EXPERTISE HUB FOR ENERGY-EFFICIENT COOLING & HEATING IN EUROPEAN SUPERMARKETS
HOW TO BUILD A NEW ECO-FRIENDLY SUPERMARKET
SCOPE OF THIS PRESENTATION

- Give guidelines for building new eco-friendly supermarkets, regarding building design, refrigeration & HVAC
- Introduce state-of-the-art energy efficient and eco-friendly refrigeration technologies, focusing on CO₂-only systems
- Discuss the different possibilities for heat recovery
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Building envelope determines the heat leakage in/out the supermarket
→ the refrigeration and heating load

Exemplar values for normative heat transfer coefficients for walls, roof and floor according to the building regulations in different parts of Europe.

<table>
<thead>
<tr>
<th>Location</th>
<th>Heat Transfer Coefficient [W/m²K]</th>
<th>Walls</th>
<th>Roof</th>
<th>Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Norway</strong> (Passive house/low-energy building)</td>
<td></td>
<td>0.10-0.12/0.15-0.16</td>
<td>0.08-0.09/0.10-0.12</td>
<td>0.08/0.10-0.12</td>
</tr>
<tr>
<td><strong>Sweden</strong> (for buildings with electric heating/heating method other than electric heating)</td>
<td></td>
<td>0.10/0.18</td>
<td>0.08/0.13</td>
<td>0.10/0.15</td>
</tr>
<tr>
<td><strong>Germany</strong> (for building projects from 2016 / passive house criteria, depending on the climatic zone)</td>
<td></td>
<td>0.28 / 0.09-0.50</td>
<td>0.28 / 0.09-0.50</td>
<td>0.28 / 0.09-0.50</td>
</tr>
<tr>
<td><strong>Spain</strong> (the value depends on the climatic zone)</td>
<td></td>
<td>0.55-1.35</td>
<td>0.35-1.20</td>
<td>0.55-1.35 / 0.35-1.2 (in contact with ground/air)</td>
</tr>
<tr>
<td><strong>Macedonia</strong></td>
<td></td>
<td>0.35</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
• For the construction, materials with low CO₂ emissions throughout the life cycle should be chosen as far as possible
• Kiwi-supermarket in Elverum, Norway, used near-produced wood as the main building material
• Wooden wall constructions contribute to a good indoor climate and a reduced demand for ventilation, in addition to the low environmental impact

https://kiwi.no/Informasjon/Fremtidsbutikken/
• Goals
  • Minimize heat load from the sun
  • Maximize the utilization of daylight
  • Minimize heat losses in winter
• How?
  • Minimize window area
  • Optimal window placement
  • Well-insulating windows
• A possibility: translucent daylight panels
  • Highly insulating porous silica aerogel (0.59 W/m²K)
  • Spread the light diffusively - no hot spots
  • Light transmission of 45%.

Rema 1000 Kroppanmarka Supermarket in Trondheim, Norway
HTTP://AEROGELNORGE.NO/NORGE-REMA-1000-KROPPANMARKA-2/
• Vestibule doors
• Air curtain to prevent mixing of outdoor and indoor air
  • Heat/cold
  • Dust, fumes insect
  • The energy source should be excess heat from the refrigeration system
INTERIOR DESIGN

- Hot products far away from the refrigerated products.
- Fruit and vegetables close to the cold room to utilize the cold leakage
ENERGY EFFICIENCY IN THE REFRIGERATION SYSTEM
R-744 (CARBON DIOXIDE) AS WORKING FLUID

Highlighted advantages in applying CO$_2$:

- **High Refrigerant Density** → Reduced compressor swept volume
  Small refrigerant lines

- **High Compressor Efficiency** → Low pressure ratio

- **High Heat Transfer Coefficients and Low Specific Pressure Drops**

Challenges / **opportunities**:

