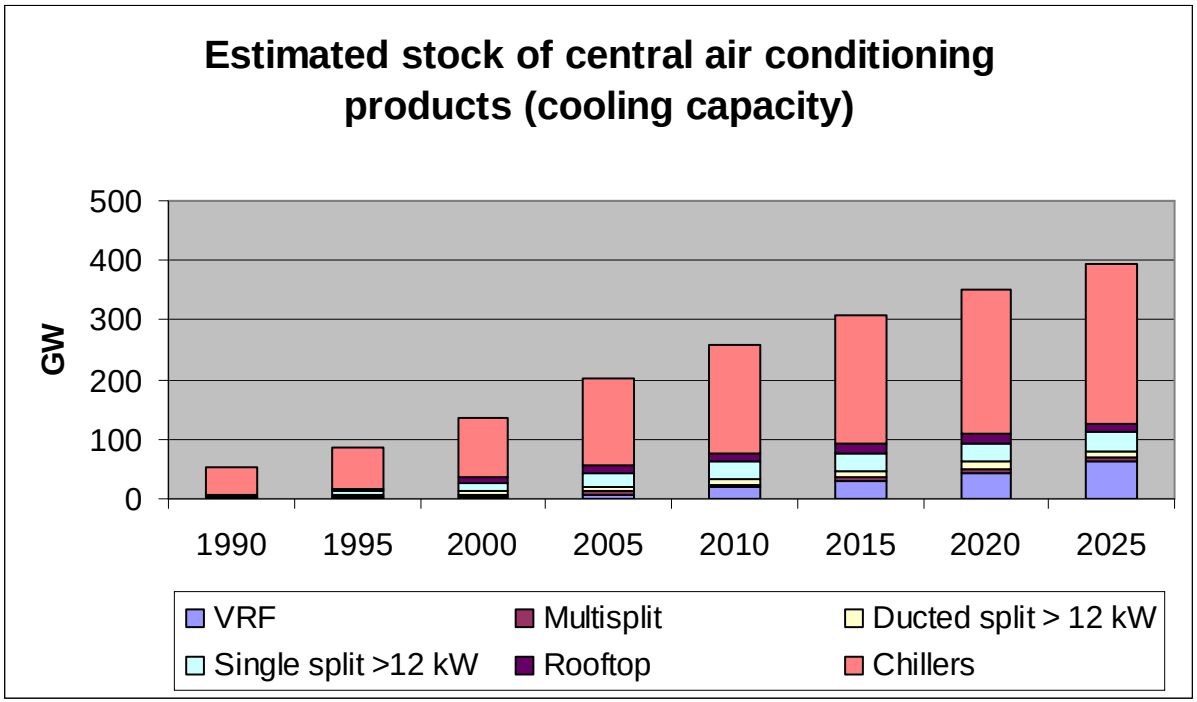
Task 2: Reversibility of sales

Product	Percentage reversible (by number)
Chillers	47% **16% by capacity**
Ducted single split systems > 12 kW	82%
Non-ducted single split systems > 12 kW	66%
Multisplit systems	64%
VRF systems	88% (includes products with heat recovery)
Rooftop units	62% (an additional 11% with gas heating)

Chillers

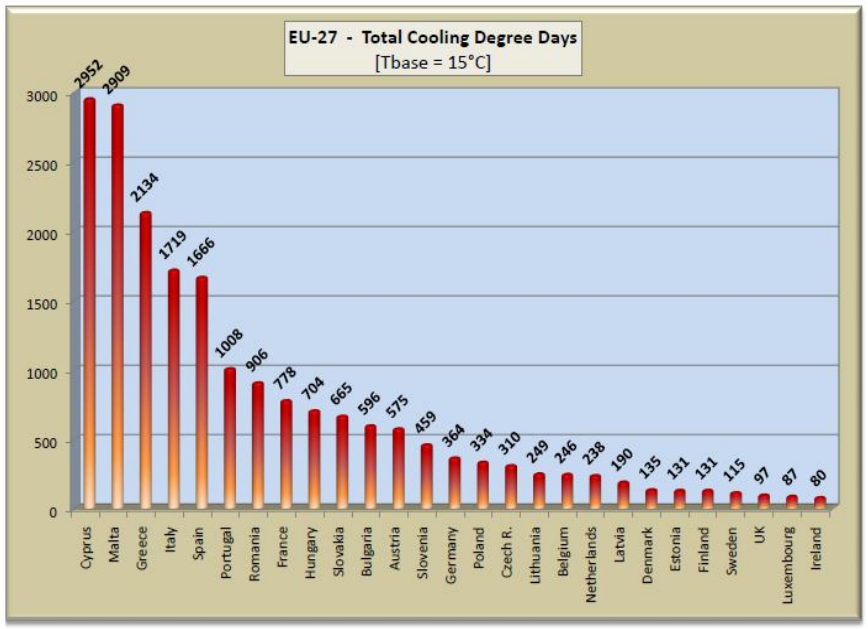
- More than 50 % of small capacity products (< 50 kW) are reversible
- Reversible products are mostly air-cooled chillers

