

# Development of high efficiency CO<sub>2</sub> Heat Pump for domestic hot water

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Chief Engineer of ECO Activities

**SANDEN Manufacturing Europe, France**



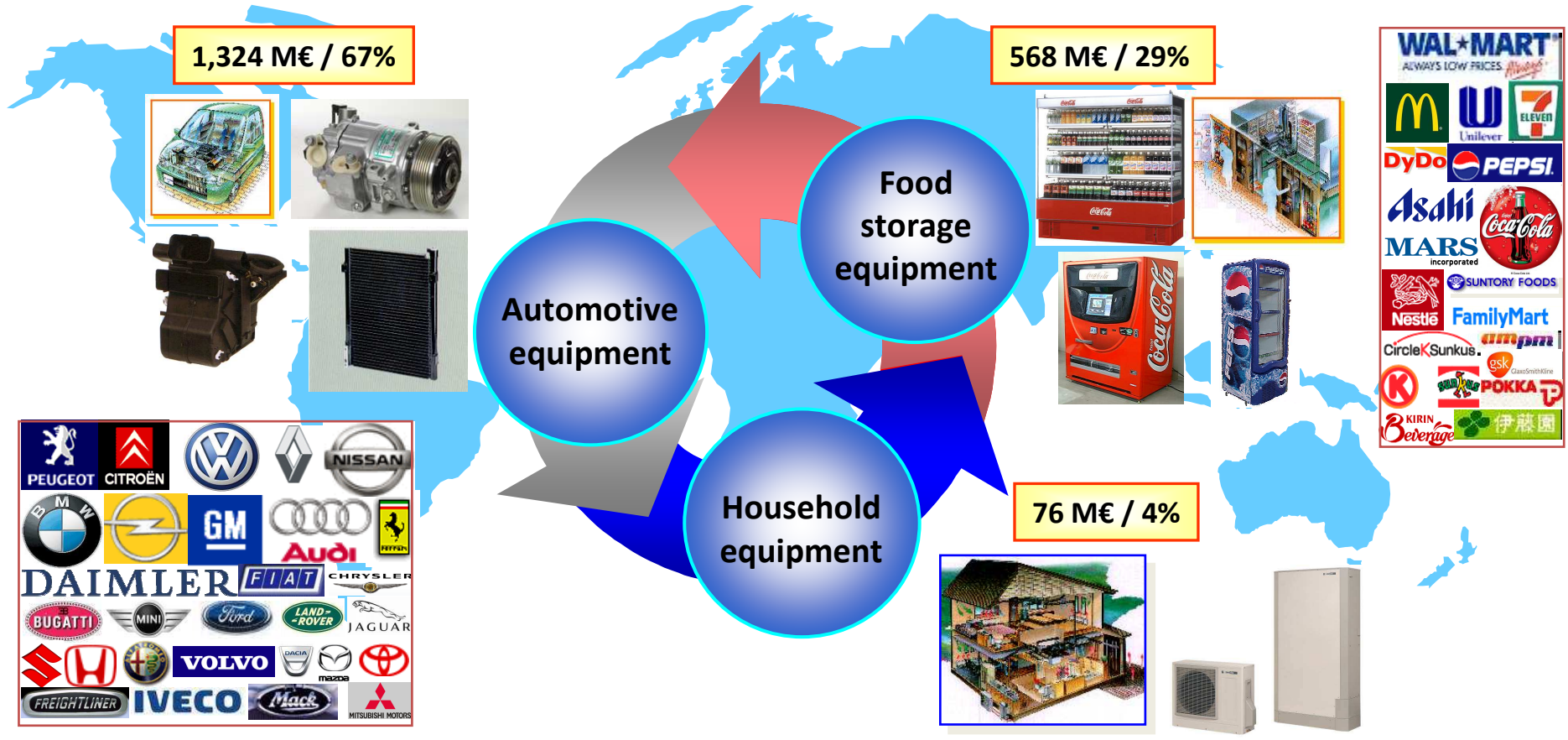
## **Development of high efficiency CO<sub>2</sub> Heat Pump for domestic hot water**

- SANDEN profile
- Regulations and needs
- CO<sub>2</sub> heat pump
- Development
- Learned Lessons from Field
- Improvements integration
- Cost Analysis

# SANDEN Group Profile



Creation	July 30., 1943
Turnover	1 968 M€ in 2010
Employees	8 750 (15 000 with JV)



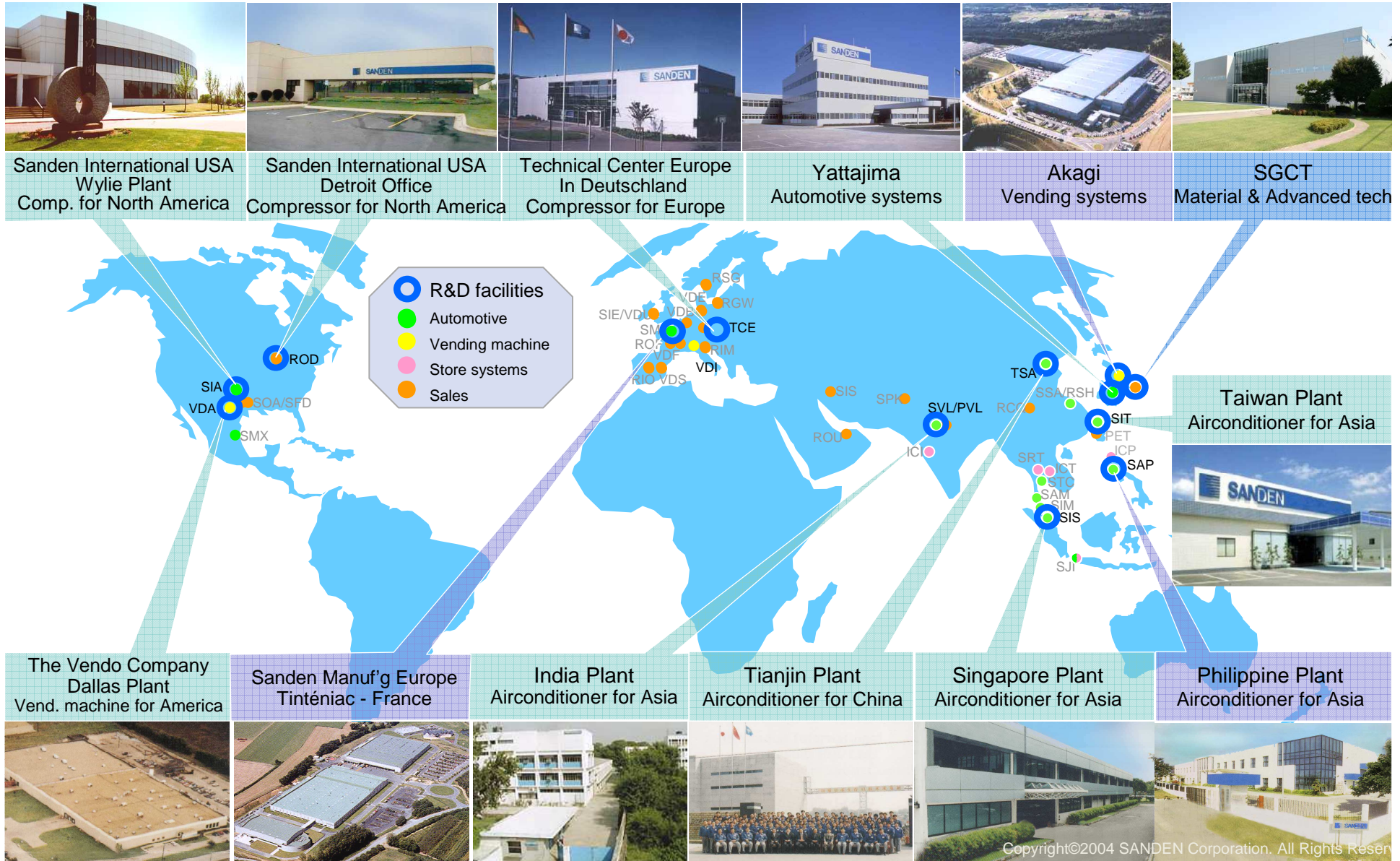
**1/4 of vehicles are air conditioned by Sanden products**  
**1/3 of food storage equipments are Sanden products**



