SUPERMARKET WITH GROUND COUPLED CARBON DIOXIDE REFRIGERATION PLANT

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ICEBO 2012
Manchester, 25.10.2012
AGENDA

1. Background on supermarkets, energy and greenhouse gases
2. Energy efficient supermarket concept and goals
3. Results
4. Conclusion and outlook
Why do we need energy efficient supermarkets?

- Supermarkets play a central role in our consumer society
- Today’s food system is built upon refrigeration
- Supermarkets are massive energy consumers
- Supermarkets create greenhouse gases

In 2011, 72.4 % of the sales share of food retail industry realized in discounters and supermarkets in Germany [1]

Supermarket:
~ 600 – 2,000 kWh/m².a (PE) [3]
Normal building:
200 – 400 kWh/m².a (PE) [4]

About 65 % of the cooling needs in Germany for frozen and refrigerated food products → over 50,000 GWh/a [2]

“Supermarket refrigeration remains the last big subsector and the strongest emission source of the fluorinated hydrocarbons (HFC) in Germany” - Kauffeld [4]
Global emissions of fluorinated greenhouse gases

F-gas contribution to greenhouse effect

Source: UBA – 12.2010
Energy breakdown in a standard supermarket

- **Electricity**: 80%
- **Heat**: 20%
- **Indoor lightings**: 29%
- **Air conditioning**: 2%
- **Outdoor lighting**: 1%
- **Freezers**: 23%
- **Refrigeration (Shelves/Cold rooms)**: 31%
- **AHU**: 2%
- **Other**: 12%

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What are (some) answers?

- Highly insulated building envelope
- Energy efficient heating and ventilating
- Use of natural heat sinks and sources
- Covered refrigerated shelves
- Waste heat recovery
- Natural refrigerants
EnOB: Research for Energy Optimized Buildings

- German federal ministry of economics and technology
- Objectives:
  - drastically reduce energy demand of buildings
  - R&D of innovative technologies
  - test & demonstrate the validity of the technologies
- www.enob.info

**Phase I**
- Concept
- Construction
- Commissioning
- Energy balance DIN 18599
- Integration of innovative systems
- Development M&V Plan

**Phase II**
- Intensive monitoring
- Automated data acquisition and analysis
- Ongoing Optimisation Objectives validation

**Phase III**
- Long time monitoring
- Operation supervision
- Information on energy performance during 5 years
Monitoringprogramm

- Over 150 datapoints, high time resolution
  - Temperature, solar radiation
  - Power-, Heat and Cold meters, refrigerant mass flow meters
- Real time data transfer via secured internet connection to Fraunhofer ISE
- Data analysis and continuous operation and control optimization
- Smart visualization techniques
Energy reduction objectives for the new supermarket

-30% reduction in primary energy consumption.

Standard supermarket:
- Lightings: 118 kWh/m²a
- Heat pump: 18 kWh/m²a
- Ventilation: 34 kWh/m²a
- Cooling: 276 kWh/m²a
- Refrigeration plant: 55 kWh/m²a
- Gas consumption: 3 kWh/m²a

Efficient supermarket (simulation):
- Lightings: 83 kWh/m²a
- Heat pump: 3 kWh/m²a
- Ventilation: 10 kWh/m²a
- Cooling: 256 kWh/m²a
- Refrigeration plant: 3 kWh/m²a
- Gas consumption: 10 kWh/m²a

-30% reduction in each category compared to the standard supermarket.
Concept overview – Key elements

- **Building Envelope:** Insulation and air tightness to Passivhaus Standard

- **Refrigeration:**
  - CO₂ refrigeration plant as only energy supply
  - No use of fossil fuels
  - Use of ground to sub-cool refrigerant and as heat source for heat pump

- **Refrigerated shelves and freezers:**
  - Use of covers and night curtains
  - LED-Lighting

- **Ventilation Air-conditioning:**
  - Activated Core Slab
  - Air handling unit downsizing
  - No air curtains
Refrigerant choice: CO$_2$ (R744)

**Benefits:**
- High environmental compatibility:
  - very low Global Warming Potential = 1
    (R404A GWP=3700)
  - Ozone Depletion Potential = 0
- Non-inflammable, nontoxic
- High volumetric heat capacity
- Higher efficiency in comparison to plants running with R134a or R404 (at low condensation temperatures…)

**Drawbacks:**
- High operating pressures (40-100bar)
- Low critical point 31°C
- Efficiency is highly dependent of the condensation temperature
  - Transcritical operation with low energy efficiency when outdoor temp. > 20°C
- This effect can be reduced through additional cooling via borehole heat exchanger
Refrigeration plant and building systems

Legende
1 Heat pump HX
2 Free cooling HX
3 Borehole HX
4 Waste heat recovery
5 Gas cooler
6 Hot water Tank
7 Air handling unit
8 activated concrete slab
9 Heat pump comp.
10 Normal cooling Comp.
11 Low pressure comp.
Low temp. freezers
Normal temp. freezers

Source: Hafner-Muschler
Heat recovery and sub-cooling with borehole heat exchanger

Effect borehole heat exchanger

COP = 3.5

COP = 2.0

COP = 1.1

COP = 1.3

+28 °C

+14 °C

-10 °C

Useful heat

Heat rejection

Heat rejection

Waste heat use

Power input

Cold production

2. Concept - Goals
Measured effect of the borehole heat exchanger

- + 6% efficiency
- Energy savings and emissions reduction: 11 MWh/a and 6 to CO₂/a
- Need further optimizations to reach targets
Solar Energy Use

- **Use of daylight**
  - 28 Skylights with microgrid integrated in triple-glazings in sales and warehouse space
  - Direct sun radiation is reflected to the outside

- **Daylight dependent artificial lighting control**
  - Energy consumption reduction of -25% in 2011
  - Energy input reduction up to 70% in summer for lighting system
Use of daylight
Energy: comparison with objectives and forecast

3. Results

![Bar Chart]

- Standard store: 276 kWh/m².a
  - Lighting: 118 kWh/m².a
  - Ventilation: 34 kWh/m².a
  - Cooling: 18 kWh/m².a
  - Heat pump: 10 kWh/m².a
  - Gas: 55 kWh/m².a
  - Total: 276 kWh/m².a

- Target - new store: 256 kWh/m².a
  - Lighting: 83 kWh/m².a
  - Ventilation: 10 kWh/m².a
  - Cooling: 8 kWh/m².a
  - Heat pump: 10 kWh/m².a
  - Gas: 10 kWh/m².a
  - Total: 256 kWh/m².a

- Results 2011: 25% reduction
  - Current: 59% reduction

- Forecast 2012: 26% reduction
  - Current: 30% reduction
Greenhouse gas emissions: reduction of the new supermarket

3. Results

- 42%
- 33%
Lessons learned and outlook:

- New concept reached 20% energy savings after 1 year
- Greenhouse gas emissions cut by over 30% after 1 year through the use of CO₂ as refrigerant
- Integrated concepts have future: combining insulation + natural refrigerants + waste heat + innovative lightings
- Further gains are possible through an ongoing system operation optimization

Outlook:

- + energy supermarkets are possible
- Hybrid BIPV systems to be developed for PV and daylighting integration
- Supermarket to grid: through PV power and waste heat usage
Thank you for your attention!

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