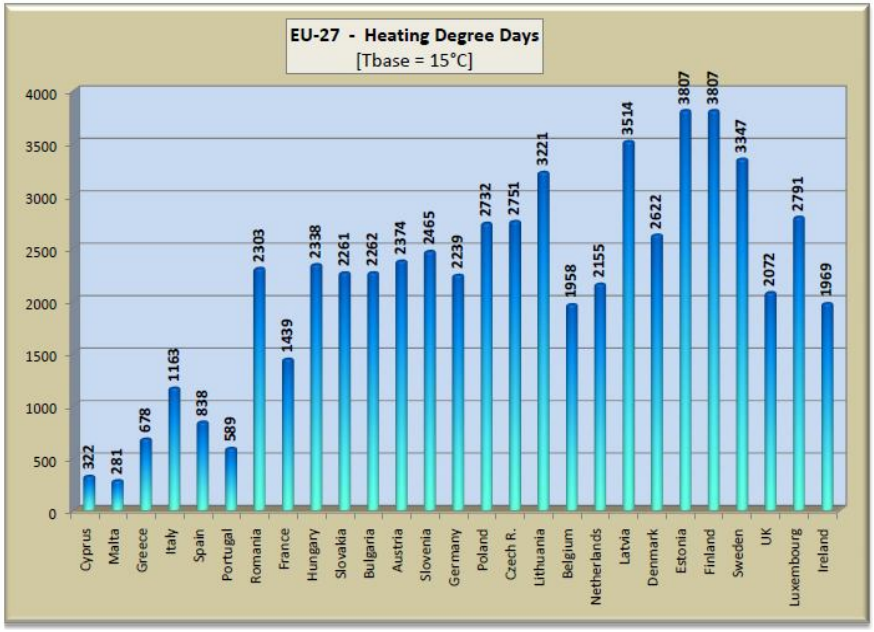
Task 2: Stock of cooling generators



- Continuous growth of the stock (chillers and VRF)
- Market saturation in 2025 for products other than chillers and VRF systems
- AC < 12 kW, stock 2010 est. About 250 GW also
- With ave EER between 2,5 and 3 = 150 - 200 GW
- Installed power plant capacity in 2006 in the EU = 635 GW (Bower, 2007)

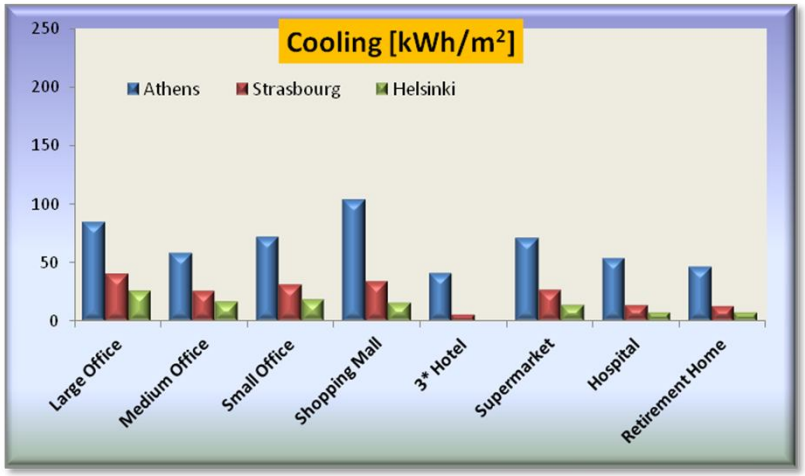
Task 3: Climate data

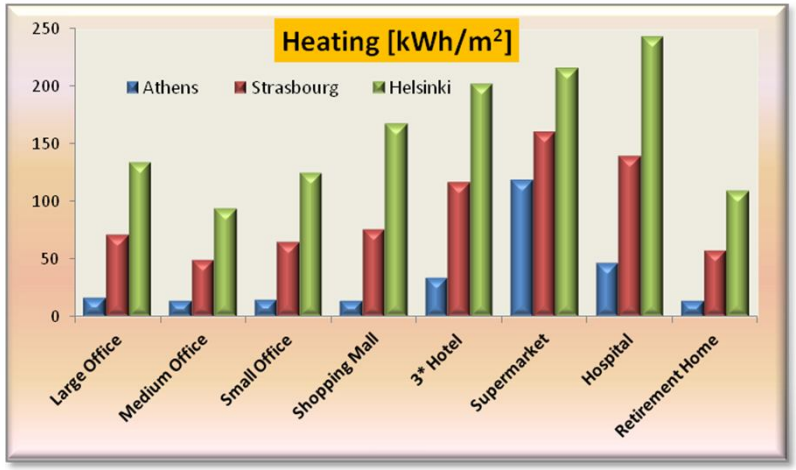




- ASHRAE's IWEC database // Helsinki, Strasbourg, Athens
- Interpolation with CDDs (Latent + sensible) and HDDs on a country basis
- Climate change and heat island effect not accounted at the moment

Task 3: Building types





- 8 typical buildings out of the 4 main building sectors modelled
- Thermal characteristics of building envelopes, set points / ventilation / occupancy / equipment / lighting scenarios
- Air conditioning product in other building sectors (e.g. pharmaceutical, telecommunication) are mainly for human comfort (BSRIA data used)

Task 3: Faults and maintenance

- Faults
  - Soft faults : cause a degradation in performance but allow continued operation of the product
    → *direct impact on energy efficiency ≠ hard failures*
  - Examples
    - Refrigerant leakage/undercharge
    - Condenser/Evaporator fouling on the air side
    - Reduced condenser/evaporator water flow

  → *No sufficient statistical data for modelling in Task 4*

  → *Maintenance is supposed to maintain the performance*

- Maintenance
  - Cost-effective in specific conditions (warm climates)
  - Information provided for maintenance is only indicative.
  - No specific focus on the energy efficiency of the product – it must work

  → *A main technical improvement : Fault Detection and Diagnosis electronic systems*

