WELCOME TO SUPERSMART WORKSHOP ON

ENERGY-EFFICIENT FOOD RETAIL STORES

Ingrid C. Claussen (SINTEF), coordinator of SuperSmart
Ingrid.C.Claussen@sintef.no

SUPERSMART

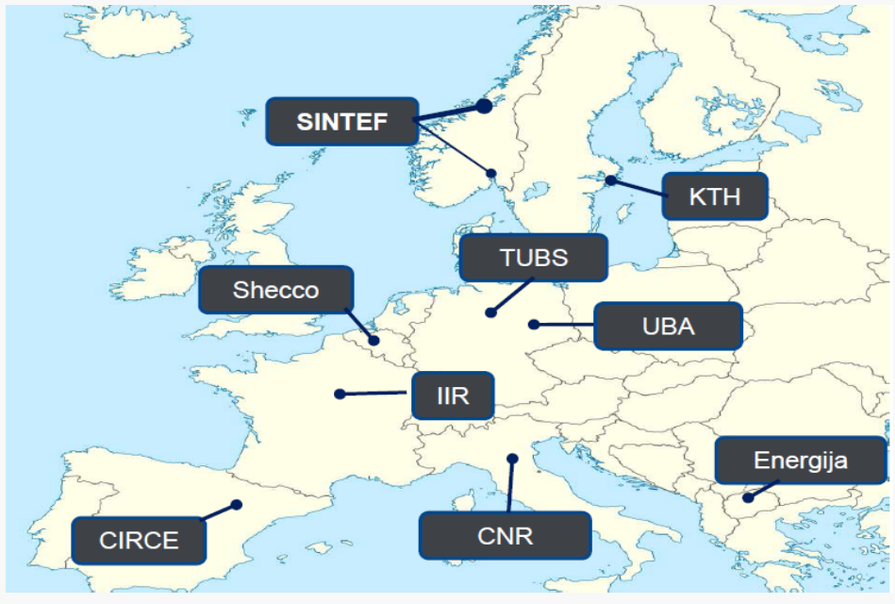
Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel

Facts and Figures

- **SuperSmart** is an EU funded Horizon 2020 Project (Grant number 696076)
- Project period: 2016 – 2019 (36 Months)
- Budget: 1468 k€

SUPERSMART

www.supersmart-supermarket.org



SINTEF
shecco
SUSTAINING OUR ATMOSPHERE
ITC
Umwelt Bundesamt
KTH VETENSKAP OCH KONST
Technische Universität Braunschweig
Energija
circe RESEARCH CENTRE FOR ENERGY RESOURCES AND CONSUMPTION
iif iir

HOW THE SUPERSMART PROJECT WORKS

- Two web-based surveys in different European languages (English, German, Italian, Spanish, French and Serbo-Croatian)

- Training through workshops in trade fairs and conferences:
  - > Presentations of new technologies
  - > Innovative discussions

- Training for supermarket stakeholders, at the stakeholders' premises, in the following topics:
  - > How to build a new eco-friendly supermarket
  - > How to refurbish a supermarket
  - > Computational tools for supermarket planning
  - > Eco-friendly operation and maintenance of supermarkets
  - > EU Ecolabel for supermarkets

- Application preparations for EU Ecolabel for supermarkets through standard Ecolabel procedures

THE SUPERSMART TEAM

The SuperSmart Team includes both Scientific and Industrial field expertise:

- **Technical universities** (KTH, TUBS)
- **Research and Technology Organizations** (national, independent, SINTEF, ITC-CNR, CIRCE)
- **SME sector** (Energija, Shecco)
- **Governmental agency** (UBA)
- **Intergovernmental Science and Technology organization** (independent, IIR)

This team is well suited for spreading information, training and promoting environmentally friendly solutions in a professional way, and to give input on governmental level.

AGENDA

Time	Title	Presenter
10:00	Welcome	Ingrid C. Claussen (SINTEF)
Part I: EU Ecolabel for Food Retail Stores		
10:05	Criteria development within the project	Kerstin Martens (UBA)
10:15	Criteria for HVAC&R and buildings of food retail stores	Samer Sawalha (KTH)
Part II: Improving supermarket energy efficiency		
10:35	Introduction	Hanne Kauko (SINTEF)
10:40	Eco-friendly supermarkets – an overview	Samer Sawalha (KTH)
11:00	Components for energy efficient supermarket refrigeration	Silvia Minetto (CNR)
11:20	Efficient and environmentally friendly refrigeration with CO_2	Armin Hafner (NTNU)
11:40	Supermarket control systems	Antonio Rossetti (CNR)

SUPERSMART

EXPERTISE HUB FOR ENERGY-EFFICIENT COOLING & HEATING IN EUROPEAN SUPERMARKETS

Part I: EU Ecolabel for Food Retail Stores

Horizon 2020
European Union funding
for Research & Innovation

KERSTIN MARTENS

CRITERIA DEVELOPMENT WITHIN THE PROJECT

WHAT IS THE EU ECOLABEL?

- Voluntary tool for the labelling of products and services with a lower environmental impact than the standard
- Recognized throughout the European Union, Norway, Iceland and Switzerland
- Managed by the European Commission since 1992

- 32 product groups and more than 38,000 products/services labelled
- Legal basis: Ecolabel Regulation (Regulation (EC) No 66/2010)
- EN ISO 14024 Type I environmental label:
  - high credibility
  - requires third-party certification
  - based on multiple criteria that take the entire life cycle into account

NATIONAL EUROPEAN TYPE I ECOLABEL FOR SUPERMARKETS

The Blue Angel for Climate-Friendly Grocery Stores in the Food Retail Sector (DE-UZ 179)

- Objective: significantly reduce the energy and refrigerant-related emissions

Nordic Swan: Nordic Ecolabelling for Grocery stores

- Objective: store has a holistic approach to its environmental activities (product range, energy conservation, waste management, transport and consumables)

Bra Miljöval: The Good Environmental Choice label for grocery shops

- Objective: promoting progress toward a sustainable society (products, management, energy, transport, waste)

WORK WITHIN THE SUPERSMART PROJECT

End of SUPERSMART

Criteria development

2016

2017

2018

Start of SUPERSMART

Preliminary Report

Technical Report

+

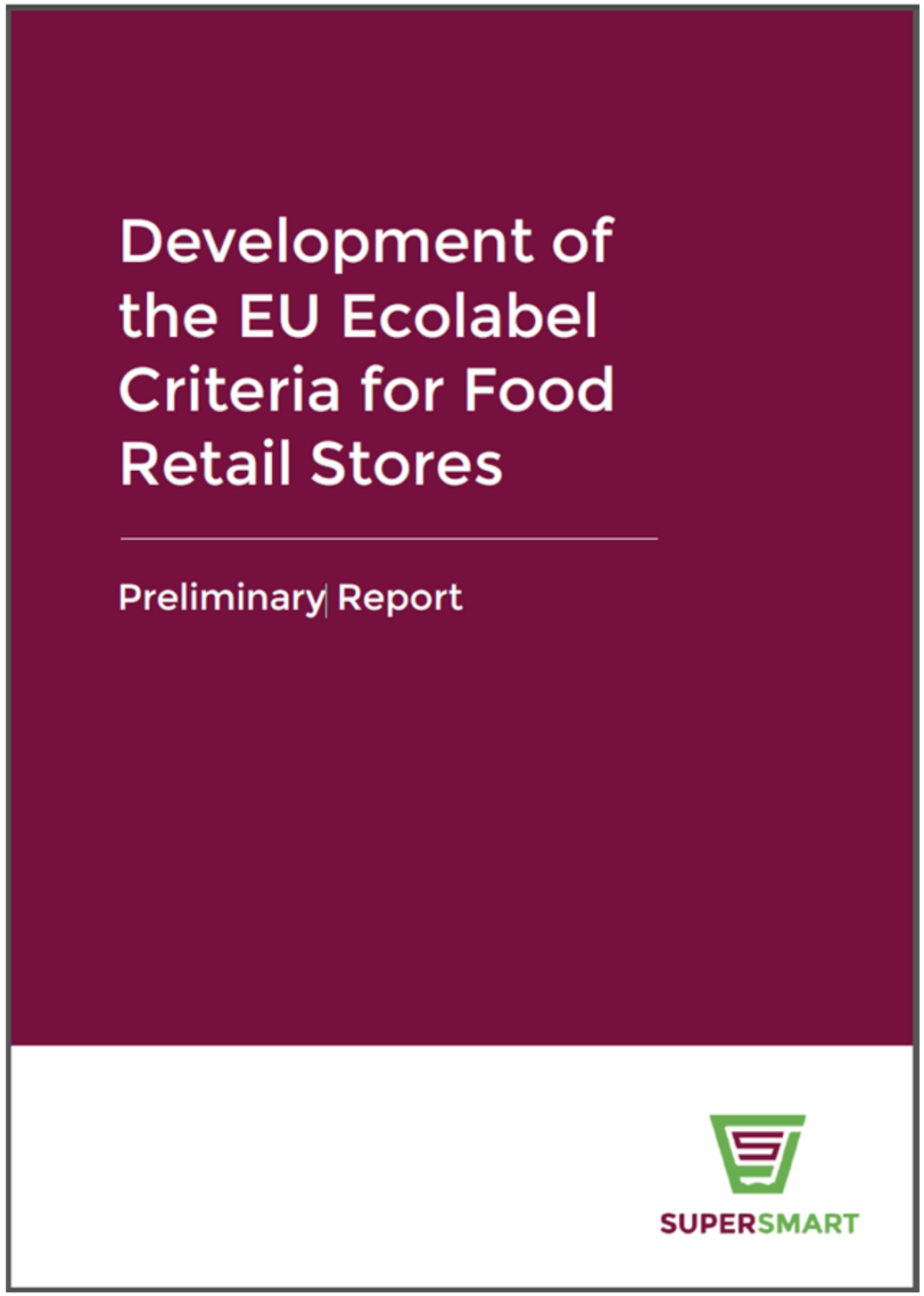
Product group proposal

Content:

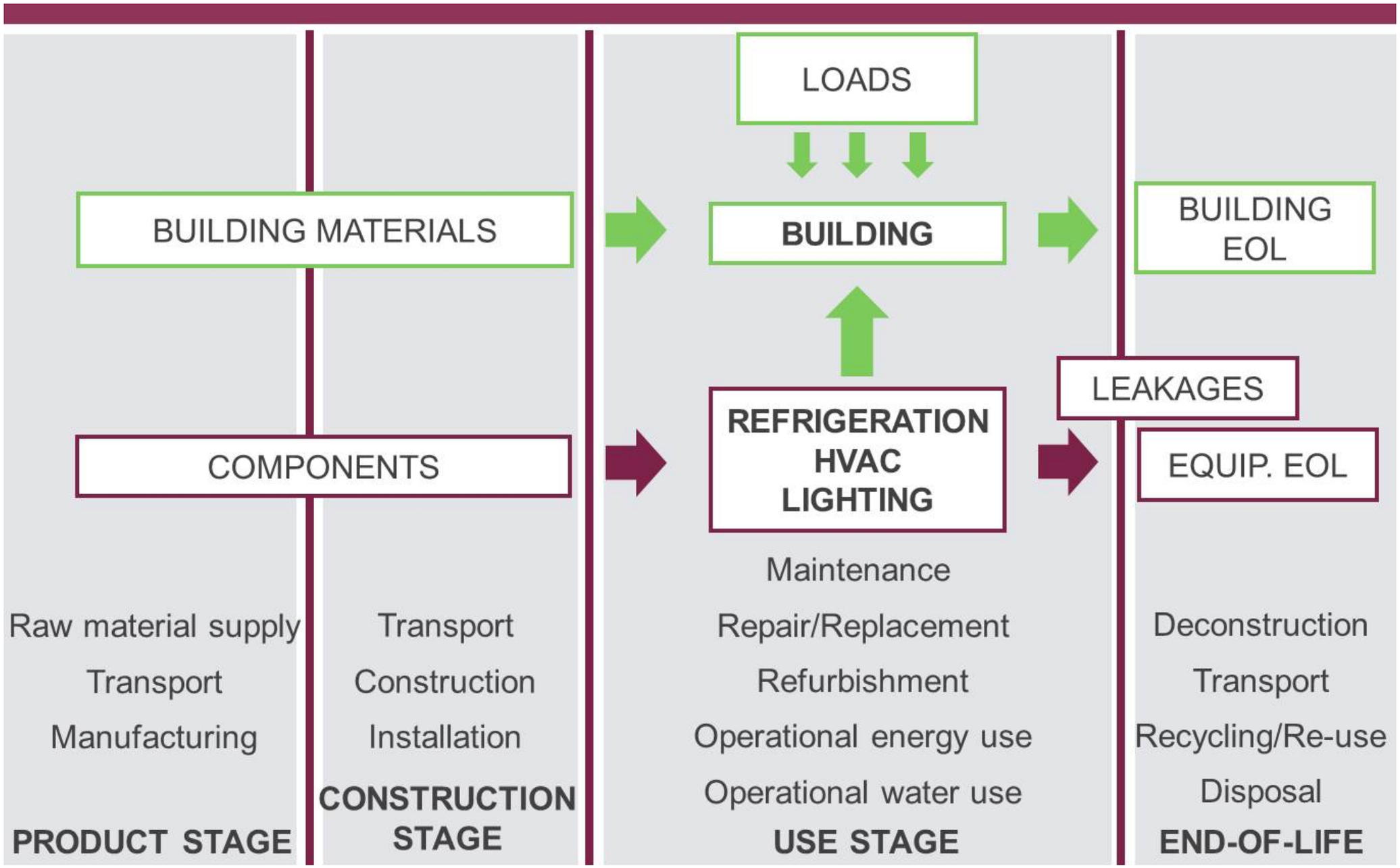
1. Product Group Scope and Definition
2. Market Analysis
3. Technical and Environmental Analysis including **LCA analysis**
4. Improvement Potential Areas

Available on:

http://www.supersmart-supermarket.info/downloads/



Life cycle stages for retail stores



Best practices related to LCA

INSTALLATIONS AND FACILITIES:	
Priority	**Best Practice**
|||	Use of natural refrigerants
|||	Reduction of refrigerant charge and leakages
||||	High efficiency equipment
||||	Monitoring and management systems
|||	Renewable energy systems
LIFE SERVICE	
Priority	**Best Practice**
||	Accomplish design building's life span (min. 50 years)
BUILDING FEATURES:	
Priority	**Best Practice**
||	Reduce roof surfaces
||	Avoid stand-alone buildings in order to reduce the surface of outer enclosures and dispense with roofs
||	Have preference for non-asphalt-based materials, (such as EPDM)
		Reduce height of spaces
||	Contribute to natural lighting
||	Environmentally friendly materials
|||	Reduce thermal loads from the outside

➢ focus for EU Ecolabel criteria developed within the SuperSmart project

HOW DID WE DEVELOP THE CRITERIA?

Basis:

1. Existing criteria of national European Type I Ecolabel (Ecolabel Regulation, Article 11)

Bra Miljöval

2. Consideration of the entire life cycle (Ecolabel Regulation, Article 6)
   ➢ Best practices related to LCA

3. Considering of legal regulations

4. Existing EU Ecolabel for other services (e.g. tourist accommodations)

5. Recommendations from a majority of experts through feedbacks during workshops and via online surveys

WHAT WE CONSIDERED

Aims:

- Criteria are applicable in whole of Europe
- Compliance verifications are applicable in whole of Europe
- About 20% of the most environmentally friendly food retail stores currently on the European market can meet the criteria

➢ for all market formats - from small traditional shops to hypermarkets

➢ independent of climatic boundary conditions

➢ for new and existing food retail stores, for own and rental properties, for stand-alone buildings and stores in shopping centers...

Solution:

FLEXIBLE APPROACH → MANDATORY REQUIREMENTS

FLEXIBLE APPROACH → POINT SCORE REQUIREMENTS

EXAMPLE FOR CRITERIA DEVELOPMENT: ENERGY AND ENVIRONMENT MANAGEMENT SYSTEMS

Mandatory: Operating of energy management system according to DIN EN ISO 50001	**Mandatory:** Annual reporting	**Mandatory:** Store has environmental officer	**Mandatory:** Creating the basis for an environmental management system	DIN EN ISO 50001 Energy management system	**Best Practice with priority 4:** Monitoring and management systems
Optional: Operating of environmental management system in accordance with EMAS	**Mandatory:** Designation of a contact person		**Optional:** Consumption monitoring: Energy and water sub-metering (up to 2 points)	DIN EN ISO 14001 Environment management system	
				EMAS Regulation (EC) No 1221/2009	
				Directive 2012/27/ EU	

Mandatory requirements
1) Energy monitoring for refrigeration system
2) Set up of environment and energy management system
Point score requirements
1) Controlled and managed processes: Refrigeration: 3 points HVAC: 2 points Lighting: 1 point Other: 1 point
2) Benchmarking mechanism implemented: 2 points
3) ISO 50001 Energy management standard implemented: 3 points
4) ISO 14001 Environment management standard or EMAS implemented: 5 points
5) Environment and energy staff hired: 2 points

OVERVIEW OF CRITERIA

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	Criterion 5: Energy consumption of the building
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 14: Store's use of goods and services
	Criterion 15: Information to customers

Technical Report with all developed criteria will be published soon!

SAMER SAWALHA

CRITERIA FOR HVAC&R AND BUILDINGS OF FOOD RETAIL STORES

OVERVIEW OF CRITERIA

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	Criterion 5: Energy consumption of the building
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 14: Store's use of goods and services
	Criterion 15: Information to customers

Good practices that minimizes the environmental impact and contribute to sustainability

GENERAL APPROACH

Mandatory requirements

Collecting points

Minimum limit

Score

Store

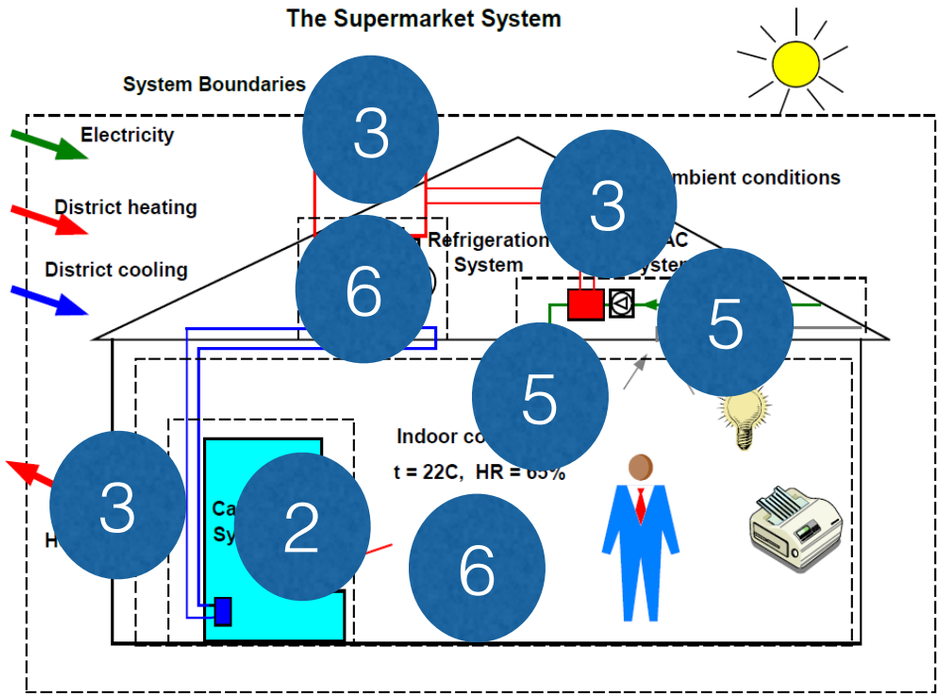
Store

Store

Store

Store

Store



>minimum/ category

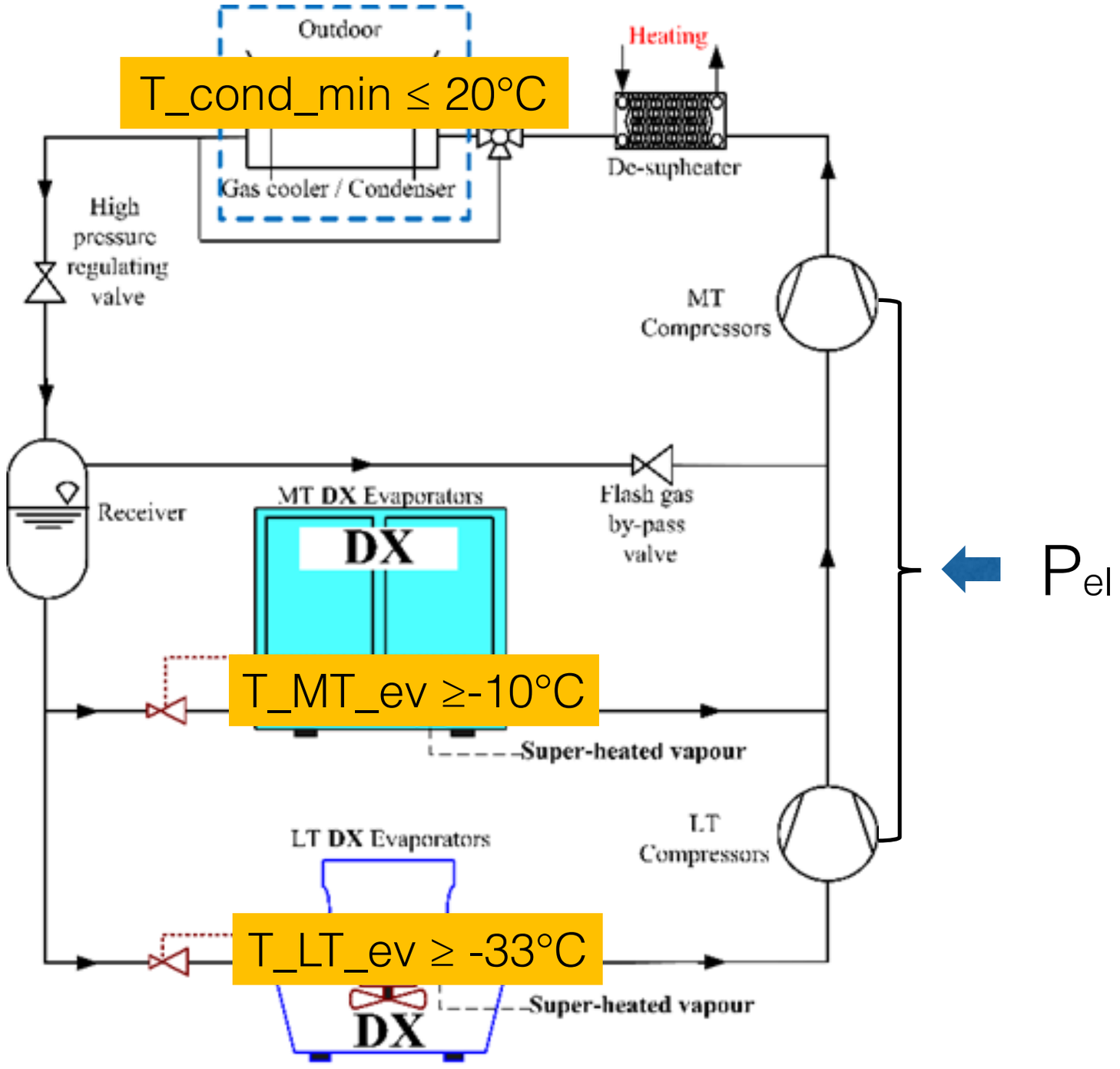
Total points out of full scale

CRITERION 1: ENERGY CONSUMPTION OF THE REFRIGERATION SYSTEM

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	Criterion 5: Energy consumption of the building
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 14: Store's use of goods and services
	Criterion 15: Information to customers

CRITERION 1: MANDATORY REQUIREMENTS

- **Evaporation temperature**
  - Minimum limit
  - Active control
- **Condensing temperature**
- **Power consumption compared to ideal cycle**

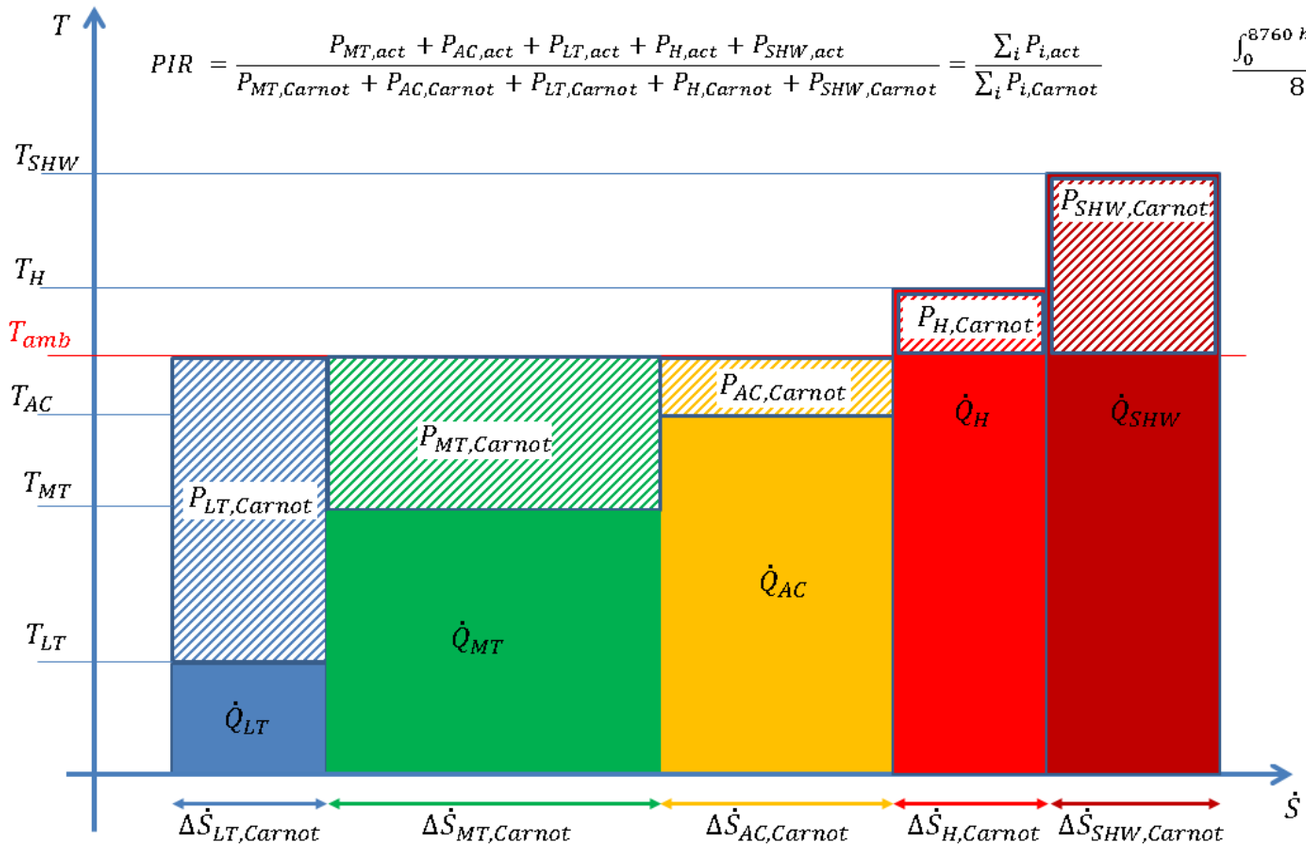


CRITERION 1: MANDATORY REQUIREMENTS

- PIR (Power Input Ratio): Ratio between P_{AC} and P_{Carnot}:
  - New system: should not exceed 5
  - Existing system: should not exceed 5.5

$$PIR = \frac{P_{MT,act} + P_{AC,act} + P_{LT,act} + P_{H,act} + P_{SHW,act}}{P_{MT,Carnot} + P_{AC,Carnot} + P_{LT,Carnot} + P_{H,Carnot} + P_{SHW,Carnot}} = \frac{\sum_i P_{i,act}}{\sum_i P_{i,Carnot}}$$

$$\frac{\int_0^{8760\ h} PIR(\tau)\,\mathrm{d}\tau}{8760\ h} \leq 5$$



P – power
$\dot{Q}$ – heat power
T – temperature
$\dot{S}$ – entropy rate
PIR – Power Input Ratio

Indices:
LT – low temperature
MT – medium temperature
AC – Air Conditioning
H – heating
SHW – sanitary hot water
Carnot – ideal Carnot cycle
act – actual power consumption

$$P_{MT,Carnot} = \dot{Q}_{MT}\left(\frac{T_{amb}}{T_{MT}} - 1\right)$$

$$P_{LT,Carnot} = \dot{Q}_{LT}\left(\frac{T_{amb}}{T_{LT}} - 1\right)$$

$$P_{AC,Carnot} = \dot{Q}_{AC}\left(\frac{T_{amb}}{T_{AC}} - 1\right)$$

$$P_{H,Carnot} = \dot{Q}_{SHW}\left(1 - \frac{T_{amb}}{T_H}\right)$$

$$P_{SHW,Carnot} = \dot{Q}_{SHW}\left(1 - \frac{T_{amb}}{T_{SHW}}\right)$$

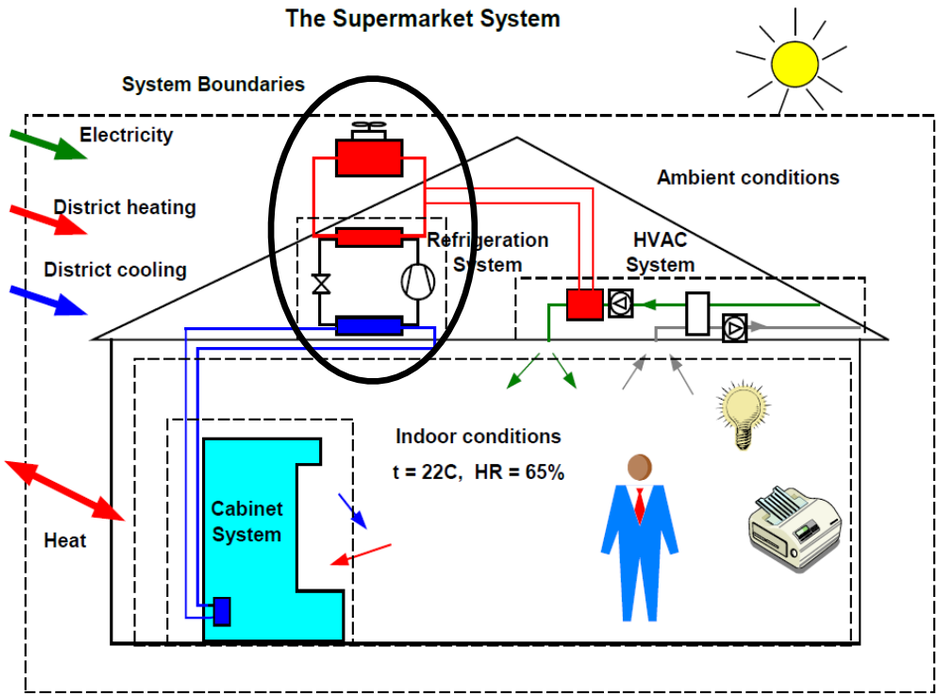
Source: Own elaboration by SINTEF and CNR

CRITERION 1: MANDATORY REQUIREMENTS

Mandatory requirements

Collecting points

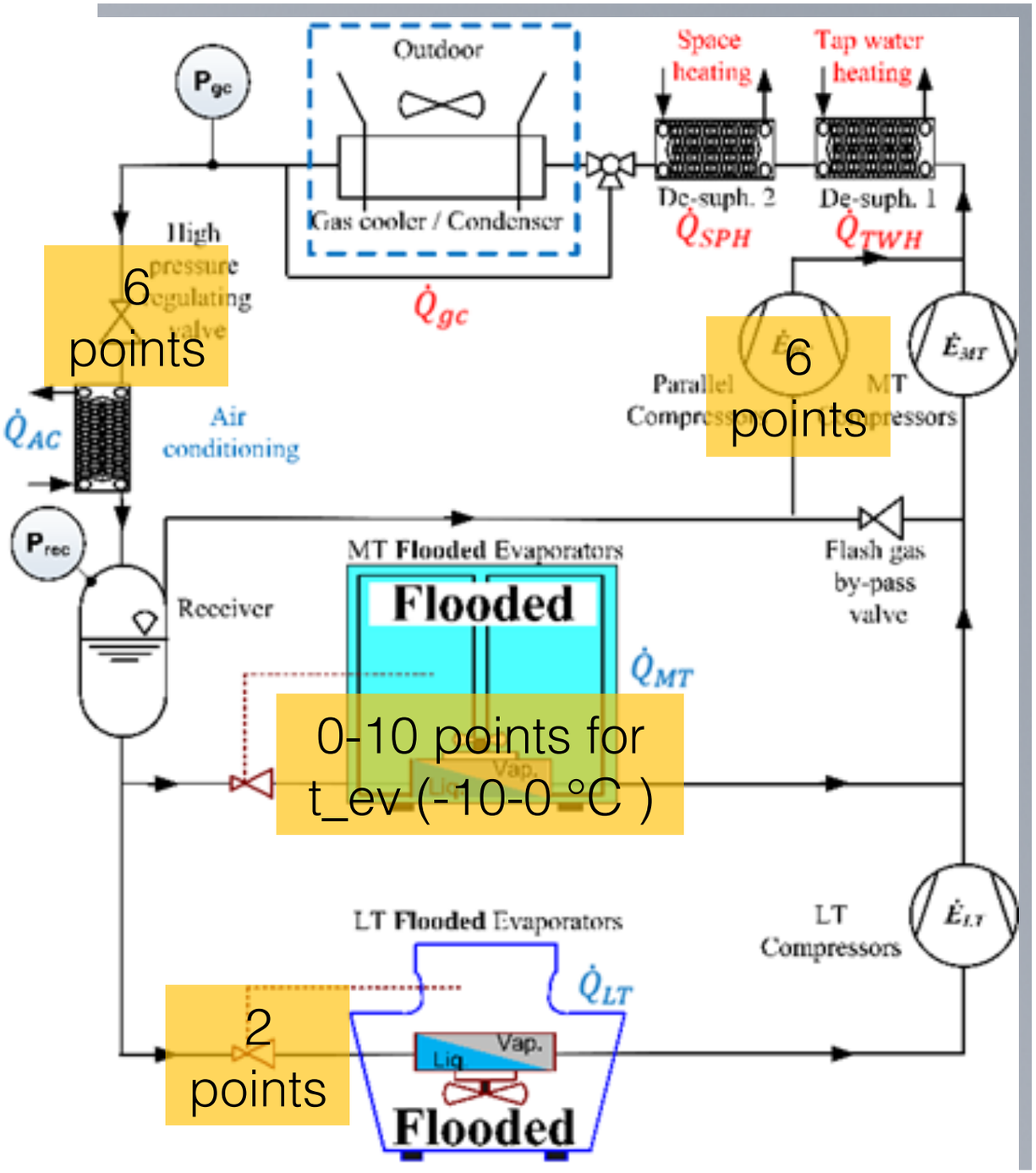
- Store
- Store
- Store
- Store
- Store
- Store
- Store



CRITERION 1: POINTS COLLECTION

- Evaporation temperature
- Parallel compression
- Electronic expansion valves
- Expansion work recovery (ejector or expander)
- ….

