EXPERTISE HUB FOR ENERGY-EFFICIENT COOLING & HEATING IN EUROPEAN SUPERMARKETS
SuperSmart is a EU funded Horizon 2020 Project

- Duration: 36 month,
- Start: 1st of February 2016
- Project Partners:
  - SINTEF (coordinator)
  - Shecco
  - CNR
  - Umweltbundesamt (Uba)
  - KTH
  - TUBS
  - CIRCE
  - Energija doo
  - IIR
SuperSmart wants to help food retailers to:

- Reduce the energy use & environmental footprint
- Increase the economic benefits by saving energy, servicing & maintenance costs
- Use the best mature technology
- Comply with all regulations & environmental commitments
Current status:

**Systems** for efficient and integrated heating and cooling solutions for the retail sector are available!

**R744 systems** are the preferred option for new installations.

They are not yet implemented to a large extend: **why**?

Which are the non-technological barriers?
• Identify market barriers

• **Remove** non-technological market barriers by

  • Education & **training** of Supermarket owners/chains, manufacturers, installers, consultants all across Europe

  • Creating an **online information hub** enabling Multidisciplinary Communication & Dissemination

• Supporting the introduction of a new **European Ecolabel for supermarkets**
SUPERSMART has three main working tasks:

1. **Removal of non-technological barriers:**
   - Workshops, seminars, awareness-raising
   - **Training for supermarket stakeholders free of charge**

2. **Support for the Development of an EU Ecolabel**
   - Development of label criteria & product group proposal
   - Supermarket stakeholders can participate, influence and comment

3. **Communication & Dissemination**
Suggested actions to remove the knowledge barriers across Europe

- Make training programs available
- Provide experienced trainers
- Provide free/low-price educational material
- Make educational material available for different technical knowledge levels

Results from the 2016 online survey
Suggested people to be trained to successfully remove the knowledge barriers

Results from the 2016 online survey

- Food retail chain and shop owners
- System manufacturers and components suppliers HVAC&R
- Consulting, contracting and engineering staff
- Servicing, repairing and maintenance staff
Energy efficient state-of-the-art supermarkets

Focus on

• Energy efficient state-of-the-art refrigeration system, integration with AC, heat recovery (Session 1 and 3)

• Computational Tools for supermarkets (Session 2)

DOWNLOAD latest TECHNICAL REPORTS on
www.supersmart-supermarket.info
- Introduce state-of-the art energy efficient and eco-friendly refrigeration technologies, focusing on CO$_2$-only systems
- Discuss the different possibilities for AC integration and heat recovery
1. ENERGY EFFICIENCY IN THE REFRIGERATION SYSTEM
2. COMPONENT ENERGY EFFICIENCY MEASURES
3. HVAC SYSTEMS
4. HEAT RECOVERY
ENERGY EFFICIENCY IN THE REFRIGERATION SYSTEM
Refrigeration systems require the main part of the energy in a Supermarket, accounting for a good half of the total energy use.
Conventional supermarket refrigeration systems are not future long-term solutions:
• Ban refrigerants GWP>150 from 2022 (centralized refrigeration system >40 kW, Primary Cycle in Cascade configuration >1500)
• 79% Reduction of GWP related emission by 2030

Which options are available for supermarket stakeholders?
• Business as usual until 2020 and then usage of recycled gas until 2030;
• Convert/retrofit with short living, new synthetic low-GWP refrigerants;
  o Future environmental Regulation?
  o Health and Safety of staff, real environmental impact, ++?
• Natural Refrigerant business orientation.
  o Long term solution
  o Investment cost no longer higher than traditional HFC I some regions (focus should be: total cost of ownership with integrated system solutions)
Example

**SAFETY DATA SHEET**

**Honeywell**

**Honeywell Solstice® N40 Refrigerant (R-448A)**

| Version 1.4 | Revision Date 10/30/2014 | Print Date 12/22/2014 |

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**WARNING! This product contains a chemical known to the State of California to cause cancer.**

Dichloromethane 75-09-2

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WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm.

Chloromethane 74-87-3

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The information contained in this safety data sheet (SDS) is additional to that contained in the CPR and the MSDS contains all of the information required by the CPR.