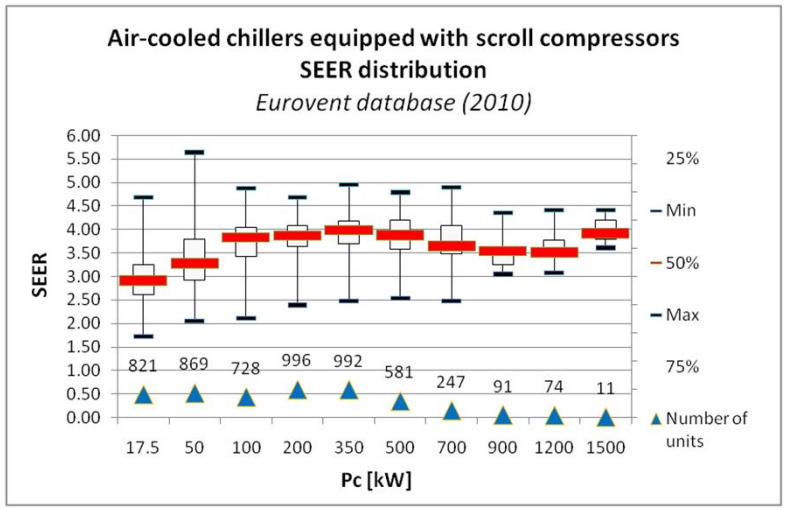
Task 3: End of life

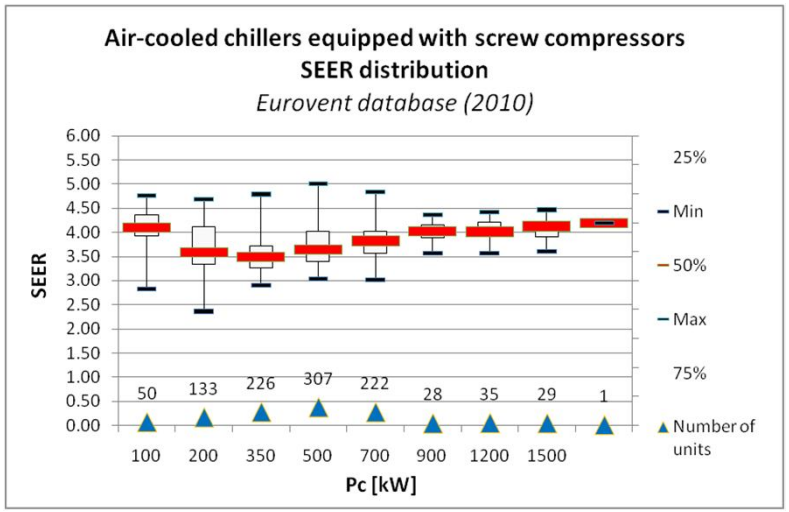
- Decommisionning and recycling
  - Products with high metallic contents, easily recyclable
  - Cu and Al with high value.
  - Large capacity units are more interesting to recycle than small capacity units
  - Casings of terminal units largely made of plastics → recycling issue
  - Identifying the constituents of products is a main barrier to an improved recycling

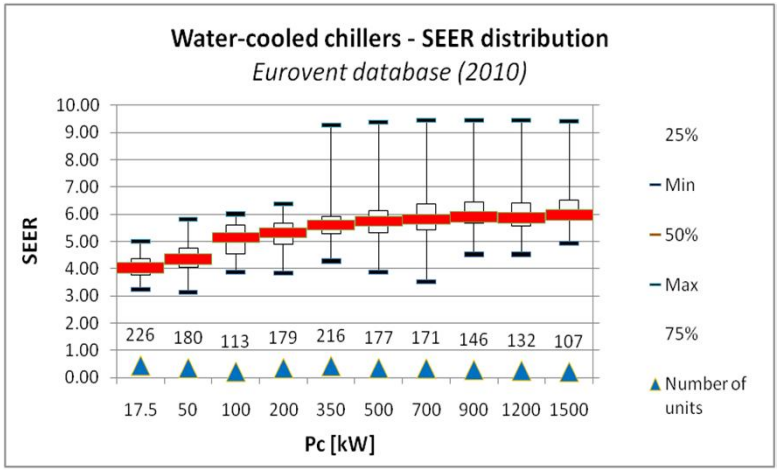
	1400 kW centrifugal chiller	8.8 kW split-system
Mechanical contractor		
Scrap value of equipment	80 € / ton x 7.34 ton = 590 €	80 € / ton x 0.12 ton = 9.6 €
Disposal cost to contractor	405 €	3.2 €
Contractor net profit	155 €	6.4 €
Scrap metal dealer		
Value of unit's metallic content	4370 €	78 €
Scrap dealer cost	1260 €	21 €
Scrap dealer net profit	3110 €	57 €

  - High value of metals may imply refrigerant is not properly collected for destruction (mainly R22 today) // actual rates seem to vary with unit size (France figures)

Task 4: Base cases, definition ex chillers



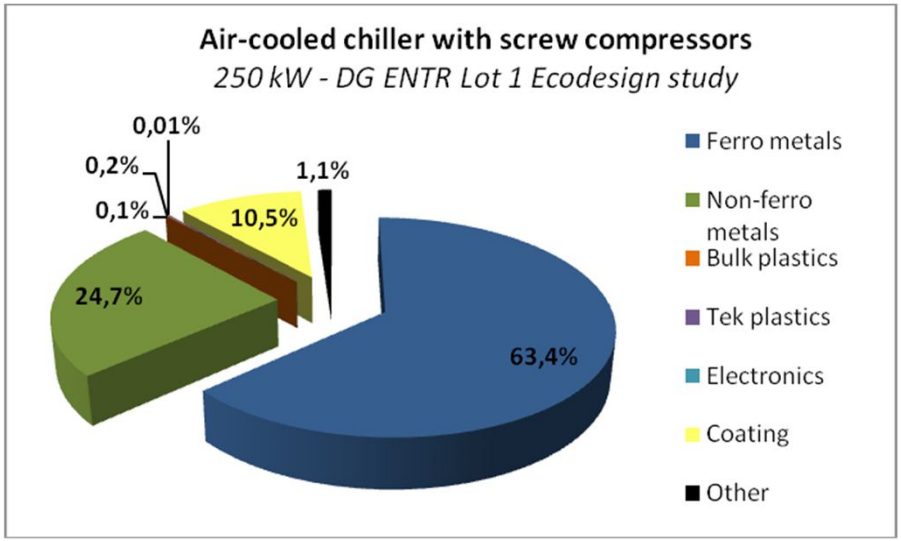




- Median EER : no significant variation with the cooling capacity
- Median scroll and screw chillers : equivalent ESEERs. Centrifugal chillers are more efficient
- Significant differences in the ESEER of water-cooled and air-cooled chillers

Task 4: Base cases, energy parameters and material content, ex chillers

Characteristics	Air-cooled chiller *Screw compressor*		Water-cooled chiller *Screw compressor*	
	Sales	**Stock**	**Sales**	**Stock**
$P_{C,\ nominal}$	400 kW		900 kW	
$EER_{nominal}$	2.72	2.29	4.77	3.82
SEER	3.76	*3.16*	5.72	*4.58*
τ_{min}	25%		25%	
EER ($\tau = \tau_{min}$)	1.06 * $EER_{full\text{-}load}$		0.92 * $EER_{full\text{-}load}$	



- Screw chillers rather than scroll chillers
- Capacity ranges (< 50 kW, > 1500 kW) not well represented
- Off-design manufacturer data
- Part-load performances fitted from SEER values

Task 4: Refrigerant charge, GWP and consumption

Base-case product	Refrigerant charge	Equivalent EU-27 GWP$^{100\ years}$	
		Sales	Stock
Air-cooled chiller	0.25 kg / kW	1455	1587
Water-cooled chiller	0.20 kg / kW		
Rooftop	0.25 kg / kW	1914	1772
Split system	0.4 kg / kW		
VRF system	0.5 kg / kW		