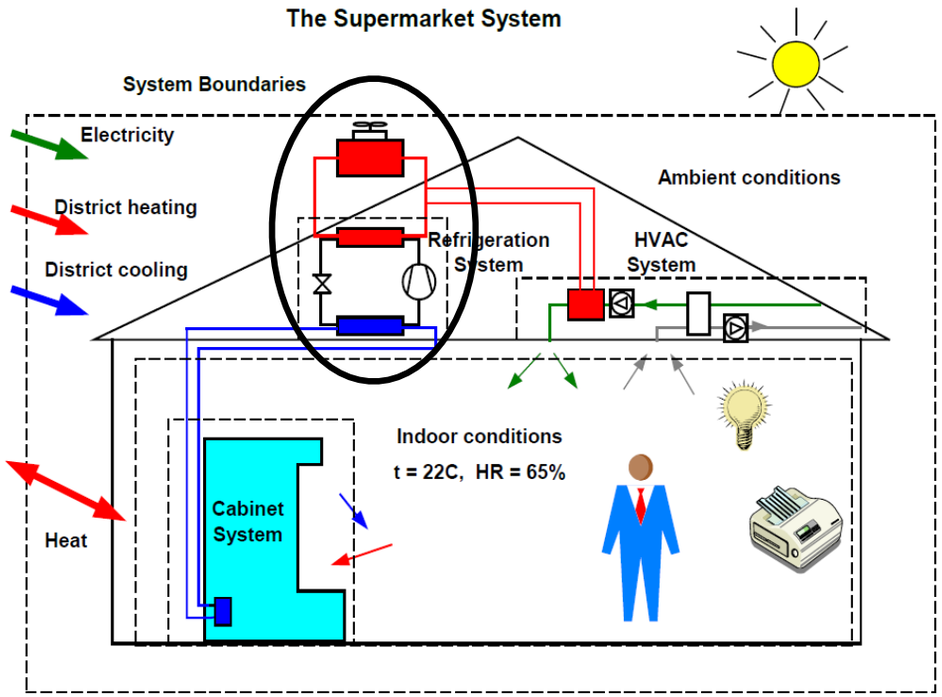
At least 50 % of the available points for this criterion must be fulfilled, i.e. 18 points



CRITERION 1: ENERGY CONSUMPTION OF THE REFRIGERATION SYSTEM

Mandatory requirements	Collecting points	Minimum limit	Score

- Store
- Store
- Store
- Store
- Store
- Store



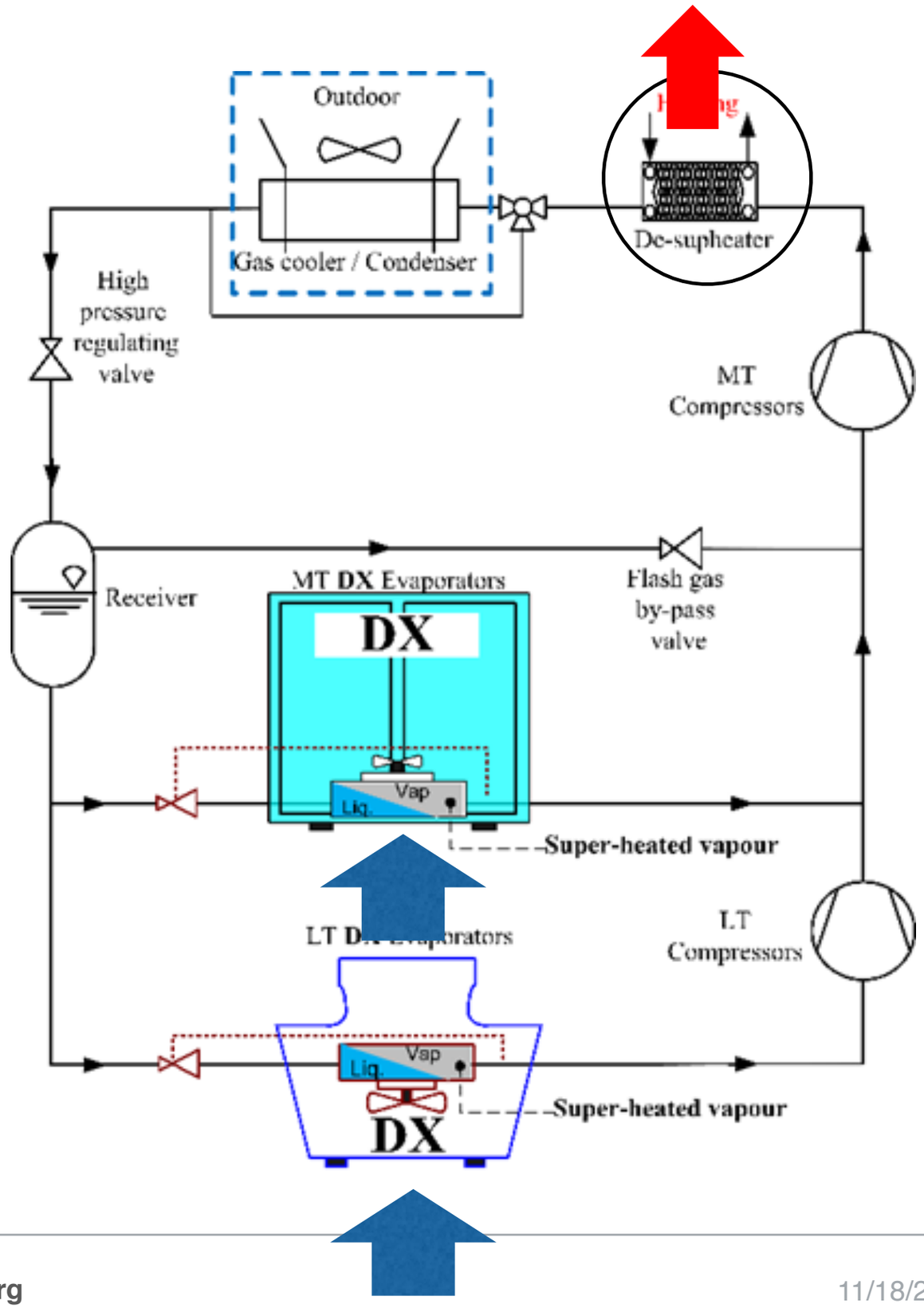
>minimum/ category	Total points out of full scale

CRITERION 2: HEAT RECOVERY

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	Criterion 5: Energy consumption of the building
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 13: Store's use of goods and services
	Criterion 15: Information to customers

CRITERION 2: MANDATORY REQUIREMENTS

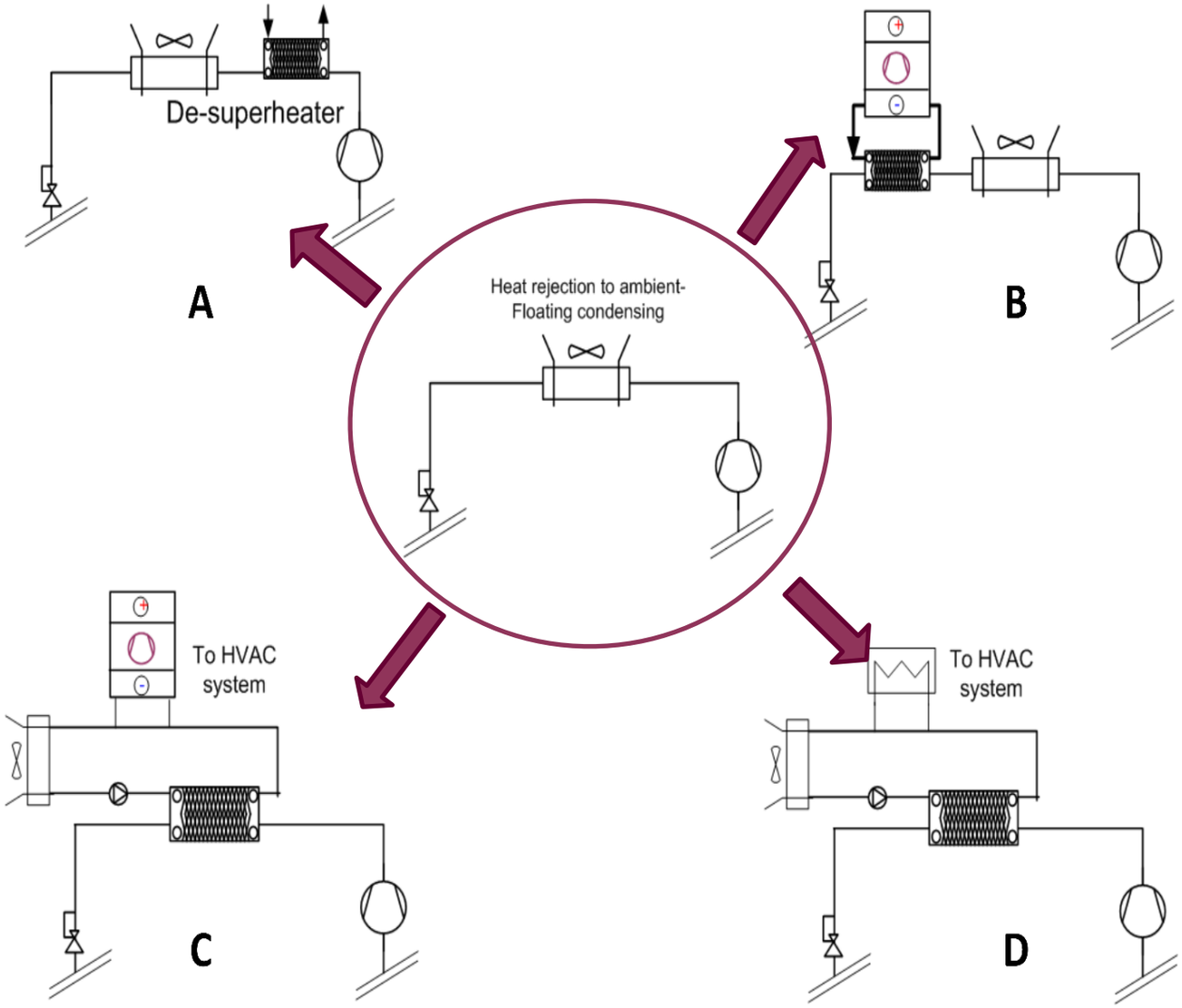
- **Heat must be recovered!**



CRITERION 2: POINTS COLLECTION

Point score requirements:

- Use of direct heat recovery (via refrigerant) into shopping area, parking, etc.
  12 points
- Water temperature required for heat recovery is lower than 45 °C.
  6 points
- Utilisation of low-grade heat for auxiliary heating (parking ice melting, etc.) or thermal storage (energy wells, etc.)
  4 points



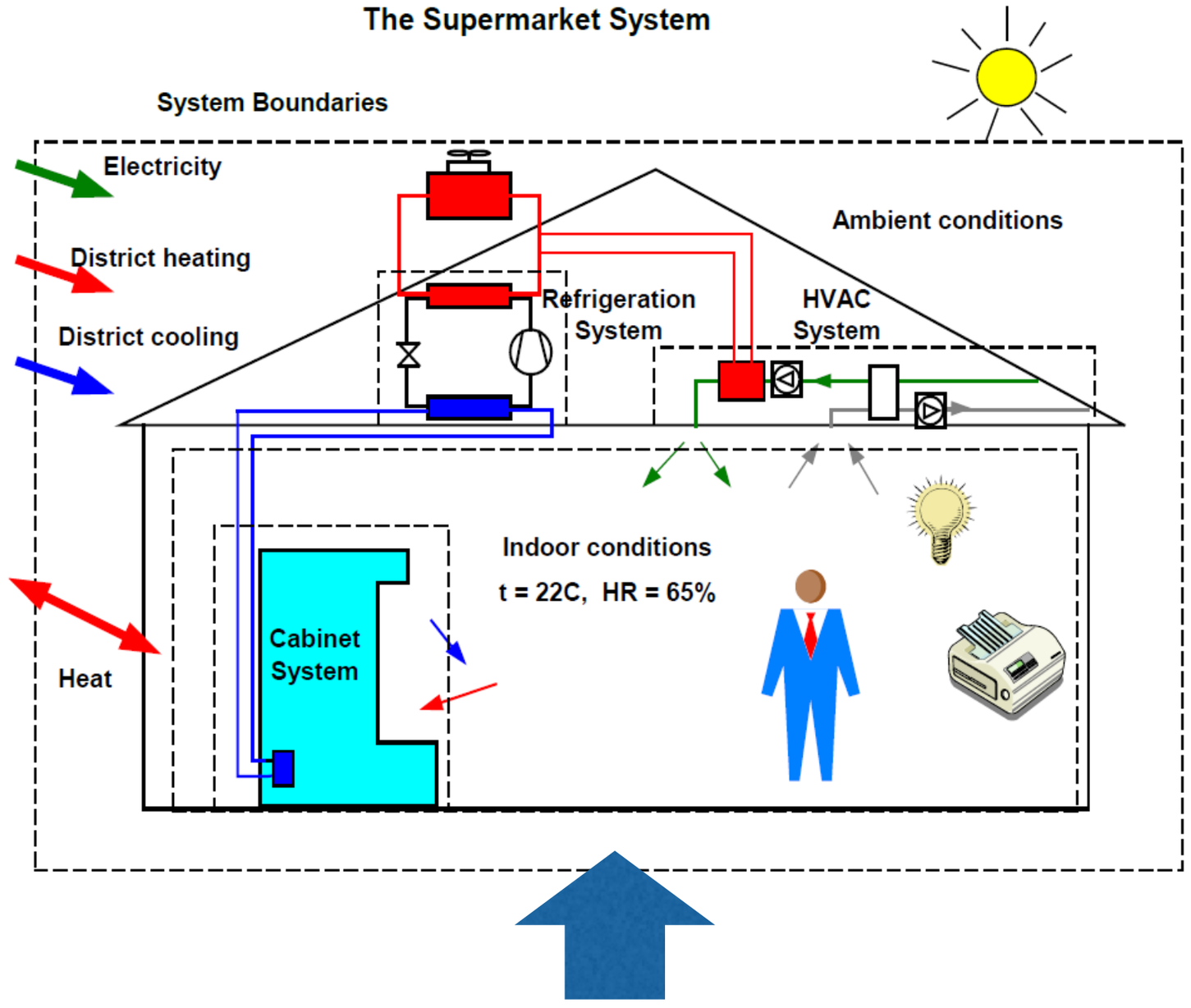
CRITERION 5: ENERGY CONSUMPTION OF THE BUILDING

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	**Criterion 5: Energy consumption of the building**
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 14: Store's use of goods and services
	Criterion 15: Information to customers

CRITERION 5: MANDATORY REQUIREMENTS

- $PEC_{act} \leq PEC_{ref}$

All energy saving measures should result in overall energy use savings



AEU to PEC

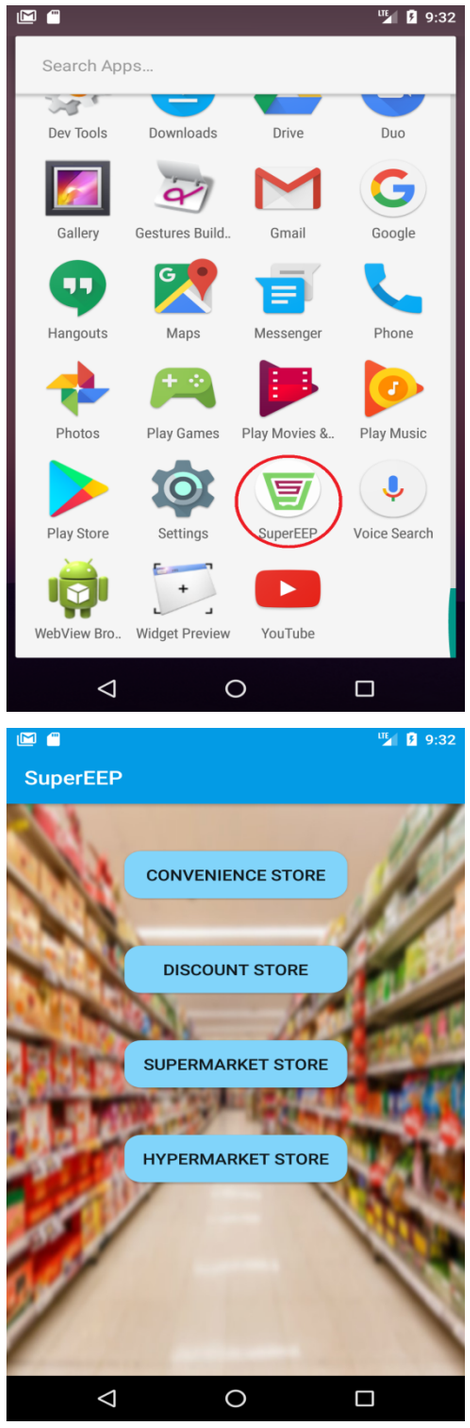
Required data for PEC_{ref} estimation:

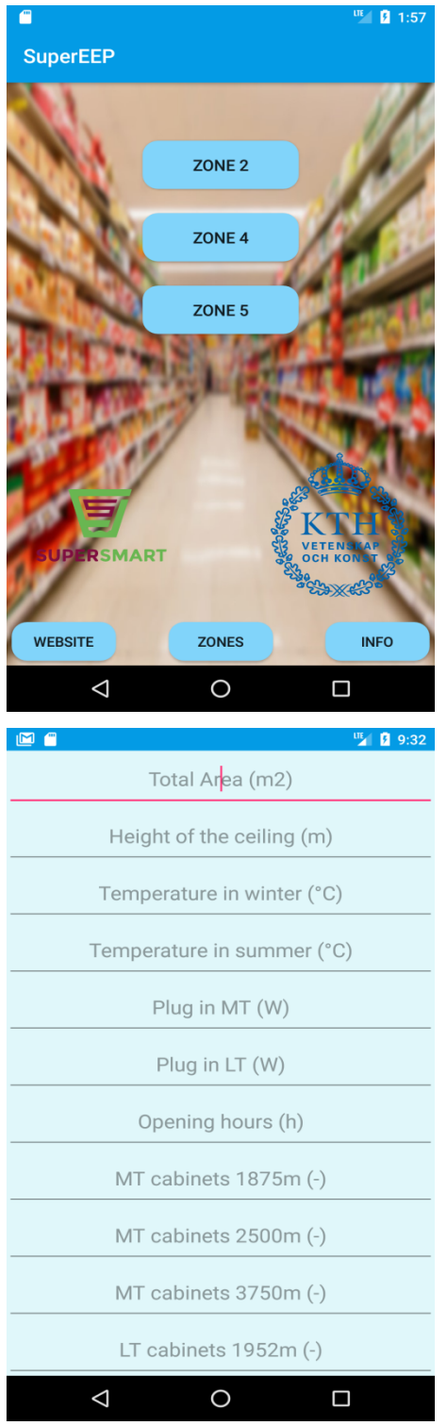
1. Sales area of the store $[m^2]$
2. Height of the ceiling $[m]$
3. Opening hours $[h]$
4. Indoor temperature (summer) $[°C]$
5. Indoor temperature (winter) $[°C]$
6. Electric power of medium temperature (MT) plug-in cabinets$[W]$
7. Electric power of low temperature (LT) plug-in cabinets$[W]$
8. Number of MT remote display cabinets (1.875 m) [–]
9. Number of MT remote display cabinets (2.500 m) [–]
10. Number of MT remote display cabinets (3.750 m) [–]
11. Number of LT remote display cabinets (1.952 m) [–]
12. Number of LT remote display cabinets (2.500 m) [–]
13. Number of LT remote display cabinets (3.750 m) [–]
14. Volume air flow HVAC system $\left[\frac{m^3}{h}\right]$
15. Lighting power $\left[\frac{W}{m^2}\right]$

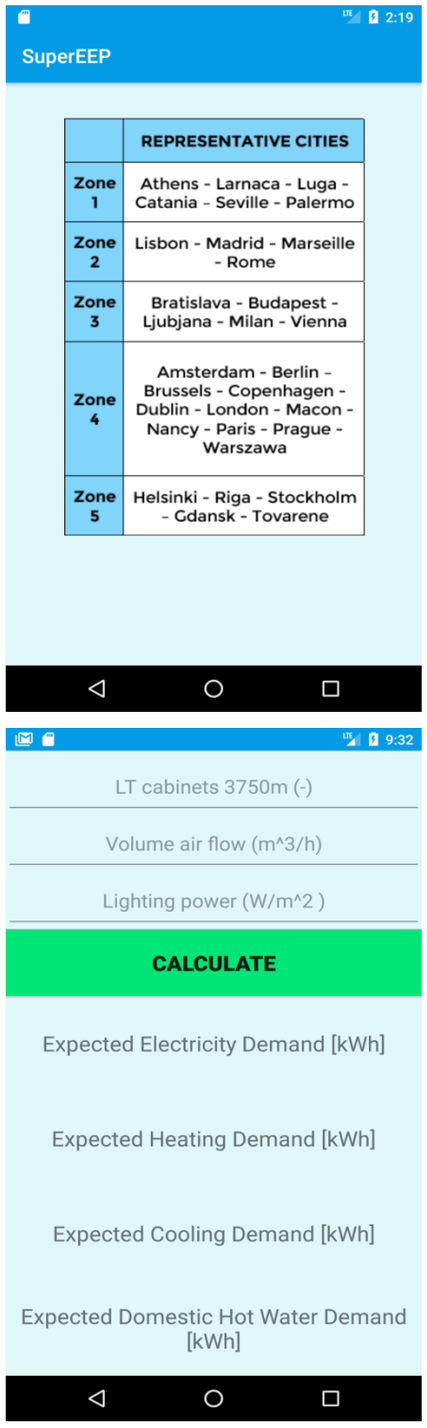
$$f_1(cost_1, x_1, \dots, x_{15})$$
$$f_2(cost_2, x_1, \dots, x_{15})$$
$$f_3(cost_3, x_1, \dots, x_{15})$$
$$f_4(cost_4, x_7)$$

$$E_{exp,electricity}\ [kWh]$$
$$Q_{exp,heating}\ [kWh]$$
$$Q_{exp,cooling}\ [kWh]$$
$$Q_{exp,DHW}\ [kWh]$$

CRITERION 5: MANDATORY REQUIREMENTS







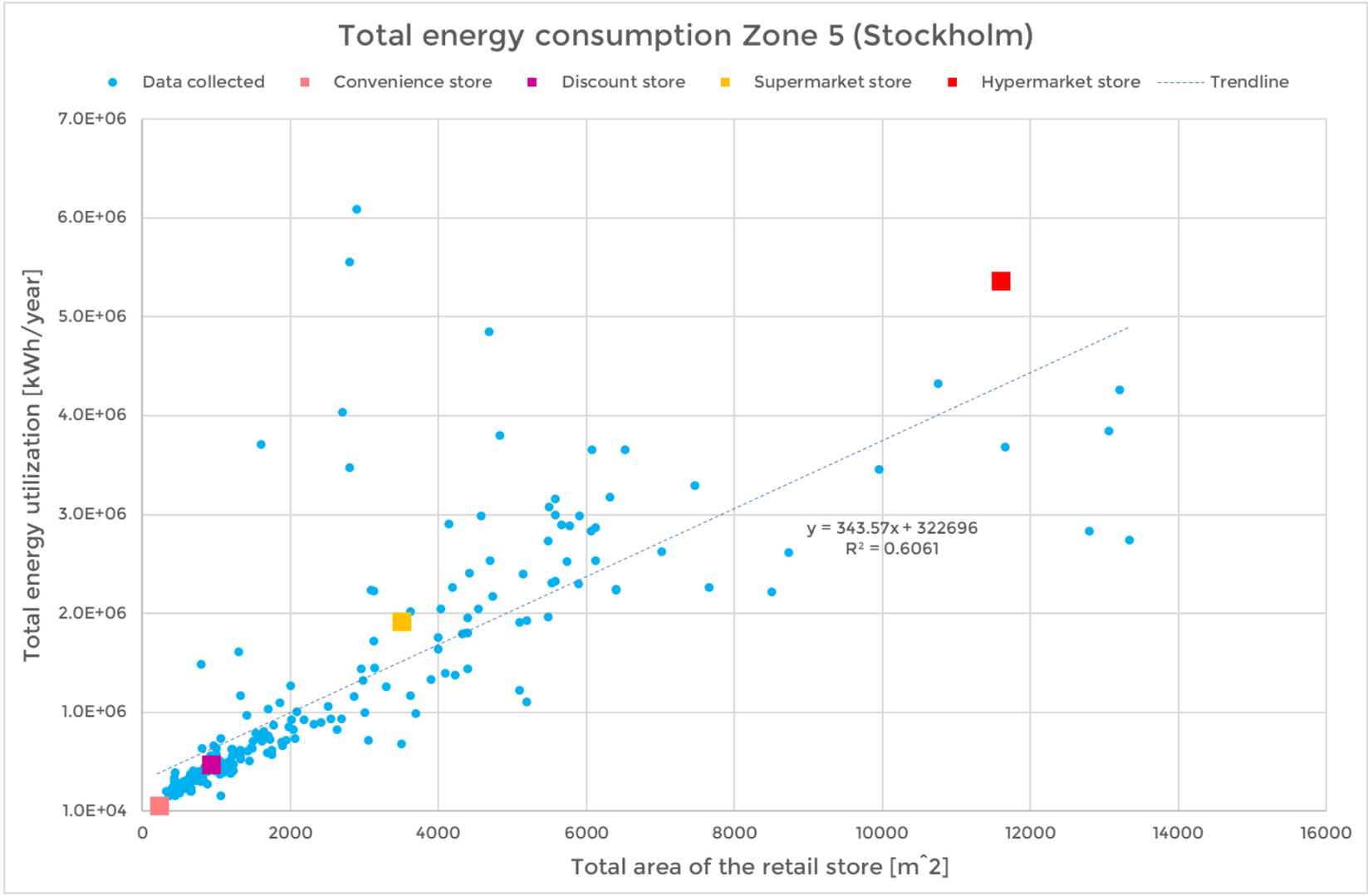
PEC$_{ref}$

Calculations based on CyberMart at KTH

CRITERION 5: POINTS COLLECTION

Suggested points scale:
- $PEC_{act} \leq 70\% * PEC_{ref}$
1 point
- $PEC_{act} \leq 60\% * PEC_{ref}$
2 points
- $PEC_{act} \leq 50\% * PEC_{ref}$
3 points

PEC_{ref}



Total energy utilization for Swedish food retail stores

OVERVIEW OF CRITERIA

Criteria areas	Criterion
HVAC&R	Criterion 1: Energy efficiency of the refrigeration system
	Criterion 2: Heat recovery
	Criterion 3: Display cabinets
	Criterion 4: Refrigerants
Building	Criterion 5: Energy consumption of the building
	Criterion 6: Energy and environmental management systems
	Criterion 7: Lighting
	Criterion 8: Use of renewable energy sources
	Criterion 9: Building materials and resources
	Criterion 10: Location and accessibility of the store
Operating of the store	Criterion 11: Waste
	Criterion 12: Water consumption and wastewater management
	Criterion 13: Labelled products sold in the store
	Criterion 14: Store's use of goods and services
	Criterion 15: Information to customers

Good practices are identified and retail stores are rewarded for their positive approach towards the environment.