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**SECTION 16. OTHER INFORMATION**
THE MARKET CHOICE: CO\textsubscript{2} REFRIGERATION SYSTEM
Highlighted advantages in applying CO$_2$:

- **Excellent thermophysical properties**
  (high vapour density and thermal conductivity, low viscosity)
  → reduced pressure losses and excellent heat transfer coefficients
  → high compression efficiency (low p-ratio)
  → reduced compressor swept volume, small refrigerant lines

- **Thermodynamic challenges / opportunities**
  (low critical temperature)
  → Increase in heat rejection loss
  → Increase in throttling loss
1st generation: Booster system

2nd generation: Booster system with parallel compression

3rd generation: Ejector supported parallel compression system
A supermarket is a complex energy system, having to satisfy chilling and freezing of valuable food at different temperature levels, and at the same time maintaining customer comfort in the sales area.

### Refrigeration System

<table>
<thead>
<tr>
<th></th>
<th>Desired temperature level [°C]</th>
<th>Typical evaporation temperature [°C]</th>
<th>Ideal/achievable evaporation temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chilled food</strong></td>
<td>1 to 14</td>
<td>-10 to -5</td>
<td>-2 (Requires flooded evaporation)</td>
</tr>
<tr>
<td><strong>Frozen food</strong></td>
<td>-12 to -18 or lower</td>
<td>-35 to -30</td>
<td>-25</td>
</tr>
<tr>
<td><strong>AC</strong></td>
<td>~20</td>
<td>~3</td>
<td>12</td>
</tr>
</tbody>
</table>
• The “booster system” represents the preferred embodiment for complete (MT and LT) supermarkets
  • Compact
  • Efficient LT (double stage compression and desuperheating with DHW production for higher efficiency);
  • Easy integration with heat recovery.

• Hot climates may need an additional subcooler (energy well, fire water tank, etc.) or evaporative cooling after the gascooler (if water is available)

• Important/critical components
  • Flash-gas bypass valve (controlling sep.- pressure)
  • Size of gascooler
The amount of vapour downstream of the high-pressure control valve increases as the external temperature rises.

Parallel compression reduces throttling losses by removing flash vapour after the high pressure control valve.

- Only operative if there is a sufficiently large amount of flash gas (opening of FGBV)
- Allows integration of AC
  - The AC evap.- outlet enters directly the separator
  - AC cooling capacity is provided by the auxiliary compressor, determining the pressure level of the separator
Utilisation of expansion work (work recovery potential)

The higher the ambient temperature, i.e. inlet temperature to the expansion device, the higher the throttling losses.

Challenge: take advantage from the increased energy recovery potential.
Ejector(s) allow for the **recovery** of expansion work, resulting in **higher capacity** and **lower compressor work** compared to a cycle with an isenthalpic expansion.
EX: Ejector supported PC system

High-pressure control valve replaced with ejectors

- Entains part of the low-pressure vapour from the MT evaporators using the fluid coming from the gas cooler and compresses it to intermediate pressure
- Extends the operation time of the parallel compressors
- Part of the MT compressor load shifted to the parallel compressor which has to overcome a significantly lower pressure lift
  - Higher overall COP, especially at high ambient conditions
• Design adjusted for operation of CO$_2$ unit in warm climates where expansion losses are high
• Ejectors may recirculate also liquid coming from evaporators:
  • Enables the use of flooded evaporators
  • Higher evaporation temperature (-25 & -2°C)

Various system layouts in the market:
• Control dependent on load:
  • Multiejector (on-off) [4]
  • Adjustable motive nozzles [5]

BEHAVIOUR OF EJECTOR SUPPORTED PARALLEL COMPRESSION SYSTEM (GENERATION 3)
EXAMPLE: 4 PIVOTING COMPRESSORS

AC-suction Group (from Separator)

Auxiliary Compressors

MT Compressors

to gascooler

MT-suction group
• Small, leak tight and cheap, however..

• Releases heat directly to the sales area
  → Increases AC need and energy costs
  → Should be avoided as far as possible

• Often based on synthetic refrigerants

• Which natural alternatives?
  a) Hydrocarbons
     1. R290 propane
     2. R600a isobutane
     3. R1270 propylene and their mixtures...
     4. R432 A,B,C (R1270/R-E170)
     5. R436 A,B (R290/R600a)
     6. R441A (R170/R290/R600a/R600)
  b) Carbon dioxide (A1)
The challenge lies in charge reduction (below 150 gr as required by UL Standard 471, 2010 and IEC 60335)....under revision...

The charge of R290 in hermetically sealed systems (without accumulator) is practically estimated in 45-50% of R404A.