- Not all sales or stock products charged with the same refrigerant
- Important differences in GWP from a refrigerant to another (R-134a and R-410A, for instance)
- An equivalent GWP to take into account the different refrigerants on the market
- Greater refrigerant charges per cooling capacity for split and VRF systems

Base-case product	Refrigerant losses over product life *Low estimate*	Refrigerant losses over product life *High estimate*	Lifetime Years
Air-cooled chiller	30% of factory charge	130% of factory charge	20
Water-cooled chiller	30% of factory charge	145% of factory charge	25
Rooftop	30% of factory charge	95% of factory charge	15
Split system	35% of factory charge	170% of factory charge	15
VRF system	35% of factory charge	170% of factory charge	15

Task 4: Energy simulation results by product

Base-case product	Annual electricity use *Cooling mode* [kWh/kWcool]		Annual electricity use *Heating mode* [kWh/kWcool]	
	Sales	**Stock**	**Sales**	**Stock**
Air-cooled chiller	136	159	*Not modelled*	*Not modelled*
Water-cooled chiller	101	116	-	
Rooftop air-conditioner	165	232	396	457
Equivalent split system	165	231	327	434
VRF system	93	128	367	436
Equivalent fan-coil unit	10.6	13.0	8.84	11.8
Dry cooler	16.7	-	-	
Cooling tower	-	21.1	-	

Methodology

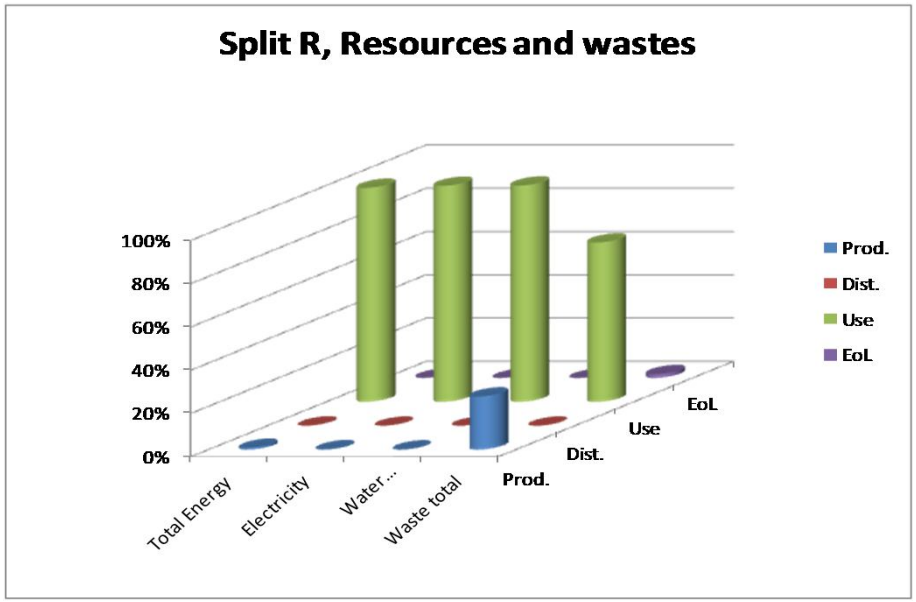
- cooling/heating demand of 8 typical buildings under 3 typical climates (Task 3)
- 9 typical systems in cooling mode and 4 typical systems in heating mode
- Each system includes one or more type of base-case product
- Weighting by market figures

Interpretation

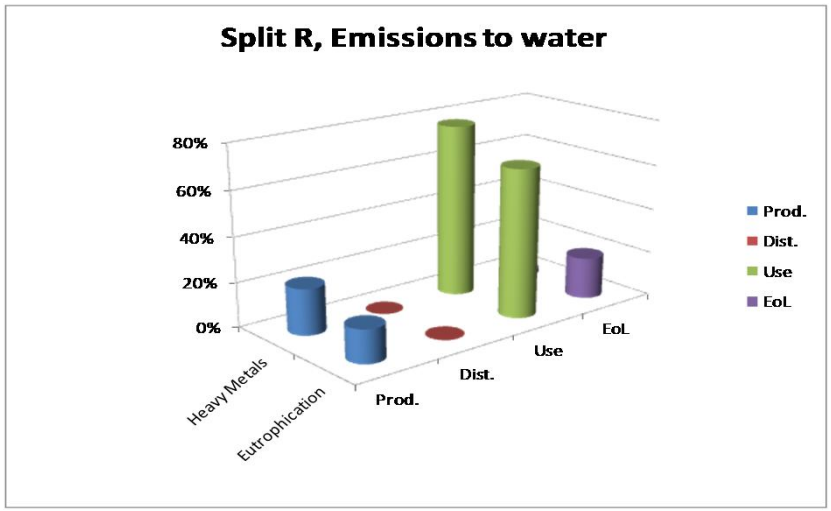
- Different product types are not always installed, on average, under the same climate

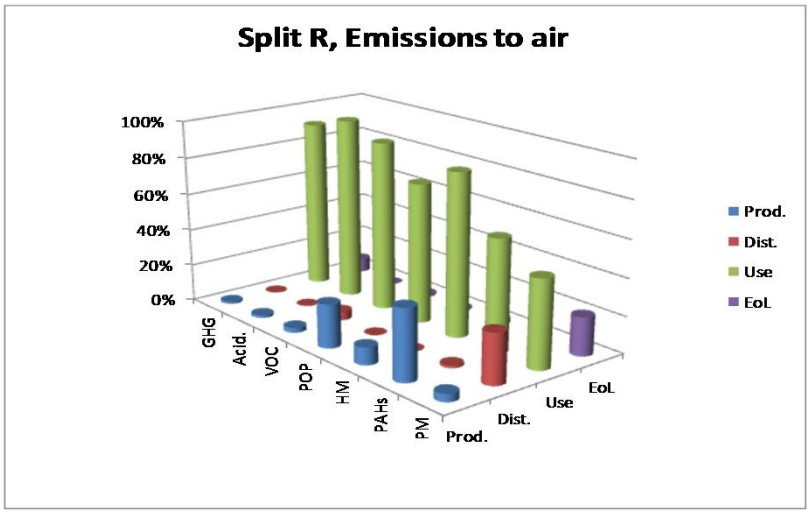
  → *Important differences between split systems and VRF systems*
- Equivalent split system (ducted products)
- Equivalent fan-coil unit (ducted products)