- Increase in heat rejection loss
- Increase in throttling loss

11.10.2016
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

**Temperature levels for refrigeration and AC in a supermarket**

<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>
REFRIGERATION SYSTEM ARCHITECTURE:
THE CO₂ EVOLUTION

1ST GENERATION:
Booster system

2ND GENERATION:
Booster system with parallel compression

3RD GENERATION:
The ejector system
• The most widely applied CO₂ only solution
• LT cabinets/evaporators are served by a separate, smaller booster compressor
• Fits best to cold climates, where the demand for AC is low
  • Hot climates may need an additional subcooler or evaporative cooling after the gas cooler
• Too low return temperature after gas cooler may also be a problem
• Crucial components
  • Flash-gas bypass valve
    • crucial for controlling separator pressure
  • De-superheaters after LT compressor
    → Waste heat suitable for DHW production
• The amount of vapour downstream of the high-pressure control valve increases as the external temperature rises.

• A solution: an auxiliary, parallel compressor
  • Sucks either a part or the entire amount of vapour from the separator and compress is directly to the gas cooler pressure
  • Only operative if there is a sufficiently large amount of flash gas
  • Reduces flash gas losses
  • Allows integration of AC
    • The AC evaporator outlet enters directly the separator
    • AC cooling capacity is provided by the auxiliary compressor, determining the pressure level of the separator

BOOSTER SYSTEM WITH PARALLEL COMPRESSION
The Ejector System - The State of the Art Technology

- **High-pressure control valve replaced with ejectors**
- **Entrain low-pressure fluid from the MT evaporators using the fluid coming from the gas cooler**
- **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
- **Particularly important in warm climates where expansion losses are high**
- **Enables the use of flooded evaporators**
  - Higher evaporation temperature
- **Control dependent on load:**
  - **Multi-ejector (on-off)** [4]
  - **Adjustable area** [5]

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

Utilisation of expansion work (work recovery potential)
Pressure and velocity inside an ejector

- **Motive flow** from gas cooler
- **Suction flow** from low pressure receiver
- Exit towards separator
- Pressure lift

![Diagram of an ejector with labels for motive flow, suction flow, mixing chamber, diffusor, and exit towards separator.](image)
EJECTOR SYSTEM WITH SMART INTEGRATION OF AC

- 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
**REFRIGERATION SYSTEM: PLUG-IN UNITS**

- **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 synthetic refrigerants**
  - Natural refrigerants (HCs) available from most suppliers
- **CO₂ available from ISA and SANDEN/Hauser**

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COMPONENT ENERGY EFFICIENCY MEASURES
- Frequency control/variable speed drive compressors
  - Energy savings of up to 25%
  - Fewer compressors
  - Improved performance at part load
  - Increased working life
• **Expansion valves: electronic instead of thermostatic**
  
  → **Adaptive adjustment during operation**
  
  → **Lower pressure difference, more radical decrease in high pressure**
• A temperature increase by 3 K reduces energy use by ~3 %

• Higher evaporation temperature can be achieved with
  → Larger heat exchangers
  → Internal heat exchanger
  → Flooded evaporators, enabled by ejector technology

• Defrosting often based on time shift → Too many defrosting cycles

• Defrost on demand: by observing the evaporation temperature (the evaporator temperature drops upon defrosting)
  → Flooded CO₂ refrigeration: once a week is sufficient!
• **Condensation temperature/high-side pressure should as low as possible.**

• **Gas cooler outlet temperatures can be lowered by using evaporative condenser/gas cooler cooling.**
  → **Serial arrangement of gas coolers should be applied with respect to heat recovery and rejection to different heat sinks**

• **Periodical cleaning air-cooled heat exchanger surfaces**
  → **Improves the heat exchange and hence reduces the energy use**
The most important measure: Glass covers or lids

→ Product temperature reduced by 4-5 K
→ Energy need reduced by at least 40%
→ Increased food safety

Approximate cooling load for an open refrigerated multi-deck cabinet

High-efficiency fan motors and fan power adjustment

Evaporator fan outside the cabinet

Anti-condensate heaters on the display doors

LEDs inside the cabinet

Better insulation material

Infrared reflecting shades and baldachins

Night covers

Improved anti-sweat heaters, edge/rim heating, dew point control

Correct product loading

ALL cabinets connected to the same compressor MUST be designed for the same evaporation temperature!
ENERGY EFFICIENCY IN THE HVAC SYSTEM
AIR HANDLING UNIT (AHU)