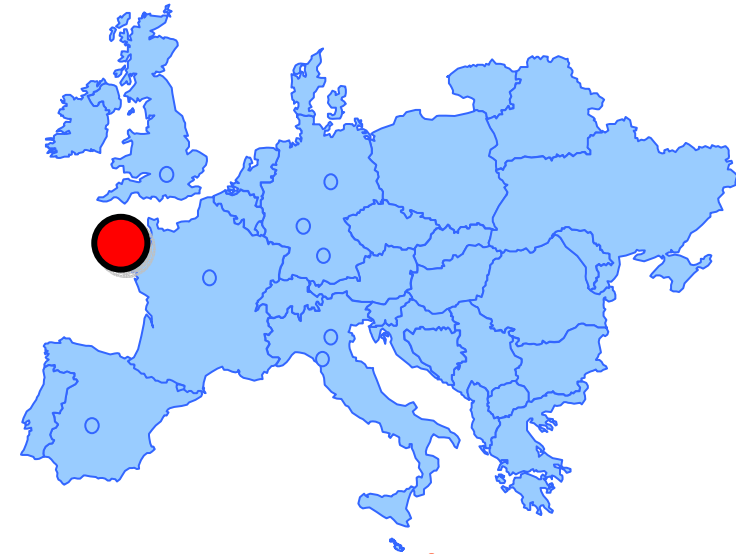
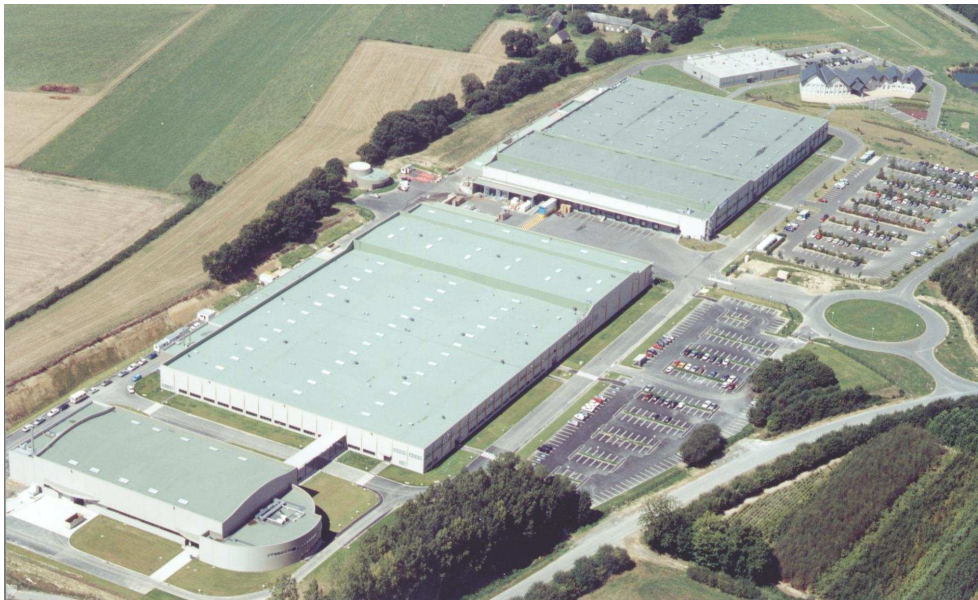
# GLOBAL FACILITIES : Mfg and R&D



With the concept of "Closer to customers"  
Global SCM and development structure with 56 facilities in 23 countries.



# Focus: Sanden Manufacturing Europe (SME)



## >> Tinténac (35)

### MANUFACTURING & DEVELOPMENT (R&D)

#### Activities :

- > Compressors + HVAC
  - 5 assembly lines
  - 180 machining
- 7 die casting units
  - > European Warranty Centre
  - > Heat Pumps
- 1 assembly line

centers



ISO 9001  
VERSION 2000  
ISO/TS 16949  
VERSION 2002

**CREATION : April 1995**

**SOP : June 1996**

**CAPITAL : 33.2 M Euros**

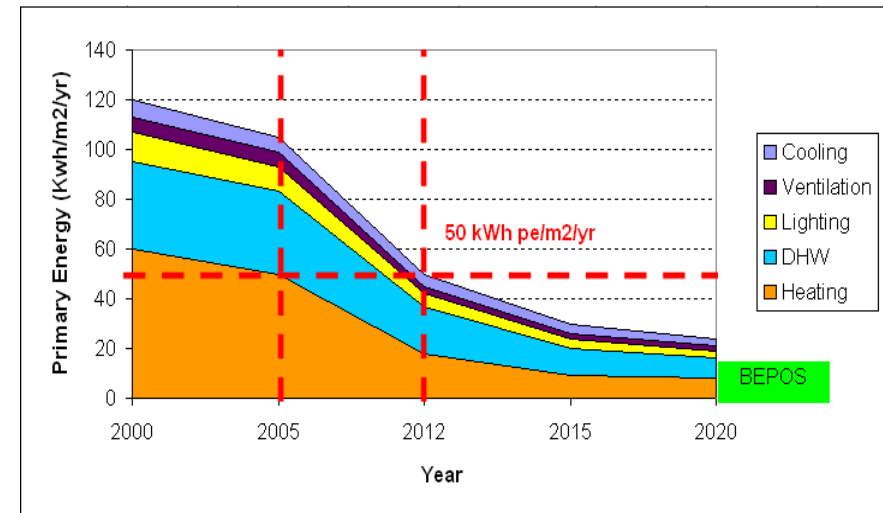
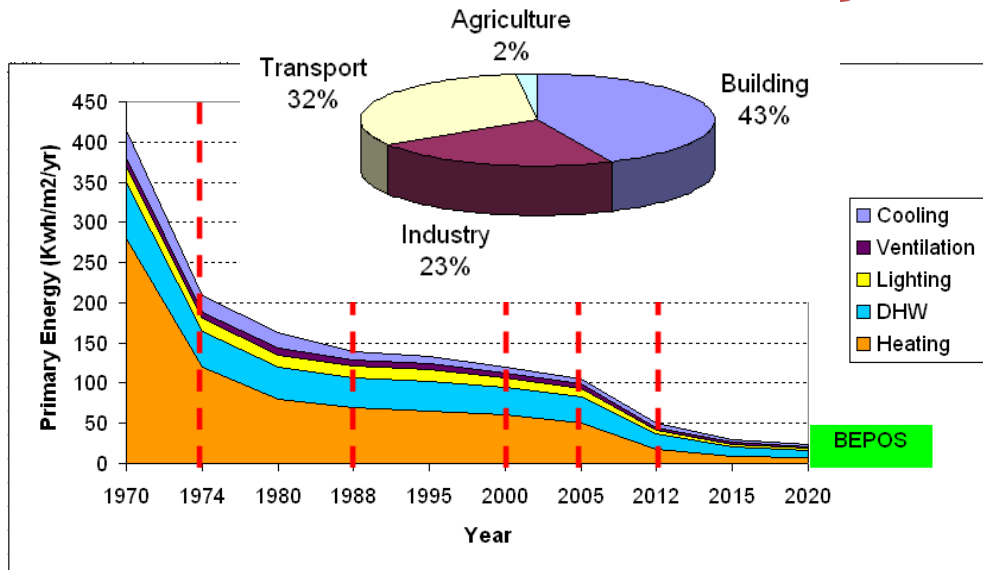
**TO : 216 M€ (FY10)**

**EMPLOYEES : 780 pers**

**TOTAL SURFACE : 22 Hect.**

**BUILDING: 5.4 Hect.**

# Thermal Regulations in France



## EU Target 3 x 20

**France:** Industrial support, customers Incentives & Challenging thermal regulations

## DHW Situation

DHW 15% of Building energy consumption ⇒ 7% of national Energy consumption

Market: 1 million unit /year for DHW

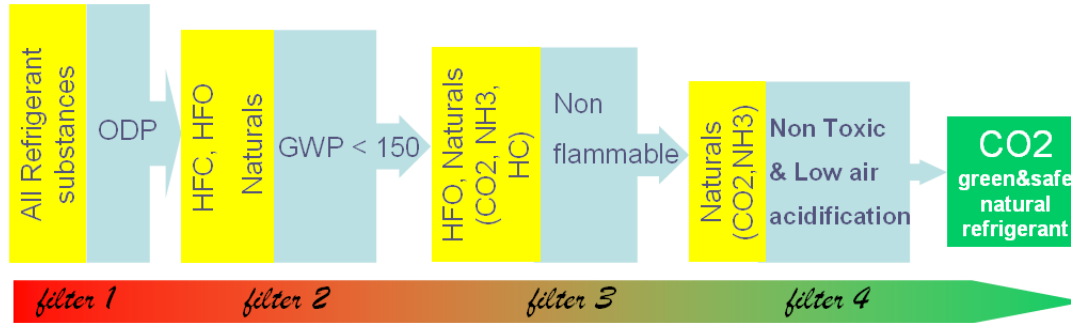
To satisfy RT2012, the Primary Energy consumption for DHW should be reduced to less than (<18 kWh\_pe/m2/yr)

## Lack of technologies for RT2012

- Solar DWH >31 kWh\_pe/m2/yr
- Electric boiler: bad efficiency (<80%) and > 54 kWh\_pe/m2/yr for standard family (50% houses actually)
- Solar DWH combined with Gas > 20 kWh\_pe/m2/yr )  
+ need maintenance + space on the roof
- Thermodynamic DHW ⇒ (>25 kWh\_pe/m2/yr)