Task 4: LCA results, environm. impact

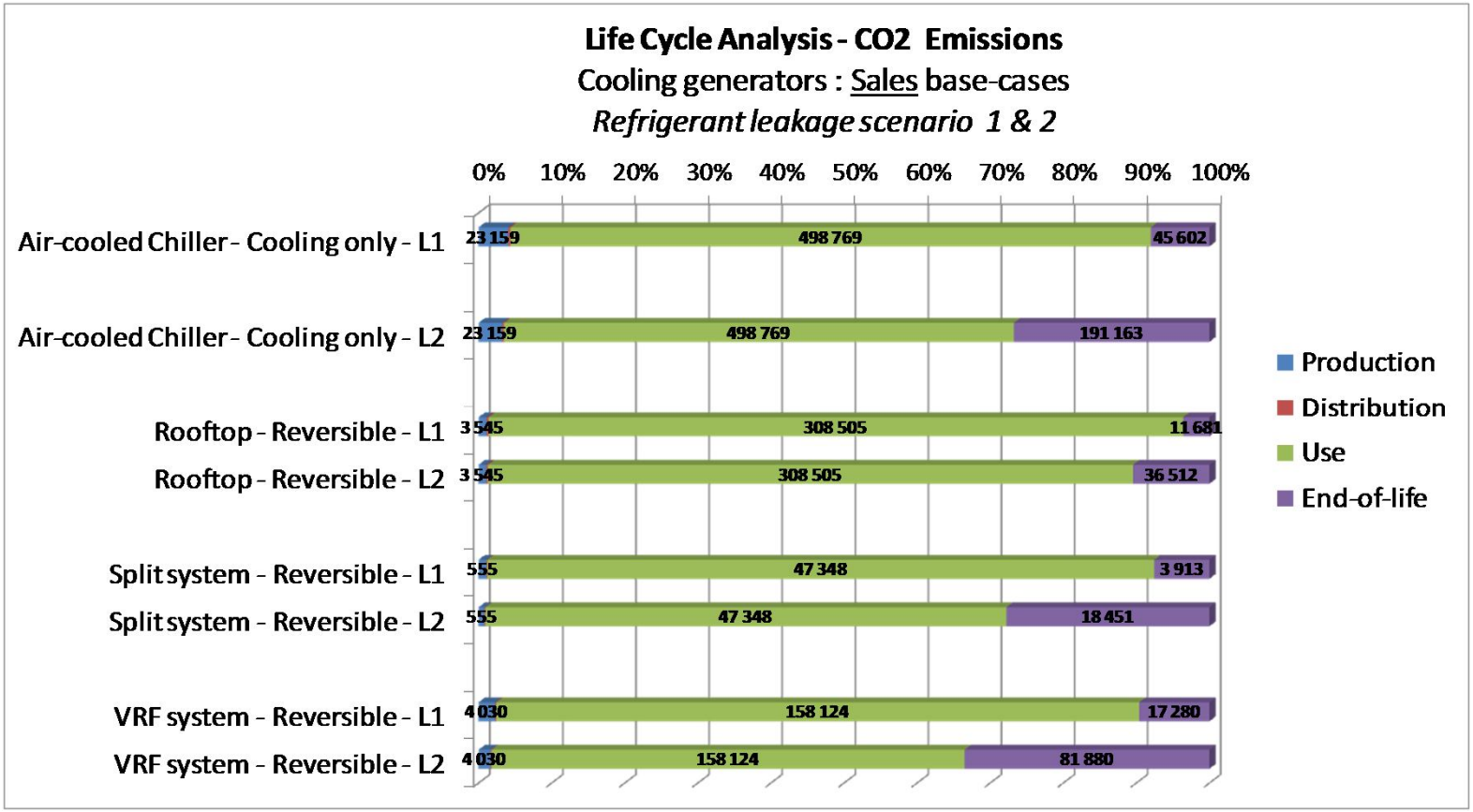


- Main environmental impacts linked to the use phase for cooling generators
- If consumption gets lower, other phases cannot be neglected (eg fan coil only used for cooling)





Task 4: LCA results, CO2eq emissions



- Reversible versus cooling only
- Uncertainty on refrigerant consumption: important consequences for all systems

Task 4: Energy consumption and CO2 emissions, Stock 2010, EU 27

	Chillers	DX	FC	HR	TOTAL
PJ	290	453	22	11	777
Twh elec	27	42	1,7	0,9	**72**
Scen 1. mt CO2 eq.	14	22	1,1	0,5	**38**
Scen 2. mt CO2 eq.	17	30	1,1	0,5	**49**

- In addition, reversible chiller electricity consumption for heating was not taken into account, which can be estimated to about 15 TWh.
- The contribution of terminal units and of heat rejection units is relatively low.