Details for all criteria will be found in the near future at:
http://www.supersmart-supermarket.info/downloads/

SUPERSMART

EXPERTISE HUB FOR ENERGY-EFFICIENT COOLING & HEATING IN EUROPEAN SUPERMARKETS

Part II: Improving supermarket energy efficiency

Horizon 2020
European Union funding
for Research & Innovation

HANNE KAUKO

INTRODUCTION

AGENDA

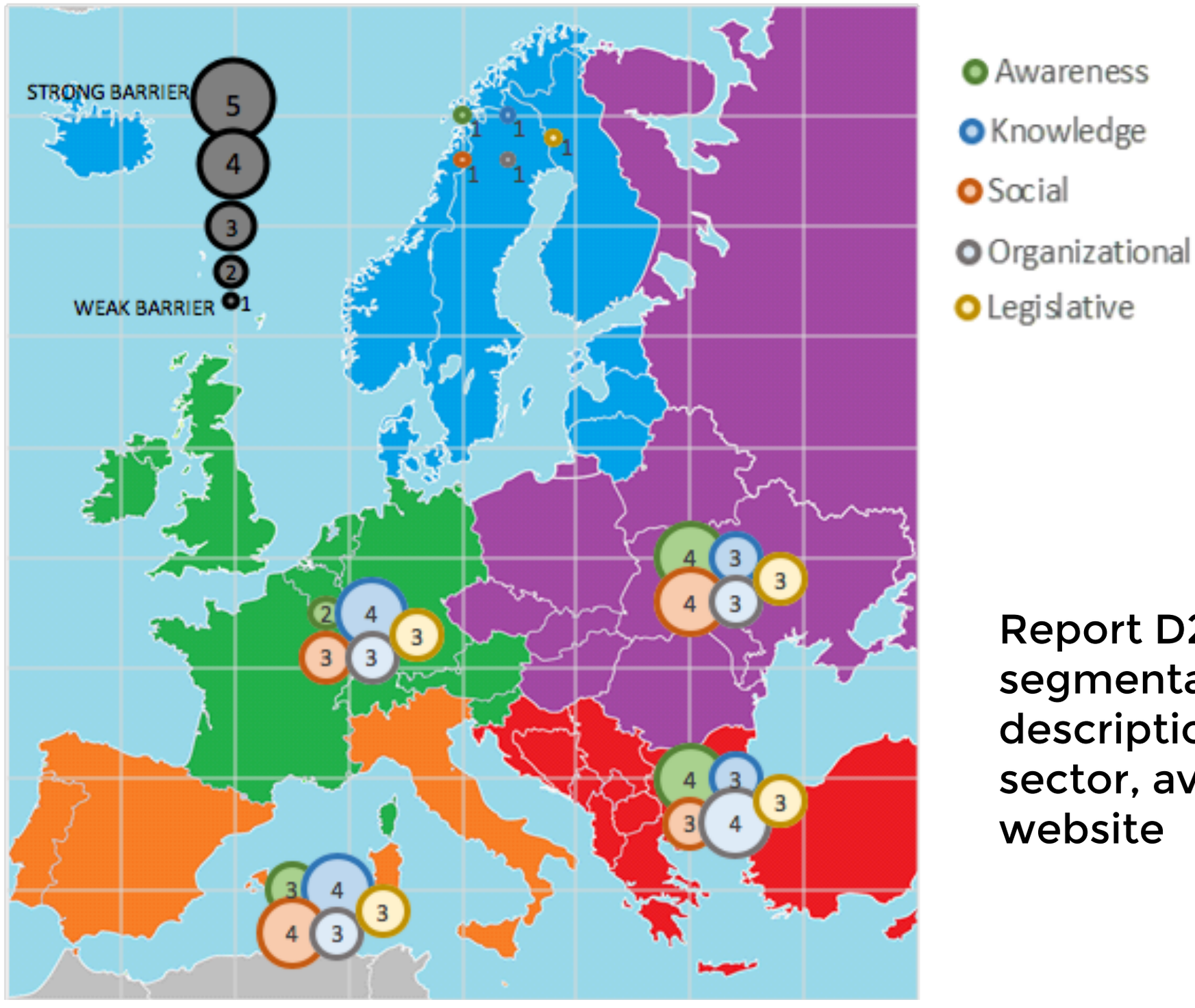
Time	Title	Presenter
10:00	Welcome	Ingrid C. Claussen (SINTEF)
Part I: EU Ecolabel for Food Retail Stores		
10:05	EU Ecolabel for Food Retail Stores I • Criteria development within the project • Criteria for the operating of food retail stores	Kerstin Martens (UBA)
10:20	EU Ecolabel for Food Retail Stores II • Criteria for HVAC&R and buildings of food retail stores	Samer Sawalha (KTH)
Part II: Improving supermarket energy efficiency		
10:35	Introduction	Hanne Kauko (SINTEF)
10:40	Eco-friendly supermarkets – an overview	Samer Sawalha (KTH)
11:00	Components for energy efficient supermarket refrigeration	Silvia Minetto (CNR)
11:20	Efficient and environmentally friendly refrigeration with CO_2	Armin Hafner (NTNU)
11:40	Supermarket control systems	Antonio Rossetti (CNR)

WP2 ON REMOVING NON-TECHNOLOGICAL MARKET BARRIERS

- Reporting barriers towards energy efficient supermarkets
- Preparation of training and awareness raising material
- Training technical staff to uptake efficient heating and cooling solutions
- Empowering supermarket stakeholdes to comply with future label criteria

HIGHLIGHTS

Systematizing of Barriers and Planning of Removal Actions



Report D2.1, Mapping and segmentation of barriers and description of supermarket sector, available on the website

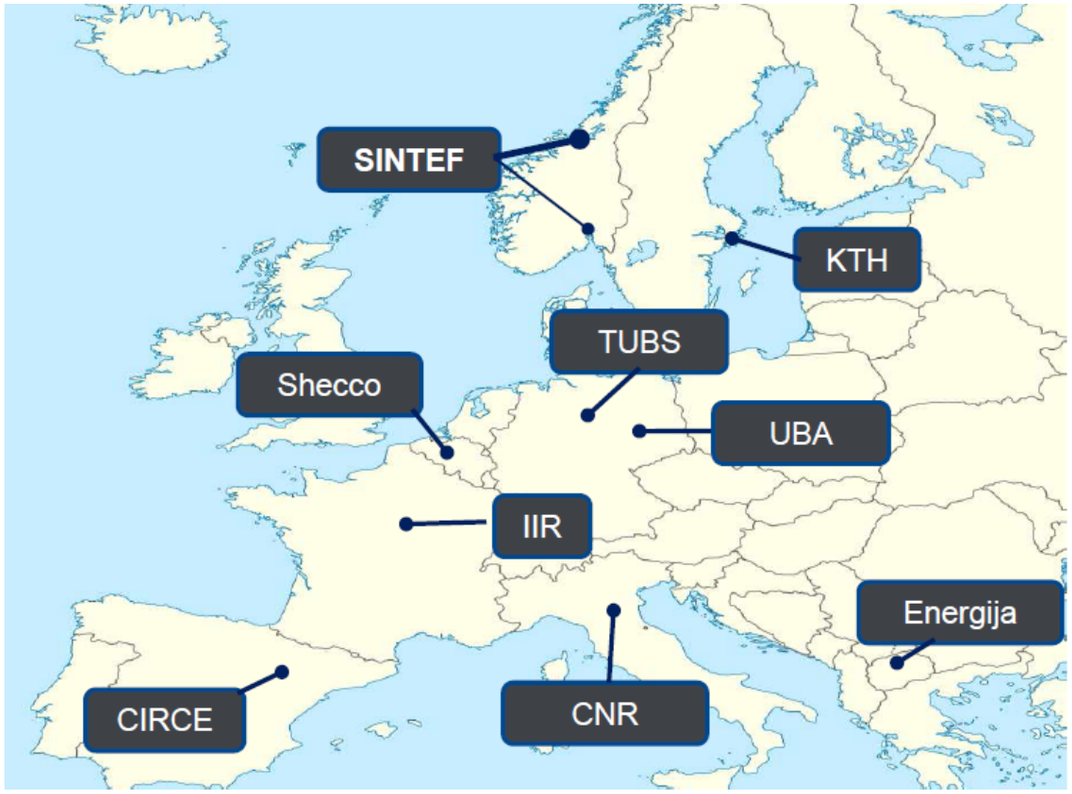
HIGHLIGHTS

Development of Training Material

HIGHLIGHTS

Dedicated Training Events

- **33** dedicated training events have been carried out - 11 more agreed or being planned
- **325** people have been reached
- **6** different countries
- Various different stakeholder groups



SAMER SAWALHA

ECO-FRIENDLY SUPERMARKETS – AN OVERVIEW

SUPERSMART

D2.2 Eco-friendly Supermarkets- an Overview

Horizon 2020
European Union funding
for Research & Innovation

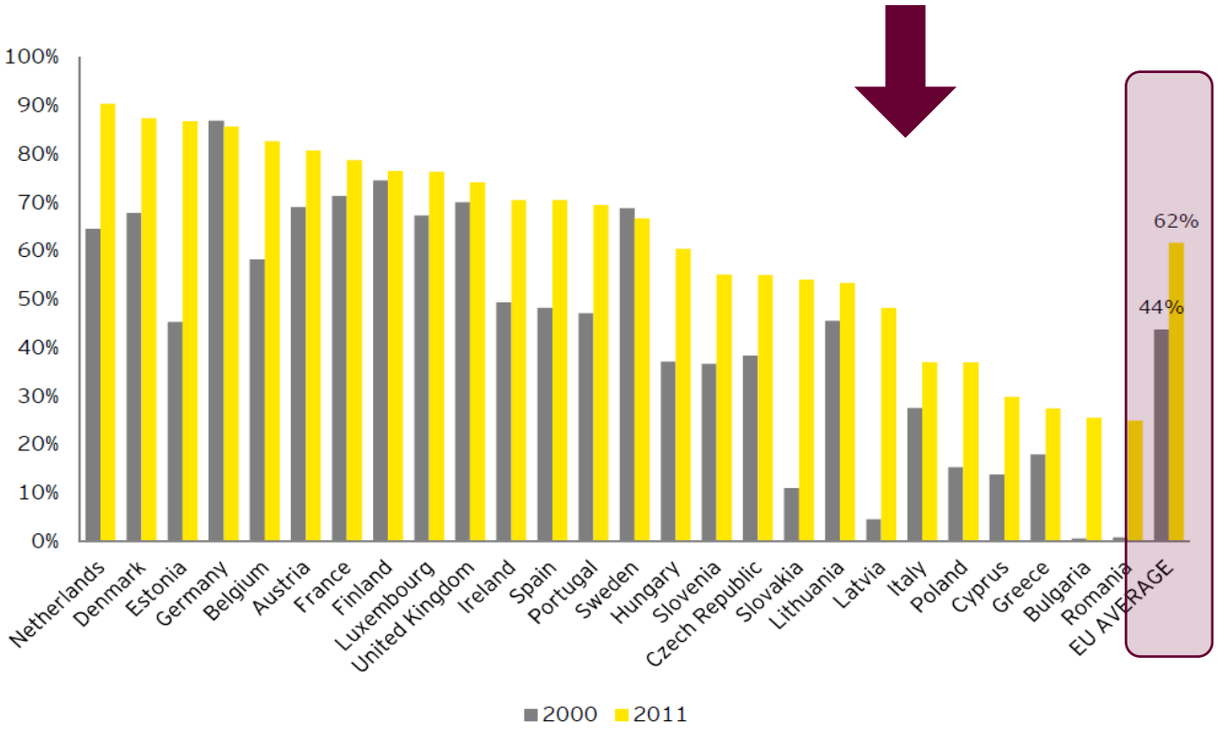
INTRODUCTION

- **Presentation outline**
  - Supermarkets status in Europe
  - Why do we focus on retail stores?
  - Conventional and state-of-the-art systems for:
    Cooling and **Heating** (Focus: **Refrigeration system**)
  - Best practices and case examples.

SUPERMARKET STATUS IN EUROPE

Several parameters show the growth of retail stores in Europe:

- **Increasing** number of hypermarkets, supermarkets, discounters and convenience stores
- **Increasing** total food retail surface area
- **Increasing** share of <u>modern food retail</u> market in European food retail market

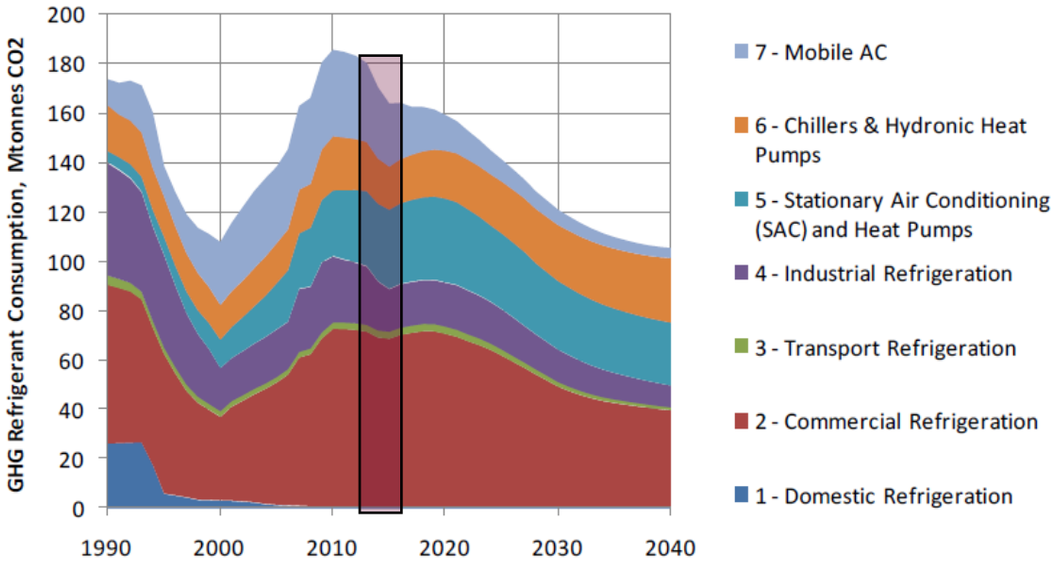


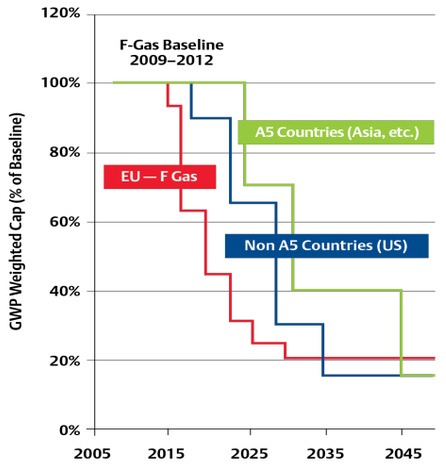
EU average:
44% (2000)
62% (2011)

- **Urbanization;**
- **Emerging middle class;**
- **Globalization;**
- **Increase of female labor;**
- **Liberalization of investment in East Europe;**

Why retail stores? Environmental impacts & F-gas regulation

1 - High GWP refrigerants



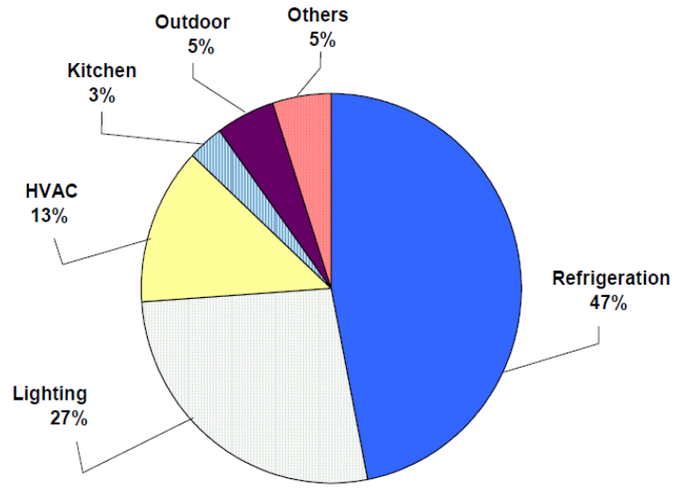


Service and maintenance bans	GWP	Timing
HFC's	2,500	Jan. 2020
'Placing on the market' (new equipment) bans		
Domestic refrigerators and freezers	150	Jan. 2015
Refrigerators and freezers for commercial use (hermetically sealed systems)	2,500	Jan. 2020
Refrigerators and freezers for commercial use (hermetically sealed systems)	150	Jan. 2022
Stationary refrigeration equipment (except equipment for temperatures below -50 °C)	2,500	Jan. 2020
Multipack centralized refrigeration systems for commercial use with a capacity of ≥ 40 kW (140 kBTU/hr) (except in the primary refrigerant circuit of cascade systems, where fluorinated greenhouse gases with a GWP of less than 1,500 may be used)	150	Jan. 2022
Movable room air-conditioning appliances (hermetically sealed equipment which is movable between rooms by the end user)	150	Jan. 2020
Single split air-conditioning systems containing < 3 kg	770	Jan. 2025

F-gas regulation

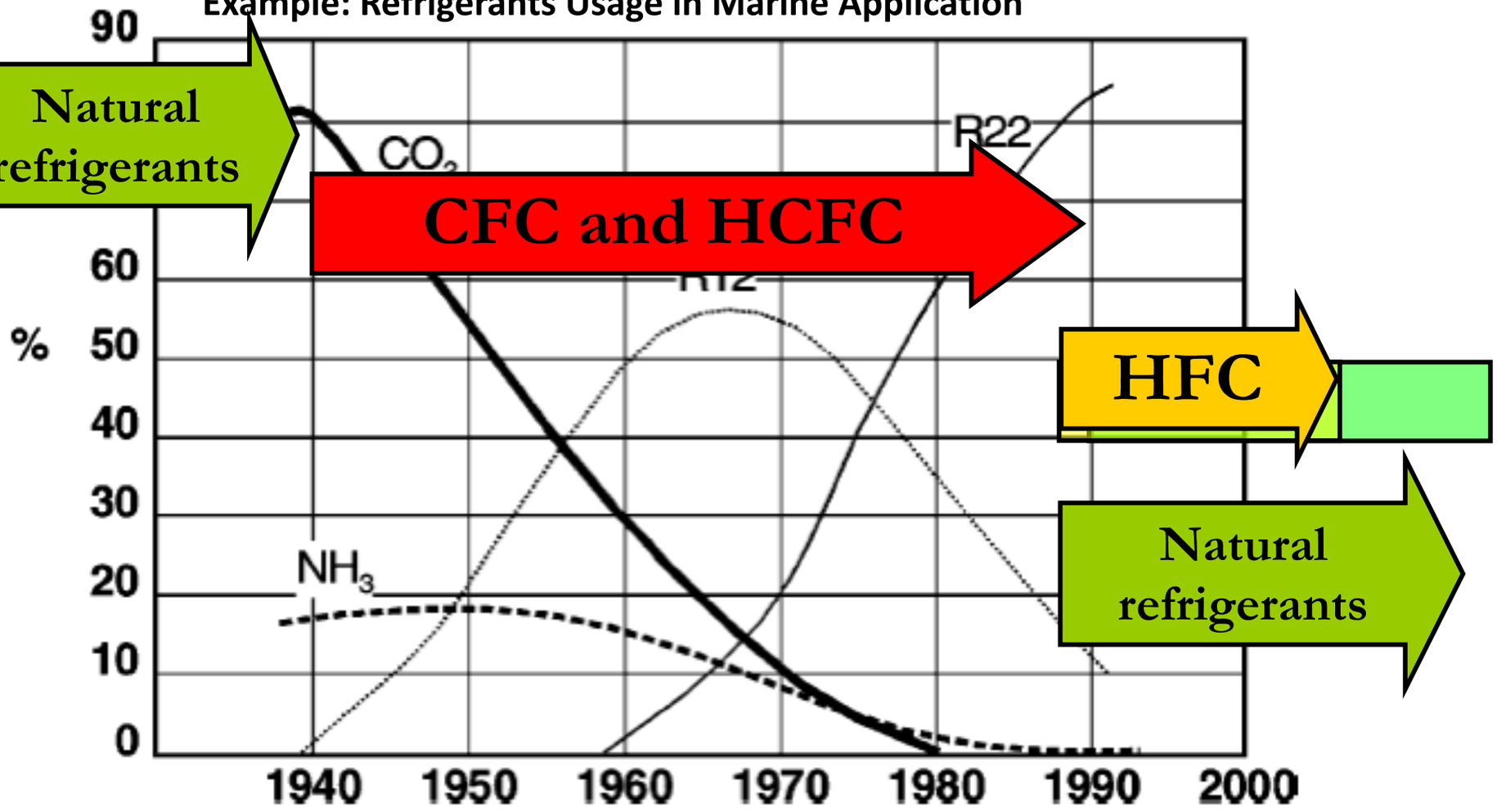
2 - High specific energy consumption among commercial buildings

- Largest part due to **refrigeration**
- Contribution of lightning is **decreasing** (modern LED lights)



USE OF REFRIGERANTS

Example: Refrigerants Usage in Marine Application



Energy use; i.e. how efficient the modern systems are?

Reference: Stera A. Lloyd's Register (1992)

REFRIGERATION SYSTEMS

Functionality: provide storage of and display of perishable food prior to sale. Mainly two temperature levels:

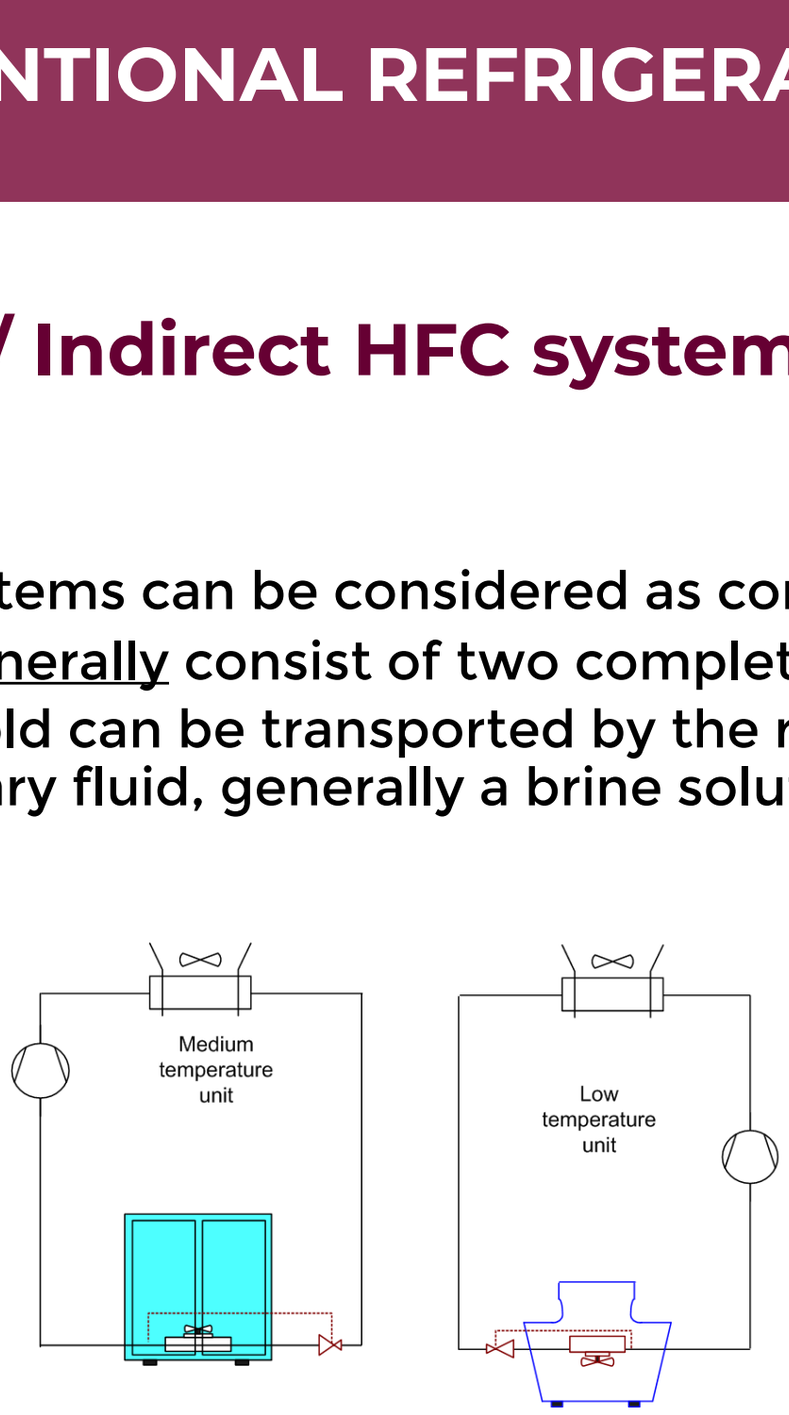
- **Medium Temperature:** Food is chilled to 1/14 °C
- **Low Temperature:** Frozen food kept -12/-18 °C

<u>Types of Refrigeration system:</u>

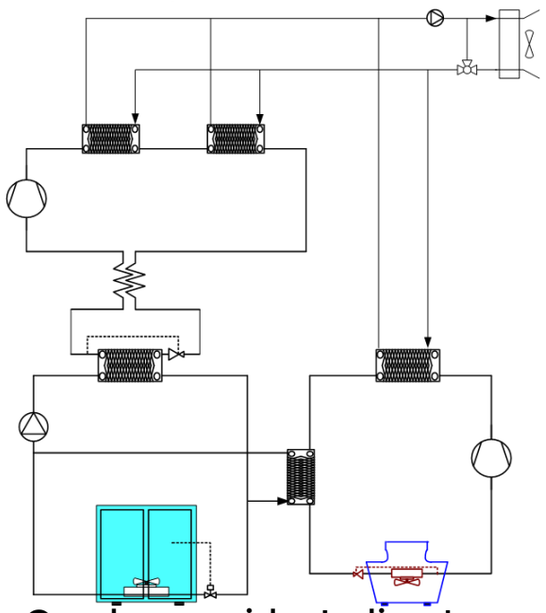
- **Stand Alone (Plug-in)**
- **Condensing Unit**
- **Centralized**

• Direct/ Indirect HFC systems

- HFC systems can be considered as conventional solutions
- They generally consist of two completely separate MT and LT loops
- Heat/cold can be transported by the refrigerant itself (direct system) or using a secondary fluid, generally a brine solution (indirect system)

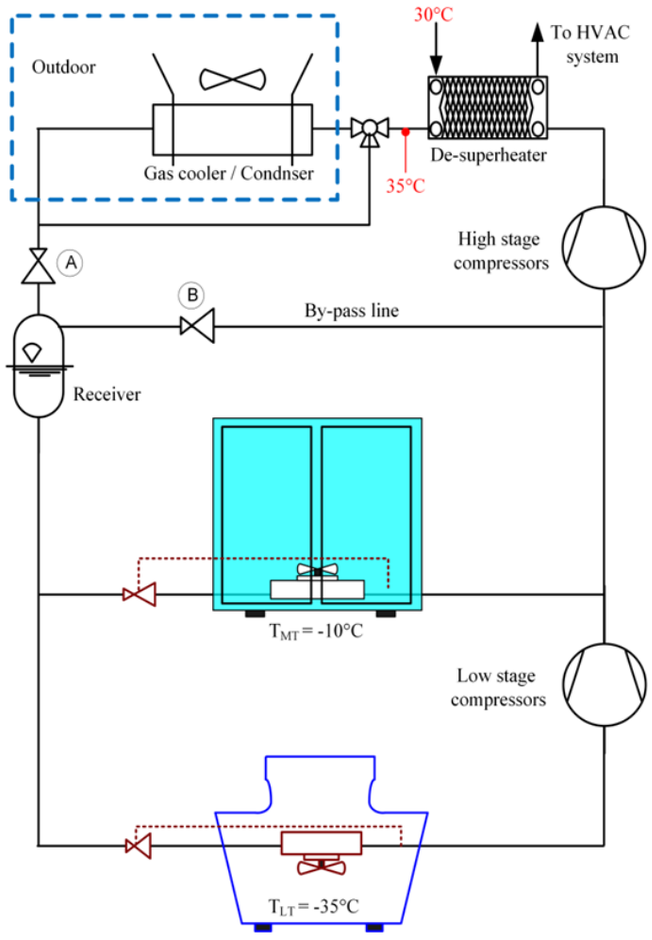


Condenser side: Direct
Med Temperature side: Direct
Low Temperature side: Direct

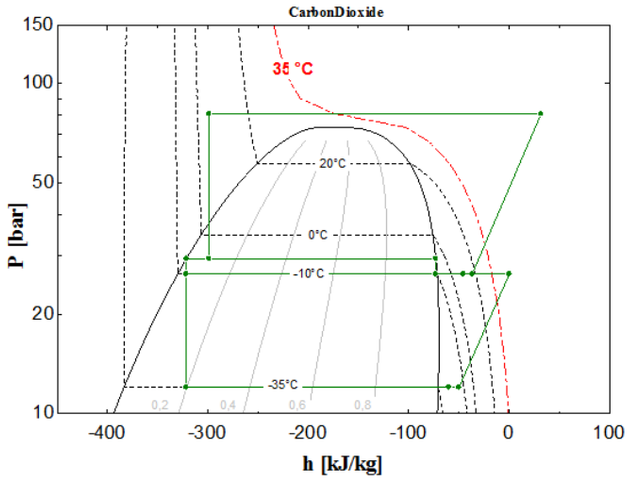


Condenser side: Indirect
Med Temperature side: Indirect
Low Temperature side: Direct

• CO2 Transcritical Booster system



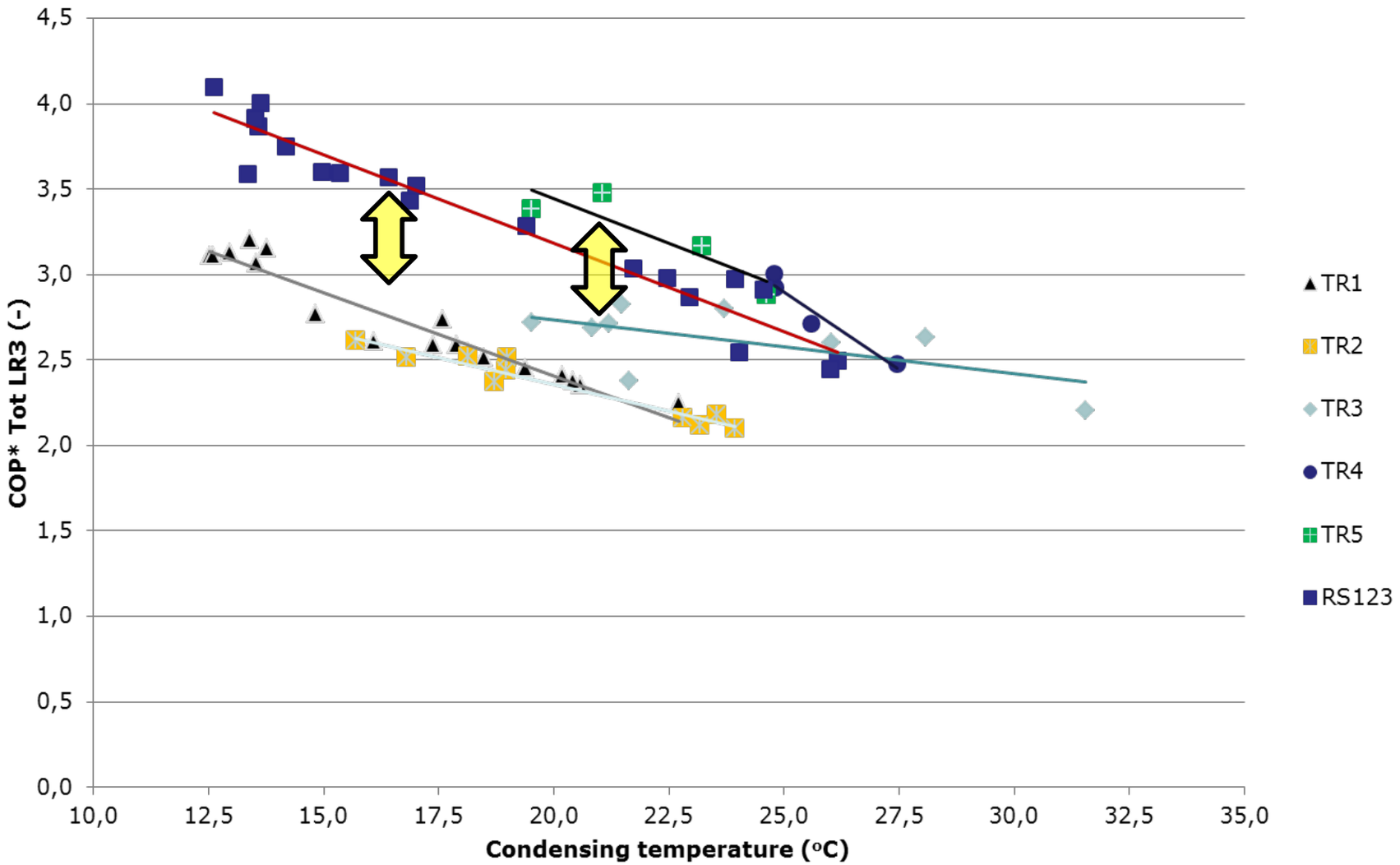
One of **latest developments** towards using climate friendly refrigerants in European supermarkets.