- 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

HEAT AND COLD DISTRIBUTION

- **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 → 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
HEAT RECOVERY

• **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**
HEAT RECOVERY

**CO₂ System Offers Efficient Hot Water Production.**

**Requires:**
- **Demand for High Temperature Lift**
- **Low Secondary Fluid Inlet Temperature**

Entropy, [kJ/kg K]  
Temperature [°C]

Compressor  
Gas Cooler  
Int. Heat Exchanger  
Throttle Valve  
Evaporator  
Receiver

Ref: Nekså
HEAT RECOVERY

$\text{CO}_2$ gas cooler heat recovery in a cold climate (with high external heating demand), shown in a temperature-entropy ($T$-$s$) diagram.

$\text{CO}_2$ gas cooler heat recovery in a hot climate, shown in a temperature-entropy ($T$-$s$) diagram.
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
ENERGY EFFICIENCY IN LIGHTING
• Corresponds to ~20% of the supermarket energy demand
• Important regarding the sales, especially for fresh products
• Energy efficiency measures
  • LED-lights
  • Lighting control based on the amount of daylight available
  • Presence detection for areas with lower usage (staff areas, etc.)
  • Room surfaces painted with matt colors with high reflectance
**ENERGY SAVING MEASURES - SUMMARY**

**Energy saving in percentage of aggregated energy consumption of the refrigeration system through different measures**

- Glass doors/lids on cabinets: 40%
- Flooded evaporator: 35%
- Air humidity in the shop area: 30%
- Frequency control of…: 25%
- Fan motor outside cabinet: 20%
- Decrease condensation temp….: 15%
- Increased evaporator temp. by…: 10%
- Baldachin: 5%
- Two-stage compression: 0%
- Proper loading of products: 0%
- Improved antisweat heaters: 0%
- Defrost on demand: 0%
- Improved lights: 0%
- Improved expansion valve: 0%
- Efficient evaporator fan: 0%
- Adjusted condensation…: 0%

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ENERGY SAVING MEASURES - SUMMARY

• Refrigeration system and HVAC
  • Central, integrated refrigeration and HVAC system with CO₂
  • Heat recovery considering temperature levels
  • Energy accumulation in the form of thermal storage
  • Intelligent system control
  • AHU unit designed for supermarkets

• Refrigerated cabinets/rooms
  • Glass lids/doors
  • Improved insulation
  • Infra-red reflecting shades and baldachins
  • Improved air curtain in open refrigerated multi-decks
  • Improved anti-sweat heaters, edge/rim heating, dew point control
  • LED lighting
  • Correct product loading
  • Improved fan and/or fan motor
ENERGY SAVING MEASURES - SUMMARY

• **Evaporators**
  • **Higher evaporation temperature through**
    • **Increased heat exchanger area**
    • **Flooded evaporators**
  • **Defrost on demand**

• **Condensers**
  • **Reduced condensation temperature**
    • **Floating condensing pressure (adjusted to ambient temperature).**
    • **Evaporative condenser/gas cooler cooling**
    • **Serial arrangement of gas coolers: 1) heat recovery; 2) heat rejection to ambient; 3) heat rejection towards alternative heat sinks, such as energy wells, water storage tanks, etc.**

• **Cleaning**
FUNDING OPPORTUNITIES?

- Separate document with financing opportunities for different European countries available in report D2.3 at the homepage of Supersmart: [http://www.supersmart-supermarket.info/downloads/](http://www.supersmart-supermarket.info/downloads/)
WHAT’S NEXT?

• Online survey on criteria for the EU Ecolabel on:
  
  www.supersmart-supermarket.info

• Next Labelling Board Assembly in spring 2017

• Stay informed and contribute to the criteria development process:
  ➢ Become a member of an Expert Panel and the Labelling Board of the SuperSmart project.
  ➢ Sign up for the expert panels and training events at:
  
  info@supersmart-supermarket.org
REFERENCES


- Gillaux, S. (2016). 100% CO₂ solutions for small and medium store formats. ATMOsphere Europe, Barcelona.


MORE REFERENCES