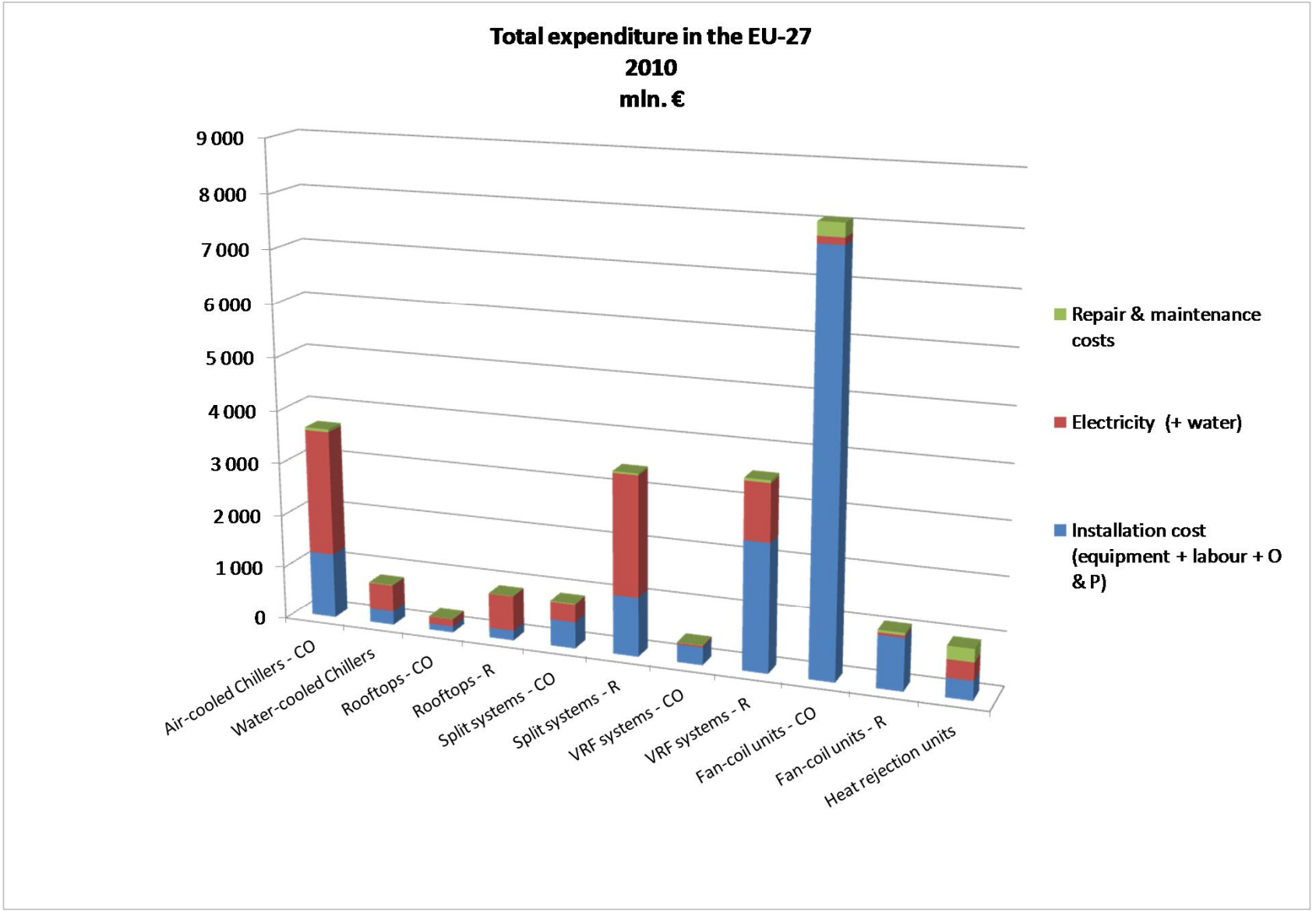
45/4600(*) about 1 % of EU27 CO2eq emissions (*)(Eurostat 2009)

90/3000 about 3 % of EU27 elec cons

Task 4: LCC, Installation costs

Data	Air-cooled chiller	Water-cooled chiller	Rooftop	Split system	VRF system	Fan-coil unit	Dry cooler
Cooling / Heat rejection capacity [kW]	400	900	80	14	50	3	200
MSP, unit alone [€]	40000	63000	12000	3500	16000 (outdoor unit) + 11700 (indoor units)	500	13000
MSP, additional equipment [€]	*Control panel, sensors*	*Control panel, sensors*	*Ductwork, insulation*	*Piping, wiring kit*	*Piping, accessories, remote control*	*Valves, controls, chilled water piping, condensate drains*	*Pumps & piping, condenser control system*
	9200	14400	400	200	4600	1100	4900
Total MSP [€]	**49200**	**77400**	**12400**	**3700**	**32300**	**1600**	**17900**
Total bare labour costs [€]	**6900**	**10800**	**5500**	**700**	**11400**	**1200**	**4400**
Installation cost (equipment + labour + O & P) [€]	**67300**	**105800**	**21500**	**5300**	**52400**	**3400**	**26700**

Task 4: Total EU-27 expenditure, in 2010



Task 5: Design options for main cooling generators

Components

- Refrigerant fluid
- Motor
- Compressor
- Heat exchangers
- Evaporatively-cooled condenser
- Fans
- Expansion valve
- Auxiliary power modes (including controllers)

Products

- Air conditioners
- Chillers

Alternatives

- to electrically driven vapour compression units using grid electricity

Task 5: Refrigerant fluid

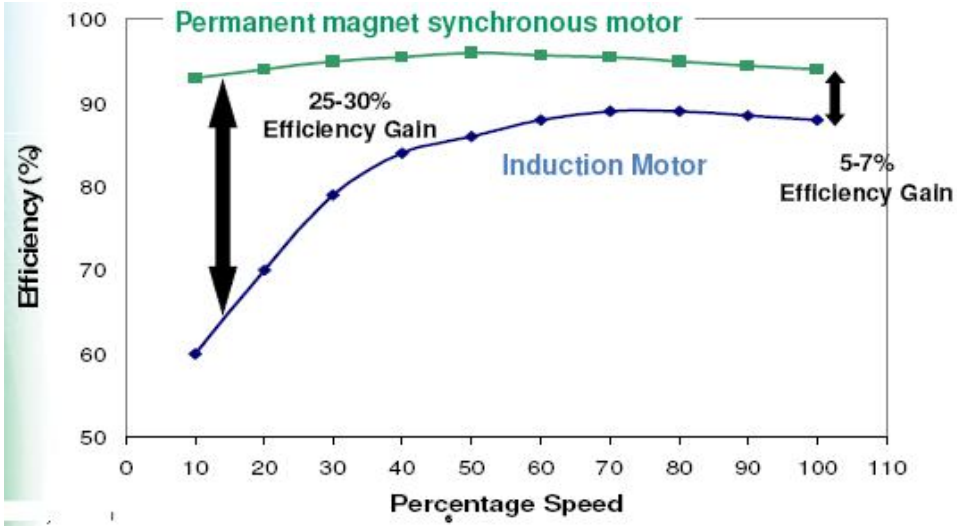
- Refrigerant fluid choice
  - Present fluids R134a, R407C, R410A (ammonia, propane)
  - Alternatives: Propane, Ammonia, R32, CO2, HFOs, H2O
  - GWPs lower, but also performance (average and peak)
  - TEWI analysis required and also LCC

- Refrigerant management
  - Leak from the product and consumption for refrigerant management
  - Importance of the 2006/842/EC directive