- «Booster»: All the heat at low temperature level is «boosted» to the medium temperature level
- «Transcritical»: High pressure stage over the critical point

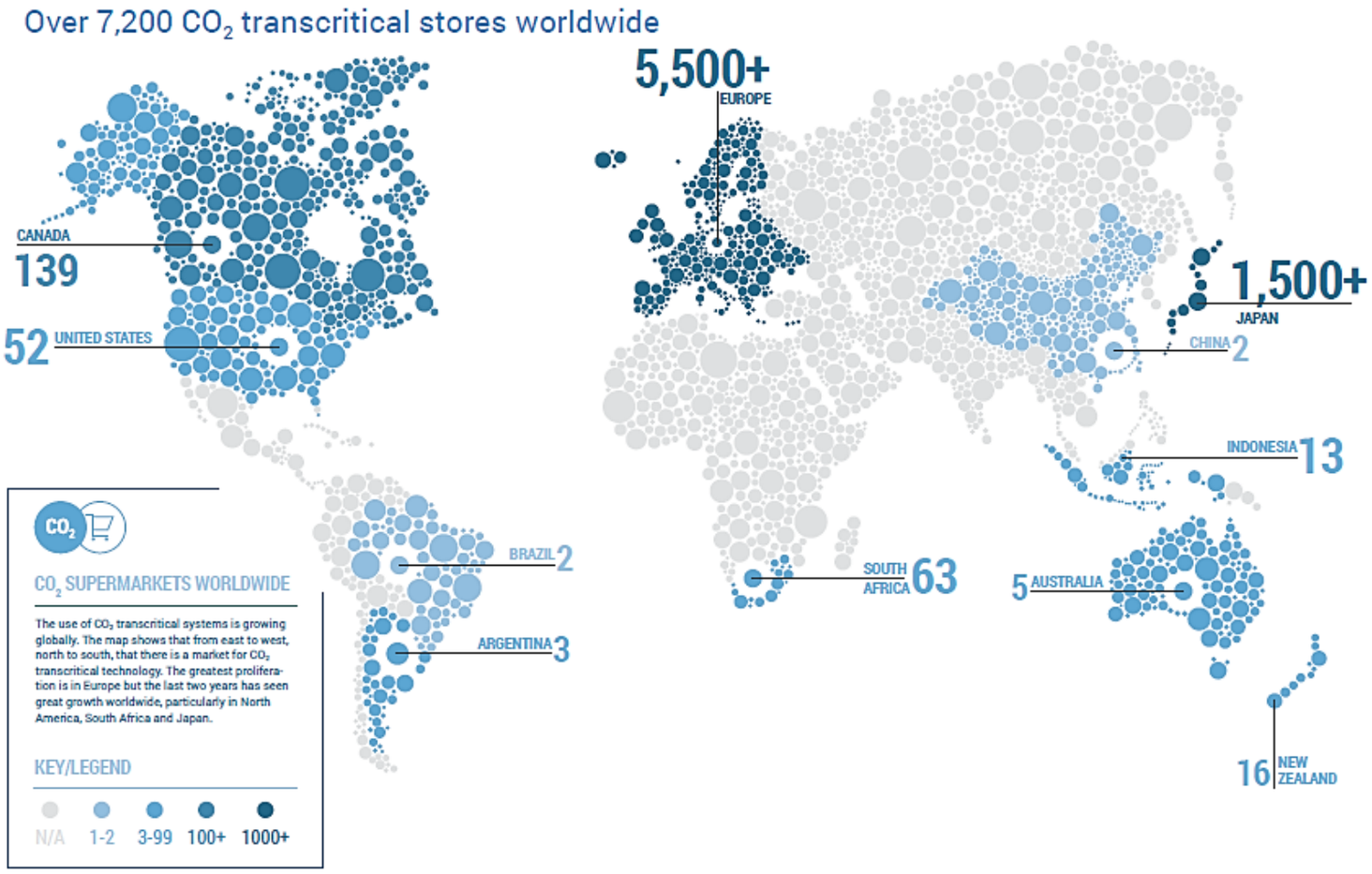
CO_2 BOOSTER SYSTEM VS CONVENTIONAL HFC IN NORTHERN EUROPE

CO2 booster system proved to be more efficient than conventional system in Northern Europe



Source: S. Sawalha et al., "Field measurements of supermarket refrigeration systems. Applied Thermal Engineering, 2017.

CO2 Transcritical Booster system in the word by 2016

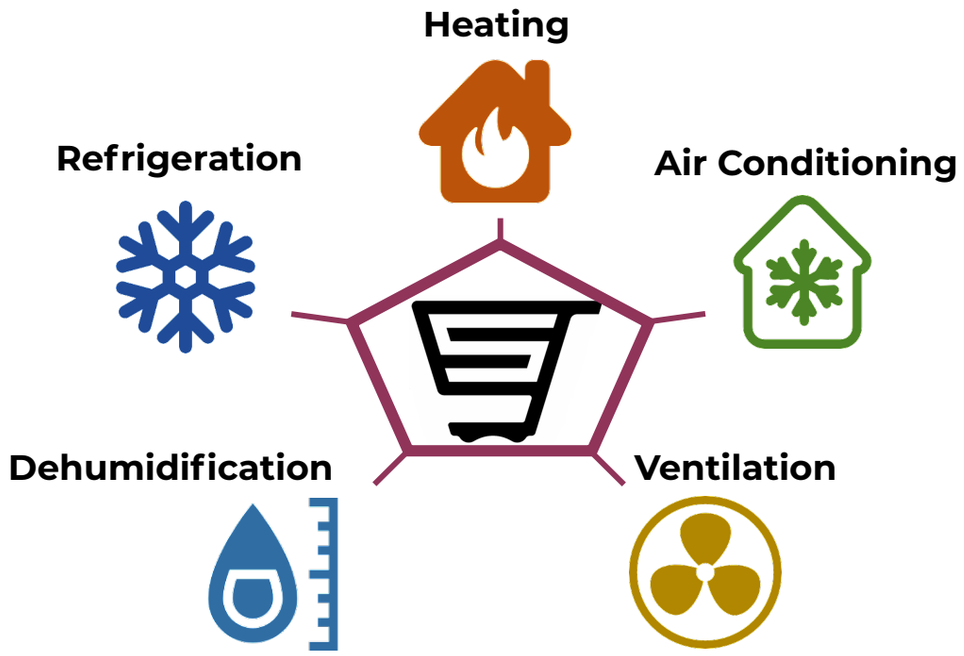


Source: Guide 2016: Guide to natural refrigerants in Japan-State of the industry, by Shecco

ECO-FRIENDLY ENERGY SYSTEMS

Conventional and eco-friendly energy systems in supermarkets:

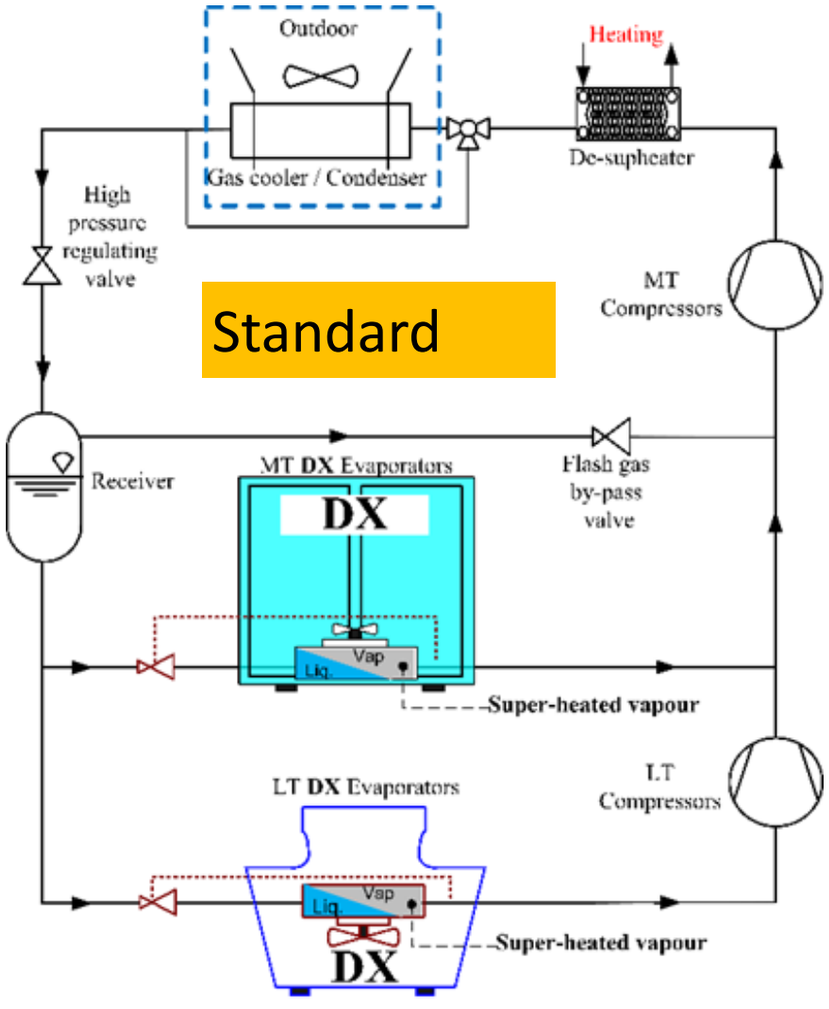
- **Refrigeration:**
  - Central system: CO2 transcritical booster system
- **Heating**
  - Heat recovery
- **Air conditioning**
  - NH3 or HCs Chillers
  - Integrated CO2 system
- **Ventilation**
- **Dehumidification**

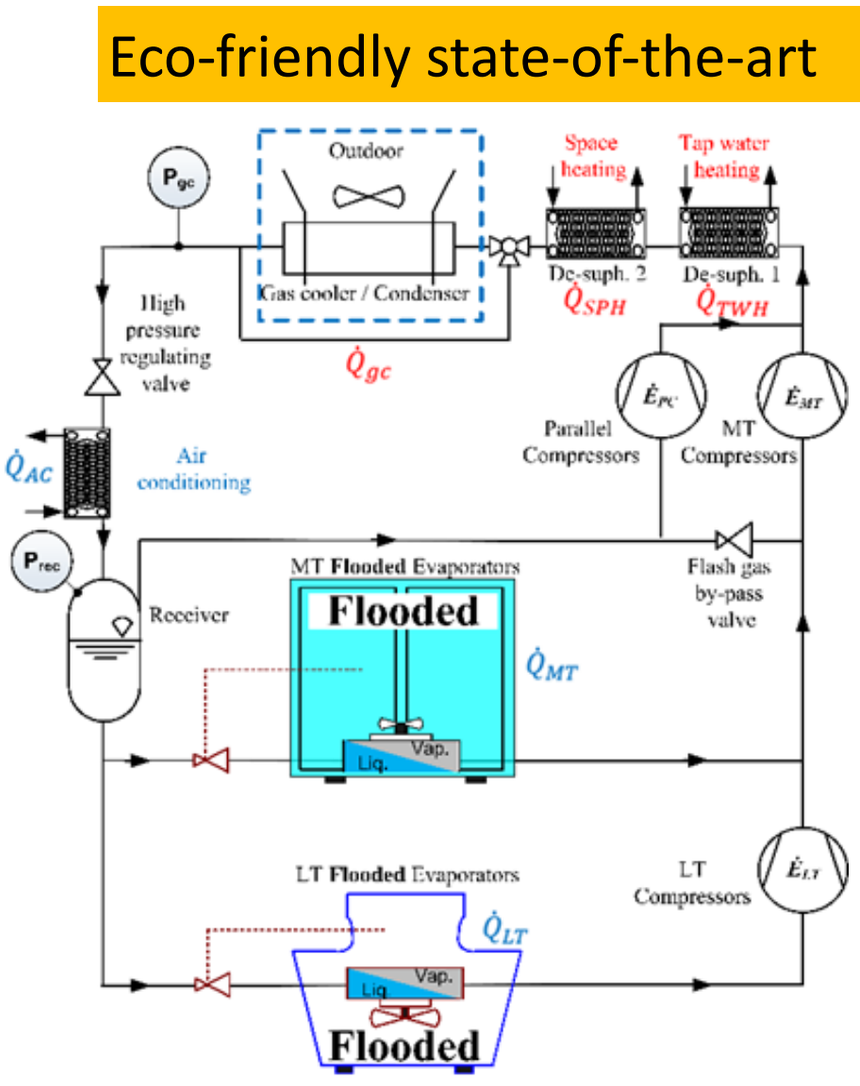


Icon made by Freepik from www.flaticon.com

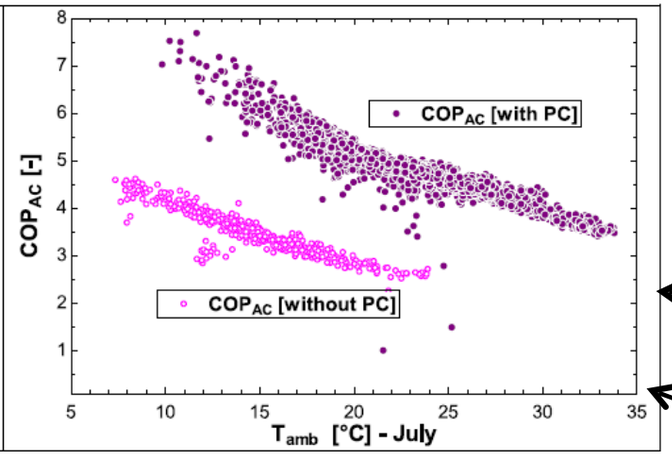
Integrated energy system:

- Heat recovery, 2-temp levels
- Parallel compression
- Air conditioning
- Flooded evaporators





ECO-FRIENDLY STATE-OF-THE-ART



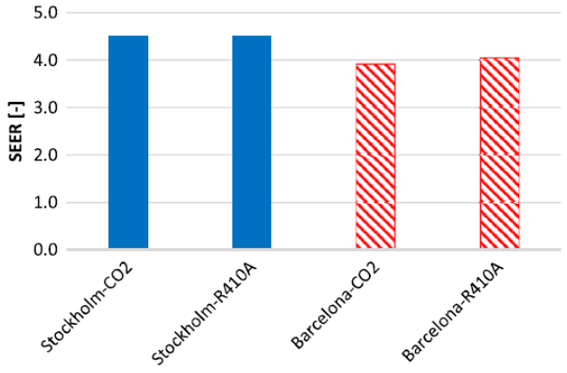
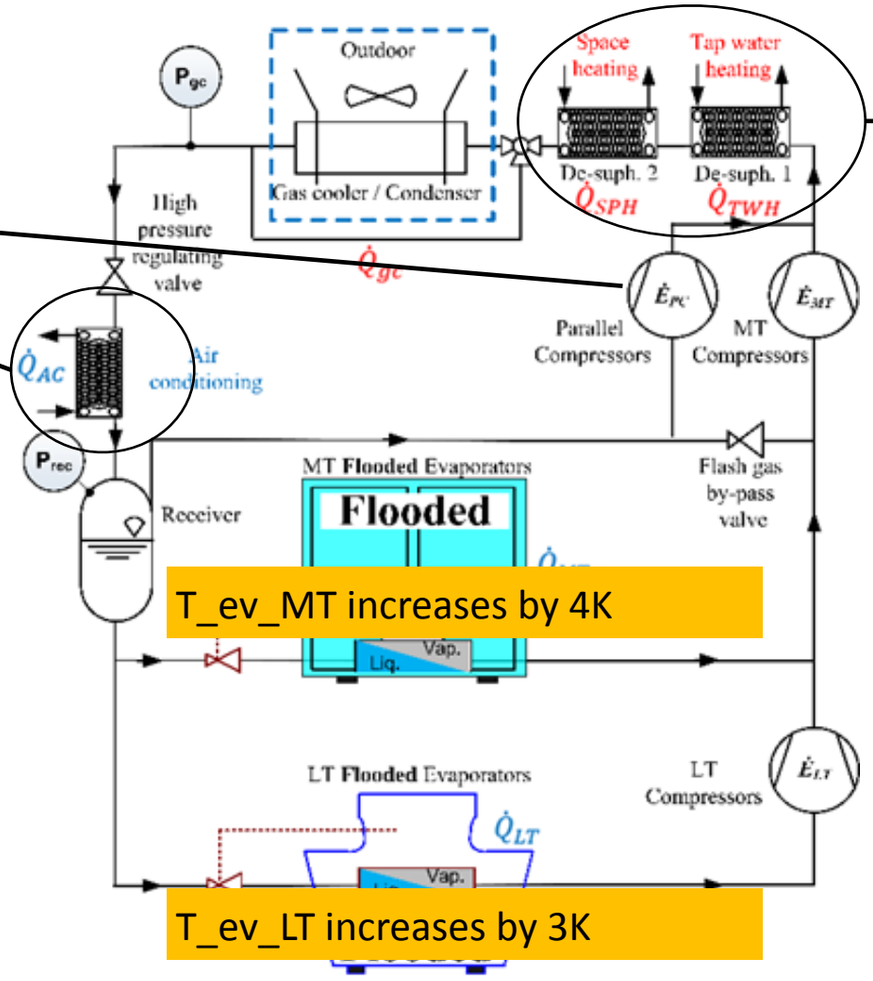
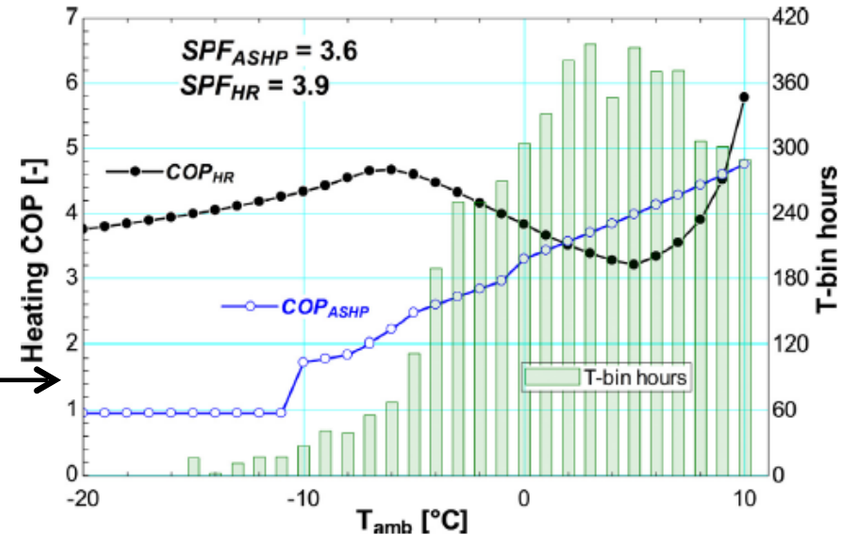


Fig. 10. Seasonal Energy Efficiency Ratio $SEER_{AC}$ of CO_2 and R410A AC solutions in Stockholm and Barcelona.





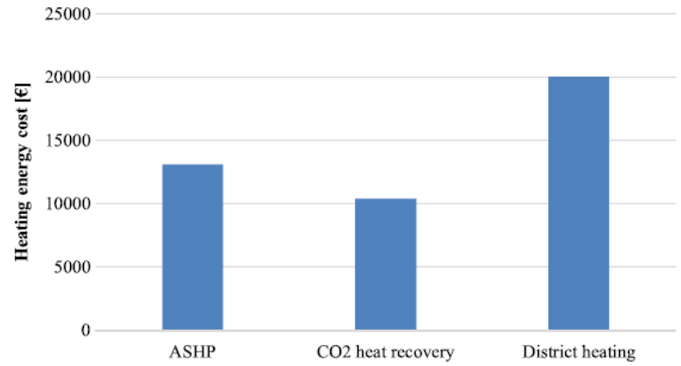
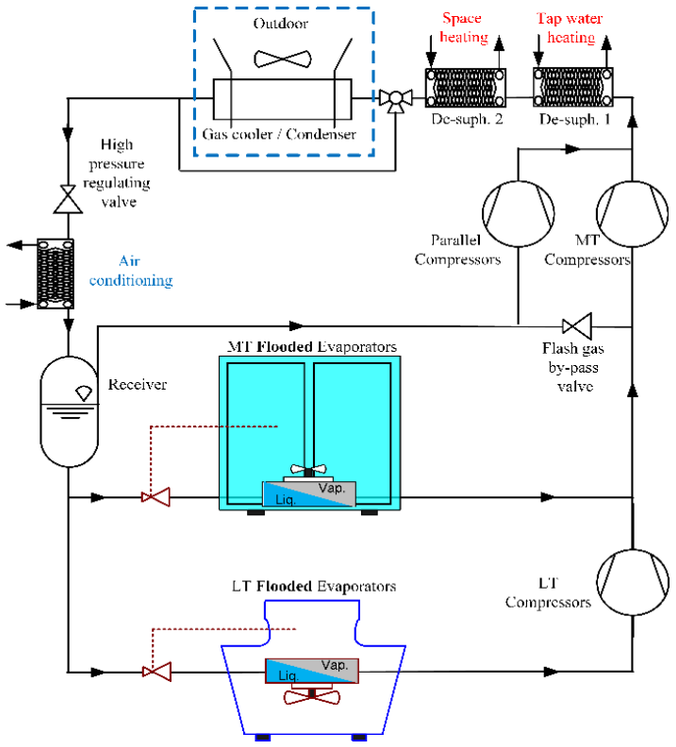


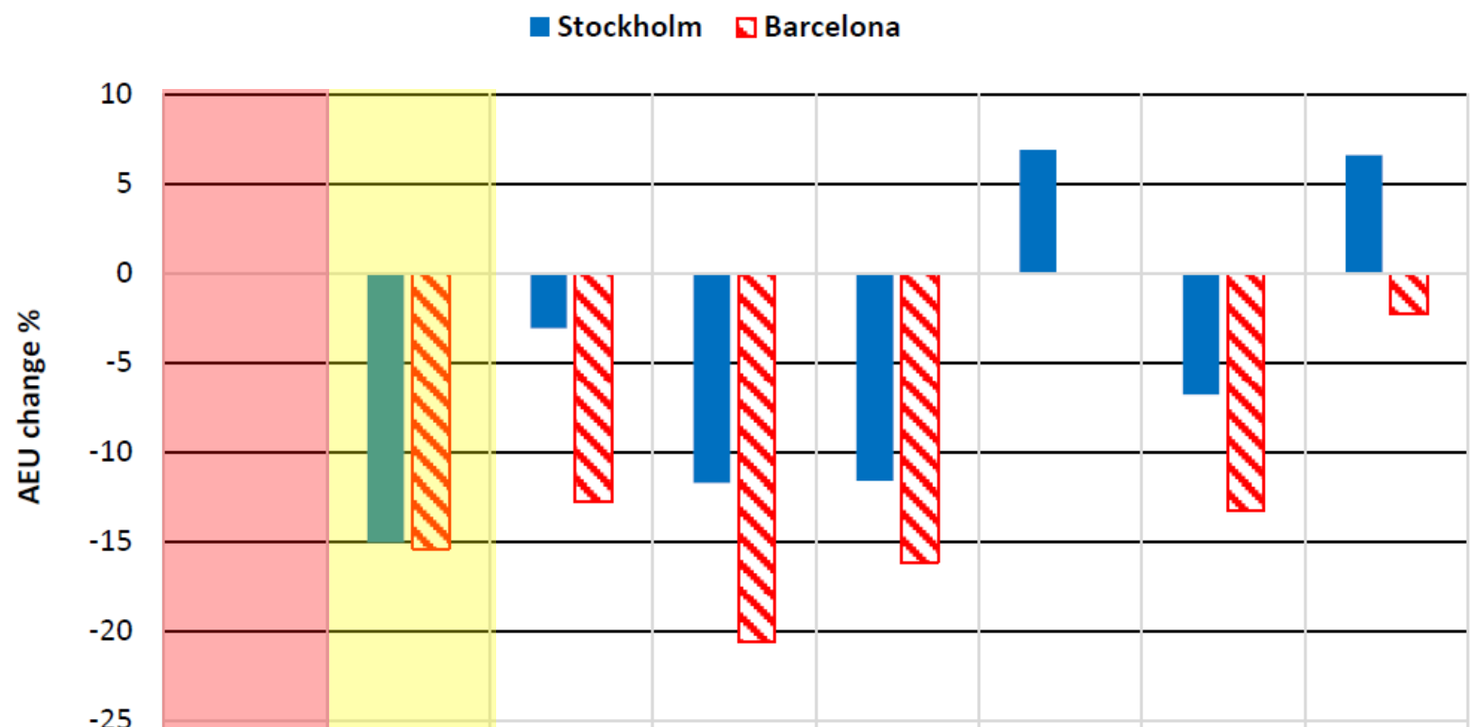
Fig. 8. Annual heating energy cost of three heating systems [euros].

Source: M. Karampour och S. Sawalha, "State-of-the-Art Integrated CO2 Refrigeration System for Supermarkets" International journal of refrigeration, vol. 86, s. 239-257, 2018.

ECO-FRIENDLY STATE-OF-THE-ART: EXPECTED ENERGY SAVINGS



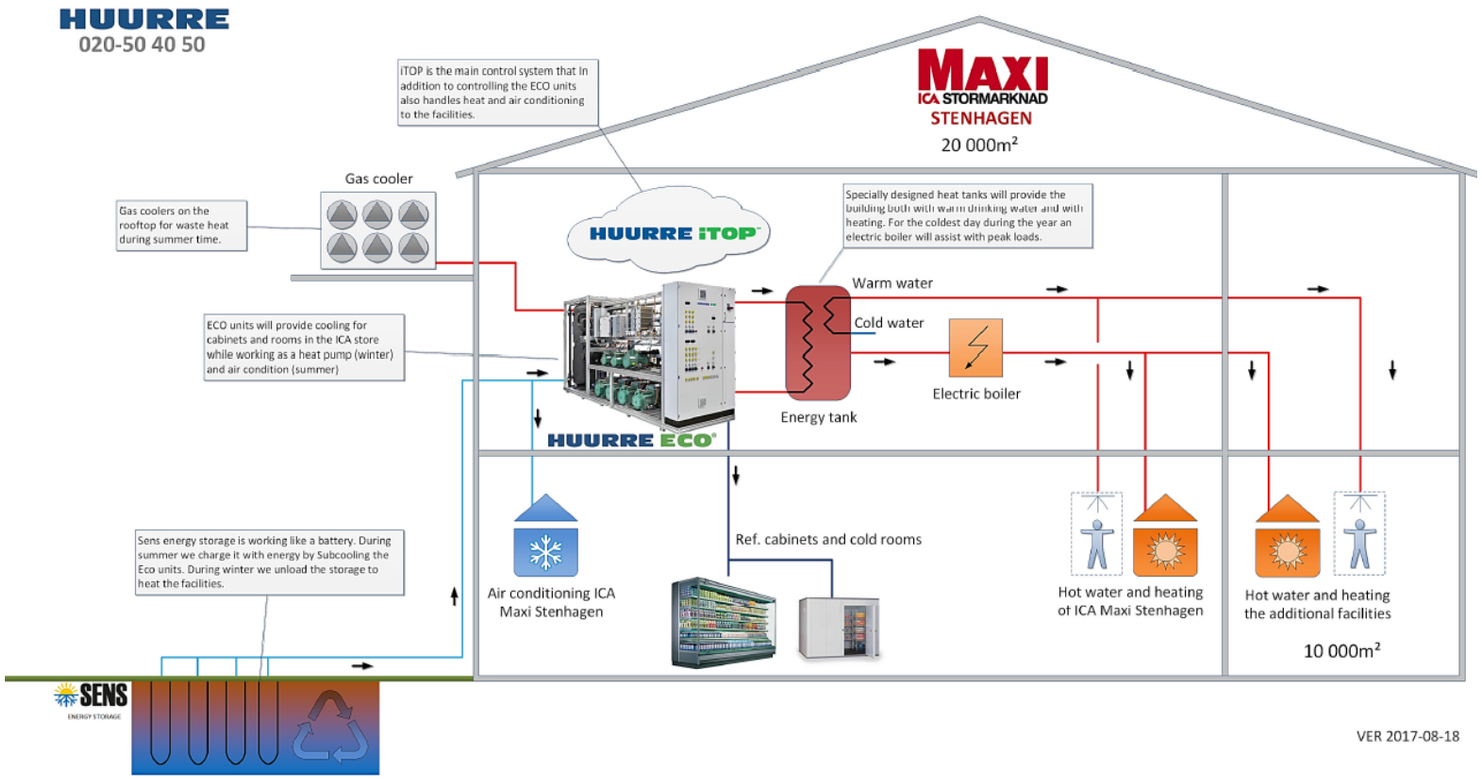
- About 25% savings in energy use compared to conventional HFC system in northern Europe
- Comparable energy use to DX HFC in southern Europe



	CO2 standard booster (ref.)	CO2 SotA (PC+flooded MT&LT)	Cascade R290-CO2	Cascade NH3-CO2	R404A DX	R404A Indirect	R449A DX	R449A Indirect
Stockholm	0.0	-15.0	-3.1	-11.7	-11.6	6.9	-6.8	6.6
Barcelona	0.0	-15.4	-12.8	-20.6	-16.2	0.0	-13.3	-2.3

Source: M. Karampour och S. Sawalha, "State-of-the-Art Integrated CO2 Refrigeration System for Supermarkets" International journal of refrigeration, vol. 86, s. 239-257, 2018.