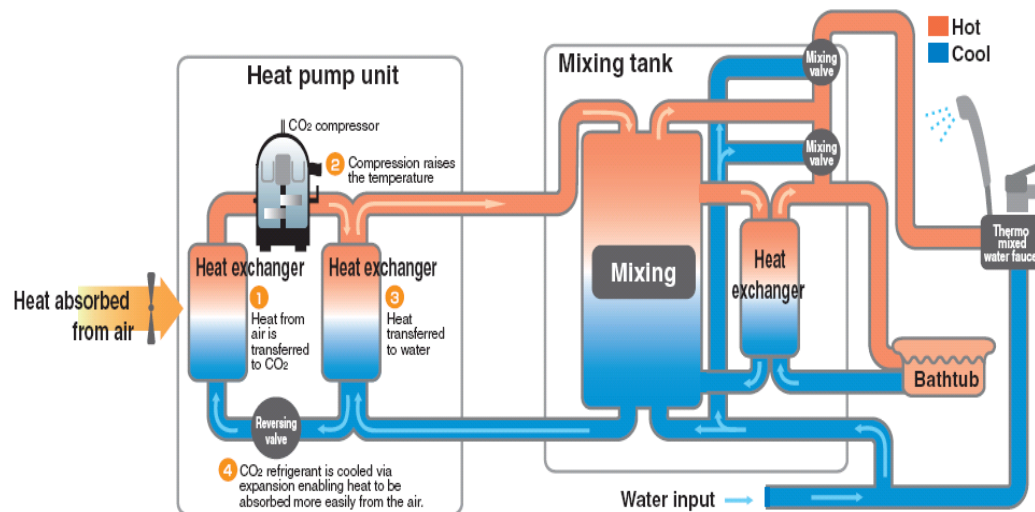
# CO<sub>2</sub> Heat Pump



## Target Applications



### Inside an EcoCute Hot Water System



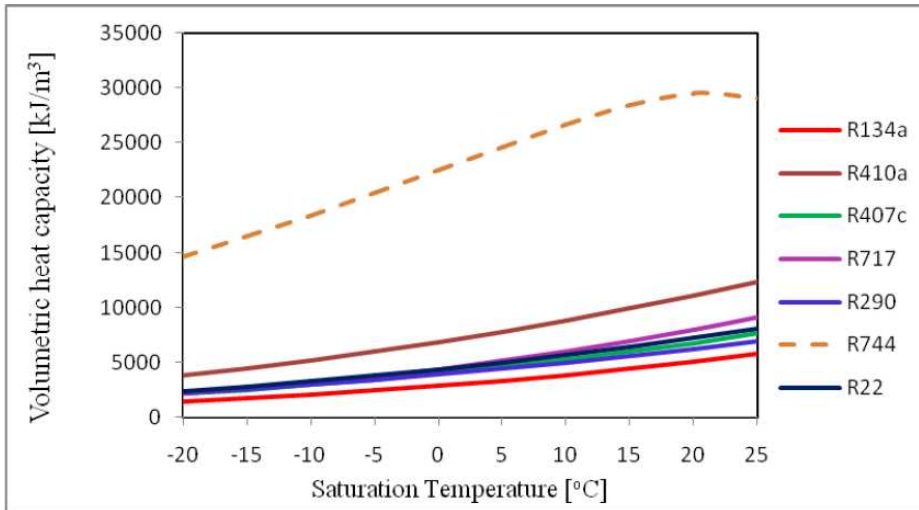
### SANDEN product for Japan

Installation	Outdoor
Heat Capacity	4.5 kW
Tank Capacity	370 Liters
Water T°	55 to 85°C
Water Quality	Soft

**2 Million units sold in Japan since 2000**  
**500k+ units per year**

How EcoCute Uses Heat in the Air to Produce Hot Water

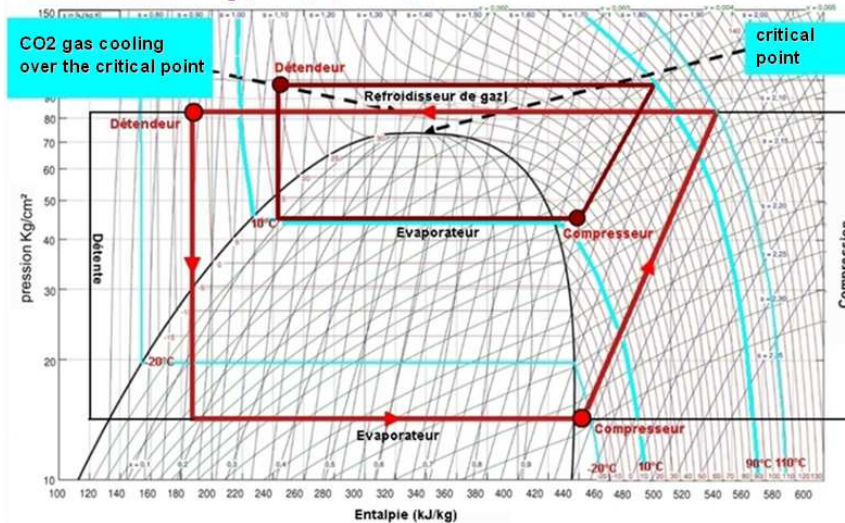
# CO<sub>2</sub> Advantages



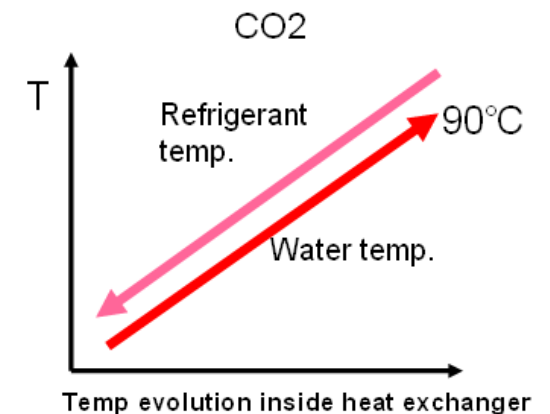
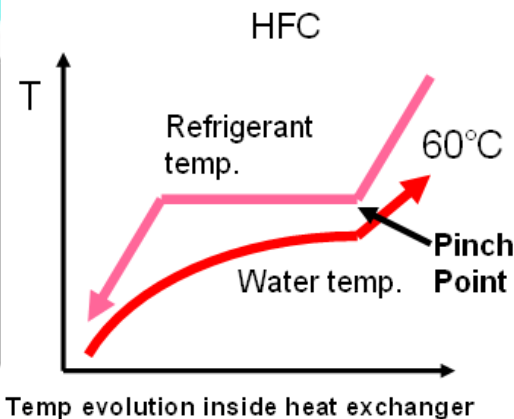
- Best Thermophysical and transport properties after Ammonia
- Transcritical  $\Rightarrow$  Lower performance in AC application for high ambient  $T^\circ$
- Transcritical with  $T^\circ$  glide turns to advantage in water heating application
- The Best for DHW application

CO<sub>2</sub> (R744) cycle with outside air  $T^\circ$  at  $-15^\circ\text{C}$

CO<sub>2</sub> (R744) cycle with outside air  $T^\circ$  at  $+20^\circ\text{C}$



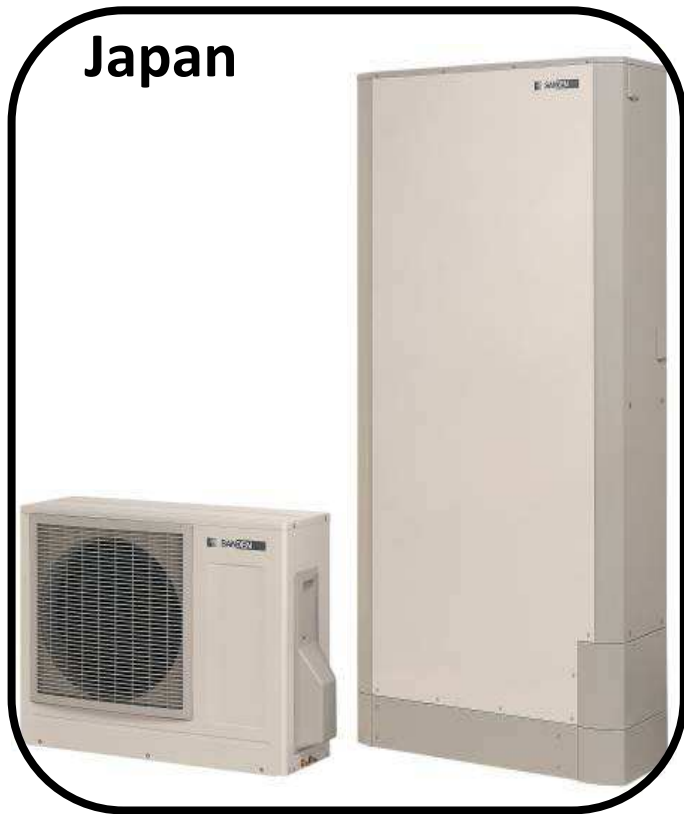
• More efficient in hot water due to absence of Pinch Point



**DHW application: wide range of conditions due the usage of R744 and the Inverter technology**

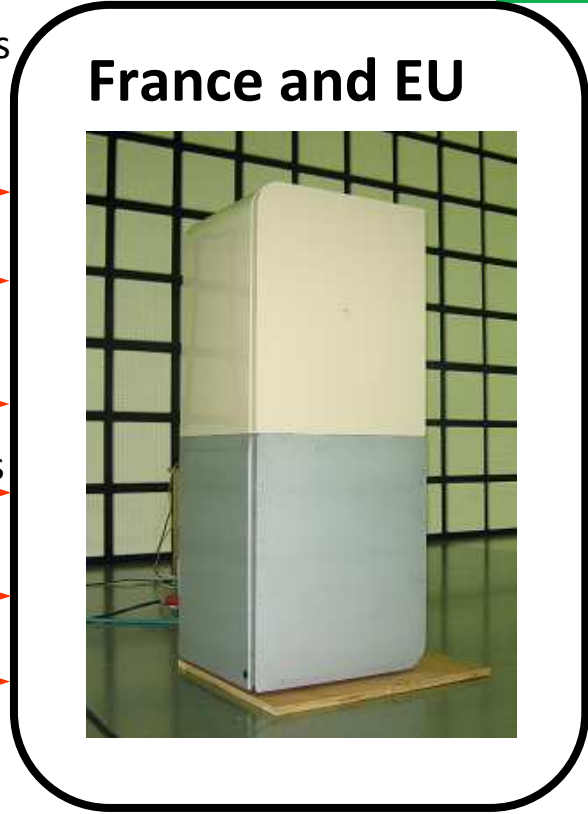
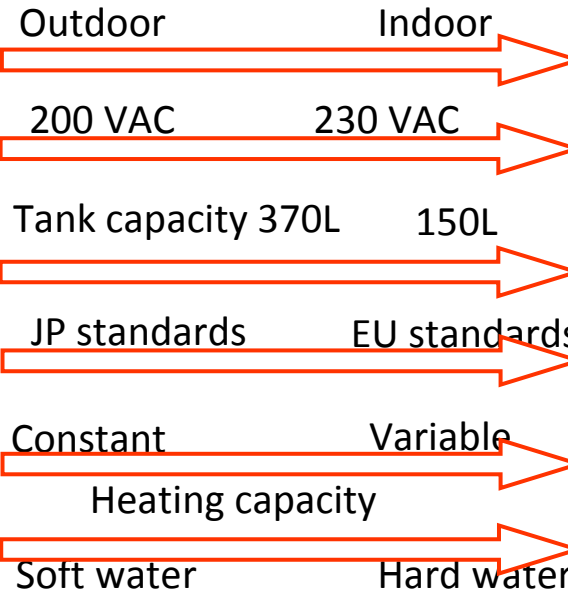