- Refrigerant charge and leakage
  - micro-channel heat exchangers, leak detection, components for hermetically sealed products (EN 16084:2011)

Task 5: Motors and VFD

- EC motor regulation
  - Not covered motors in (semi-)hermetic compressors and < 750 W
- EC motor is a key BAT
  - BAT motor peak efficiency from 85 % for ~ 100 W till more than 95 % for 50 kW motor output
- EC motor + VFD also
  - VFD also very efficient with EC motors, losses less than 2 % peak load, and less than 5 % part load



Source (Barrett, 2011)
50 kW rated motor input

Task 5: Compressors

Design efficiency

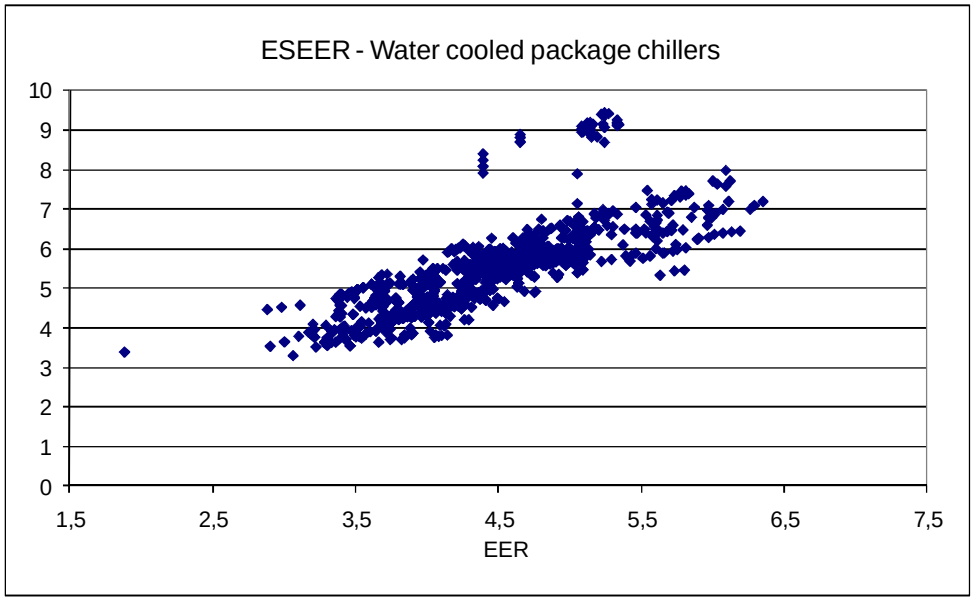
- Rotary BAT -> Scroll
- Scroll BAT 80 % (Is. eff)
- Screw BAT 85 % (Is. eff)
- Centrifugal BAT ?

Off design efficiency

- Choice of the peak. eff
- Variable peak eff
- Economizer

Unloading

- VFD versus tandem operation for scroll
- VFD + fix scroll for VRF
- VFD for screw
- EC + VFD + magnetic bearings for centrifugal compressors = oil free centrifugal chiller



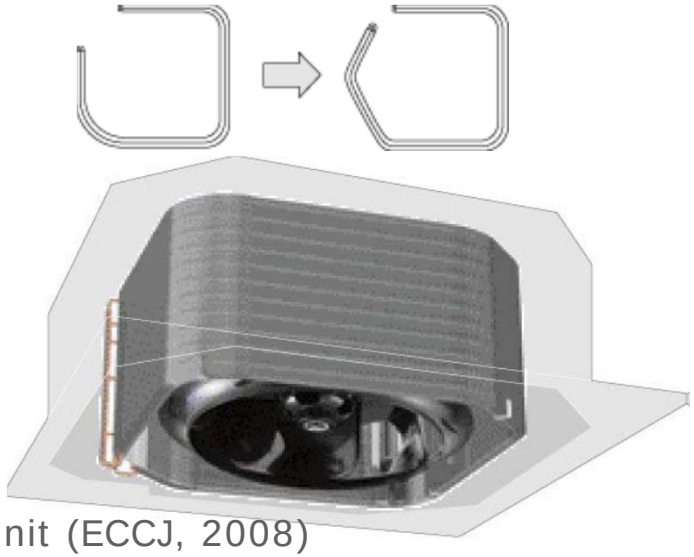
Small size oil free cent compressors (BNAT)

Oil flooded compression (BNAT)

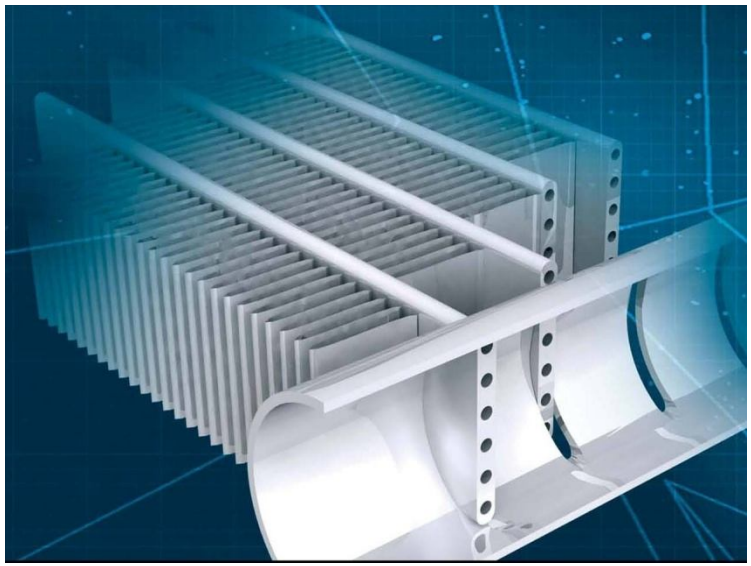
Task 5: Heat exchangers

Increase heat transfer intensity

Increase heat transfer area at fixed kW (and flow)



Cassette indoor unit (ECCJ, 2008)



