BOLOGNA

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R290 retrofit of an R454B inverter-driven heat pump: thermodynamic analysis, issues and possible developments

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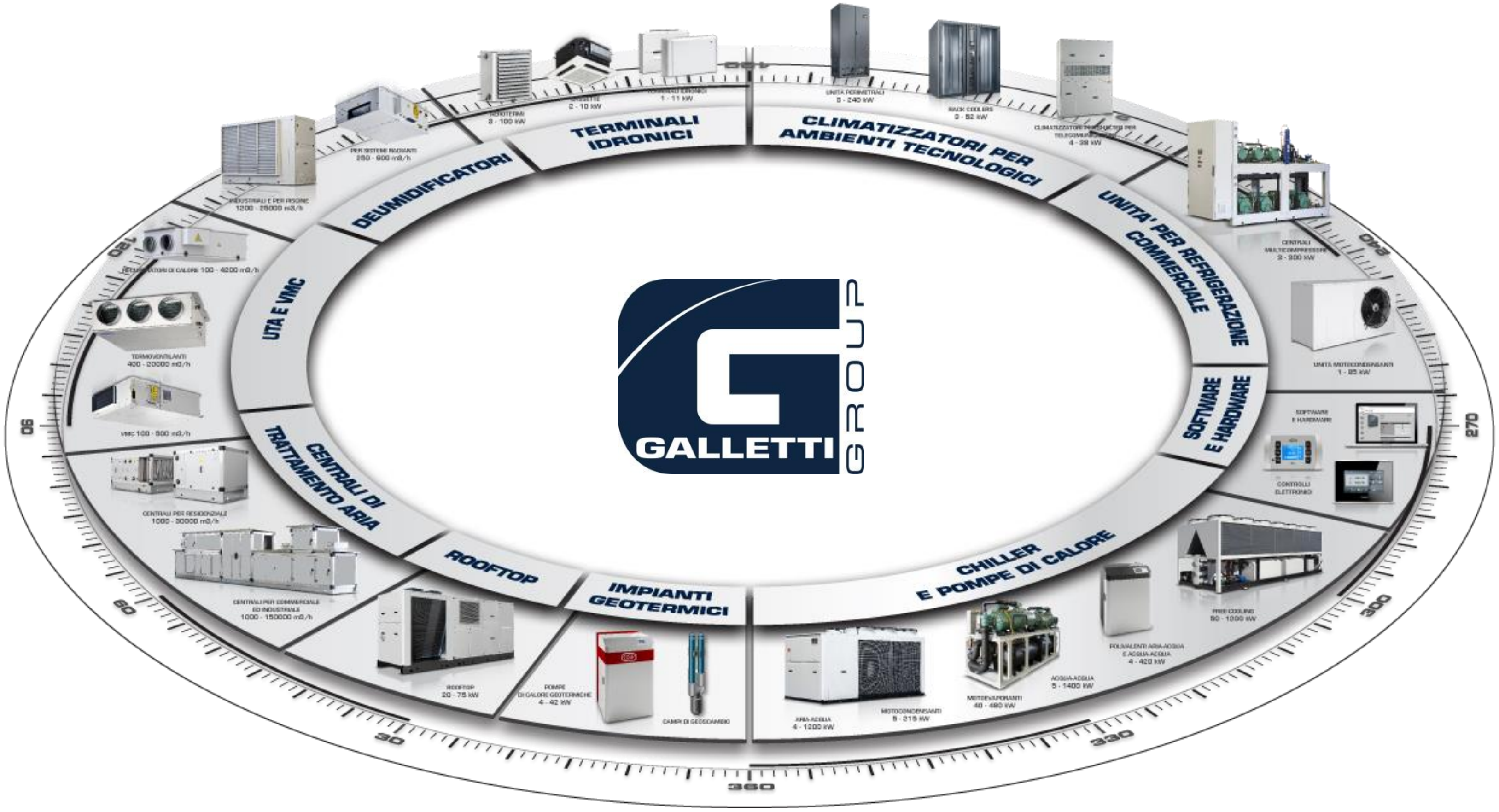
Galletti - Mission

Leader in manufacturing of chillers, heat pumps and hydronic units. Application in comfort and process cooling/heating plants.