# Development : Adaptation



**Japan**

Split type      1 block -2 Modules



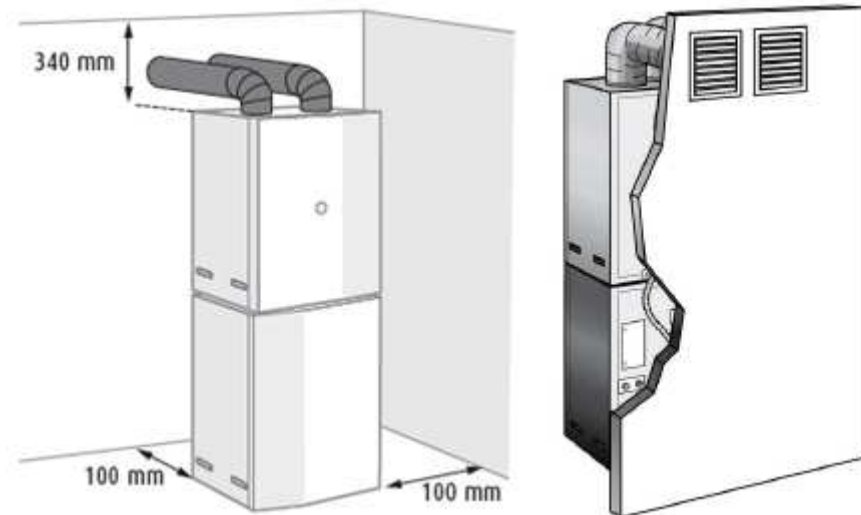
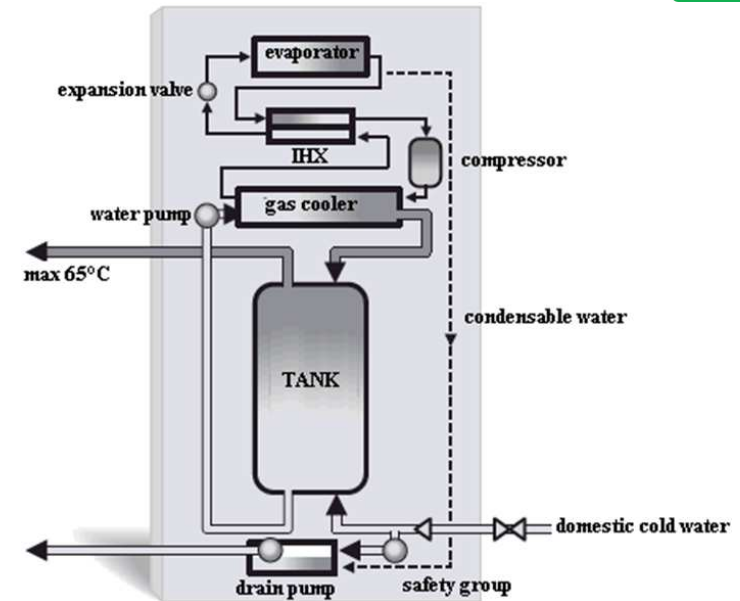
**France and EU**

	2008	2009	2010	2011	2012
Basic Development	→				
Field Tests		→			
Build Assembly line		→			
Product improvement			→		
SOP and Market				→	
Range Extension					→

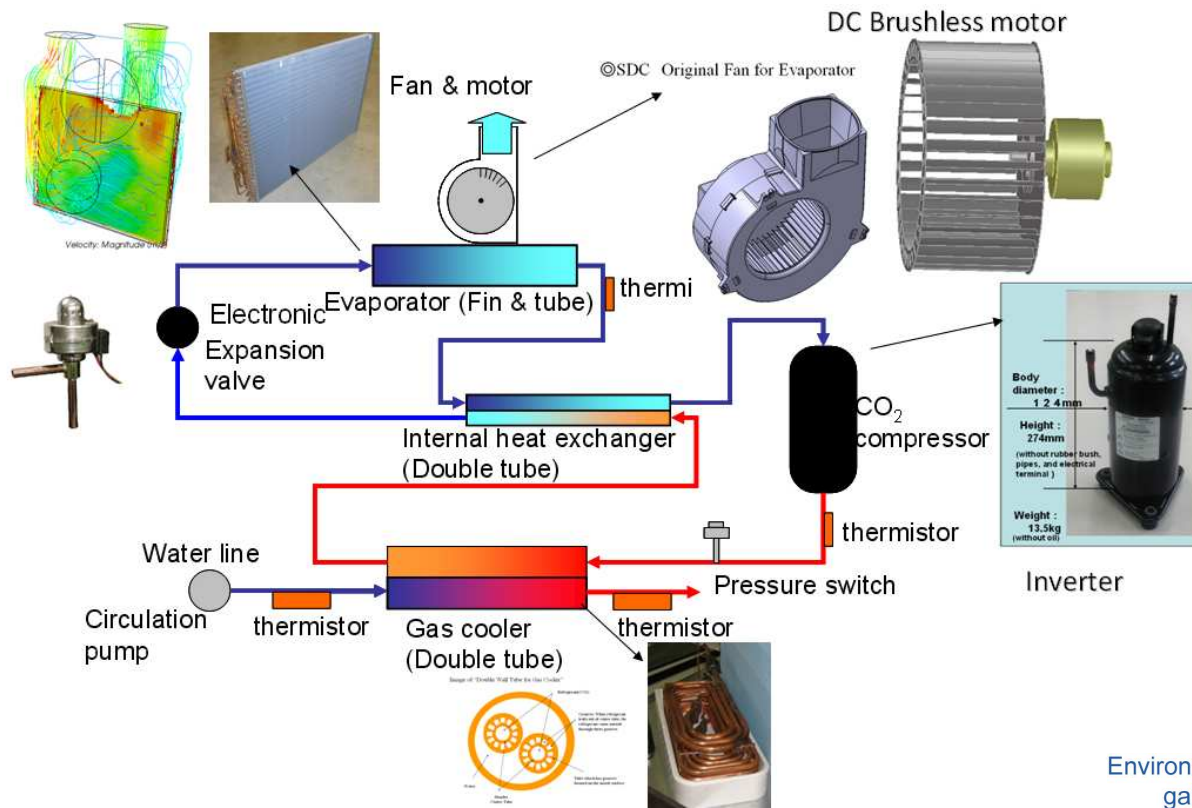
# Development : specifications



-System-	
Installation	Indoor
Power supply	1Φ-230VAC 50 Hz
Annual COP (PARIS)	3.0 (100% HP <b>no elec backup</b> )
Noise	40dBA
Temperature range (Outdoor)	-15 to 43°C (no backup)
Temperature range (Indoor)	Higher than 0°C
-Heat pump unit-	
Refrigerant	CO <sub>2</sub>
Outer size	670X780X680mm
Weight	Less than 76kg
Heating capacity	4.5 and 3.5kW
Duct size	D200mm
-Tank unit-	
Tank volume	150 liters
Outer size	960X780X680mm
Weight	Less than 50kg
-1st control Logic	
Eco mode or Comfort mode	Eco mode: full heat during the night and daily heat if middle T° sensor is cold < 50°C