Decrease pressure drop

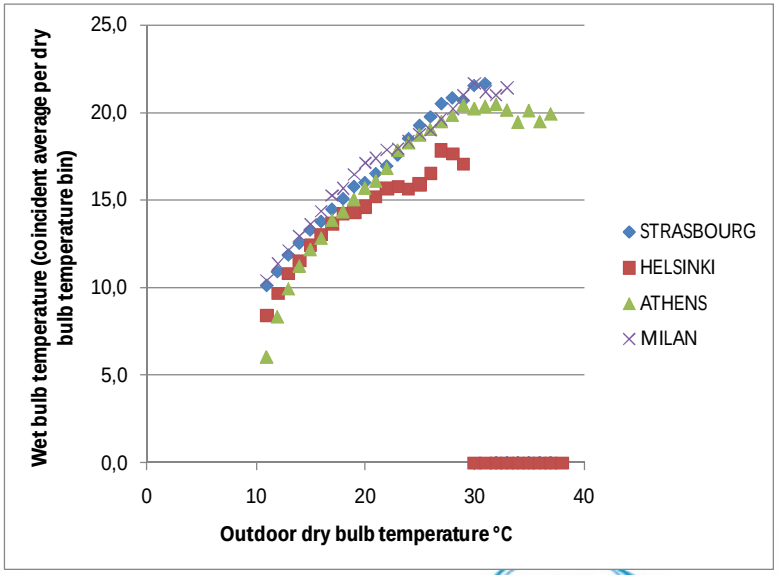
Reduce heat exchanger volume (refrigerant charge)

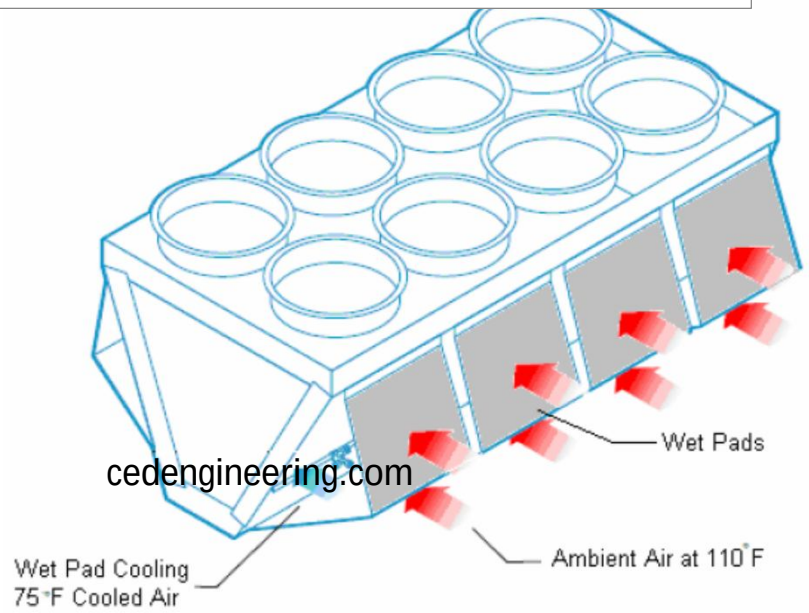
Minichannel heat exchangers (Carrier, 2007)

Task 5: Evaporatively-cooled condensers

- Wet pad or direct coil aspersion
- Important potential in dry climates and at peak conditions.
- Maximum potential gains est. from 15 % (Helsinki, Milan) to 25 % (Athens
- Water consumption to wet the pad

  < water economized from avoided electricity production by power plants.





Task 5: Change in product architecture/design

- Air conditioners in AHU
  - Free cooling, hybrid evaporative, desiccant
- Chiller free cooling
  - Direct operation via the refrigerant cycle
  - By addition of a supplementary water/air coil
- Chiller optimization for non standard operations
  - High temperature difference chilled water design
  - High temperature chillers optimized designs
  - Optimized multiple chiller operation

Task 5: Alternative cooling solutions

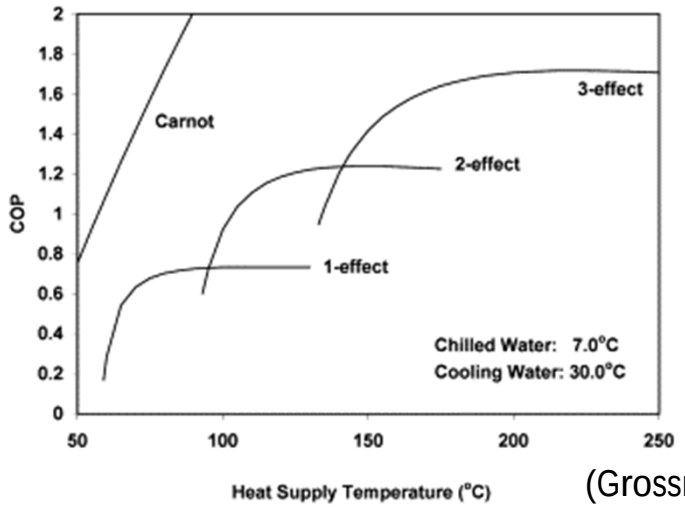
Evaporative cooling

Integration of solar/waste heat

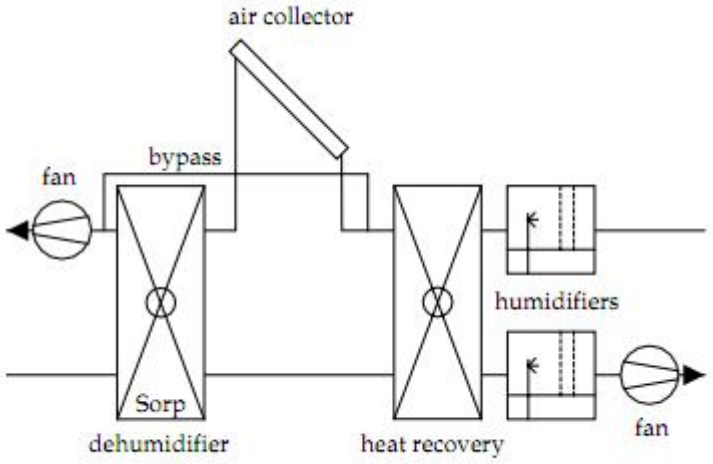
- Ab(ad) machines
- Desiccant cooling (possibly hybrid solution with classical air conditioner)
- Stirling free piston (BNAT)

Other physic principles (B?)NAT

- Magnetocaloric, Peltier, Thermoacoustics



(Grossman, 2002)



source Höfker

Thank you

Questions ?

More information on: www.ecohvac.eu