ICA Maxi Södertälje (Sweden)

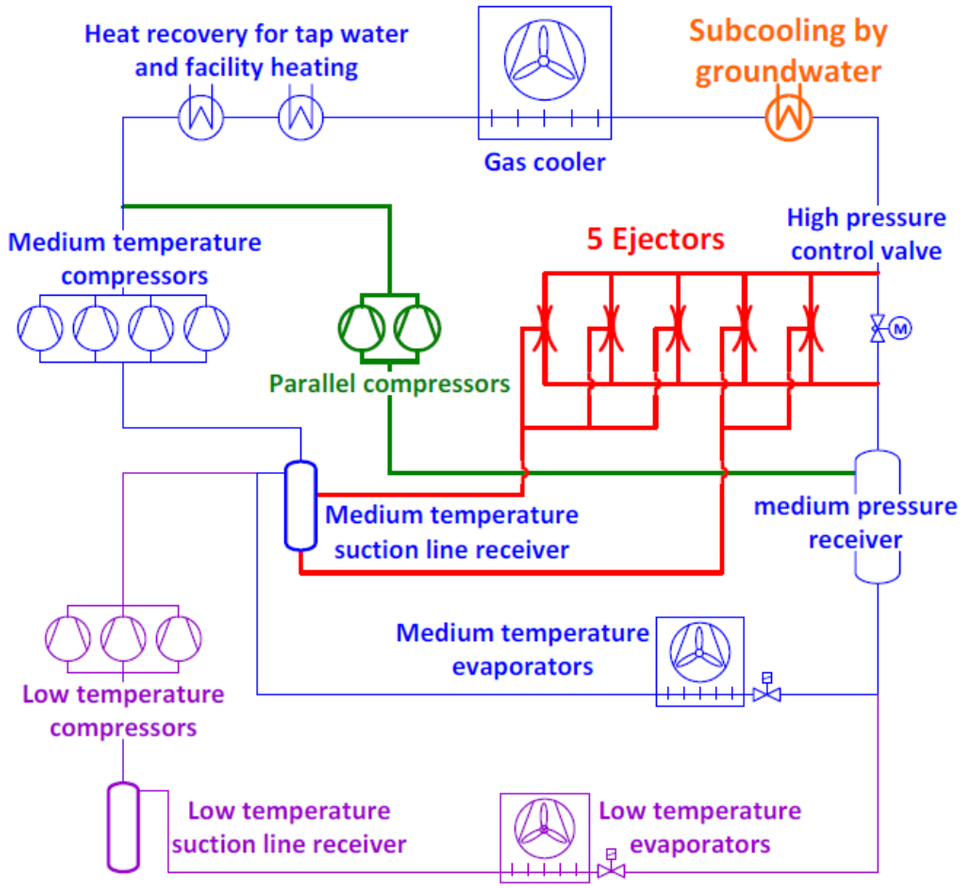


Opening Year: 2017

Eco-friendy caracheristics:

- Flooded MT evaporator with liquid ejector
- Glass doors on cabinets and freezers
- Real-time energy measurements monitoring
- Heat recovery
- Air conditioning
- Parallel compression
- Geothermal thermal storage

Migros Ibach (Switzerland)



Opening Year: 2014 (refurbished)

Eco-friendy caracheristics:

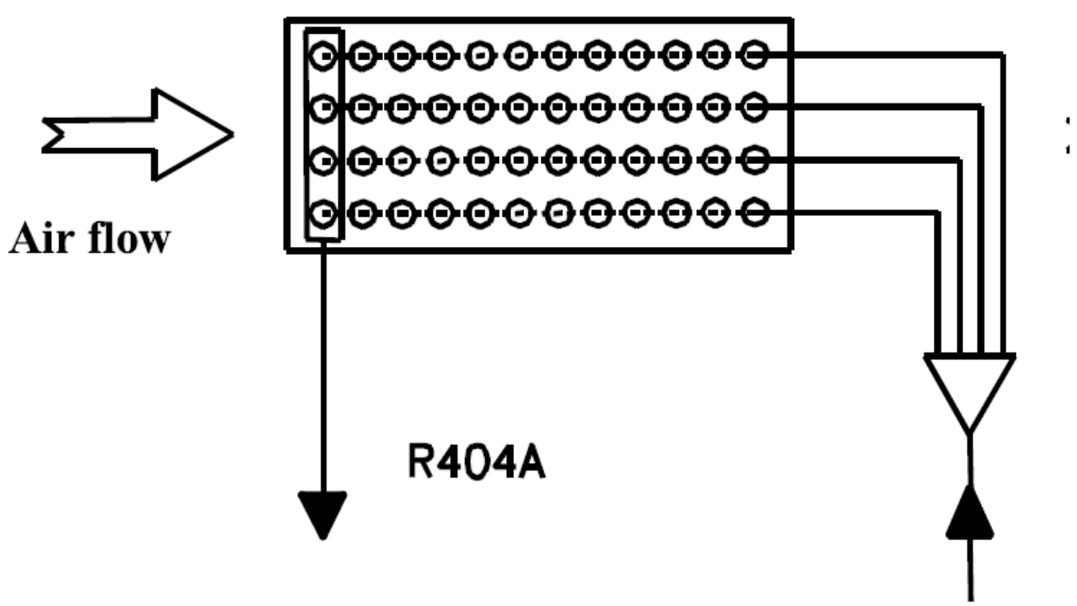
- CO2 refrigeration system using multi-ejector technology
- Parallel compression
- Partially flooded evaporators
- Tap water heating and facility heating
- Sub-cooling by ground water in summer

SILVIA MINETTO

COMPONENTS FOR ENERGY EFFICIENT SUPERMARKET REFRIGERATION

EVAPORATORS IN DISPLAY CABINETS

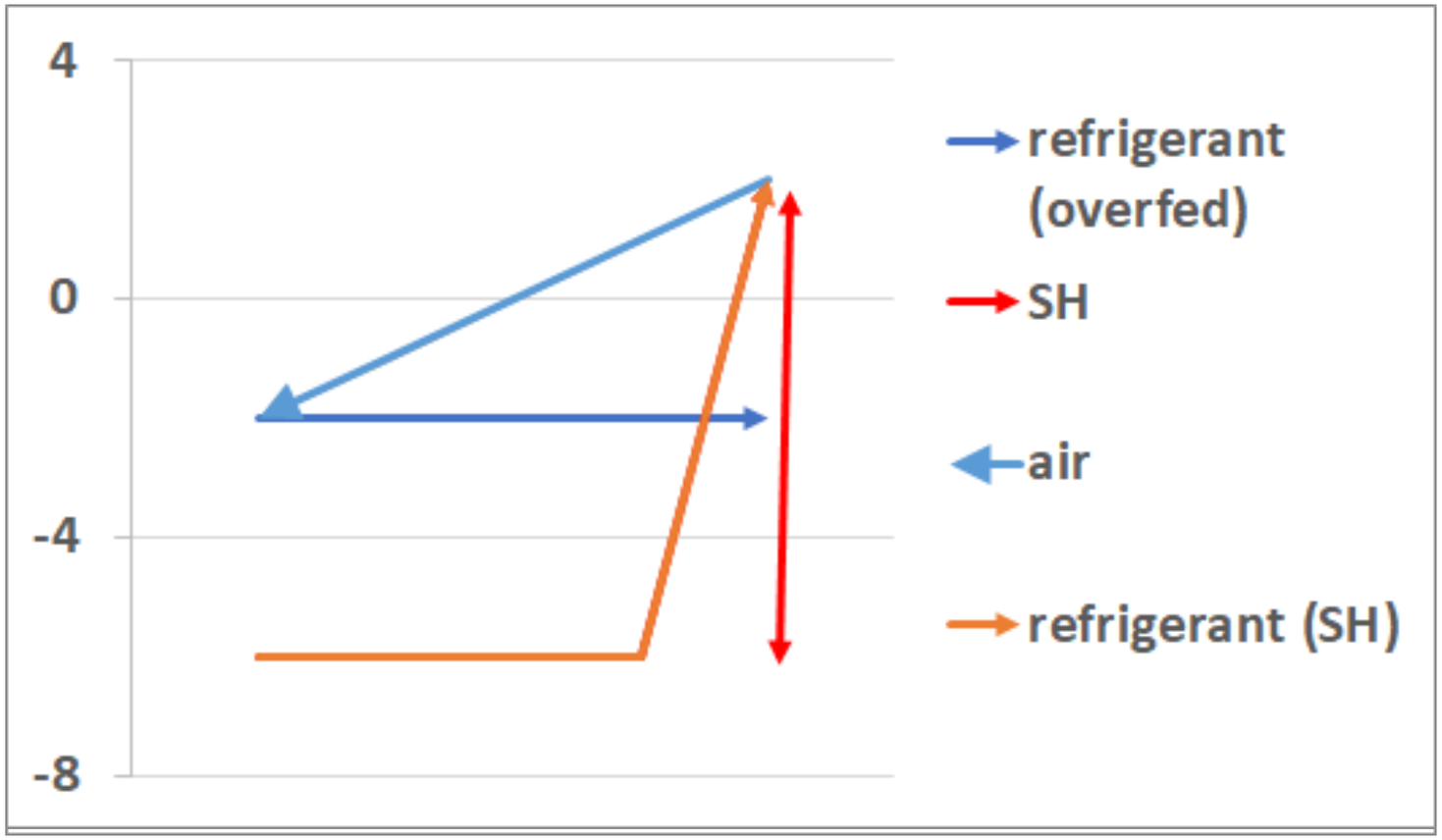
- Evaporators in refrigerated display cabinets: **fin and tube heat exchangers**, **multiple circuits** on refrigerant side and **forced ventilation** with low frontal velocity (poor convective heat transfer coefficient)
- Refrigerant mass flow through evaporators typically controlled by **thermostatic valves**, with a minimum superheat set at 5-8K, but higher values are found in the field (15 K)
- The presence of the superheated area determines an overall penalisation of the heat exchanger performance



EVAPORATORS IN DISPLAY CABINETS

Superheat in ideal evaporators

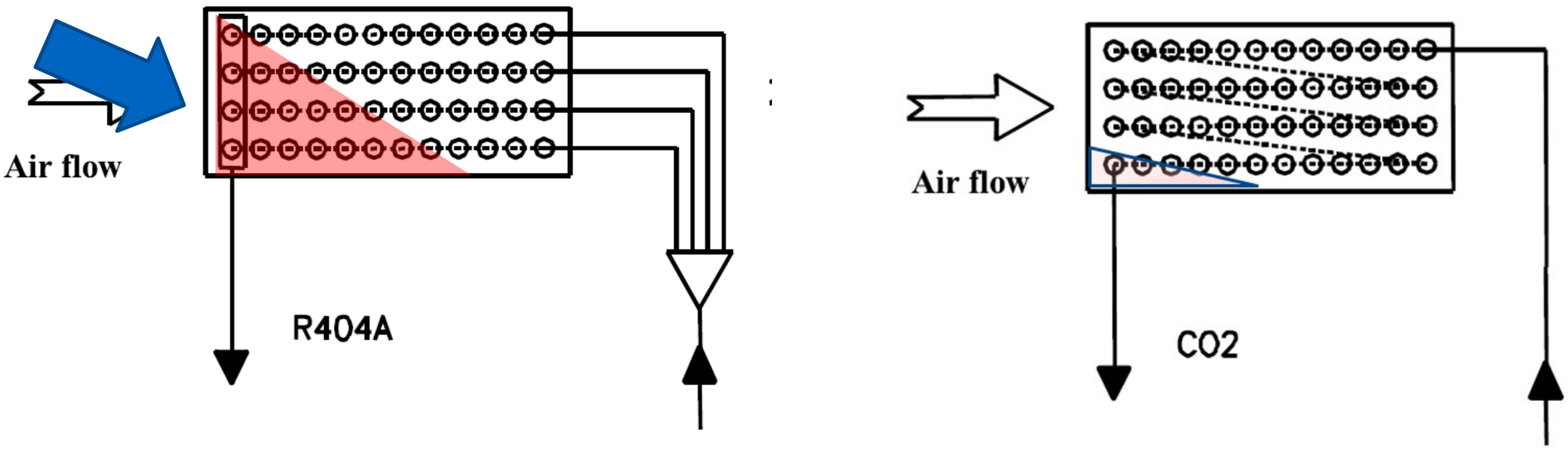
- Whatever the heat transfer surface, the imposed superheat determines the highest evaporation temperature for a given air inlet temperature
- If there is no superheat, this limit is removed: in an ideal evaporator, the maximum evaporation temperature corresponds to the required air temperture at evaporator exit



EVAPORATORS IN DISPLAY CABINETS

The effect of airflow maldistribution

- **Air flow to the evaporator is not uniform** on the coil, due to the position of the fans

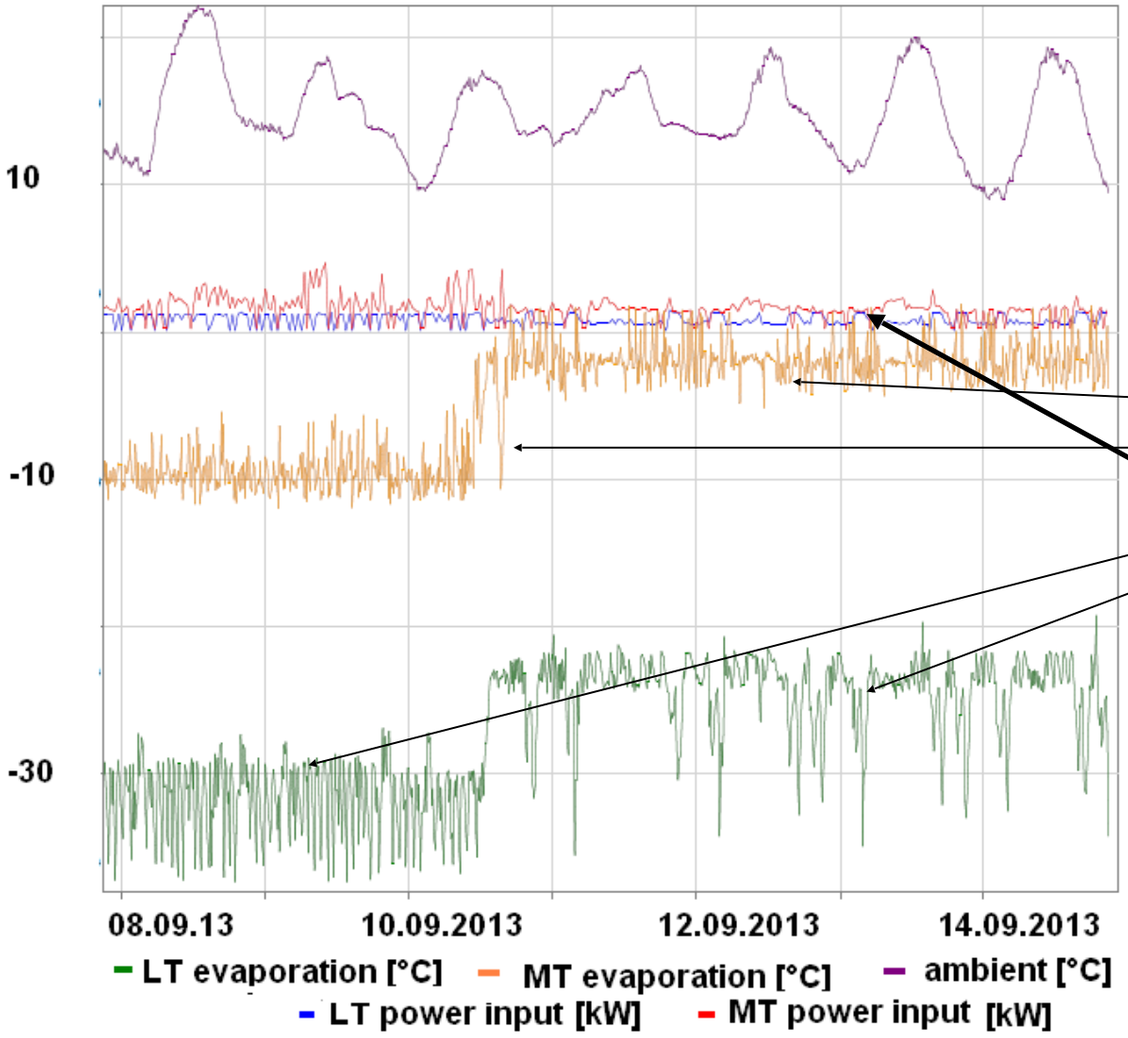


- Circuits not in the main air stream are affected by incomplete refrigerant evaporation; liquid droplets force the thermostatic valve to reduce total mass flow
- Circuits in the main air stream increase their superheat
- A large part of the heat transfer area is dried out, thus penalising the overall performance
- CO_2 allows for lower number of circuits, thus reducing the drawbacks air flow unbalancing

Girotto et al. Commercial refrigeration system using CO2 as the refrigerant. IJR27 (2004)

EVAPORATORS OVERFEEDING

- If there is no superheat, it is possible to increase the evaporation temperature, while maintain the same performance on the air side (same cooling capacity)
- No issues with airflow maldistribution (no thermostatic control)
- Higher evaporation temperature allows for higher EER



Data from the field

Increase evaporation temperature:
from -10°C to -3°C for MT
from -32°C to -23°C for LT
With the same performance on the air side

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

EVAPORATORS OVERFEEDING

Summary

- **Higher evaporation temperature** results in
  - **Higher EER**
  - **Less defrost cycles**
  - **Smoother operations**

- Evaporators overfeeding calls for **proper expansion device control** (no more based on traditional superheat value)
- Overfed evaporators (vapour quality 0.9-1.0 at evaporator exit) requires **suitable liquid management** before compressors
  - **liquid ejectors** to recirculate it by expansion work recovery from the high pressure fluid
  - or adequate internal **heat exchangers** to evaporate it
  - or **specific circuit arrangements** to take care of the accumulated liquid by utilising it where possible

OVERFED EVAPORATORS
Final recommendations

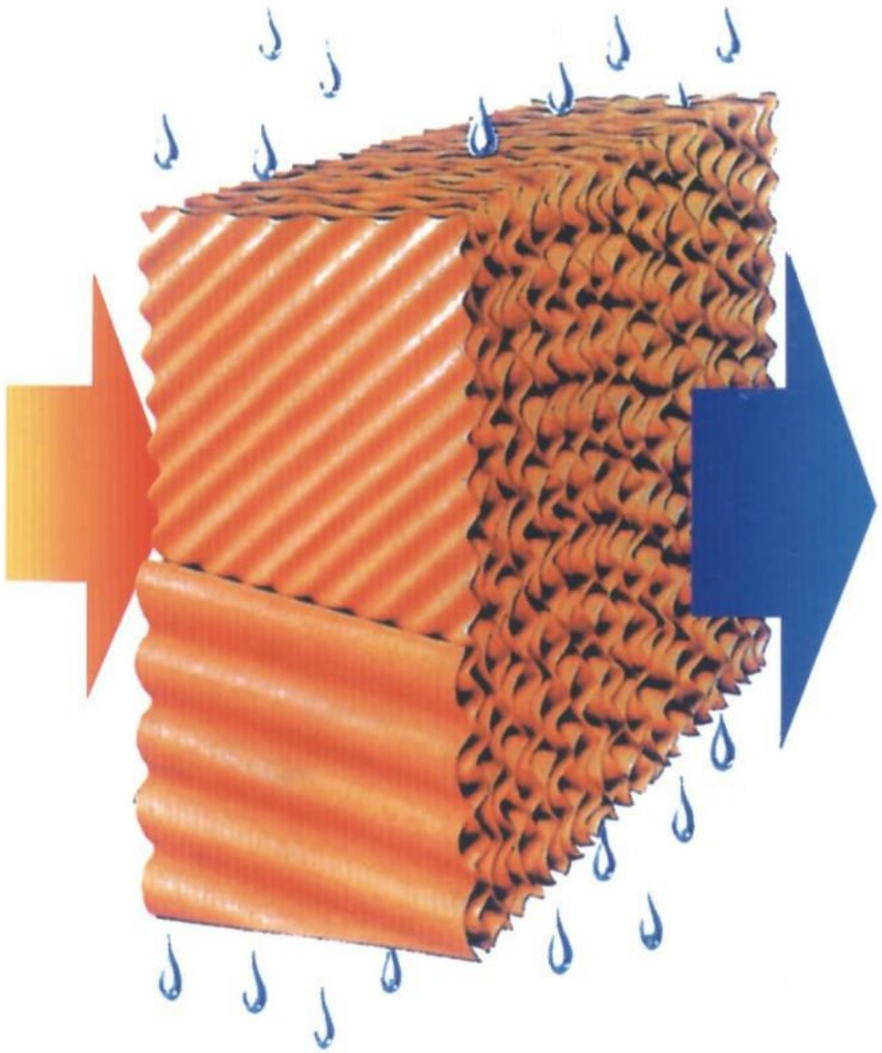
- To get the benefit of higher evaporation temperature by evaporator overfeeding, the evaporator surface MUST be maintained (**no smaller evaporators are allowed!**)
- ALL cabinets connected to the same compressor MUST be designed for the same evaporation temperature!

EVAPORATIVE COOLING

Air in

35°C, 60%R.H

(t_{wet}=28.2°C)



Air out

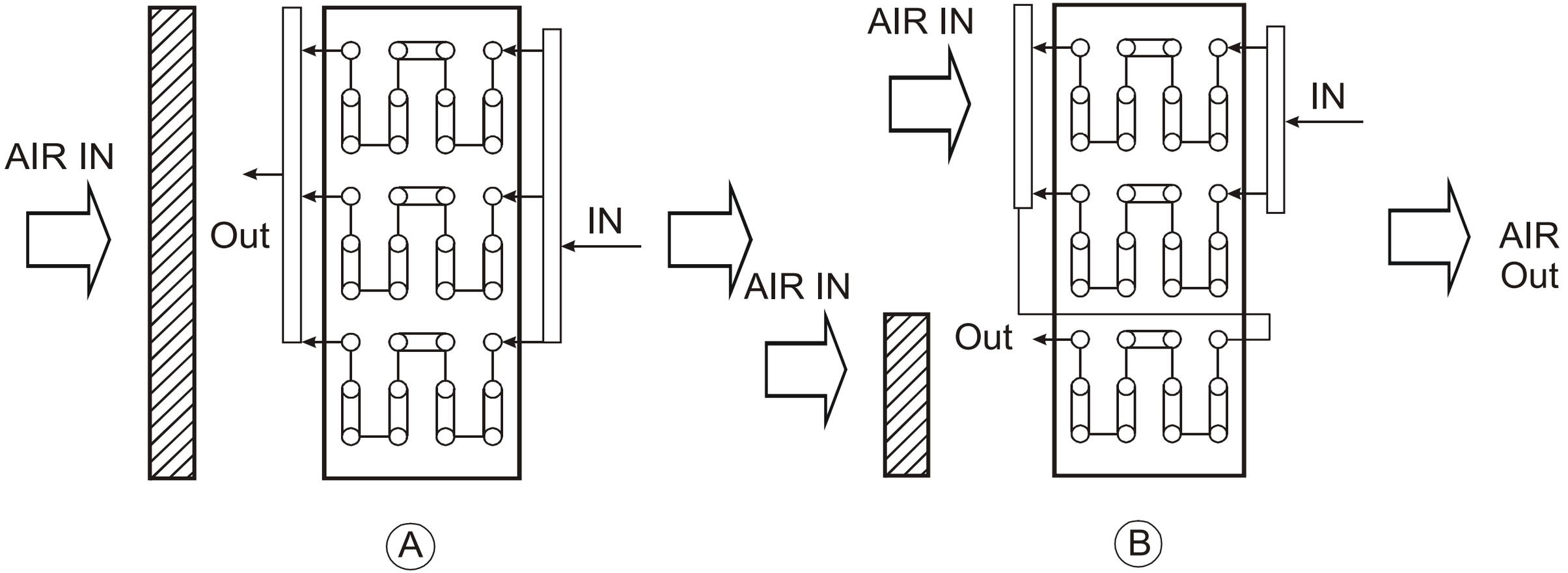
29.6°C, 89.5%R.H:

Assumed Efficiency 80%

Mitigates cooling capacity drop and EER penalisation during peak temperature hours

EVAPORATIVE COOLING
for gas coolers

Due to the non-isothermal heat rejection, in gas cooler it is possible to use evaporative cooling only in the last part of the gas cooler



100% evaporative cooling **33% evaporative cooling**

Large water saving with limited «only refrigeration» EER penalisation (B vs A)

Lower fan consumption (B vs A)

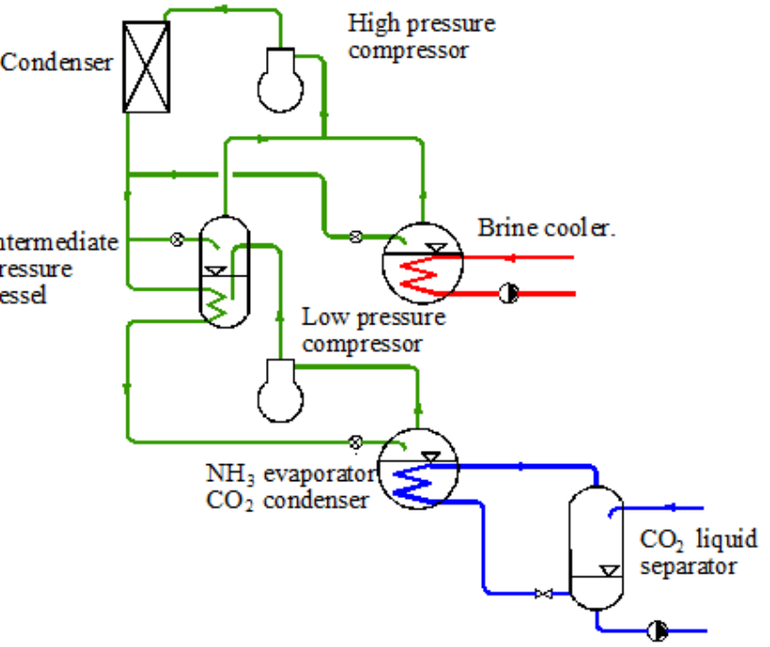
Fornasieri et al, 2008Refrigeration Systems for Hot Climates using CO_2 as the Working Fluid. 8th IIR GL Conference , Copenhagen

ARMIN HAFNER

EFFICIENT AND ENVIRONMENTALLY FRIENDLY REFRIGERATION WITH CO_2

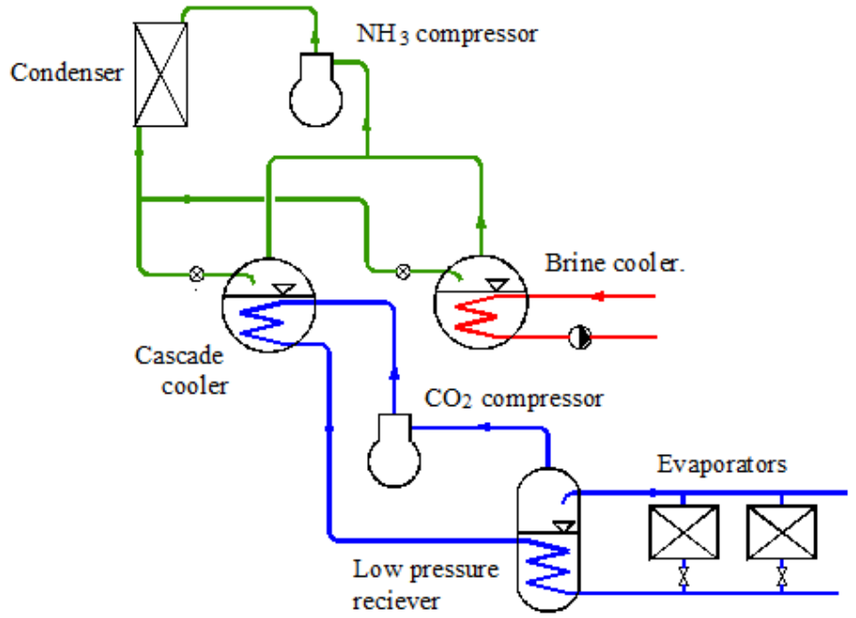
CO_2 COMMERCIAL REFRIGERATION: EARLY 1990