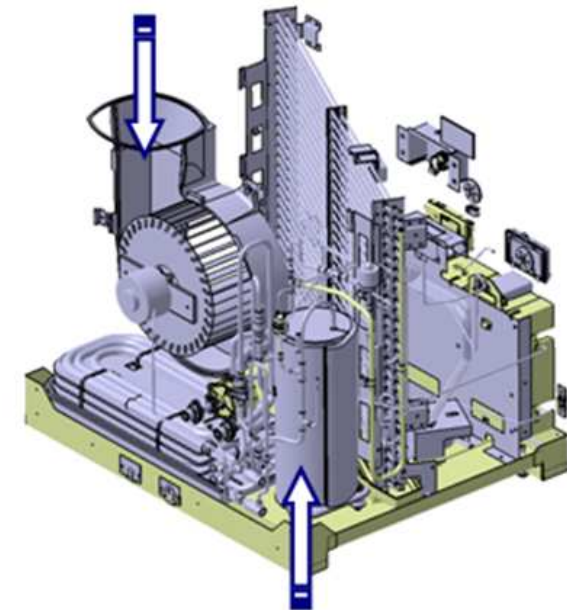


# Development : SANDEN Heat Pump technology

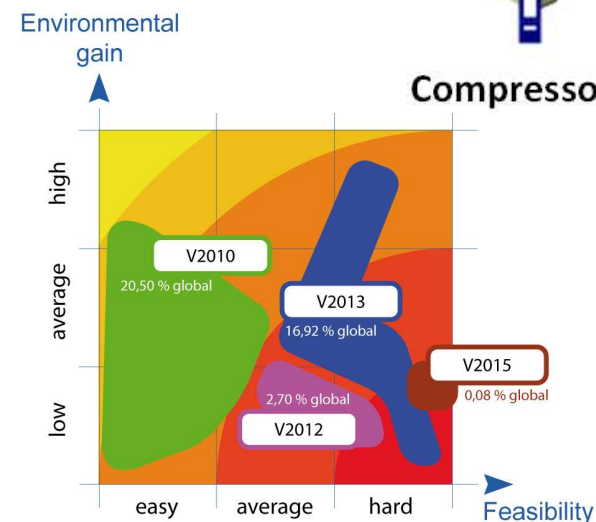


View 1

Motor fan



Compressor



## Life Cycle Analysis study done:

- Bring environment friendly products to the market.
- Evaluate the product total impact on the environment.
- Creation of a Life Cycle Analysis tool to optimize:
  - Design (materials and product performances)
  - Production and logistics (up- and downstream)
  - Life operation and usage (> 80% of impact)
  - End of life solutions



# Specs: Water T°, heat and Tank capacities



## T° and Heat Capacity selection

Peak COP for Proto#1				Heat pump COP					
heat capacity	outlet water temperature	out door temperature			heat capacity	outlet water temperature	out door temperature		
		2°C	7°C	20°C			2°C	7°C	20°C
2.5kW	55°C	2.32	2.75	3.85	2.5kW	55°C	116.0%	105.8%	106.6%
	65°C	2	2.6	3.61		65°C	100.0%	100.0%	100.0%
	75°C	1.97	2.37	3.02		75°C	98.5%	91.2%	83.7%
3.5kW	55°C	2.44	2.71	4.58	3.5kW	55°C	107.5%	99.3%	115.1%
	65°C	2.27	2.73	3.98		65°C	100.0%	100.0%	100.0%
	75°C	2.04	2.26	3.5		75°C	89.9%	82.8%	87.9%
4.5kW	55°C		3.11	4.4	4.5kW	55°C		105.4%	114.3%
	65°C	2.51	2.95	3.85		65°C	100.0%	100.0%	100.0%
	75°C	2.17	2.35	3.44		75°C	86.5%	79.7%	89.4%

	Average
55°C	108.7%
65°C	100.0%
75°C	87.7%

✓ T° 65°C

NO # @ EN-STD  
Conditions 7°C

✓ T° 65°C good compromise for size, COP, water availability, bacteria killing, reduce scaling risks, etc.

## Heat Capacity & COP

Heat capacity	outlet water temperature	COP			Average
		2°C	7°C	20°C	
2.5	55°C	0.951	1.01	0.84	93.6%
	65°C	0.881	0.95	0.91	
	75°C	0.966	1.05	0.86	
3.5	55°C	1	1	1	100.0%
	65°C	1	1	1	✓ Noise 40 dBA
	75°C	1	1	1	
4.5	55°C	1.15	0.96		104.4%
	65°C	1.106	1.08	0.97	
	75°C	1.064	1.04	0.98	X Noise 44 dBA

## Tank capacity selection

Daily DHW requirement (high values)			
Tapping post	Nb of people	Nb liters DHW at 60°C	Nb liters DHW at 65°C
Sink	1-2	25	23
	3-4	35	32
	5-6	45	41
Wash basin	1-2	30	27
	3-4	50	45
	5-6	70	64
Shower	1-2	50	45
	3-4	80	73
	5-6	110	100
Bath	1-2	120	109
	3-4	190	173
	5-6	250	227
Source: Ademe			
	total 4 people	165	150
	total 6 people	225	205

• Tank capacity of 150 liters with a daily boost can cover the need of DHW of a 6 people family

• Heat up of 150 liters in 2h29min in ECO mode

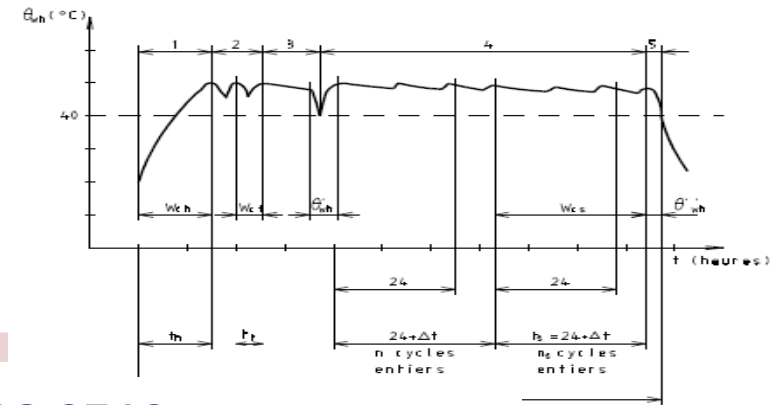


# Development: Lab tests



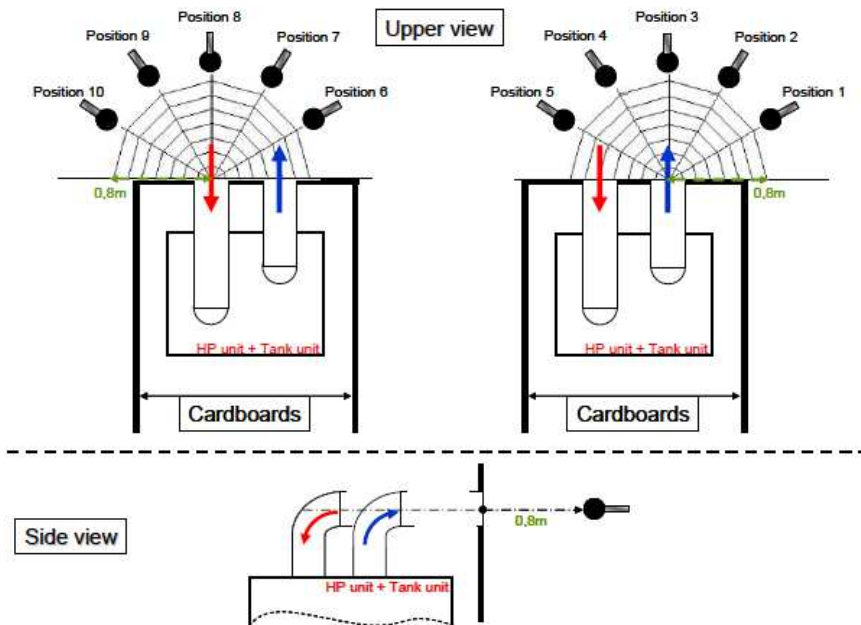
## Tests with Old Standard EN255-3

COP (EN255-3)	7°C	3.4	<b>Best in class</b>
	15°C	4.15	
	20°C	4.3	
Seasonal COP (EN255-3 / 13°C)		4.0	

