Development of a high temperature CO2 Heat Pump for space heating

Dr.-Ing. Georges KHOURY
SANDEN Manufacturing Europe, France
5-7 Nov 2012
Development of a high temperature CO2 Heat Pump for space heating

- SANDEN profile
- House heating in France
- CO₂ as Refrigerant
- CO₂ Heat Pump for space heating
- Test Results
- Cost Analysis
- Conclusions
SANDEN Group Profile

- **Creation**: July 30, 1943
- **Turnover**: 2,041 M€ in 2011
- **Employees**: 8,750 (15,000 with JV)

- **1,364 M€ / 67%**
- **595 M€ / 29%**
- **82 M€ / 4%**

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

- **Core technology**: Heating, Cooling

**Products**:
- **Automotive equipment**
- **Food storage equipment**
- **Household equipment**
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)

>> Tinténiac (35) in Bretagne

MANUFACTURING & DEVELOPMENT (R&D)
Activities:
  > Compressors + HVAC
    - 5 assembly lines
    - 180 machining centers
    - 7 die casting units
  > European Warranty Centre
  > Heat Pumps
    - 1 assembly line

CREATION : April 1995
SOP : June 1996
CAPITAL : 33.2 M Euros
TO : 207 M€ (FY11)
EMPLOYEES : 800 pers
TOTAL SURFACE : 22 Hect.
BUILDING: 5.4 Hect.
2. Heating technologies repartition in France

- **Houses**
  - Old dwellings:
    - 1990: 10.6%, 8.8%, 7.1%
    - 2000: 29.0%, 38.2%, 49.2%
    - 2010: 25.4%, 22.2%, 19.0%
  - Recent dwellings:
    - 1990: 9.0%, 7.7%, 5.9%
    - 2000: 44.0%, 43.8%, 47.6%
    - 2010: 24.4%, 28.8%, 33.2%

- **Apartments**
  - Old houses:
    - 1990: 13.0%, 15.6%, 25.7%
    - 2000: 19.1%, 11.0%, 5.6%
    - 2010: 13.1%, 11.0%, 5.5%
  - Recent dwellings:
    - 1990: 9.0%, 7.7%, 5.9%
    - 2000: 44.0%, 43.8%, 47.6%
    - 2010: 24.4%, 28.8%, 33.2%

- **Increase of electric systems share**

- **Old houses**: mainly Gas and Fuel Boilers
• High T° HP is an alternative to fuel and gas boilers

• It allows to reduce significantly CO₂ emissions

• And reduces the energy bill
CO₂ (R744) has a big advantage
A refrigerant that climbs easily to high Temperature

2. Heating technologies repartition in France

A heating system with an outlet below 65°C covers only 34% of the market.

Propose a solution that covers at least 90% of the market!

Analysis of the existing requirements in case of refurbishment

Only 34% of the market is accessible for HP below 65°C
3. CO₂ (R744) as refrigerant

- CO₂ green & safe natural refrigerant
- High efficiency
- Non flammable
- Non-toxic & Low air acidification

Target Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>CO₂ Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Conditioning</td>
<td>Ice Cream Conservation</td>
</tr>
<tr>
<td>Beverage Cooling</td>
<td>Ice Machines</td>
</tr>
<tr>
<td>Dryers</td>
<td>Display Cases</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td></td>
</tr>
</tbody>
</table>

Inside an EcoCute Hot Water System

- Heat pump unit
- Mixing tank
- Heat exchanger
- CO₂ compressor
- Compression raises the temperature
- Heat transferred to water
- CO₂ refrigerant is cooled via expansion enabling heat to be absorbed more easily from the air
- Mixing of hot and cool water
- Hot and cool water available
- Thermostatic water faucet
- Water input

SANDEN product for Japan

<table>
<thead>
<tr>
<th>Installation</th>
<th>Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Capacity</td>
<td>4.5 kW</td>
</tr>
<tr>
<td>Tank Capacity</td>
<td>370 Liters</td>
</tr>
<tr>
<td>Water T°</td>
<td>55 to 85° C</td>
</tr>
<tr>
<td>Water Quality</td>
<td>Soft</td>
</tr>
</tbody>
</table>

3 Million units « Ecocute » sold in Japan since 2000
500k+ units per year

How EcoCute Uses Heat in the Air to Produce Hot Water
Aquaeco2 - CO₂ HP for DHW in EU (domestic hot water)

- Aquaeco2 the most efficient of the market and the most silent (40dBA)
- COP 3.42 @ 7 °C EN16147 (LCIE)
- T°water storage @ 65°C
- DHW solution for RT2012 (French new thermal regulation for buildings)
- COP Field Tests measurements

COP Aquaeco2 (2.7) = 2 x COP classical (R134a) (data ADEME-INPAC 2012)
4. CO$_2$ for space heating?

CO$_2$ (R744) is the best for DHW

Modest performance for space heating with a classical system

Tin=10$^\circ$ C & Tout=70$^\circ$ C
COP = 4.2 (high)

Tin=45$^\circ$ C & Tout=70$^\circ$ C
COP = 2.1 (medium)
4. CO₂ for space heating?