CO_2 as heat transfer fluid



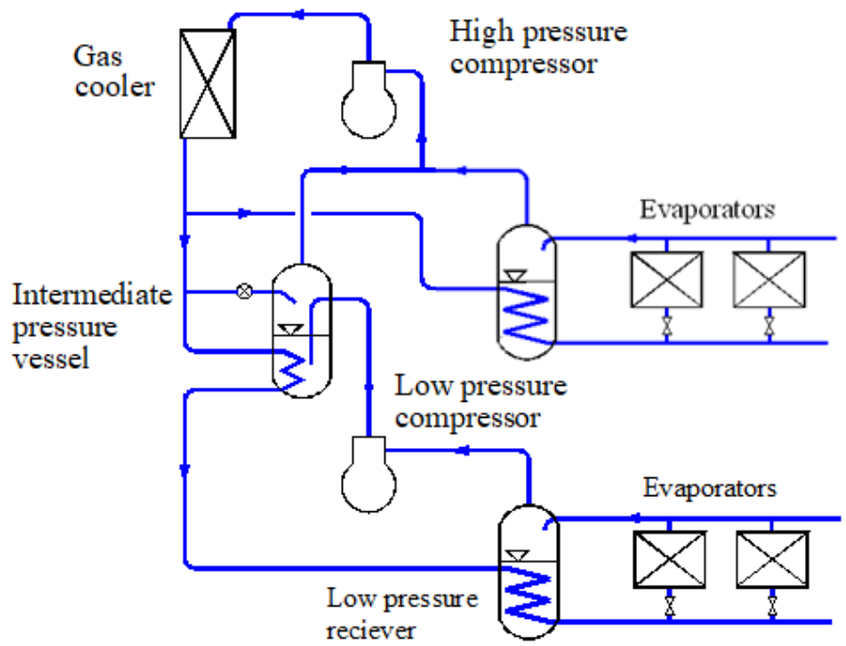
Rolfsmann, Sweden 1995

CO_2 in low temp cascade stage



Bakken, Norway 1993

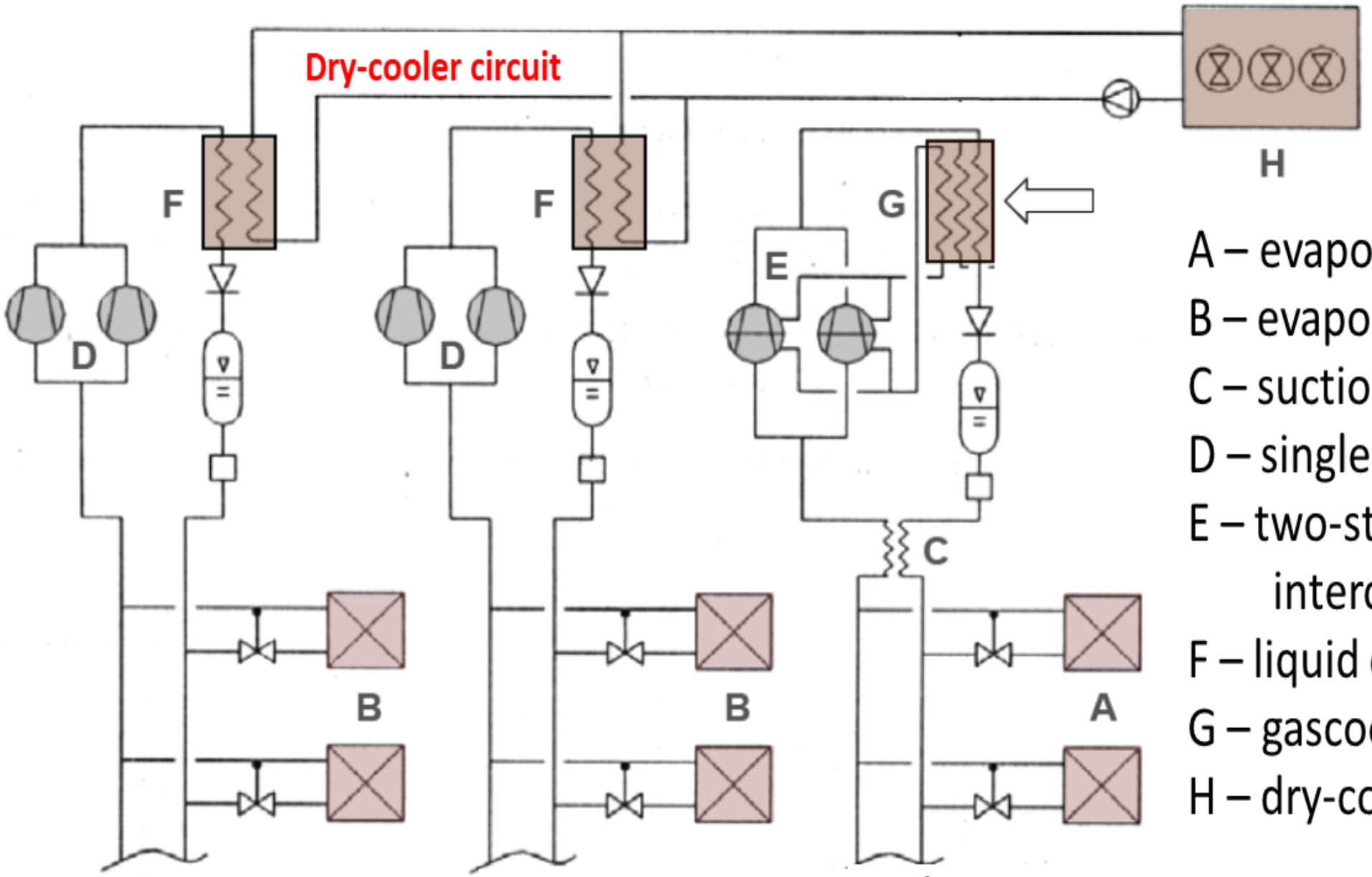
CO_2 transcritical /(subcritical)



All-CO_2 (Proposal)

Generation 0

FIRST ALL-CO_2 COMMERCIAL REFRIGERATION SYSTEMS

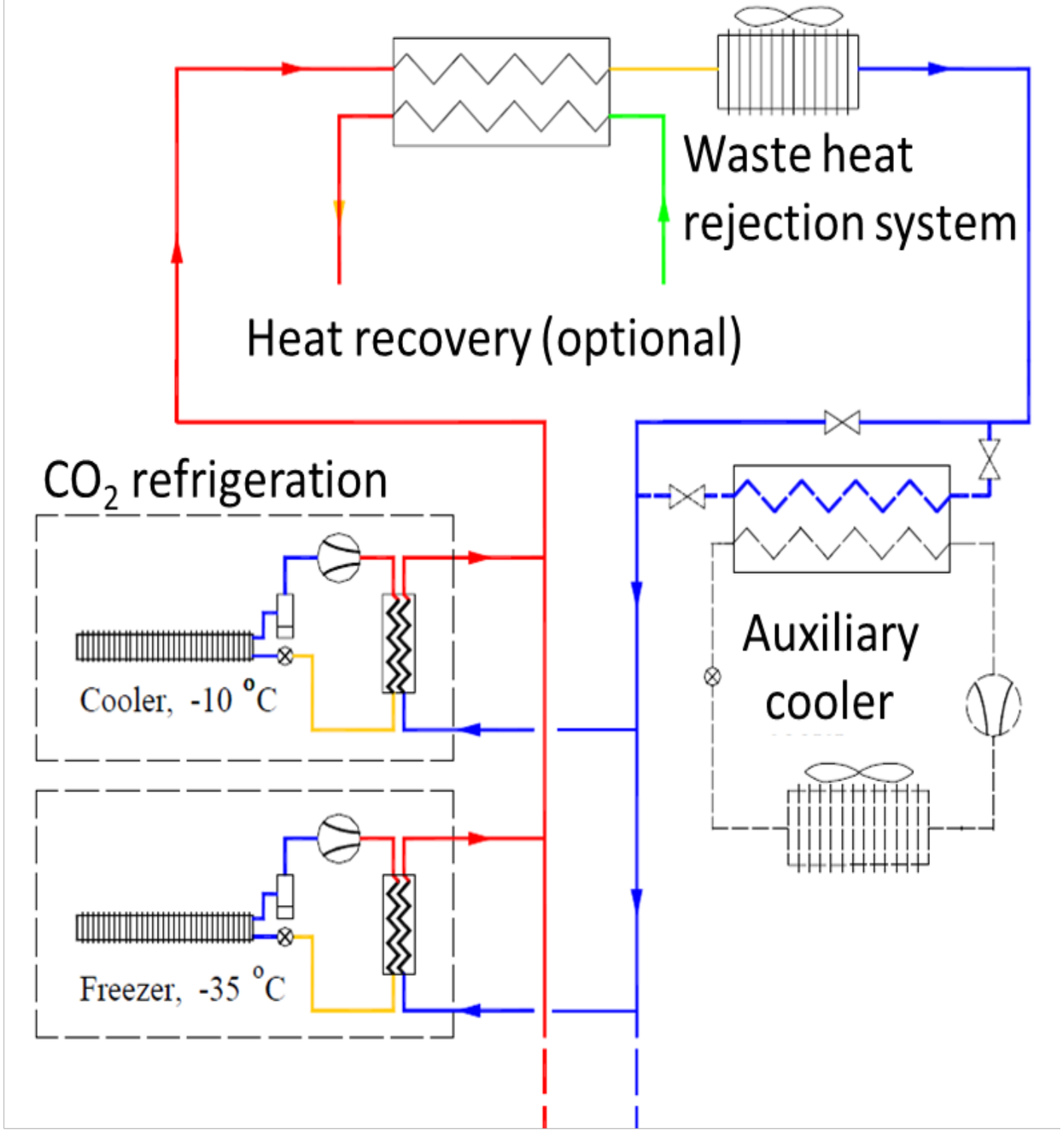


A – evaporators, LT
B – evaporators, MT
C – suction gas heat exchanger
D – single stage compressor
E – two-stage compressor + intercooling
F – liquid cooled gascooler
G – gascooler with intercooler
H – dry-cooler

Girotto et al.

Distributed System Design with CO_2 [self contained display cabinets = today: water loop system]

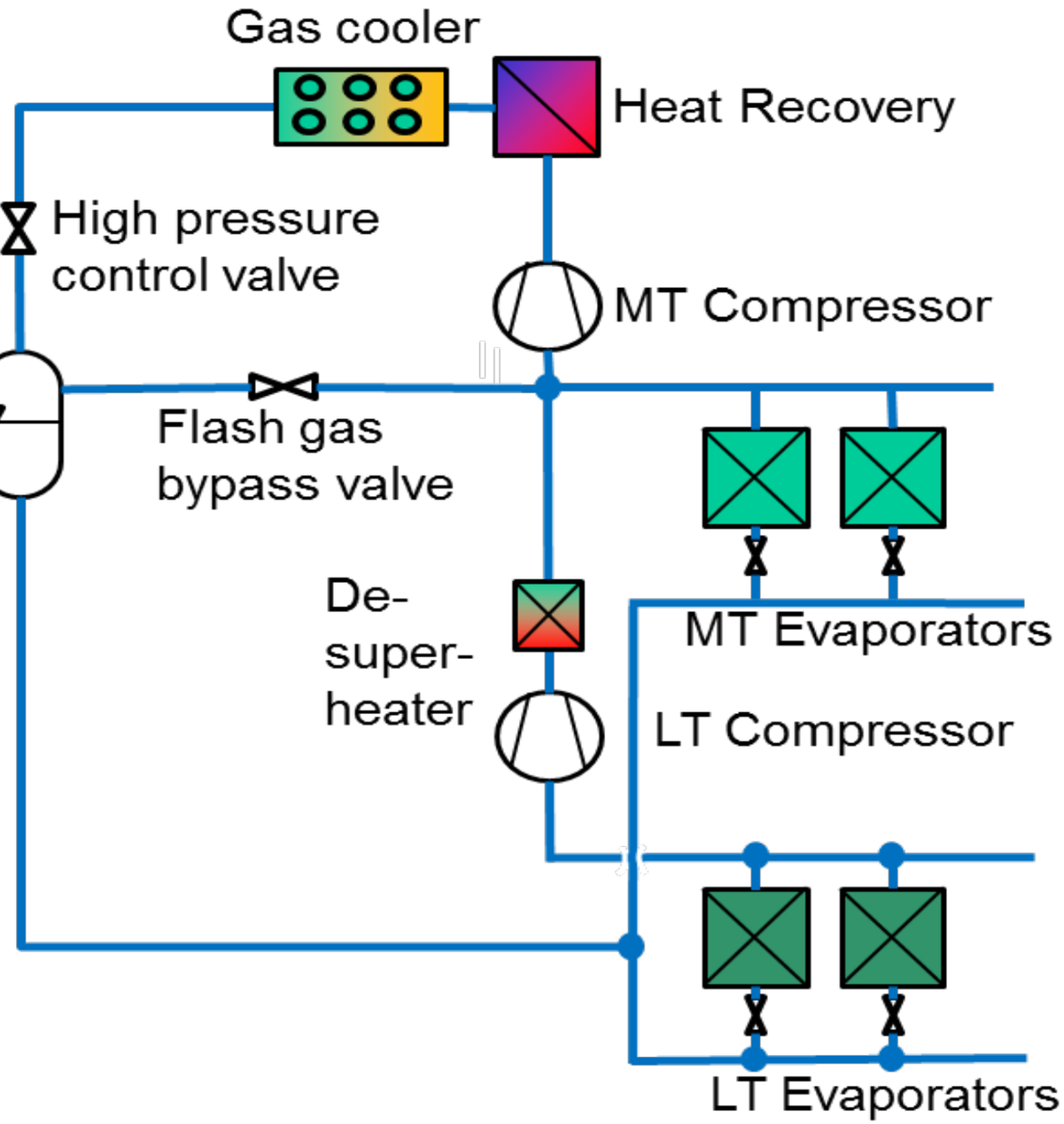
Concept presented by SINTEF at:
Carbon dioxide interest group
[Cdig] meeting in Dresden 2004



Transcritical CO_2 system

Standard CO_2 booster unit

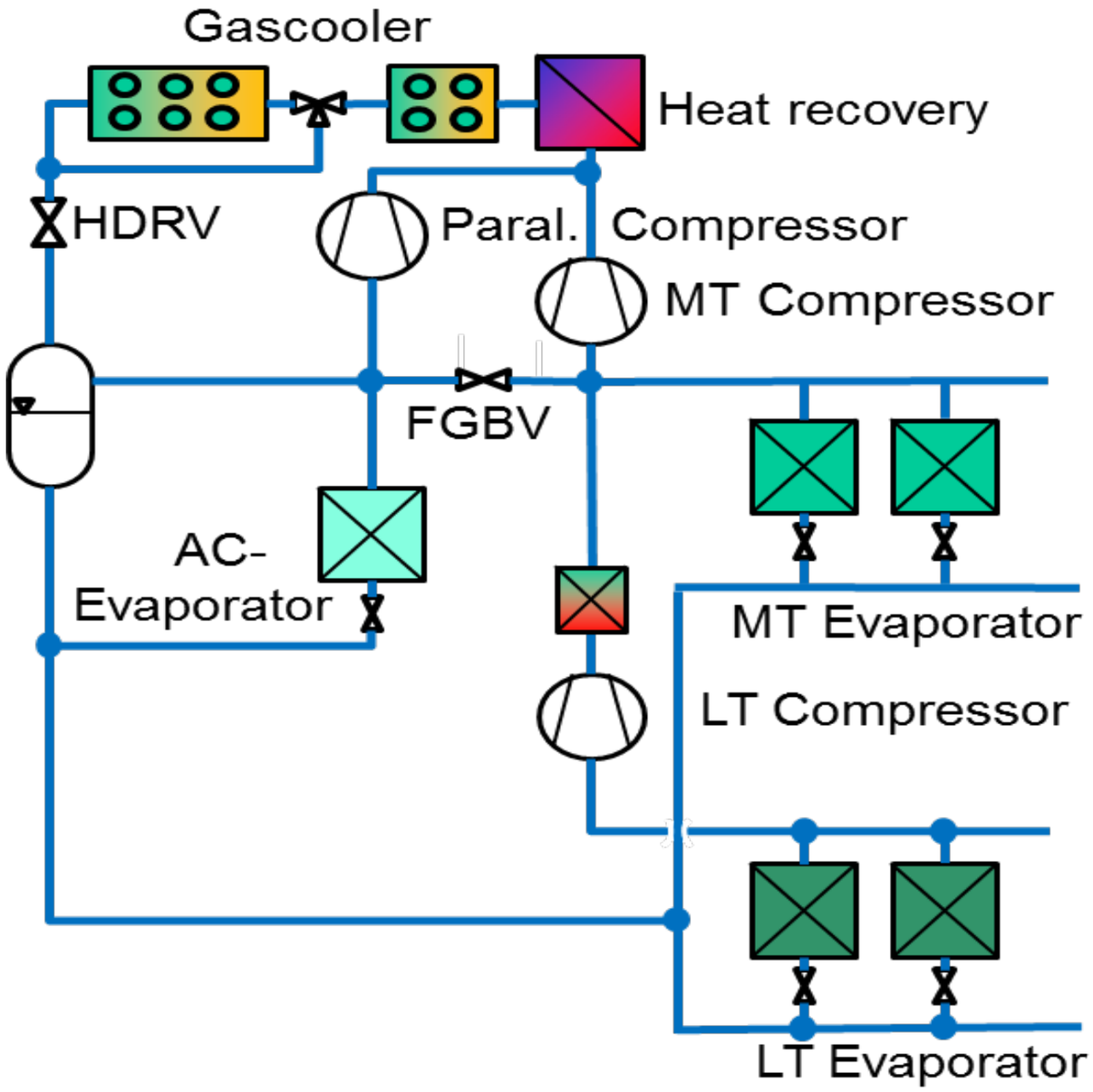
- First unit in 2004/ Switzerland (Linde)
- > 25 000+ units worldwide
- Higher SEER as HFC units in moderate climate regions
- No efficient integration of AC (only MT temperature level



CO_2 COMMERCIAL REFRIGERATION: GENERATION 2

CO_2 Parallel Compression Booster

- First unit in Switzerland 2008 (enex)
- > 5000+ units worldwide
- Higher SEER as HFC units in most European regions
- Good / Efficient integration of AC possible



Advantages by applying CO_2 as working fluid:

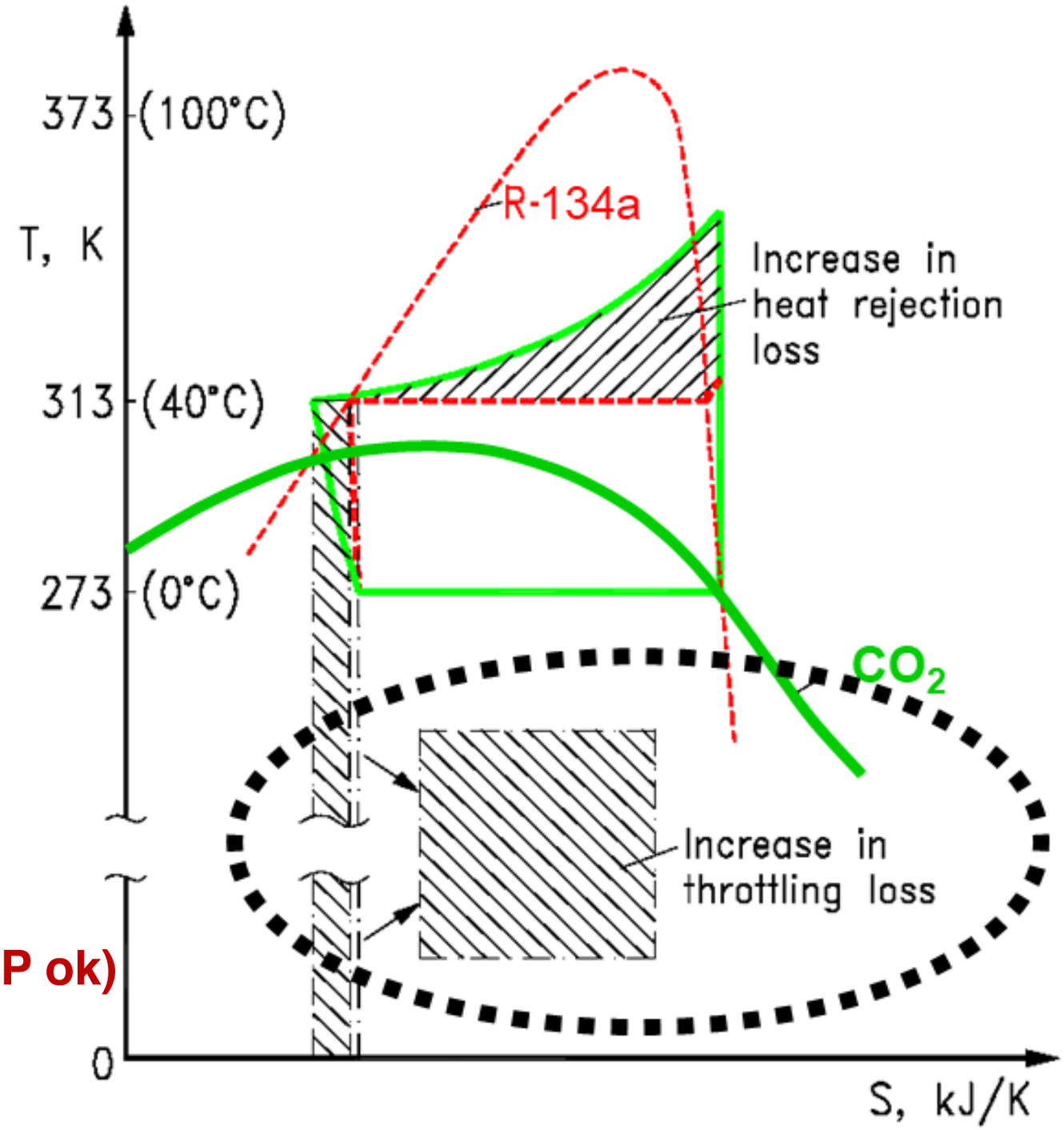
- high refrigerant density → reduced compressor swept volume small refrigerant lines

- high compressor efficiency → low pressure ratio

- high heat transfer and low specific pressure drop

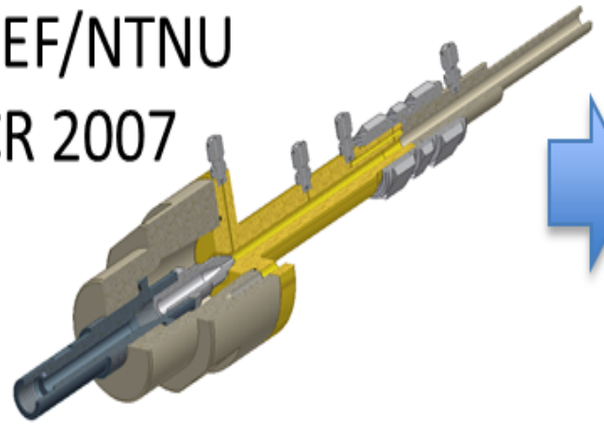
Challenges:

- **Increase in heat rejection loss (→ HP ok)**
- **Increase in throttling loss**

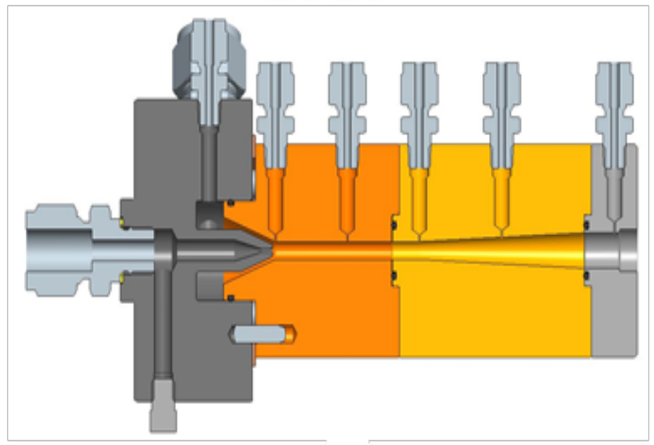


EJECTOR TECHNOLOGY DEVELOPMENT

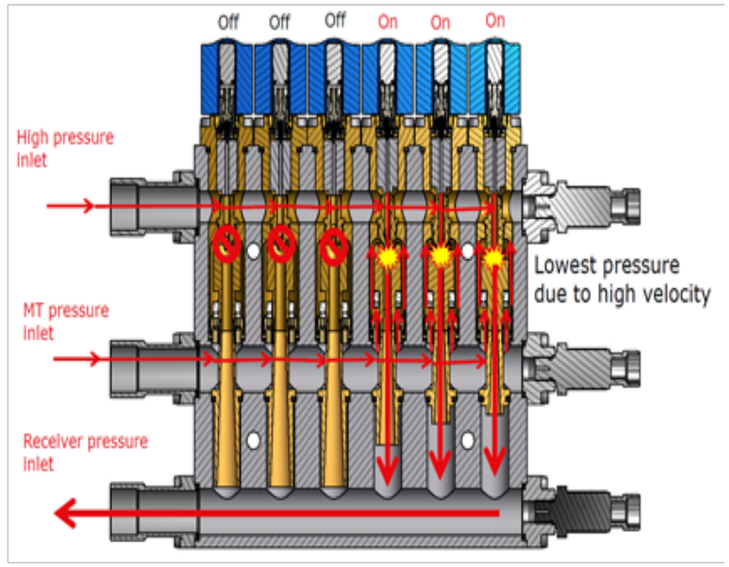
2007
SINTEF/NTNU
@ ICR 2007

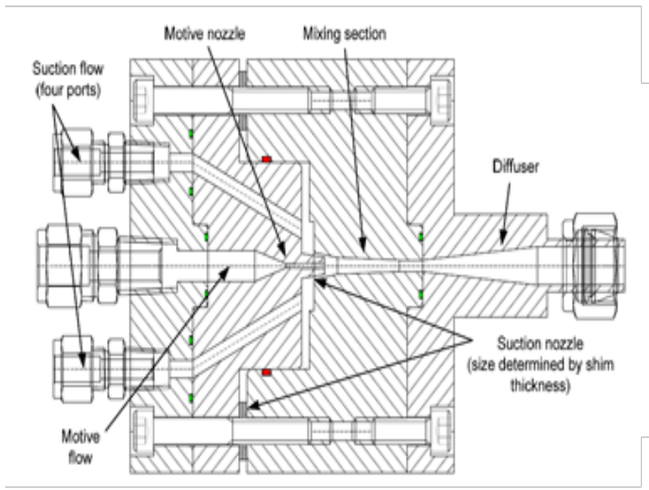


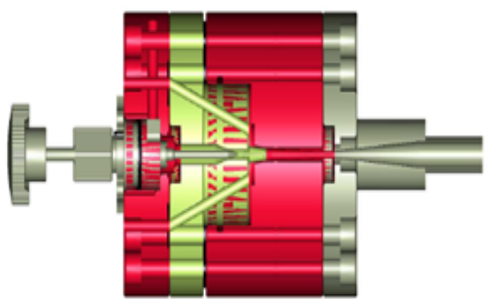
2010



2015





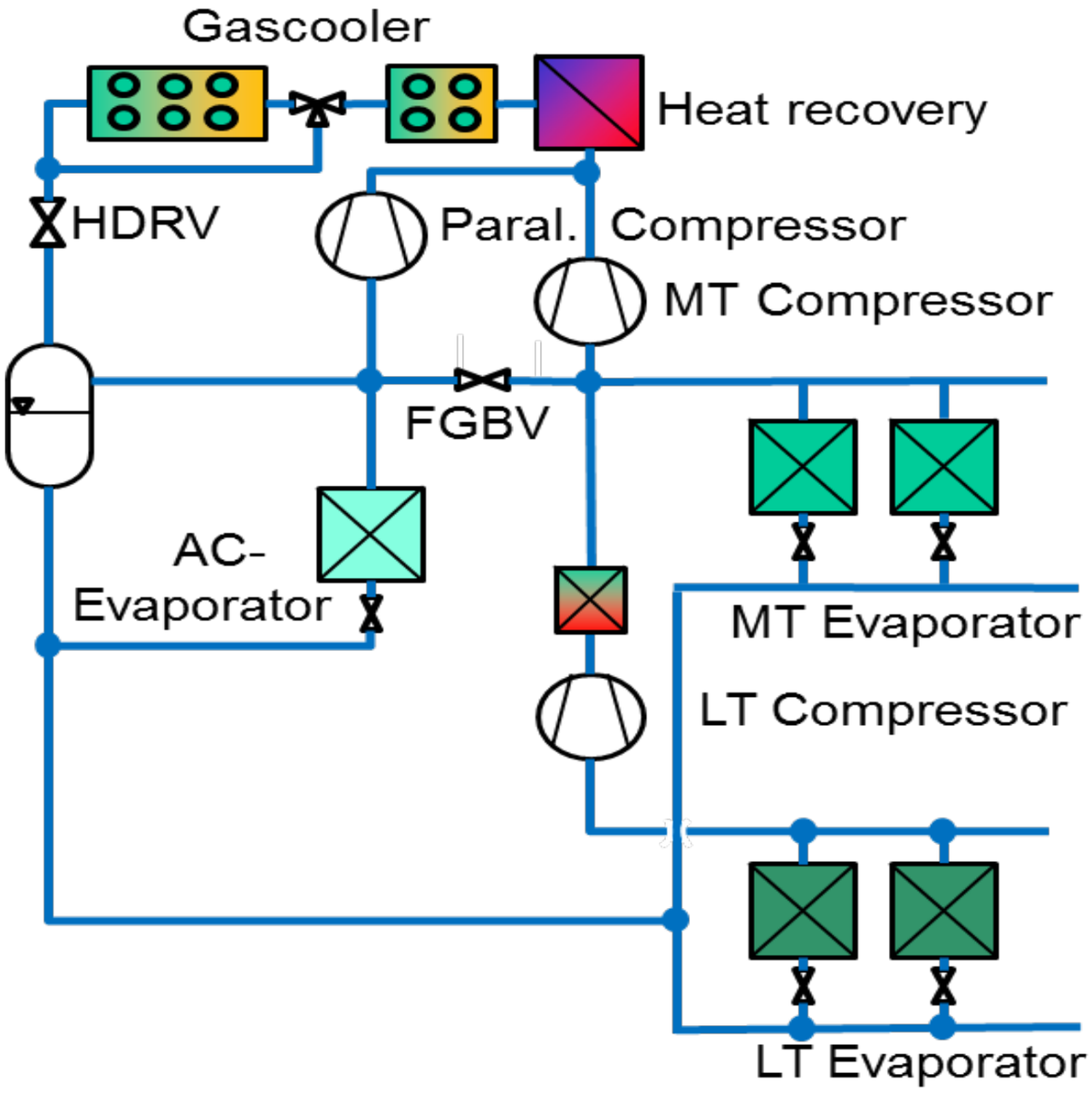


2017

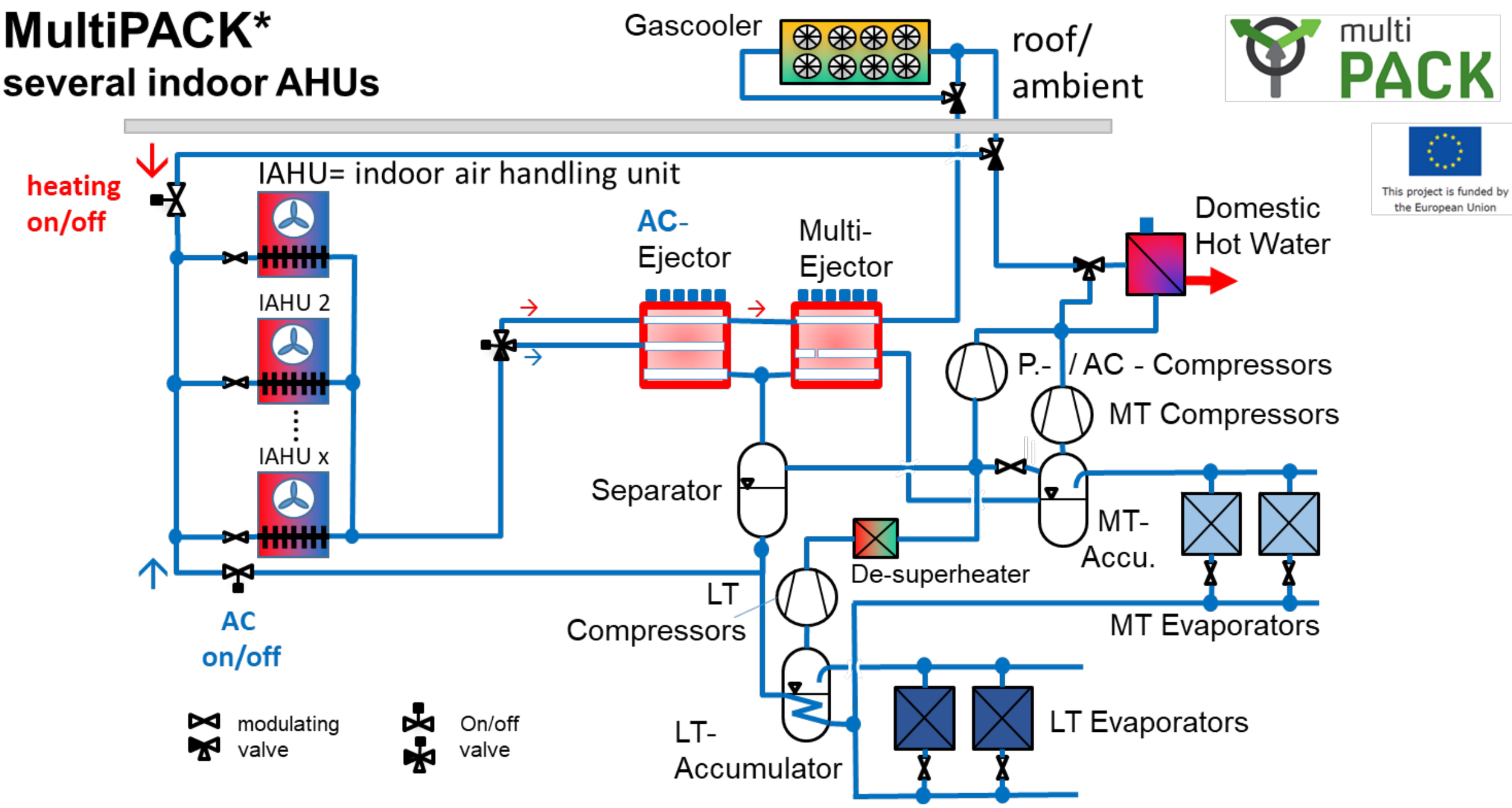
2004 → Work from S. Elbel & P. Hrnyak

CO_2 Parallel Compression Booster with Ejector Support

- First unit in Switzerland 2014 (enex)
- < 800+ units worldwide
- Higher SEER as HFC units globally
- Good / efficient integration of AC
- **Flooded evaporators all year**