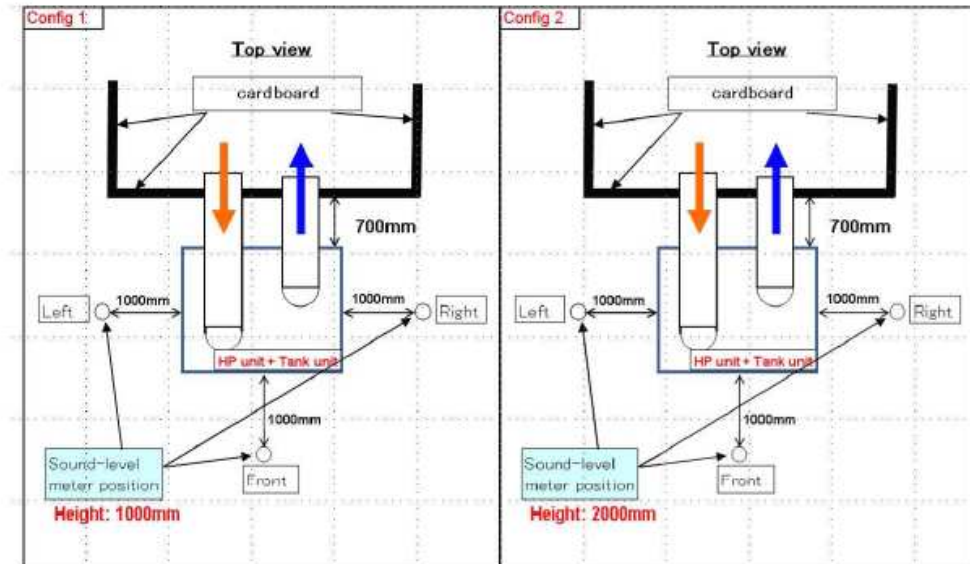


## Acoustic Tests according to ENV 12102 and EN ISO 3746

### Outdoor noise configuration

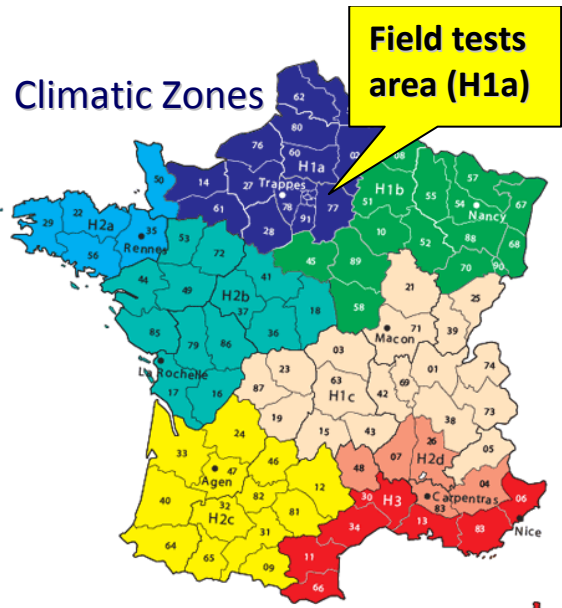


### Indoor noise configuration



Indoor & Outdoor Noise < 40 dBA

# Field Tests



**10 prototypes version 2 installed in 10 Field tests houses**



Site No	Proto No	Family number	First operation mode	Wall
1	proto No2	3WE5	confort	concrete block
2	proto No3	3	confort	concrete block
3	proto No5	4	nigh	store
4	proto No6	3 or 2	nigh	concrete block
5	proto No4	5	confort	concrete block
6	proto No1	1	nigh	concrete block
7	proto No9	3	nigh	store
8	proto No8	4	confort	concrete block
9	proto No7	5	nigh	concrete
10	proto No10	3 or 5	confort	concrete block

**Field Tests Families sizes from 1 to 5 people**



**Field Tests : Nice Weather during installation !!!**



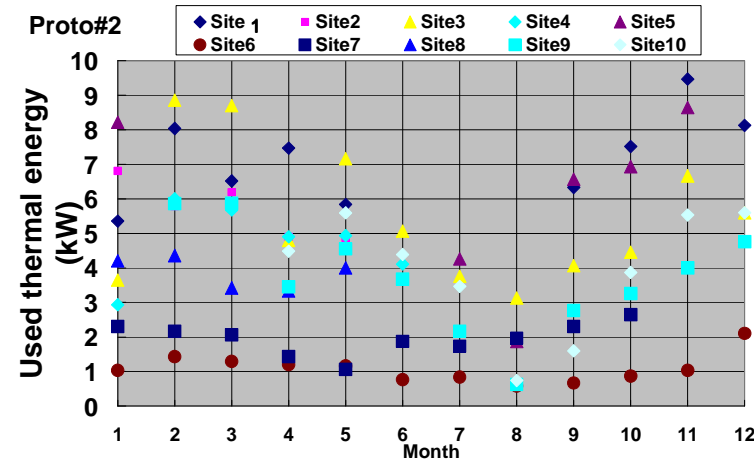
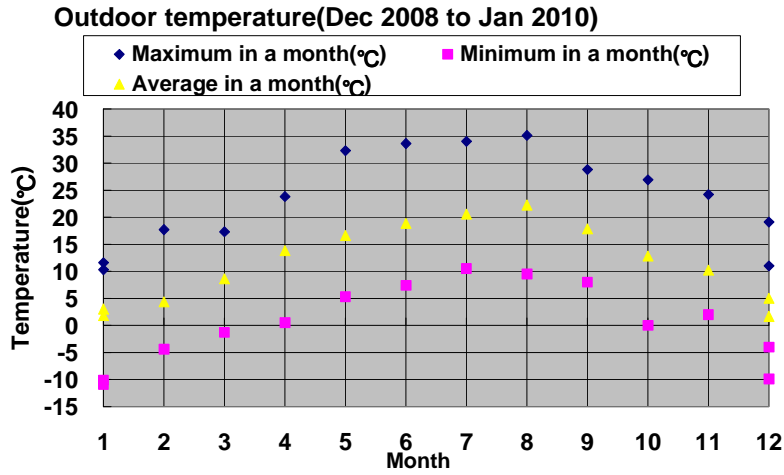
**Good Sign ???**



# Already positive impact on Global Warming !!!

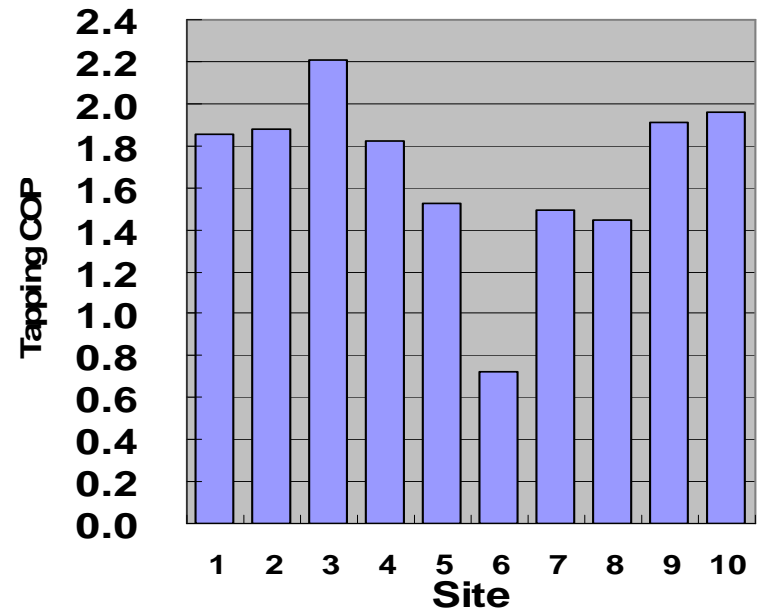
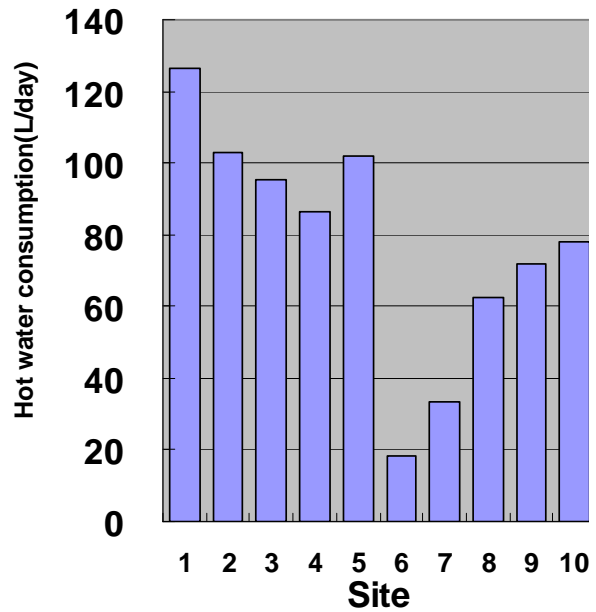


# Field Tests results Proto #2



Outdoor air T°: -11 to 36°C

Hot water consumption decreases significantly during summer



Hot water consumption 18 - 126L/day @ 65°C

Tap annual COP below 2.2  
Improvements required to achieve target 3.0



# Field Tests first conclusions



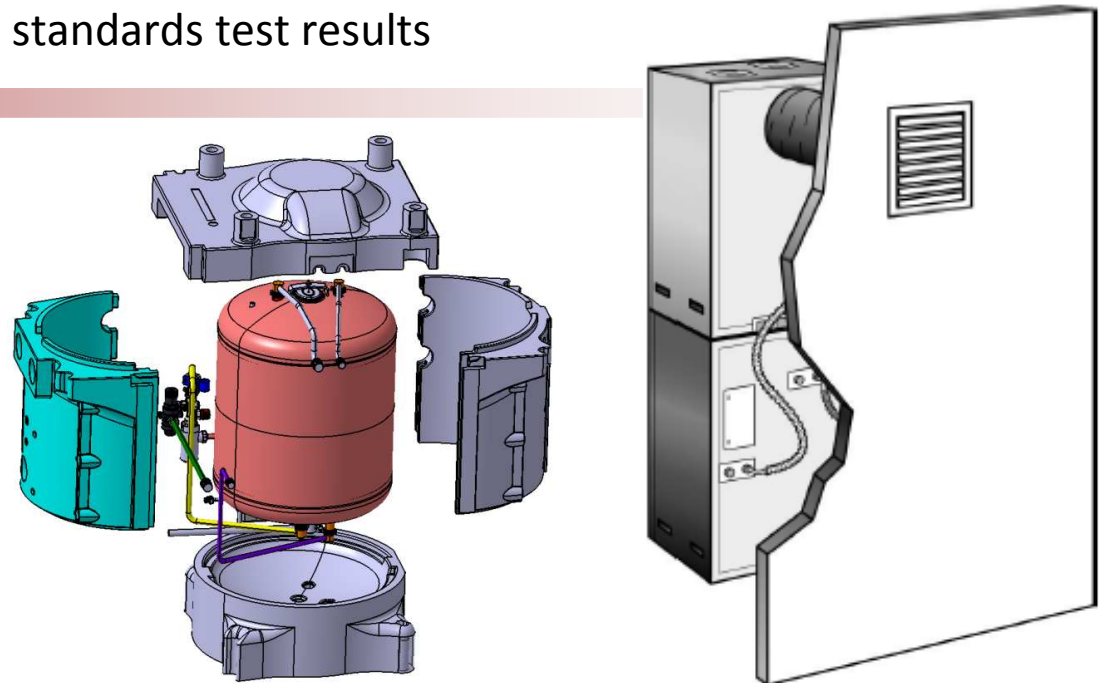
## Main Feedback

- Users satisfaction of hot water availability (2.5 hours to heat up 150 liters in Eco mode)
- Very low Noise level
- No failures and no scaling issues
- The annual Tapping COP depends much more of hot water consumption than outdoor conditions
- Installation without difficulties but it takes time (1 day / installation)
- Efficiency lower than target (3.0) and standards test results