360° products and services



Galletti AIR CONDITIONING

HiRef

CETRA

ENEREN renewable energies

HiDew Dehumidifiers

TECNO REFRIGERATION

GH Service

Summary

- **Introduction: actual and future refrigerant scenario**
- Thermodynamic analysis of a R290 heat pump
- Issues in using R290 in heat pumps
- Future developments and applications of R290 chillers and heat pumps

Introduction - Refrigerant scenario

GWP: **G**lobal **W**arming **P**otential

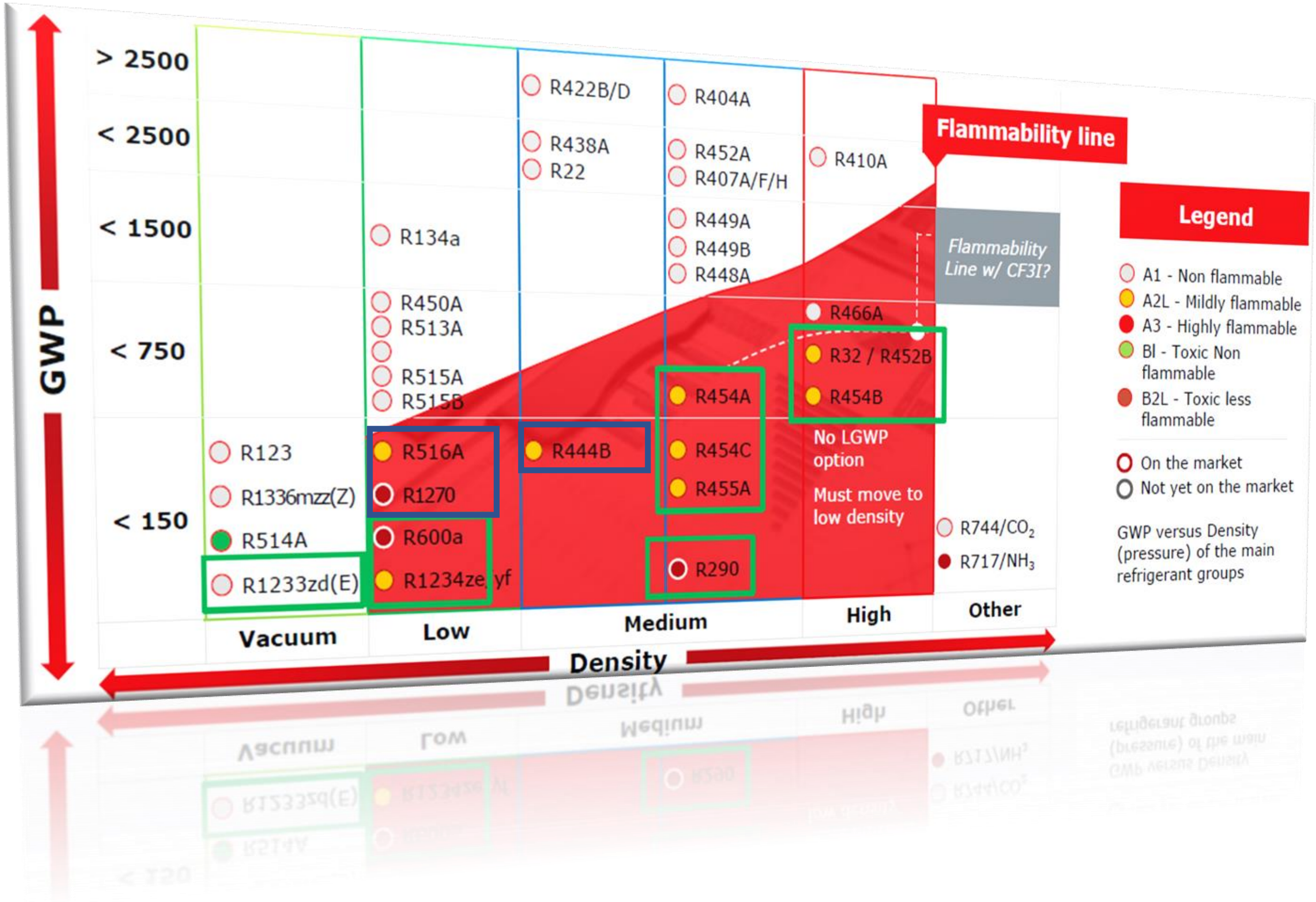
Provides a common scale for measuring the **climate effects** of different gases and it's measured in **carbon dioxide equivalent**: for any gas, it is the mass of **CO_2** that would warm the Earth as much as the mass of that gas, in 100 years

Example: GWP of R454B is 467, so in 100 years a leak of 1 ton of R454B is equivalent to emitting 467 tonnes of CO_2.
By definition, GWP of CO_2 is equal to 1.