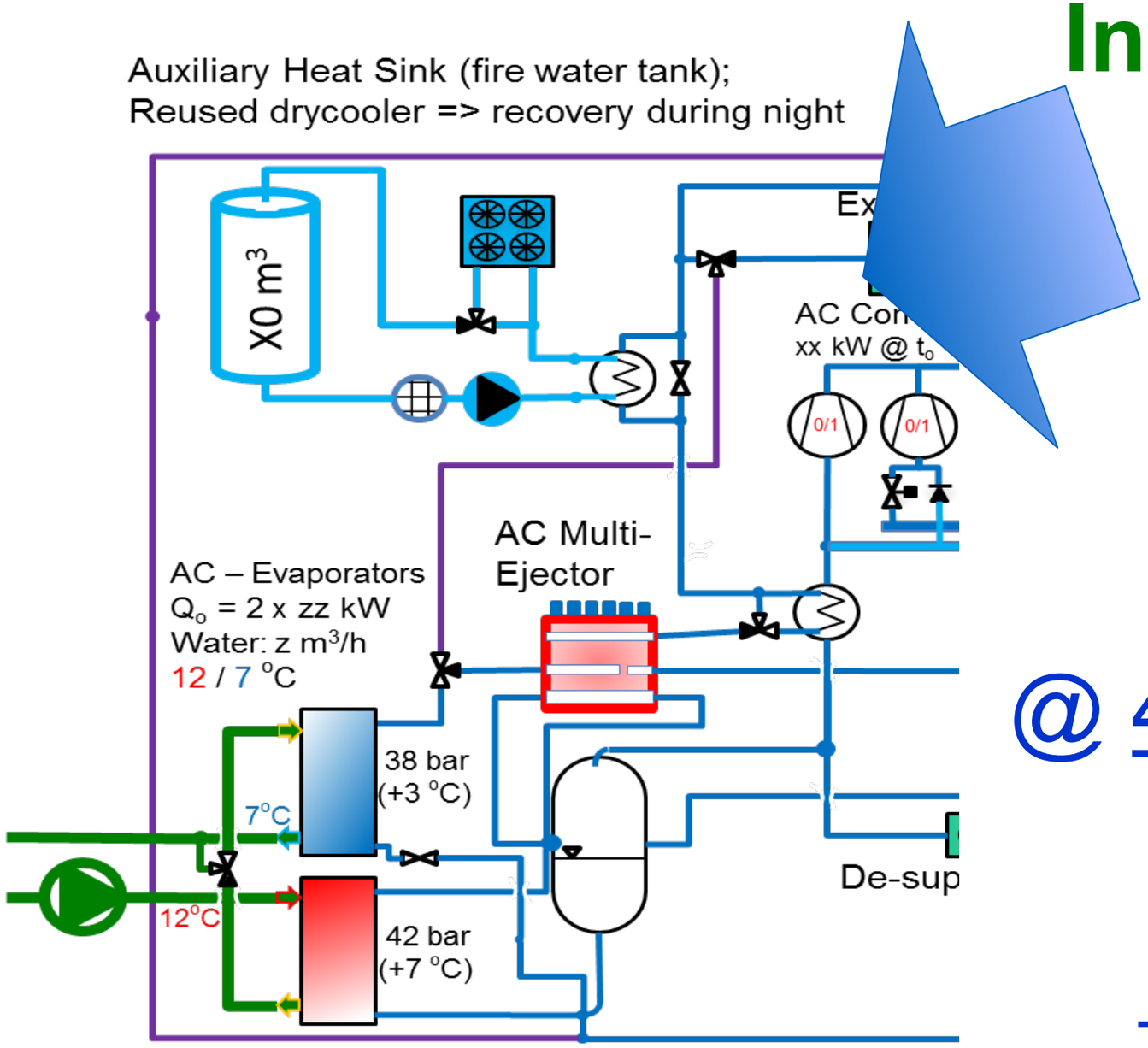


MULTIPACK DEVELOPMENTS



* www.ntnu.edu/multipack

ADVANCED INTEGRATED CO_2 SYSTEM



Including an energy efficient chiller

Chilled water:

12°C → 7°C

@ 42 bar comp. suction pressure!

+7°C saturation temp.

≡ 42 bar

REMARK FROM GUSTAV LORENTZEN

"In principle any thermodynamic loss may be reduced as much as desired by increased expenditure in technical resources; optimization is an economic question"

ANTONIO ROSSETTI

SUPERMARKET CONTROL SYSTEMS

MONITORING SYSTEMS

- http://www.supersmart-supermarket.info
- DOWNLOADS
- Report 6 - Eco-friendly operation and maintenance of supermarkets

MONITORING SYSTEMS - DEFINITIONS

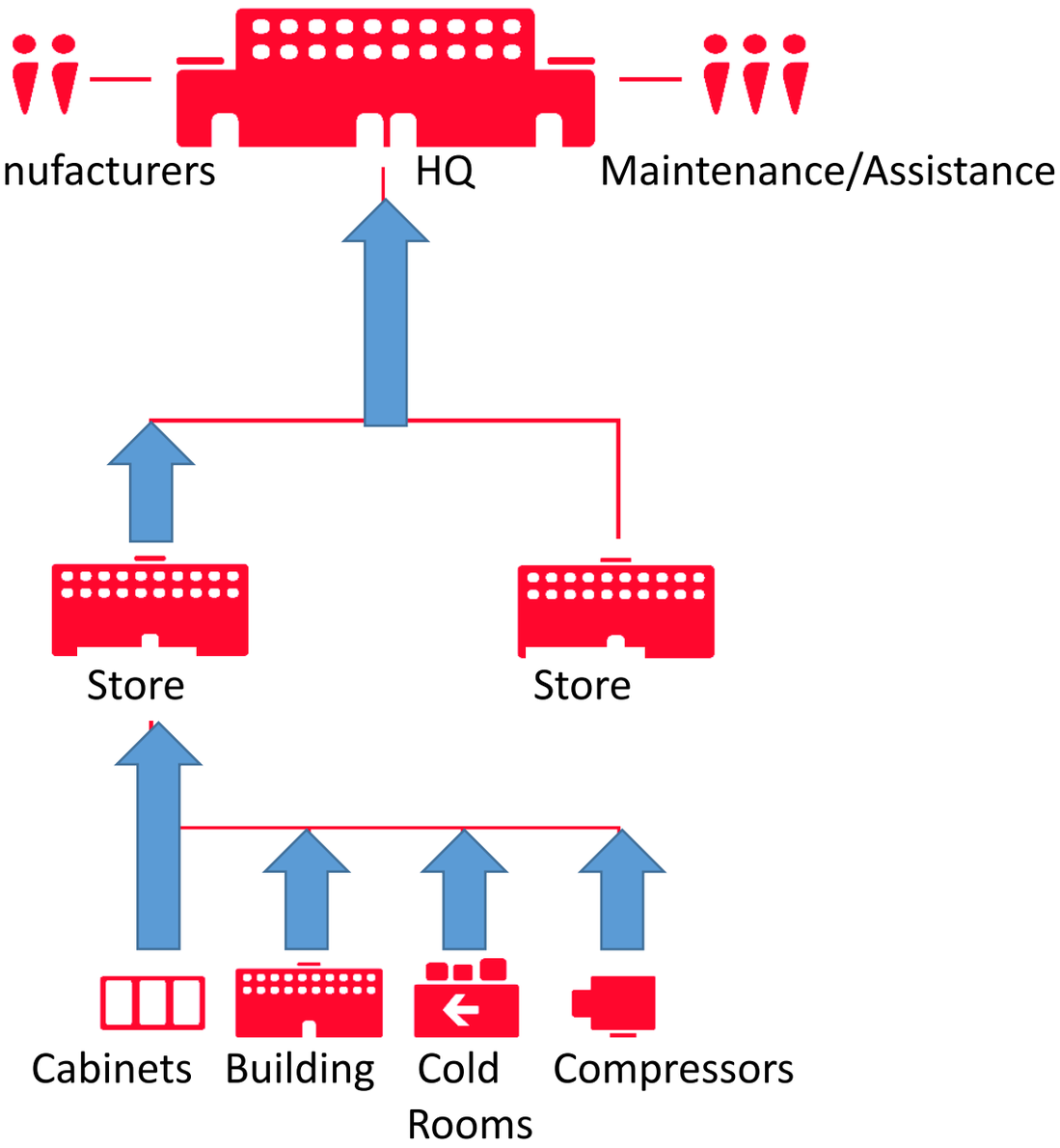
- «Monitoring Systems» and «Monitoring Solutions» are commonly used to refer to a wide range of different systems, with different characteristics and features

- Based on their capabilities and scopes, three different categories can be identified:

1. Monitoring Systems
2. Remote Control and Planning Systems
3. Integrated and Optimized Control Systems

1- MONITORING SYSTEMS

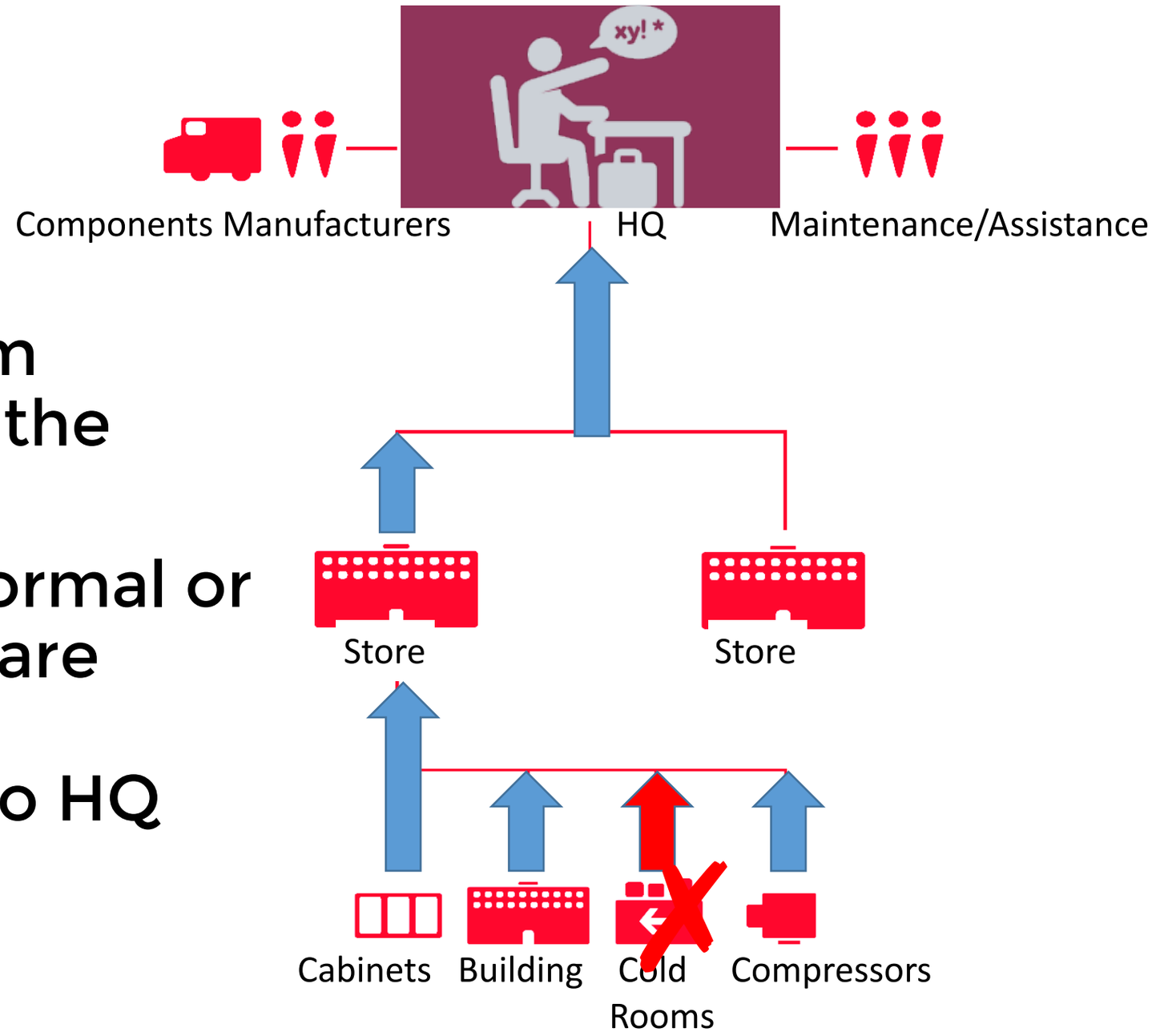
- The system centralizes the data



Graphics from

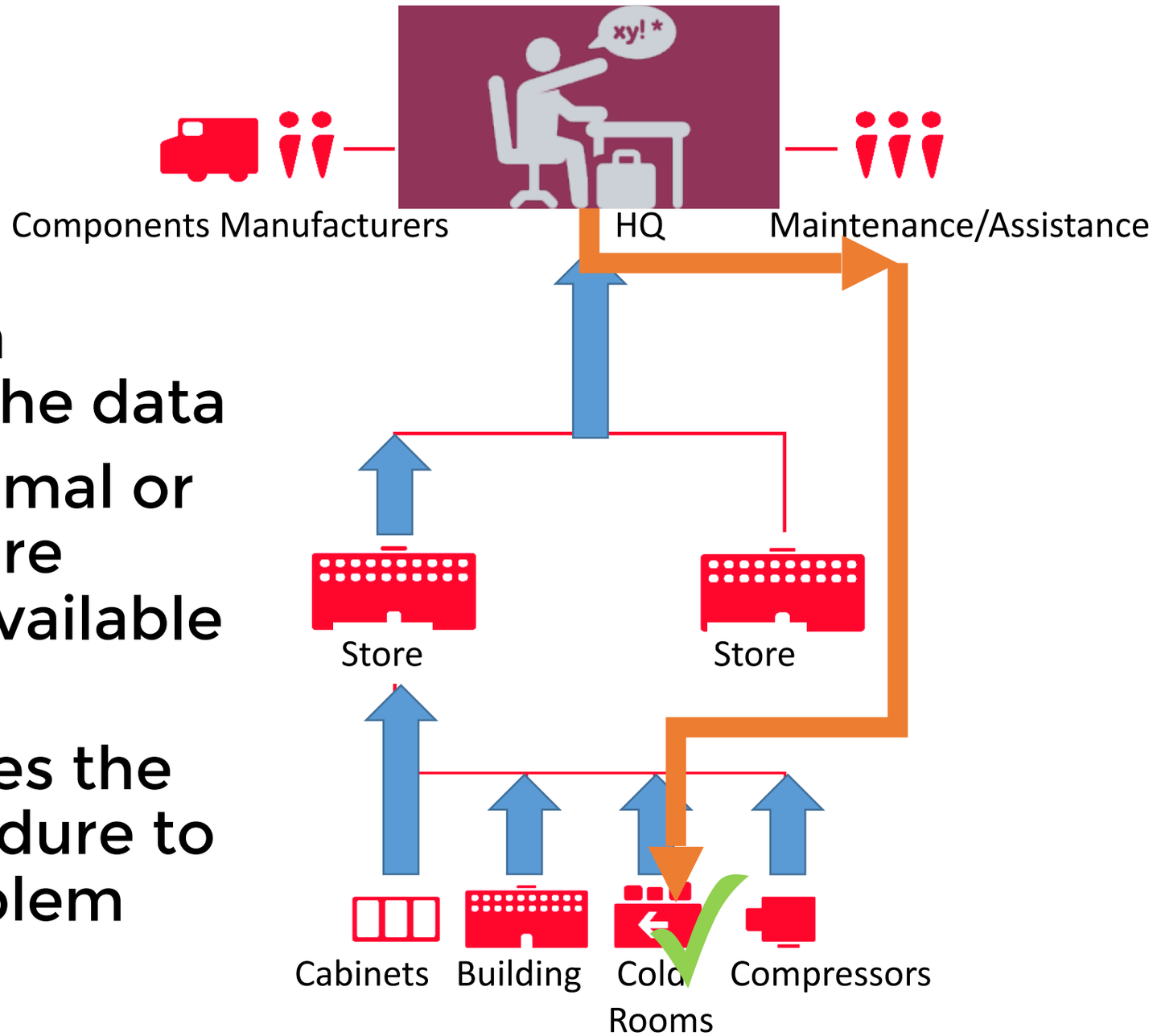
1- MONITORING SYSTEMS

- The system centralize the data
- Non-conformal or fault data are promptly available to HQ



Graphics from

- The system centralize the data
- Non conformal or fault data are promptly available to HQ
- HQ identifies the right procedure to fix the problem

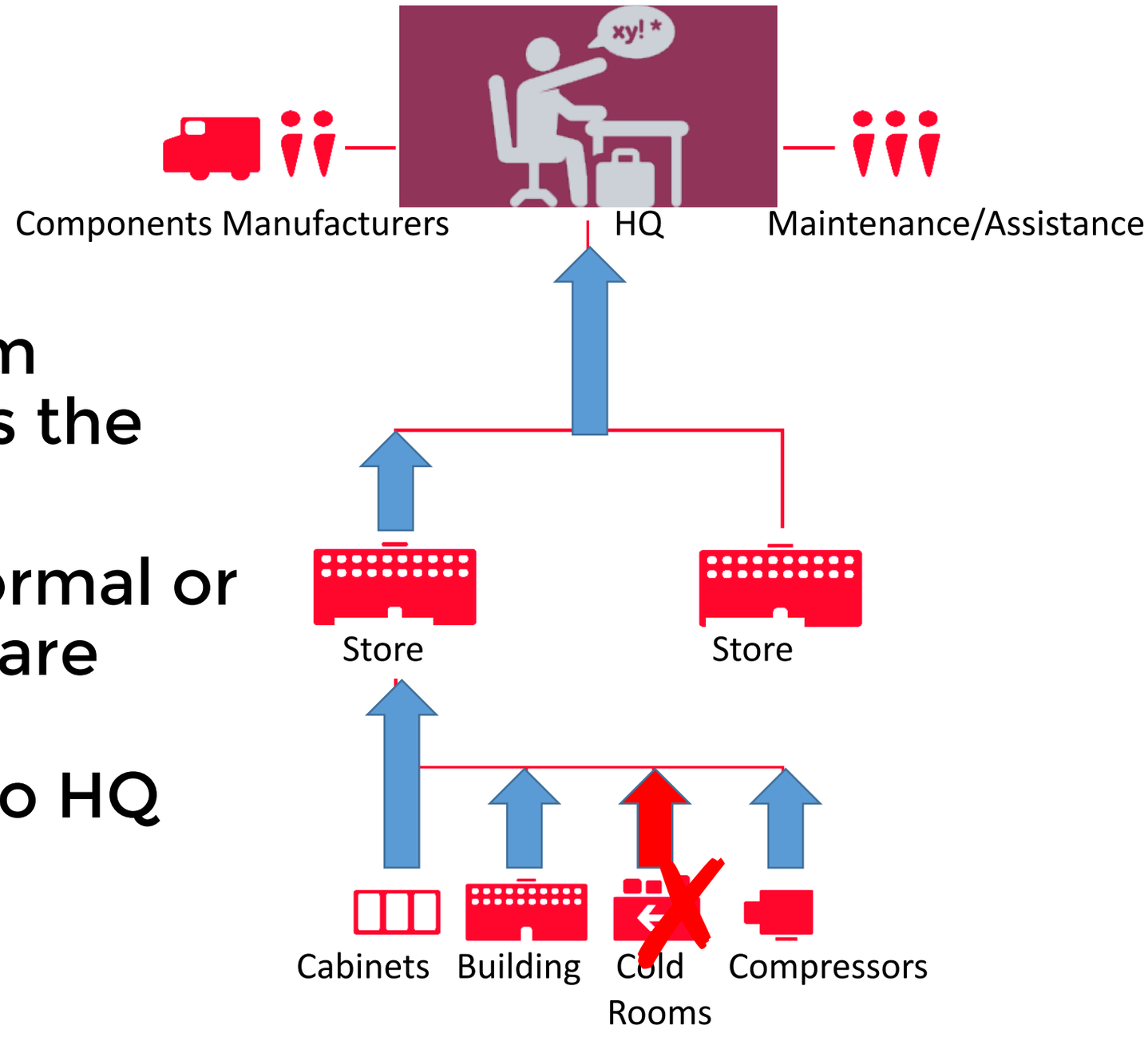


1- MONITORING

Graphics from

2- CONTROL SYSTEMS

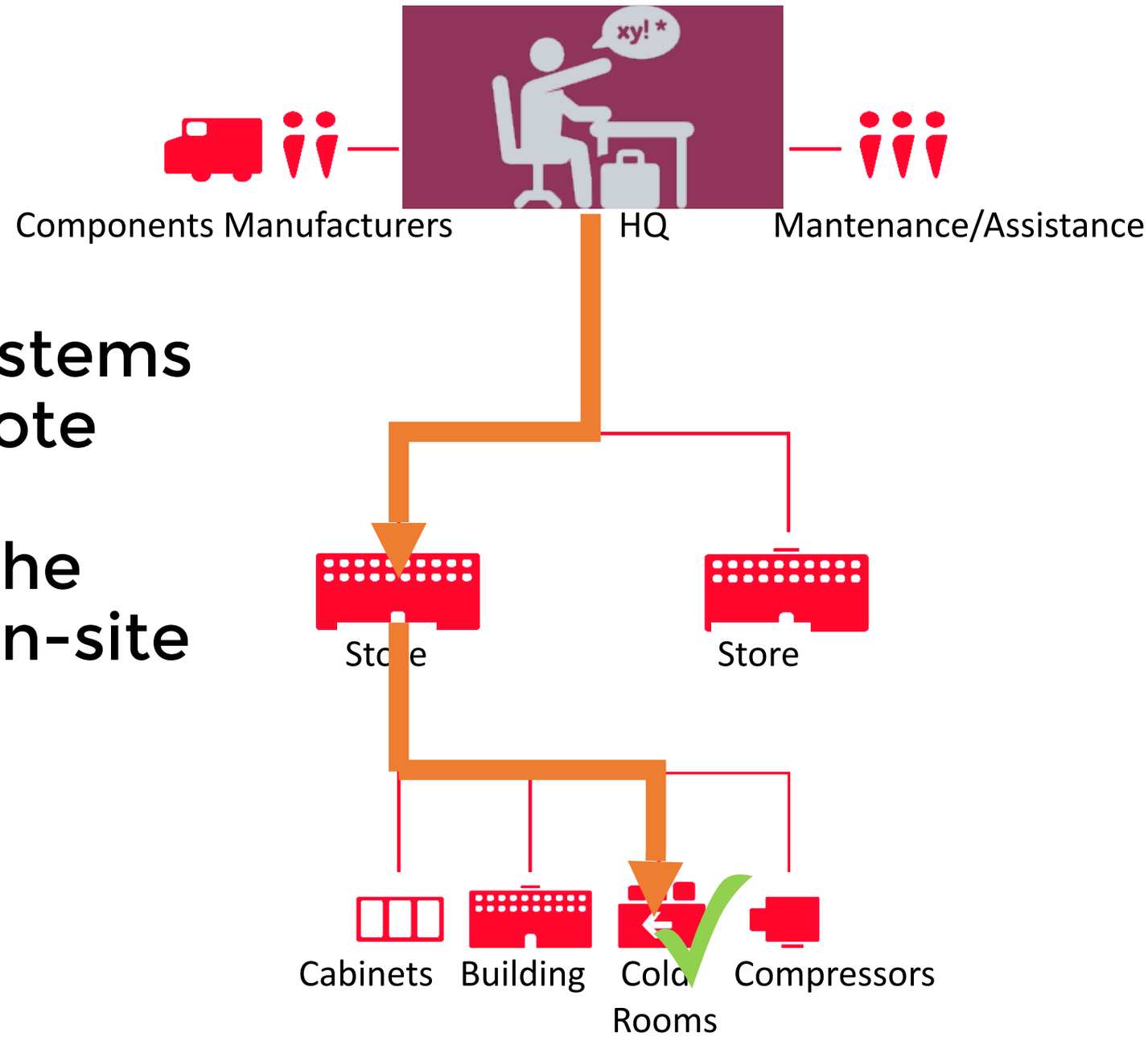
- The system centralizes the data
- Non conformal or fault data are promptly available to HQ



Graphics from Danfoss

2- CONTROL SYSTEMS

- Control systems allow remote operation reducing the need for on-site service

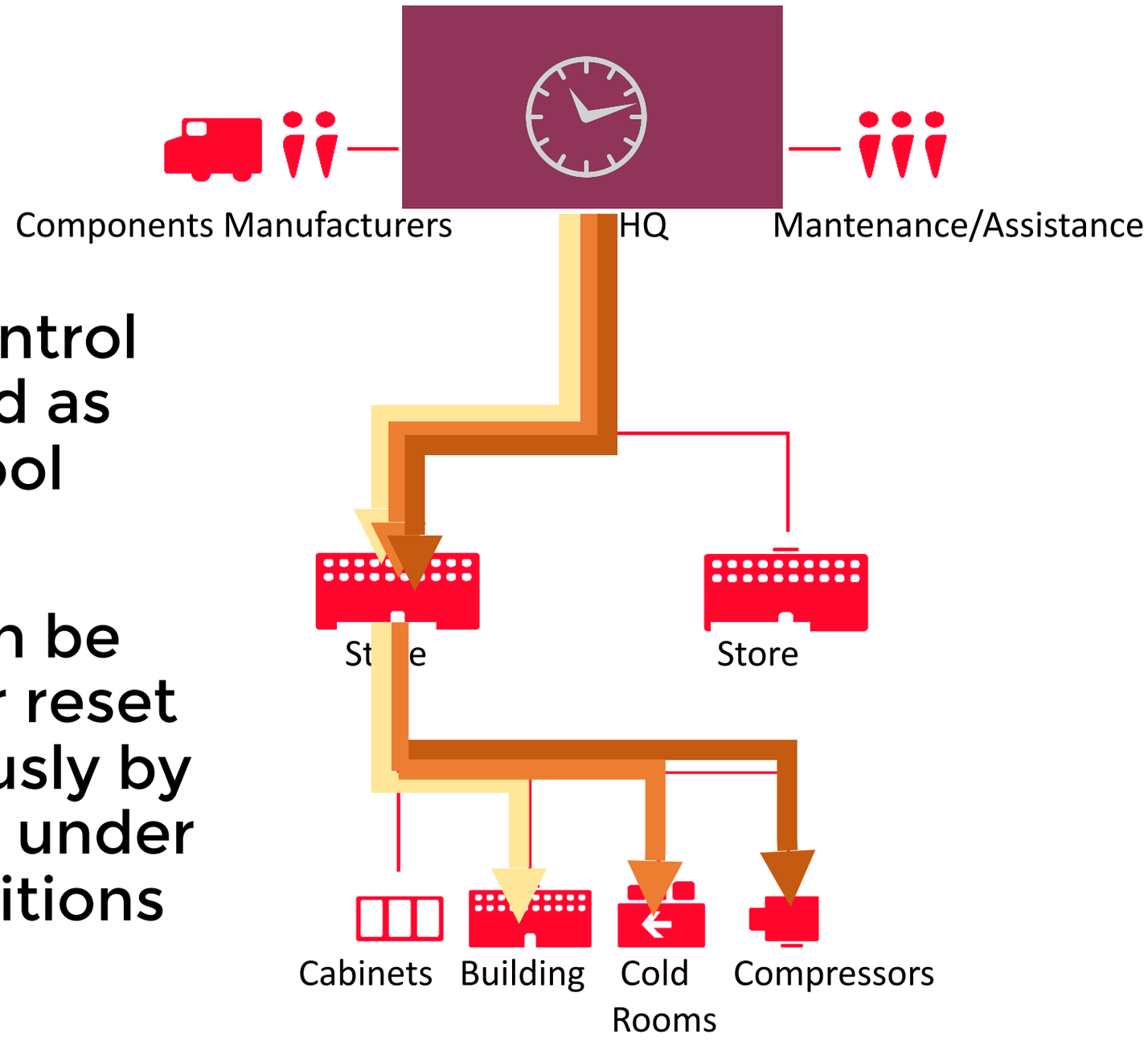


Graphics from Danfoss

2- CONTROL SYSTEMS

- Remote control can be used as planning tool

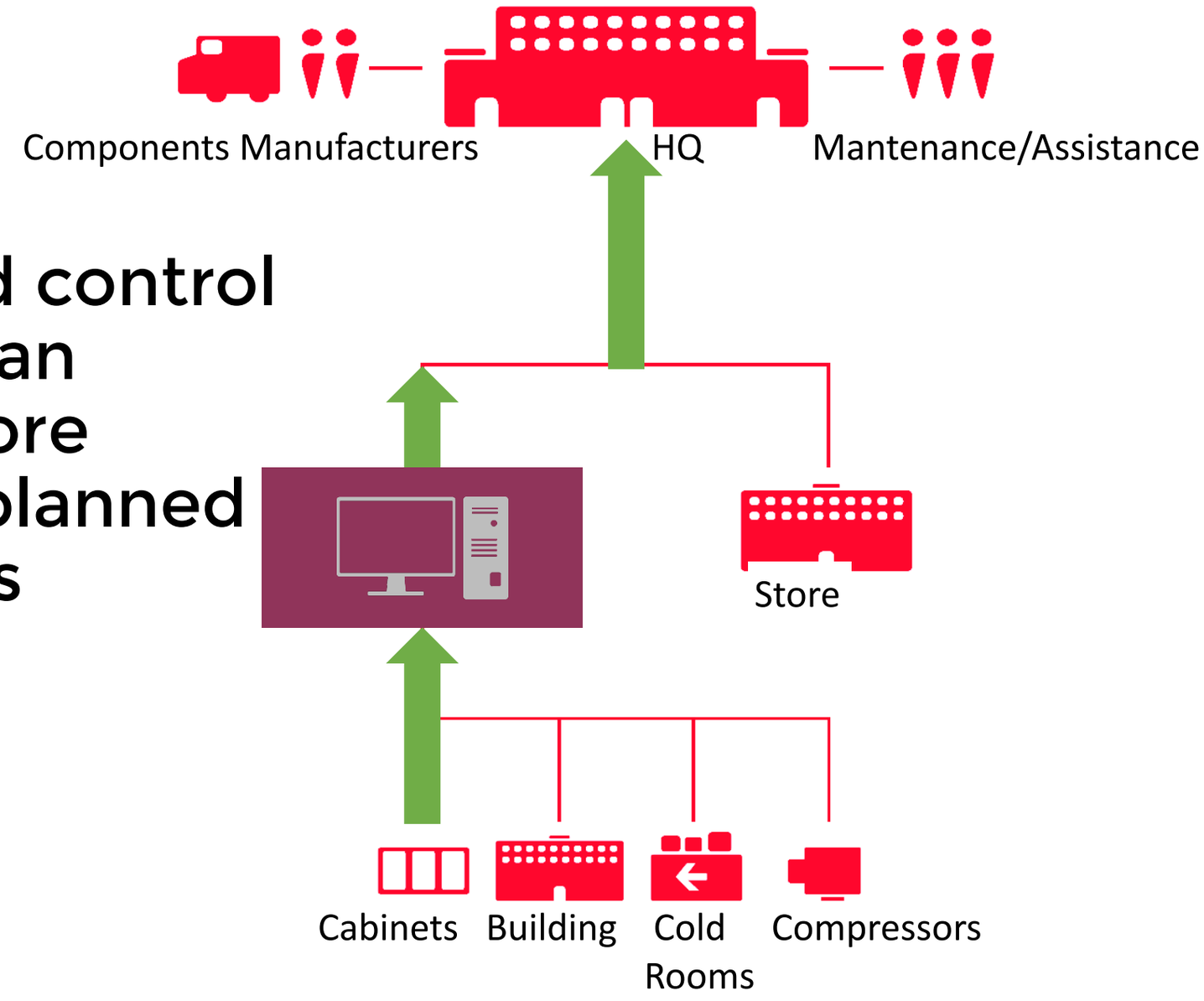
- Set-ups can be changed or reset autonomously by the system under given conditions



Graphics from Danfoss

3- INTEGRATED CONTROL SYS.