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## Main Improvement items

- Limit HP operation time
- Improve Stratification
- Reduce Heat losses of tank and pipes
- Reduce Installation time
- Aesthetic aspect



# Field Tests first conclusions



## Main Feedback

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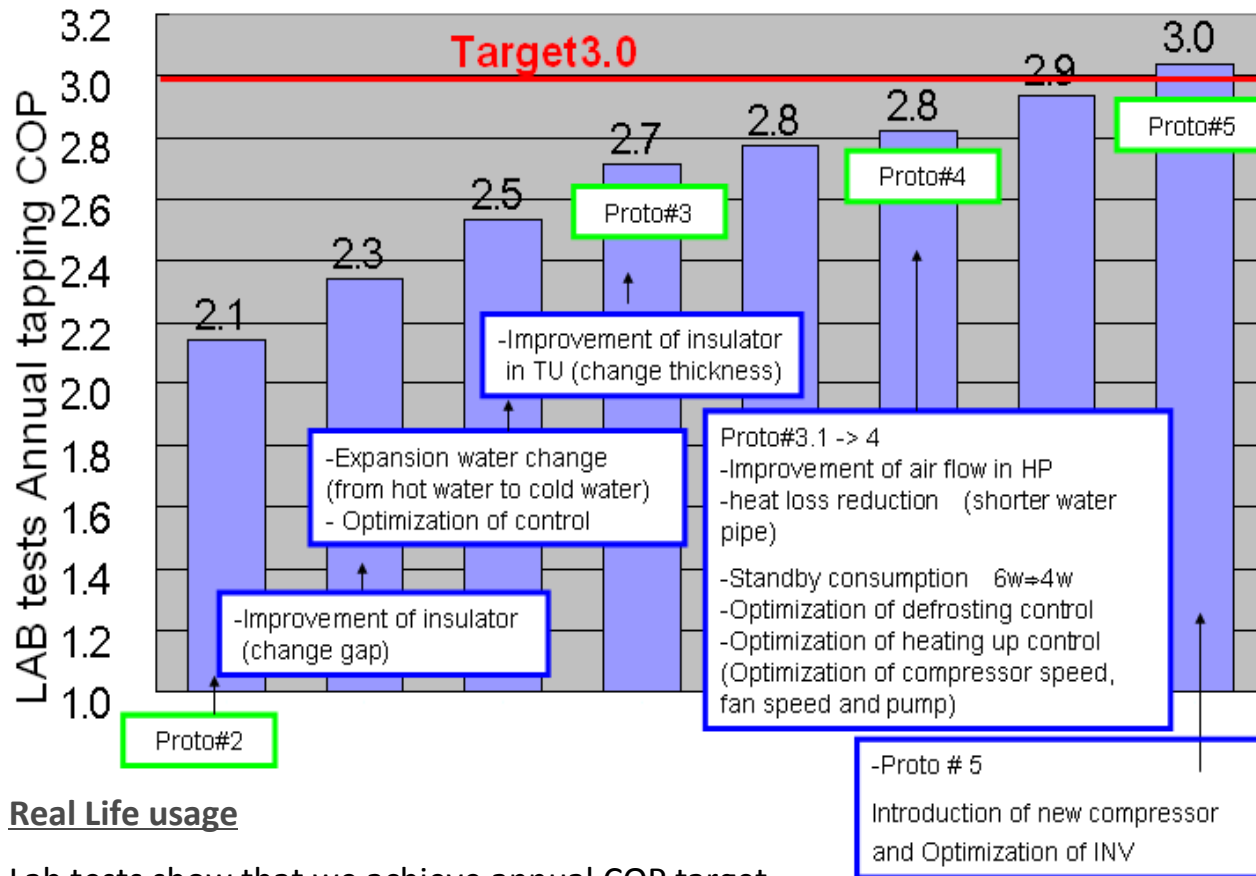
- Reduce Heat losses of tank and pipes

Warm ambiance but bad on COP !!!



Some chicken eggs found on one prototype

# Performance Target achieved



**COP 3.2 & Pes = 22 W**

**Annual consumption  
16 kWh p\_e/m2/ yr (H1)  
13 kWh p\_e/m2/ yr (H3)**

## Real Life usage

Lab tests show that we achieve annual COP target

**COP (Eco mode) close to 3 with Proto#5 and for the final product (Dec2011)**

**Target achieved ✓**

Standard EN16147 with air T° at 7°C with cycle L

**COP = 3.2** (cycle L ~ 100 liters tapping) and Pes = 22 W

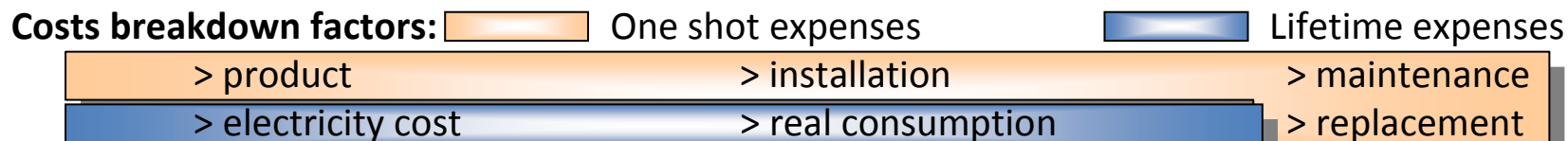
# COST: CO<sub>2</sub> DHW HP vs other technologies



3 cases studied (all units /year):

\* source: benchmarking & ADEME data

Housing	DHW @ 40°C	DHW @ 60°C	Incl. syst. losses	Elec. Consumption (e. boiler)
Family of 4 people	200 l	120 l	144 l @ 60°C	3051 kWh
Family of 6 people	300 l	180 l	216 l @ 60°C	4577 kWh
Small tertiary appl.	500 l	300 l	360 l @ 60°C	7627 kWh



**Competing electrical technologies:**

	Calories source	Free Calories	COP (EN 16147)
Electrical boiler	N/A	No	0.8
High quality HFC DHW HP	Ambient air	No	2.5 @7°C
	Exhaust air	Yes	2.3 @20°C
	Outside air	Yes	2.5 @7°C
Solar water heater	Sun	Yes	N/A (~ 2.2)
SANDEN CO <sub>2</sub> DHW HP	Outside air	Yes	3.2 @7°C