The charge is mainly concentrated in HP side:

- condenser(+liquid pipes) internal volume reduction
- optimisation of fluid mass flux

One of the latest achievements: 120 gr of R290 for 1 kW - 1000l bottle cooler

*Padilla Fuentes Y et al., LOW-CHARGE PROPANE REFRIGERATION SYSTEM TECHNOLOGY FOR SINGLE AND MULTI-DOOR BOTTLE COOLERS, ICR 2015, August 16 - 22 - Yokohama, Japan
The challenge lies in trade off between cost and performance.

Critical components availability:

Piston and rotary hermetic compressors available from about 350W cooling capacity at -5°C.

Two-stage rotary compressors for MT and LT applications available from about 0.5 m³/h.

Compressor efficiency and components optimisation are key-challenges for competition with HCs.

No ejectors currently available below 4.0 kW at -5°C. Research is ongoing.
COMPONENT ENERGY EFFICIENCY MEASURES
What we need:

efficient compressors

Example pilot R744 compressor
- Why do we need to evaporate at -8°C to keep air at +2°C? (and -33°C to keep air at -22°C)

Fig. 9. Temperature profile of the evaporator, with R404A and CO₂.

Girotto et al. Commercial refrigeration system using CO₂ as the refrigerant. IJR27 (2004)
We want higher evaporation temperature to maintain performance and save energy.

- Higher evaporation temperature can be achieved with:
  - Larger heat exchangers
  - Internal heat exchanger
  - Overfed evaporators

What is needed?
- no superheat
- maintain once-through coils with individual expansion valve
- allow multiple evaporators in parallel

What we propose is:
- Overfed evaporators (90-100% vapour at exit)
- Valve opening controlled by air temperature
- Excess liquid removed by ejector
Data from the field

Increase evaporation temperature:
da -10°C a -3°C per MT
da -32°C a -23°C per BT
With the same performance

...and less defrost cycles!

Minetto et al. Recent installations of co2 supermarket refrigeration system for warm climates: data from the field. 3rd IIR International Conference on Sustainability and the Cold Chain, London, UK, 2014
Remind that:

To get the benefit of higher evaporation temperature, the evaporator surface MUST be maintained (no smaller evaporators are allowed!)

ALL cabinets connected to the same compressor MUST be designed for the same evaporation temperature!
100% evaporative cooling

33% evaporative cooling

Fornasieri et al, 2008 Refrigeration Systems for Hot Climates using CO$_2$ as the Working Fluid. 8$^{th}$ IIR GL Conference, Copenhagen
<table>
<thead>
<tr>
<th>Energy consumption</th>
<th>No precooling</th>
<th>100% precooling</th>
<th>30% precooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok</td>
<td>100%</td>
<td>93%</td>
<td>95%</td>
</tr>
<tr>
<td>Tripoli</td>
<td>100%</td>
<td>93%</td>
<td>94%</td>
</tr>
</tbody>
</table>

Constant thermal load on evaporators

Gas cooling is a non-isothermal process; cooling of the air stream investing the last part of the gas cooler is possible, with limited penalisation in COP and relevant water saving.
ENERGY EFFICIENCY IN THE HVAC SYSTEM
• AHUs designed for supermarkets should be employed
  • Often AHUs designed for offices used in supermarkets

• Necessary features
  • Heating with waste heat from the refrigeration system (system COP↑)
  • Permanent magnet (PM) motor with 90% efficiency, low noise, vibration
  • Dehumidification (system COP↑)
  • Bypass possibilities
  • Lower pressure drops

Supermarket AHU unit by Systemair, employed in REMA 1000 Kroppanmarka in Trondheim

• Heating/cold climates: Floor heating
  • Improved customer comfort
  • Even temperature distribution in the store (natural air flow direction)
  • Possibility for zonal temperature control
  • Thickness of pipes and floor must be considered
  • Floor has thermal capacity $\rightarrow$ slow response, but reduces heating peaks

• Cooling/hot climates: several air coolers distributed in the sales area
  • Smaller stores: possibility to utilize CO$_2$ directly from the refrigeration system
  • Beneficial transport properties of CO$_2$ enable reduced pumping power, and lower temperature lift

Local space heating and cooling units utilizing CO$_2$ directly from the central refrigeration system as the heating/cooling medium by Enex

HEAT RECOVERY

04
Transcritical CO₂ systems are particularly well suited for heat recovery owing to high discharge temperatures.

Heat sinks (from highest to lowest temperature level):
1. Hot storage tanks
   - Domestic hot water (DHW) heating
   - Supply air in the AHU/air curtain
2. Floor heating
3. Snow melting
4. Energy wells
   - Charge during summer, discharge during winter
   - Free cooling to AHU
   - Stable heat sink for CO₂, reducing the

Excess heat from supermarket should be utilized in nearby businesses or residential buildings.
CO₂ system offers efficient hot water production.