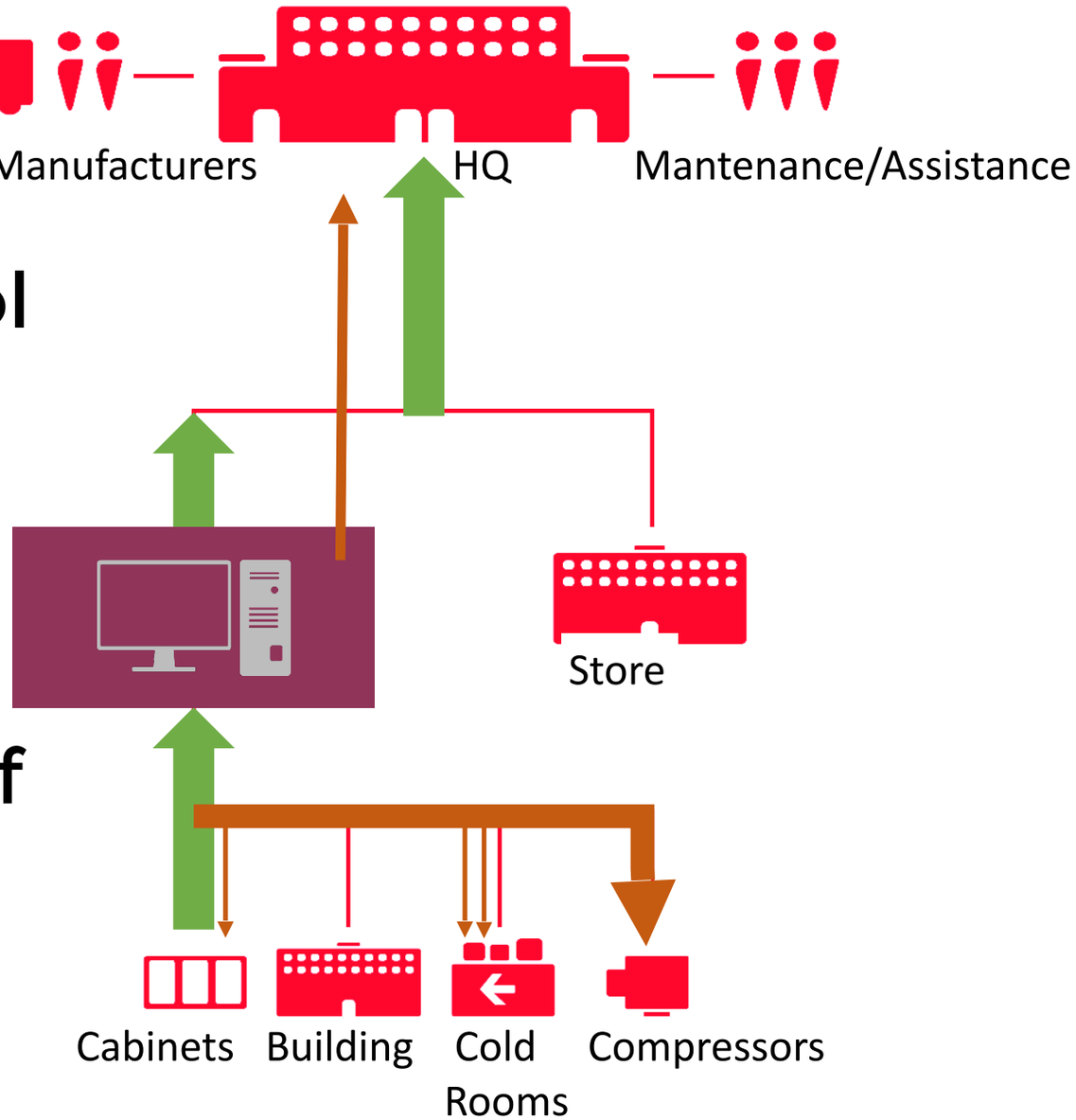
- Integrated control systems can handle more complex planned operations



Graphics from Danfoss

3- INTEGRATED CONTROL SYS.

- Integrated control systems can handle more complex planned operations
- The system can take advantage of sub-system interaction



Graphics from Danfoss

SIGNALS AVAILABLE TO MONITORING SYSTEMS

- Data collected by monitoring systems can be classified in three categories:

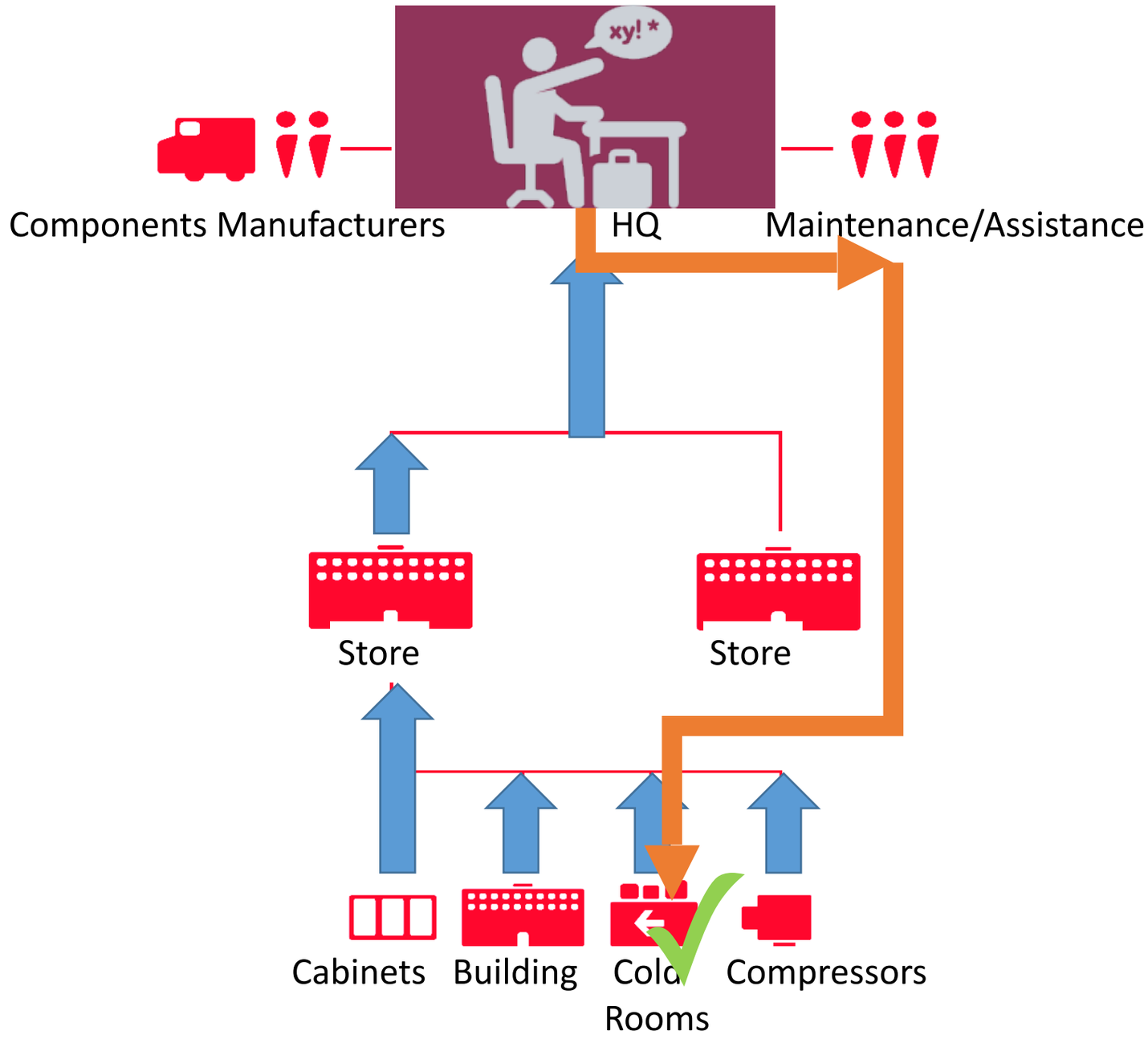
- Measures/States
- Controllers data
- Component data

ADDITIONAL MEASURES/STATES:
- Door opening
- External ambient data
- Anti-sweat system status

OTHER CONTROLLERS
- ***Renewable energy storage / management***

OTHER DATA
- Components data
- Maintenance plans

Grafica



1- MONITORING

Graphics from

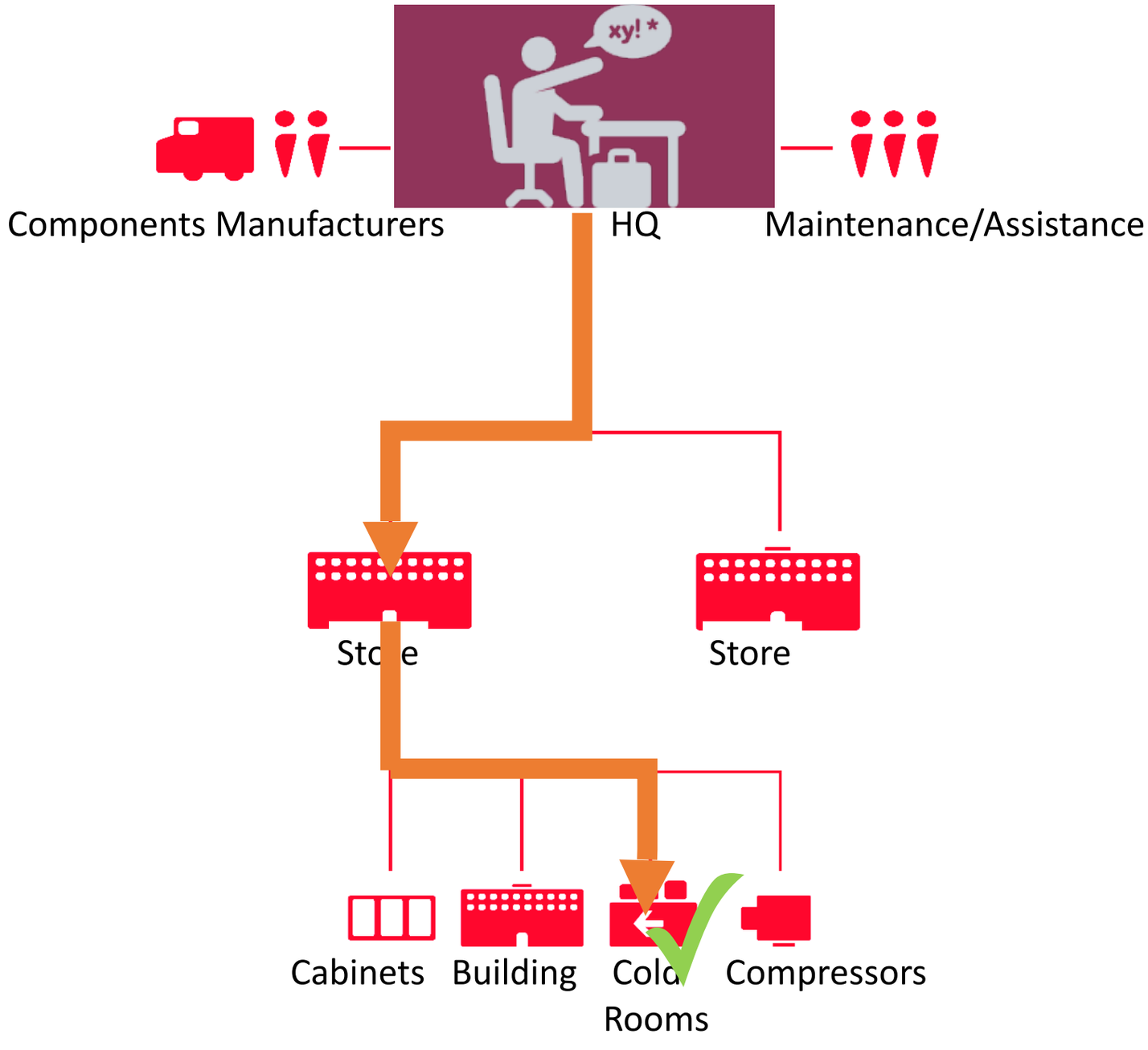
MONITORING SYSTEMS

- Monitoring systems are powerful tools for **management,** providing a centralized **database** containing:

  +Historical data of all the sensors installed
  +Historical data of all the set points and controller status
  +List of equipment and components
  +Test and inspection intervals
  +Maintenance schedule plans &
  +Service performed and outcome
  +Safety procedures

- Monitoring systems represent also an effective tool to improve food **quality** (continuous temperature monitoring and recording) and reduce food **waste** (prompt identification of non conformal system behaviors)

2- CONTROL SYSTEMS



Graphics from

CONTROL SYSTEMS

- Control systems include all the functionalities of monitoring systems

- In addition, they allow to change the system set points and parameters of the local controllers, permitting to:

+Define a **virtual control room** accessible form multiple platform (PC, Tablet…).
Access to this environment can be granted to specialized technicians, consultants, suppliers, …, **as need** reducing service time

+**Improve the overall system performance** by means of try-and-error procedures

PLANNIG TOOLS

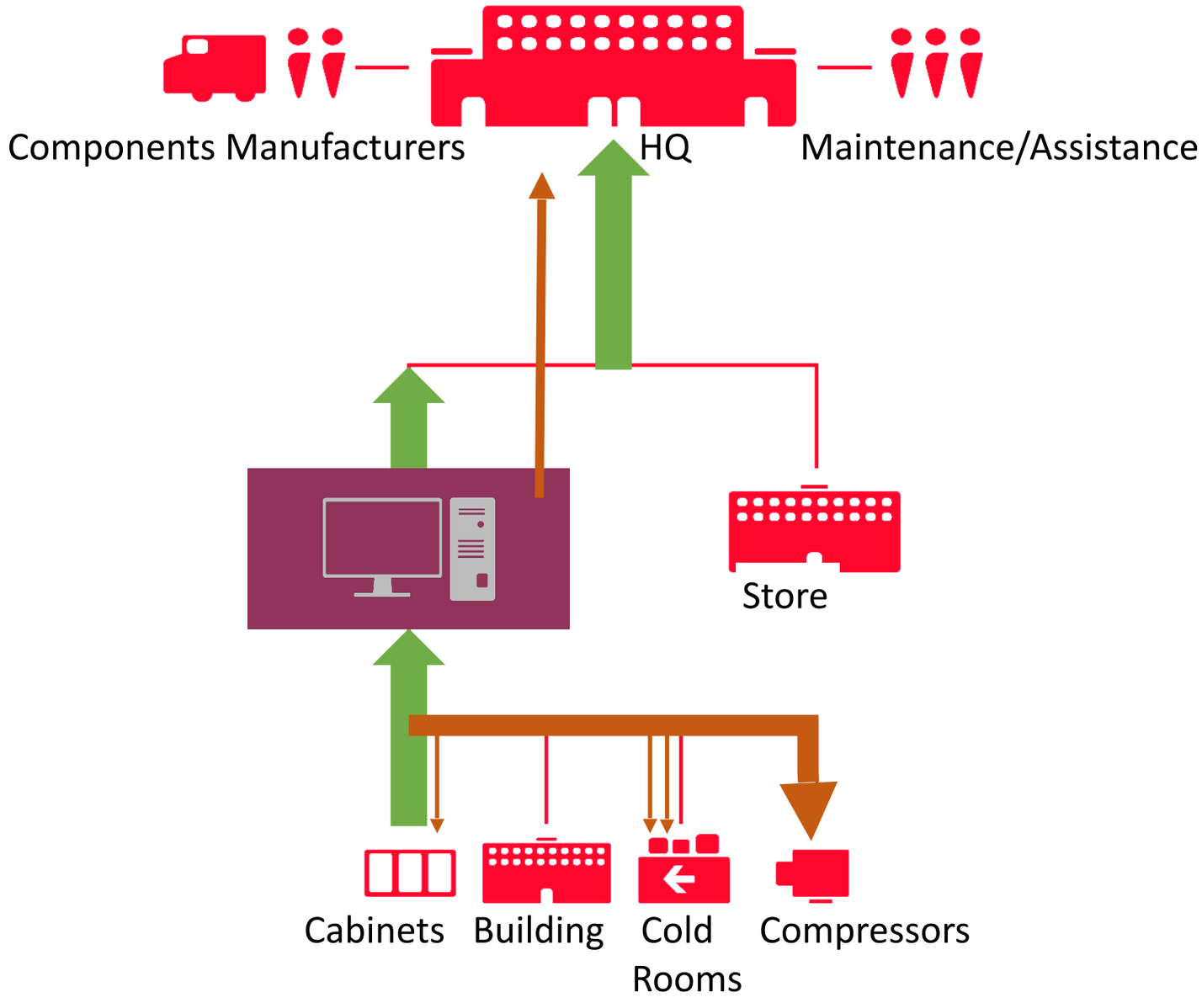
- Control systems represent the simplest type of «Smart Systems»

- Autonomous operations can be programmed into the system as function of the opening time/day of the week… :
  - Internal external light control
  - HVAC & Refrigeration set-up
  - Defrost timing
  - Reset to default set-points

Grafica CAREL

- Security procedures can be implemented (Ex. 1.send alarms;
  2.component protective shutdown;
  3.switch to a predefined backup configuration)

3- INTEGRATED CONTROL SYS.



Graphics from

INTEGRATED AND OPTIMIZED CONTROL SYSTEMS

- Integrated and optimized control systems are the natural development of the control system

- These systems are representative of the global trend toward «Smart Systems» and «Internet of Things».

- They can positively impact on different aspects such as Energy Saving, Food Quality, System reliability…

- … nevertheless require high integration between the systems and high overall complexity.

INTEGRATED AND OPTIMIZED CONTROL SYSTEMS

Optimized control examples:

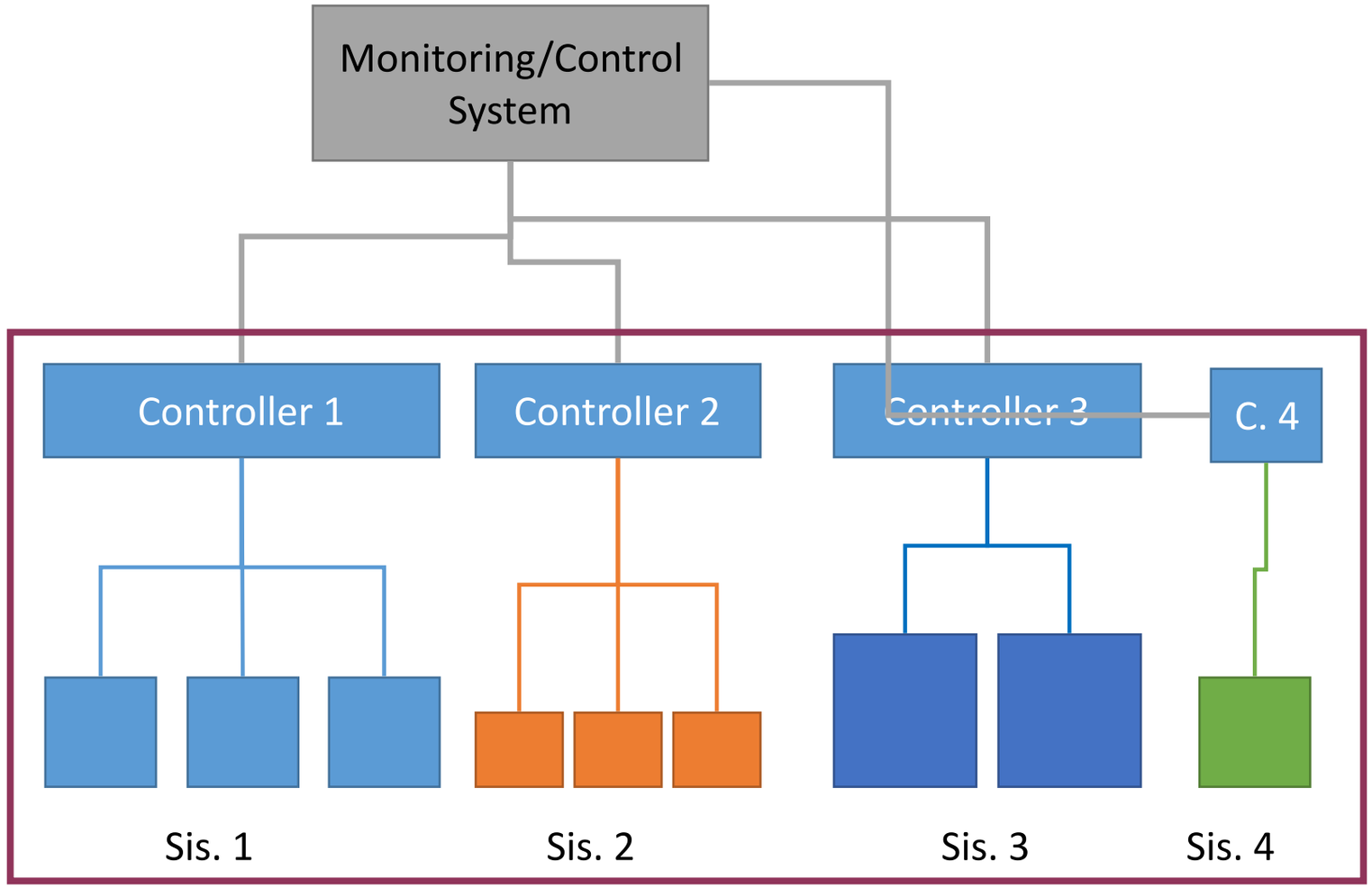
- **Anti-sweat optimized control**, based on the actual ambient temperature and humidity.
- **Optimum light control,** as function of the opening time and the weather condition.
- **Optimized suction pressure level,** based on the compressors ON/OFF cycles.
- **Optimized condensation pressure level**, based on external ambient temperature, to maintain the total energy consumption of compressors and fans to its minimum.
- **Smart defrost**, as a function of the actual ambient temperature and humidity.
- **Predictive HVAC system control**, on the basis of the internal and external ambient condition, building inertia and air quality, including the use of free-cooling option.

MONITORING SYSTEMS AND COMPLEXITY

- All systems can benefit from monitoring systems

- All systems (except the simplest ones) can benefit from Control & Planning system

- Only complex and integrated system can take advantage of the more sophisticated Integrated control System

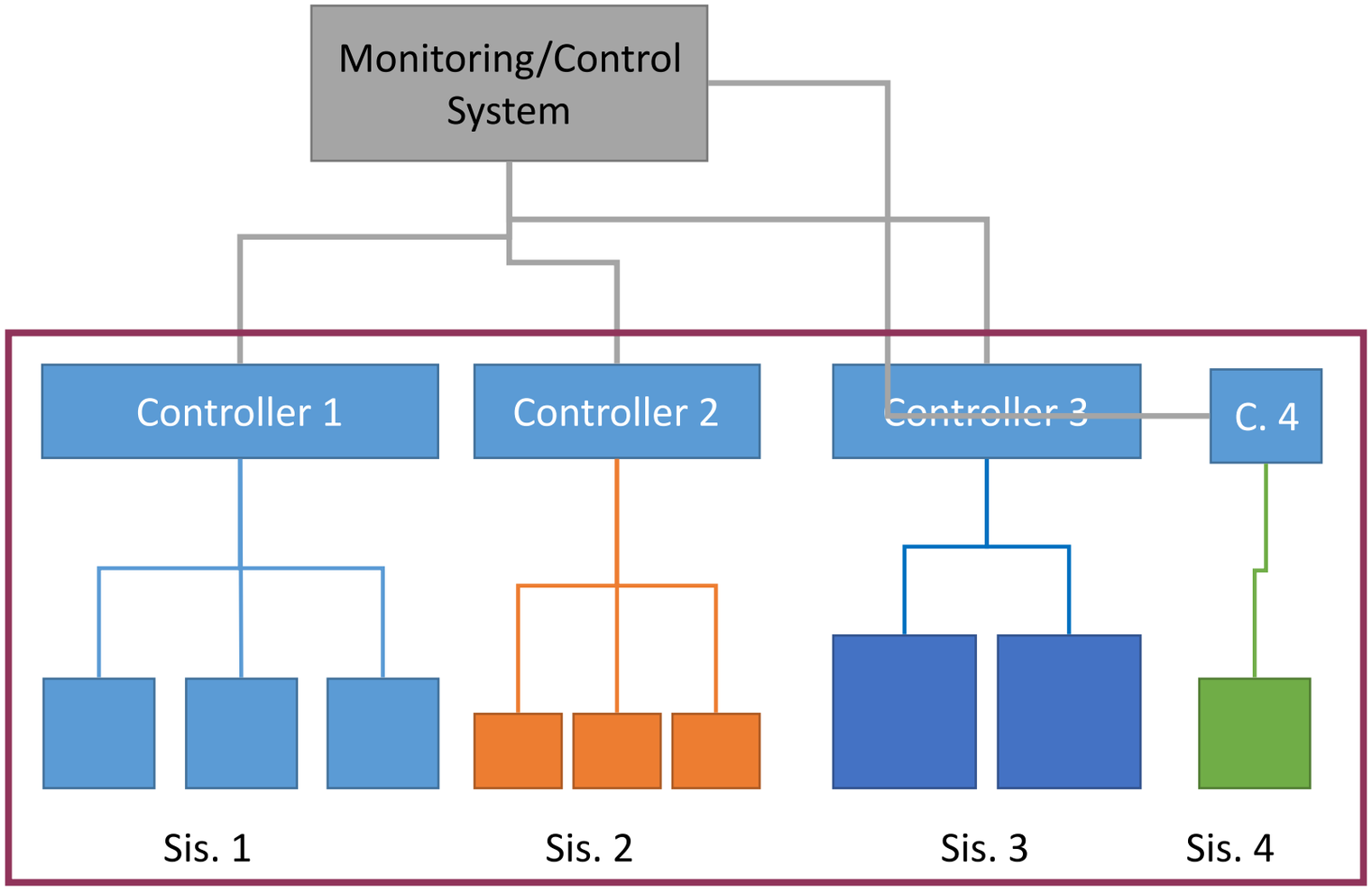


MONITORING SYSTEMS AND COMPLEXITY

- Monitoring & Control Systems are themselves subsystem that need maintenance and constant attentions as all the other subsystems

- They can provide significant improvements, but only if used and interpreted by trained a professional figure (or team) with expertise in **data analysis** and **HVAC&R systems**

"Excellence, is not an act, but a habit"



This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement N° 696076