**New Standard EN16147 (PrEN255-3)  
COP 3.2 (Best in the Market)  
Conditions 7°C air T° and Cycle L**

**SPF for CO<sub>2</sub> system  
is set up with a  
DHW T°=65°C !!  
Other systems: 52.5°C**

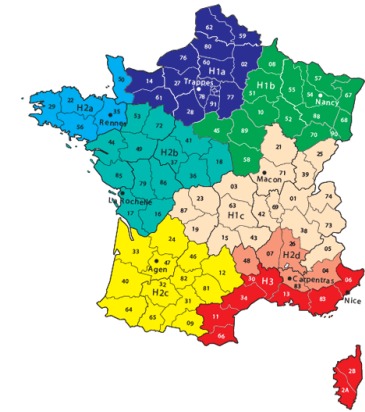


# COST: CO<sub>2</sub> DHW HP vs other technologies

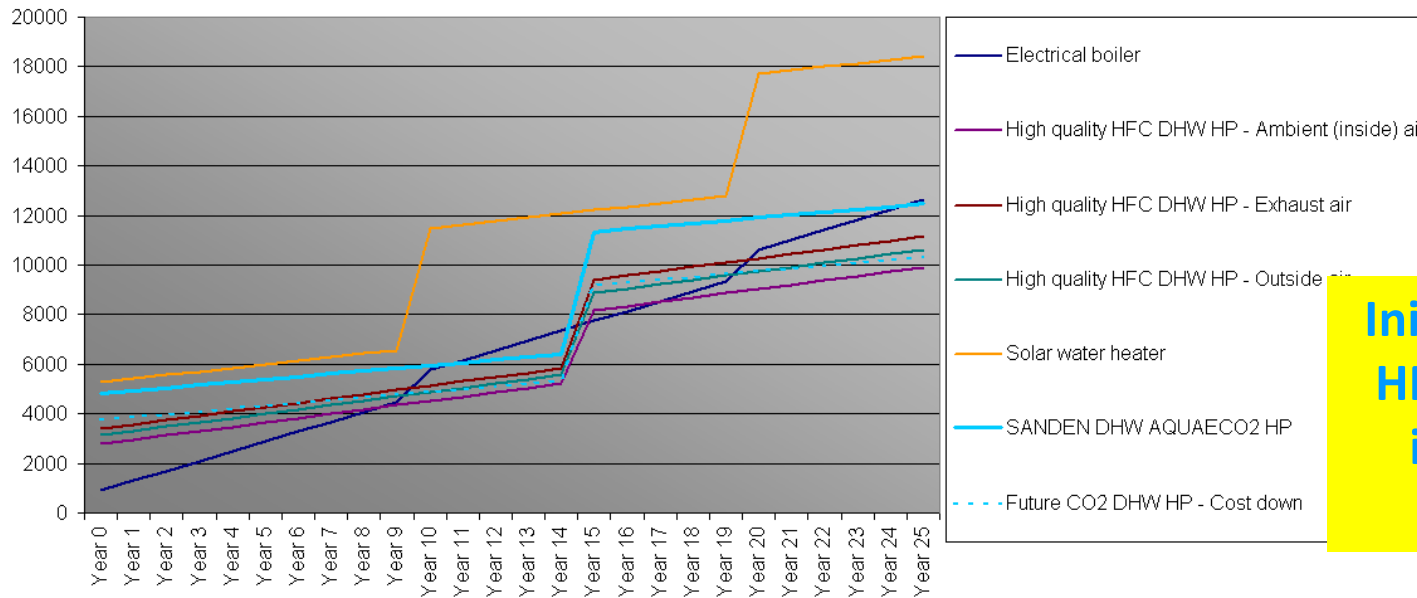


## Example of France: H2b climate case (mild)

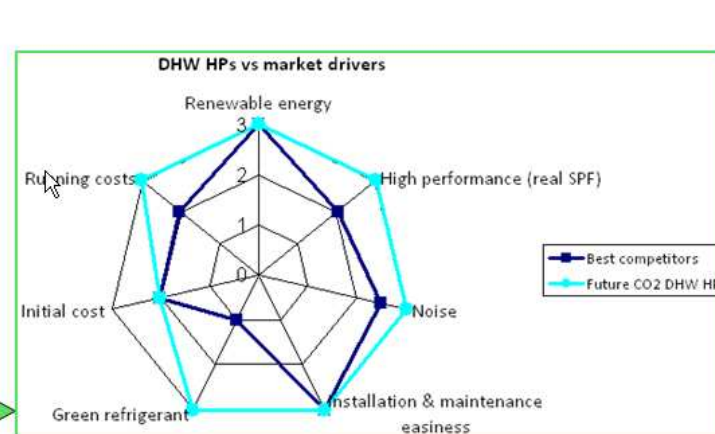
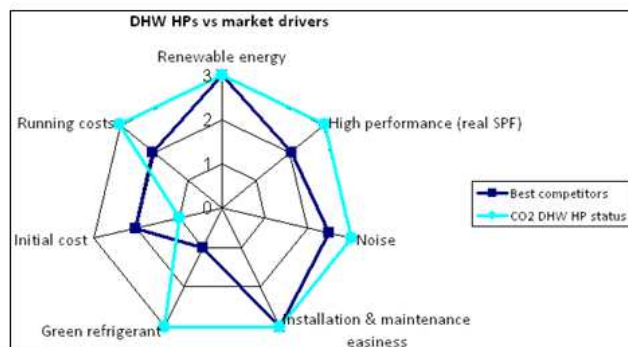
\*source: Eurostat 2011 for electricity prices; market survey for products, installation and maintenance costs



Real DHW cost per technology type for a 4 people family



**Initial cost of CO<sub>2</sub> DHW HP is compensated by its very low energy consumption.**

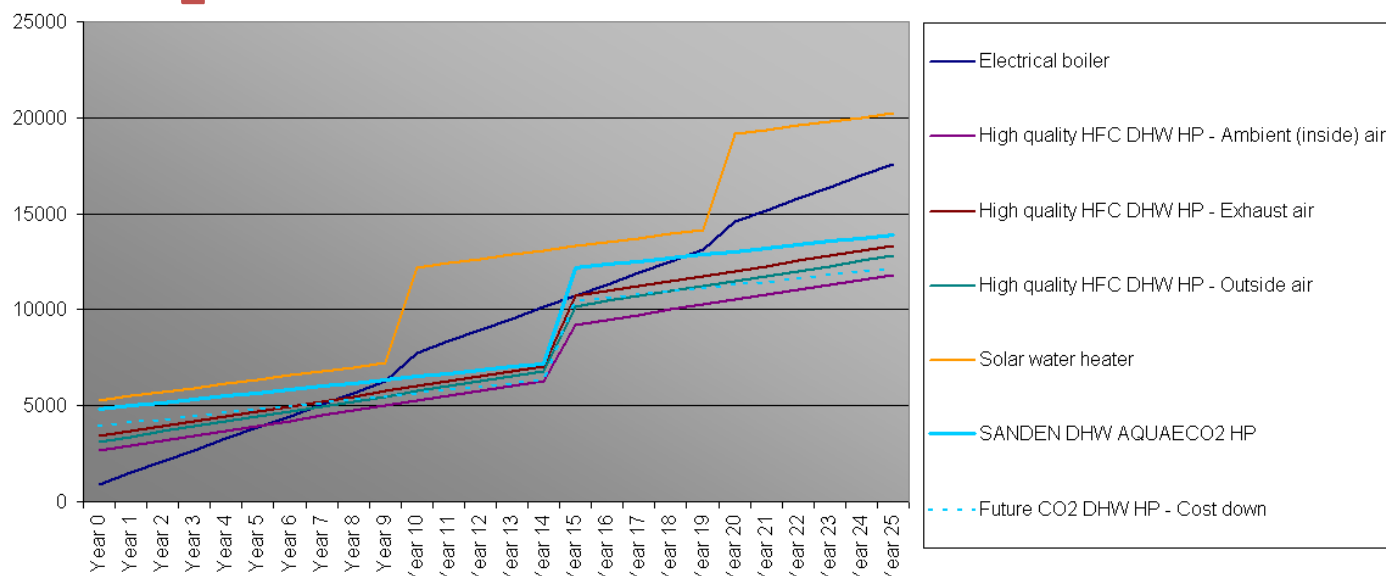


Positive evolution through:  
 > recognition of CO<sub>2</sub> efficiency  
 > volume effect

# COST: CO<sub>2</sub> DHW HP vs other technologies

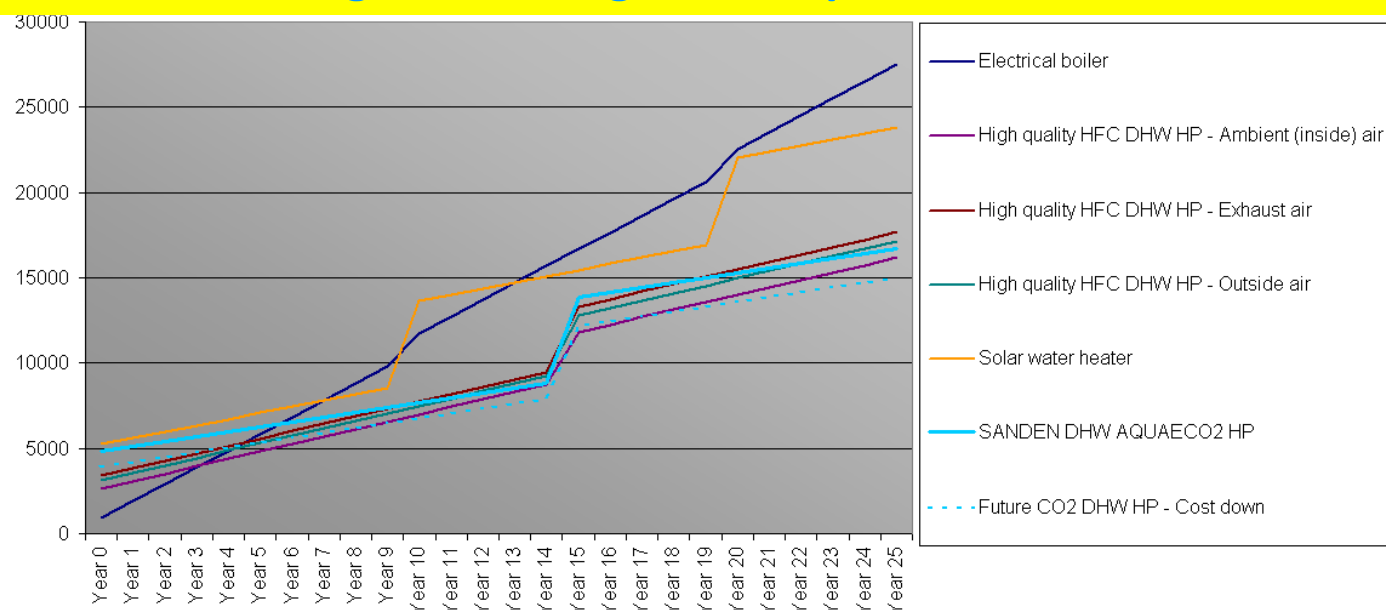


**Large family  
(6people)**



**DHW high consumption (300 to 500l @ 40°C per day) allows CO<sub>2</sub> DHW HP to get advantage vs competitors.**

**Small  
Tertiary**



# Conclusion



Market drivers	Best competitors	CO <sub>2</sub> DHW HP status
Renewable energy	Green	Green
High performance (real SPF)	Orange	Green
Noise	Orange	Green
Installation & maintenance easiness	Green	Green
Green refrigerant	Red	Green
Initial cost	Orange	Red
Running costs	Orange	Green

Red → Green (for cost)  
 Product range  
 Automotive experience  
 Cost savings on construction





faster to Europe

**natural refrigerants**

11-12 October 2011 in Brussels

Thank you for your attention



Contact: [info@sanden-europe.fr](mailto:info@sanden-europe.fr)