F- gas revision:

	2026	2030
Best case scenario	Ban of all the heat pumps with **Pdes<50 kW and GWP>150**	Ban of all the heat pumps with **GWP>150**
Worst case scenario	Ban of all the heat pumps with **GWP>150**	

Introduction – Refrigerant Scenario



Vacuum density refrigerant:
Risk of refrigerant circuit contamination in case of leakeage being internal pressure lower than atmospheric pressure

Blends of R1234ze or R1234yf:
R516A, R1270, R444B may be banned because of **Pfas**

Only choices: natural refrigerants

R1270 (Propylene)
R600a (Isobuthane)
R717 (Ammonia)
R744 (Carbon Dioxide)
R290 (Propane)

Natural Refrigerant

Introduction - Why Propane?

	GWP	Flammable	Toxic	Temperature range	Pressure range	Thermodynamic cycle
R1270 (Propylene)	3	Yes	No	-48°C ; 91°C	0,5 bar ; 40 bar	Subcritic
R600a (Isobutane)	3	Yes	No	-11°C ; 135°C	0,5 bar ; 30 bar	Subcritic
R290 (Propane)	3	Yes	No	-48°C ; 96,7°C	0,5 bar ; 35 bar	Subcritic
R717 (Ammonia)	0	Yes	Yes	-33°C ; 132°C	0,5 bar ; 100 bar	Subcritic
R744 (Carbon Dioxide)	1	No	No	-50°C ; 60°C (Supercritic)	6 bar; 150 bar	Transcritic/ Supercritic

- Non **toxic** refrigerant
- No need for **supercritical** or **transcritical** cycles
- Mid pressure refrigerant - **lower pressure to manage**
- High temperature range – **extended envelope**

Natural Refrigerant

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Thermodynamic analysis

Step 1: Retrofit of existing unit **R454B → R290**

1) Goal: rated heat output **35 kW, water 30/35°C @7(6)°C**
2) Minichannel air coil, 3 rows (diameter 5 mm)
3) Brazed plate heat exchanger
4) Inverter-driven compressor, displacement 88 cc

↓

Replacement with **R290 optimized compressor**, displacement 100 cc

Kept same piping diameter, line components and heat exchangers

Thermodynamic analysis

Results of step 1: Water 30/35°C, Air Temperature 7(6)°C

	R454B	R290
Evaporating Temperature	-4,1°C	**-7,4°C**
Condensing Temperature	41,3°C	40,3°C
Compressor rps	5100	**7050**
COP	3,60	3,50
SCOP	3,40	3,14

Due to lower density of refrigerant, keeping the **same heat exchangers and line components**, pressure drops increase, and **overall energy loss increase**, so:

- Compressor must run at a **higher velocity** to meet the heat load required
- Evaporating temperature decreases (dT=-3,3K), so the thermodynamic cycle is less efficient and the **risk of frosting increases** also at higher ambient temperature
- Seasonal energy efficiency decreases

Direct retrofit is not sustainable!

Thermodynamic analysis

Step 2: Thermodynamic optimization

1) Increased air heat transfer surface: from **1 coil 3 rows**, to **2 coil 2 rows**. Optimization of heat exchange, due to lower pressure drop → **Higher evaporating temperature**