Requires:
- Demand for high temperature lift
- Low secondary fluid inlet temperature

Ref: Nekså


CO₂ gas cooler heat recovery in a cold climate (with high external heating demand), shown in a temperature-entropy (T-s) diagram.

CO₂ gas cooler heat recovery in a hot climate, shown in a temperature-entropy (T-s) diagram.
• No separate AC compressor
• AC loop cooled down by evaporating CO₂ in natural circulation from the separator
• Easier regulation with only two evaporation pressure levels
• Three-stage gas cooling
• Heat recovery
• Possibility for regulation through by-passing
Integrated refrigeration and HVAC solution for REMA 1000 Kroppanmarka supermarket, Trondheim


1. Red loop: Hot storage tanks, supplying AHU, DHW (and floor heating if needed)

2. Blue loop: Floor heating

3. Purple loop: Energy wells

3 temperature levels
- Refrigeration system and HVAC
  - Central, integrated refrigeration and HVAC system with CO$_2$
  - Heat recovery considering temperature levels
  - Energy accumulation in the form of thermal storage
  - Intelligent system control
  - AHU unit designed for supermarkets
- Evaporators
  - Increase evaporation temperature through
    - Increased heat exchanger area
    - Overfed evaporators
BEST PRACTICE

06
Examples from Europe and World

- Sweden
- Germany
- Norway
- UK
- Switzerland
- Spain
- Italy
- U.S.
- Romania
- Japan
ICA Kvantum Täby (Sweden)

Opening Year: 2013

Eco-friendly characteristics:

- First ejector-based system in Sweden
- One liquid ejector
- Glass doors on cabinets and freezers
- Real-time energy measurements monitoring
- 4 K higher MT evaporation temperature by using overfed evaporators (liquid recirculation by ejectors)
Migros Ibach (Switzerland)

Opening Year: 2014 (refurbished)

Eco-friendly characteristics:
- CO2 refrigeration system using multi-ejector technology
- Parallel compression
- Partially flooded evaporators
- Tap water heating and facility heating
- Sub-cooling by groundwater in summer
With Five vapour and liquid ejectors:

- MT evaporation temperature could be raised from -8 °C to -2 °C
- LT evaporation temperature increases from -33 °C to -25 °C
REMA 1000 Kroppanmarka (Norway)

Opening Year: 2013 (refurbished)

Eco-friendly characteristics:

- Energy Saving Prize in Trondheim in 2014.
- CO2 as the refrigerant, heat recovery at multiple temperature levels
- Doors/lids in all refrigerated cabinets
- Aerogel facades, and demand controlled lighting based on amount of daylight available
- Energy wells for storage of heat and cold, four 170 m deep boreholes (energy wells) …
Iper Hypermarket (Italy)

Opening Year: 2016

Eco-friendly characteristics:

- CO2 refrigeration system using multi-ejector technology, designed for energy-efficient operation at ambient temperatures up to 38 °C
- Heat recovery for DHW production
- Integrated control of light, HVAC and refrigeration; control system designed by Danfoss
- The centre is LEED Gold certified, designed and constructed to use less water and energy and reduce greenhouse gas emissions
Join
SuperSmart Workshop on EU Ecolabel criteria for food retail stores
@ISH

Wednesday, March 15, 2017
2:00pm 5:00pm

SuperSmart holds its 2nd Labelling Board Assembly
The workshop will make further progress to define criteria for a future EU Ecolabel for Food Retail Stores. This time, we focus on the building's energy use and environmental factors (buildings, energy management systems, lighting, use of renewable energies etc.).
THANK YOU!

www. supersmart-supermarket.info
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 696076.
Traditional ejector lay-out:
All the mass flow processed by the compressor flows through the ejector
In this lay-out, they recover part of the expansion work, which is used to pre-compress vapour before compressor suction. Vapour is then removed at intermediate pressure by auxiliary compressors.

- Ejectors boost parallel compressor operations
- Evaporators overfeeding for optimal use of heat transfer area;
- Excess liquid out of evaporators circulated by ejector, which recovers part of the expansion work
Including:
- Parallel compressors,
- Evaporator overfeeding by liquid ejector recirculation,
- Vapour pre-compression by ejectors.