Sanden CO₂ system: New cascade and New control

The upper stage recovers the excess of heat in the first stage through an intermediate heat exchanger (refrigerant/refrigerant).

Sanden reinvents the CO₂ with a new patented technology.
### Systems comparison

<table>
<thead>
<tr>
<th></th>
<th>Classic system</th>
<th>Injection system (1GC)</th>
<th>Classic cascade system (1GC)</th>
<th>2 stage system (2GC)</th>
<th>New cascade system (2GC) + classic control</th>
<th>New cascade system (2GC) + new control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heating</strong></td>
<td>Heating</td>
<td>Heating</td>
<td>Heating</td>
<td>Heating</td>
<td>Heating</td>
<td>Heating</td>
</tr>
<tr>
<td><strong>Maximum heating capacity</strong> (Priority:COP)</td>
<td>5.3kW</td>
<td>7.2kW</td>
<td>8.4kW</td>
<td>5.7kW</td>
<td>7.8kW</td>
<td>8.6kW</td>
</tr>
<tr>
<td><strong>Maximum heating capacity</strong> (Priority:heating capacity)</td>
<td>5.3kW</td>
<td>7.2kW</td>
<td>9kW</td>
<td>6kW</td>
<td>8.1kW</td>
<td>10.4kW</td>
</tr>
<tr>
<td><strong>COP</strong></td>
<td>2.1</td>
<td>2.3</td>
<td>2.3</td>
<td>2.6</td>
<td>2.6</td>
<td>2.6</td>
</tr>
</tbody>
</table>

![Graphs showing pressure vs. enthalpy for different systems](image)

- Possibility to make space heating and produce DHW simultaneously

A Sanden Cascade system with a new specific control logic boost the CO\(_2\) efficiency and heat capacity for space heating application.

Sanden reinvents the CO\(_2\) with a new patented technology
With CO₂ Heat Pump, High Temperature heating is feasible and production of DHW without back-up
Project: CO₂ air/water High Temperature Heat Pump

✓ Consortium in Japan with 3 partners:
   1) Central Research Institute of Electric Power Industry
   2) Hokkaido Electric Power Co., Inc.
   3) Sanden Co. Ltd

✓ Target:
Introduce to market a high Temperature CO₂ Heat pump.
Propose a solution to replace central boiling heating systems. Such systems with water loop are popular in the North of Japan.
Development of CO₂ HP

Result: Product since February 2012 in Japanese market

CO₂ High Temperature air/water heat pump for central heating

<table>
<thead>
<tr>
<th>MODEL</th>
<th>EDS-C90A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Capacity*</td>
<td>kW</td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>mm</td>
</tr>
<tr>
<td>Length</td>
<td>mm</td>
</tr>
<tr>
<td>Depth</td>
<td>mm</td>
</tr>
<tr>
<td>Weight</td>
<td>kg</td>
</tr>
<tr>
<td>Noise</td>
<td>dBA</td>
</tr>
<tr>
<td>Outlet Temperature</td>
<td>℃</td>
</tr>
</tbody>
</table>

*Temperature Air 7℃
Temperature water inlet 30℃

Remote controller
5. Tests of CO2 HP

Field Tests in Japan

Individual House 120 m² according to new thermal regulation (equivalent to BBC in France)

Kiyota, Sapporo city
Field Tests in France since February 2012

- 3 different areas
- Local Installers without any special previous training
- Positive feedback & COP ~2.5
- Need to optimize the control
In space heating mode, Sanden CO₂ becomes as efficient as HFC in TOP market products

For high temperature space heating, R744 reaches the classical HFC level

In case of a multifunction heat pump (space heating & DHW), R744 would be more efficient than HFC

GWP R744 = 1
GWP (HFC)~2000 & HFC represent 3% of the « Global Warming »
6. Cost Analysis for high $T^\circ$ HP in case of boiler replacement

**Annual average cost for a 100m² house in France**

<table>
<thead>
<tr>
<th>Fuel boiler</th>
<th>Electric</th>
<th>CO2 HP</th>
<th>Savings HP/boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>2295 €</td>
<td>3376 €</td>
<td>1350 €</td>
<td>945 €</td>
</tr>
</tbody>
</table>

With an efficient HT heat pump, the savings amount for an average 100m² house is around 945€

HP (11 kW) Investment of 9000 € (after Tax credit recovery)
Fuel Boiler ~5000 € (including installation with all taxes included)
ROI = 8 years (replace existing boiler)
ROI = 4 years (new installation – versus a new boiler)

The average energy consumption for house heating is estimated at 255 kWh/m².year
It is equivalent to an average annual consumption of 2 550 liters of fuel for a 100 m² dwelling (Source ANAH).
Conclusions

- CO₂ HP a green & safe alternative for gas and fuel boilers
- CO₂ global efficiency is much higher than HFC
- Comfort is ensured at very low outside temperatures
- First product on worldwide level
- ROI starting from 4 years
Thank you for your attention