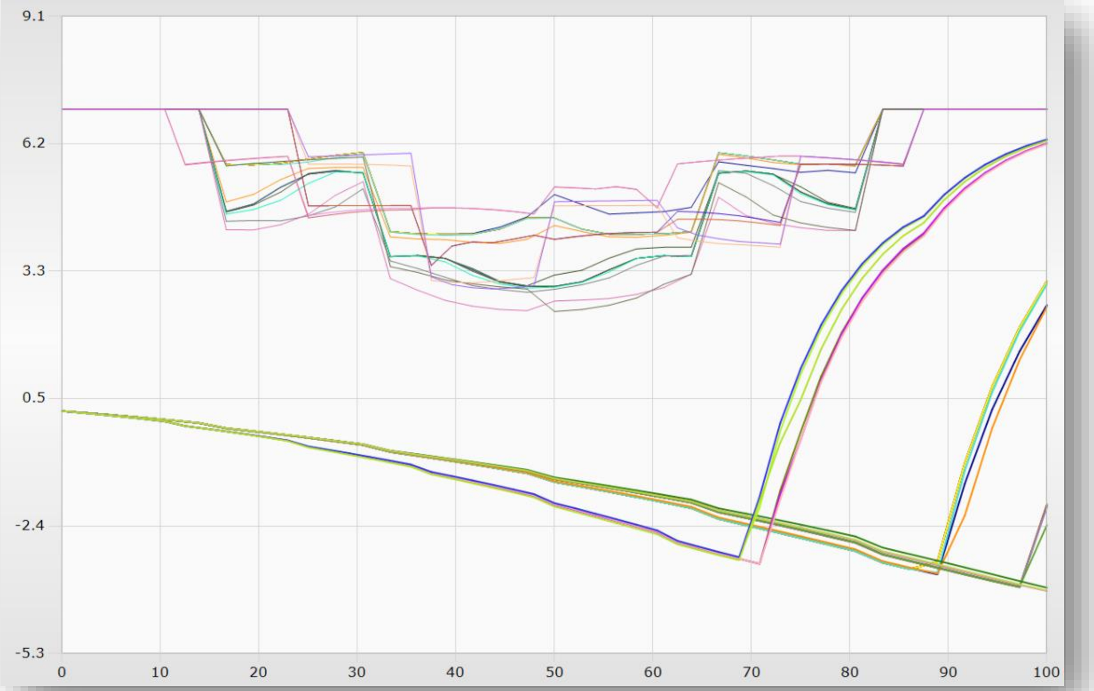
2) Optimized plate heat exchanger: asymmetric plates, different plate corrugation.

3) Optimized line components (higher kv) and piping diameter: **reduction of energy losses** inside pipes due to friction.

Thermodynamic analysis

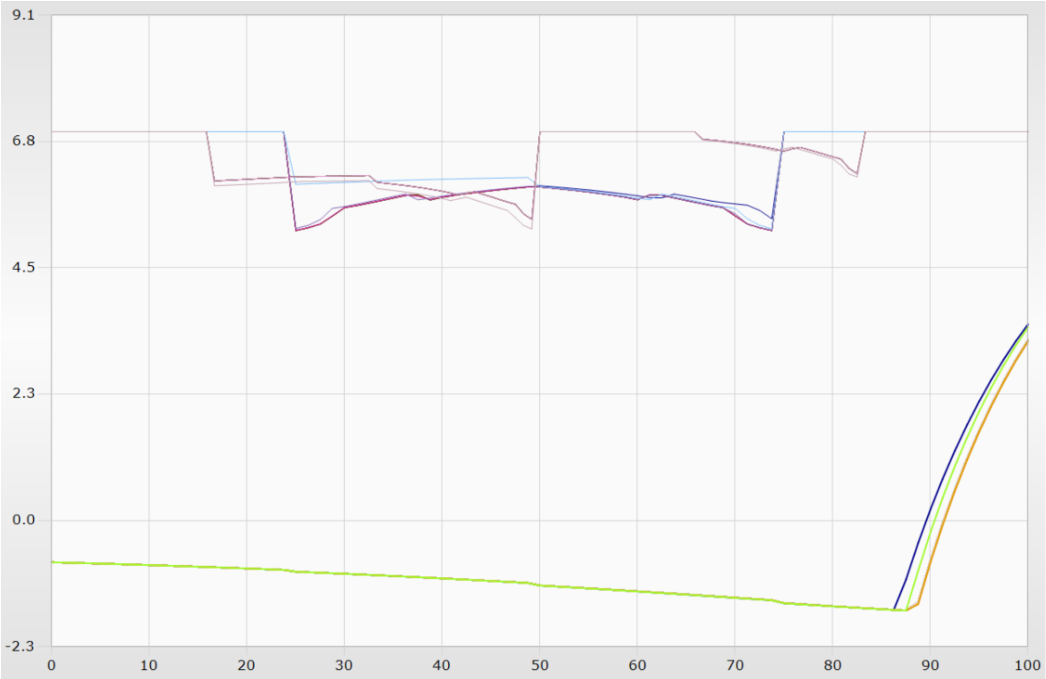
Temperature profiles in finned coil heat exchanger

Before optimization



3,5K of saturation temperature **lost** due to pressure drop inside the heat exchanger

After optimization



0,7K of saturation temperature **lost** due to pressure drop inside the heat exchanger

Thermodynamic analysis

Results of step 2: Water 30/35°C, Air Temperature 7(6)°C

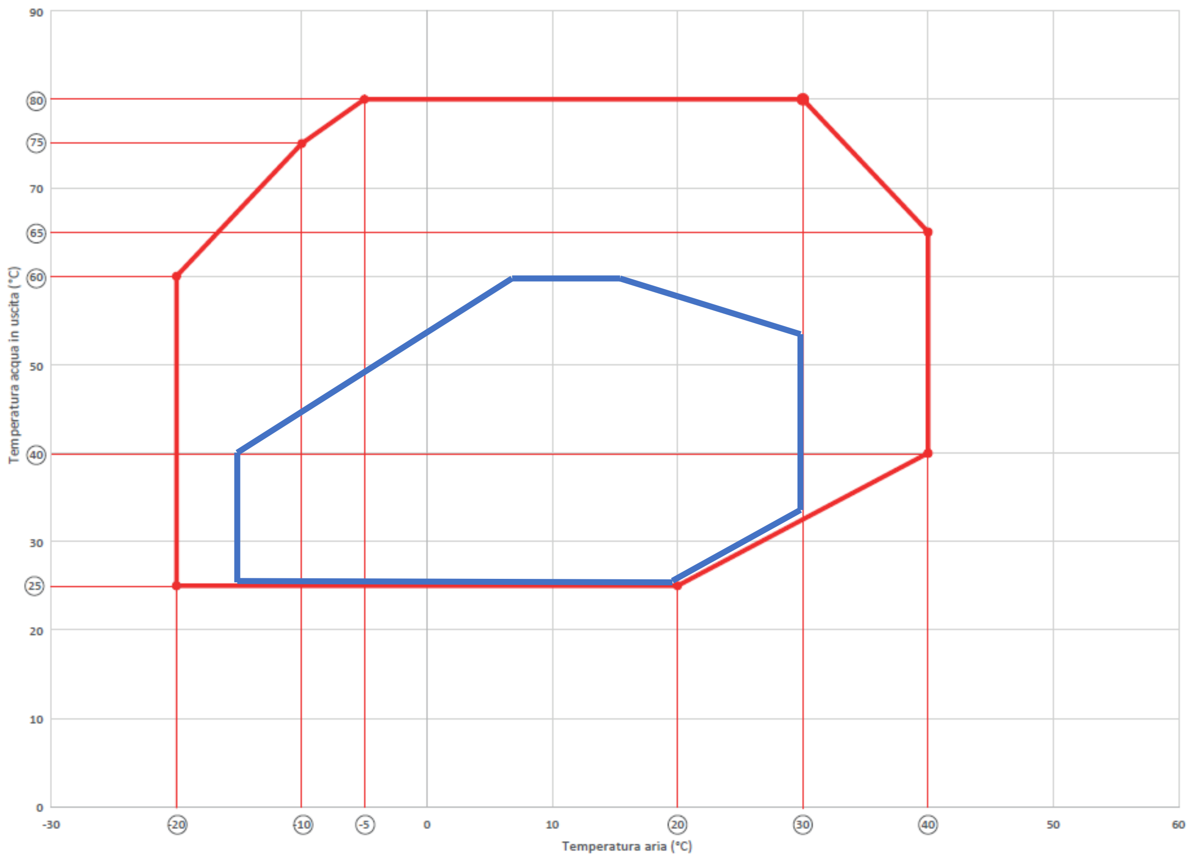
	R454B	**R290**
Evaporating Temperature	-4,1°C	**-4°C**
Condensing Temperature	41,3°C	38,3°C
Compressor rps	5100	**5500**
COP	3,60	3,74
SCOP	3,40	4,02

With optimized components:

- Compressor could run at a **lower velocity**
- Evaporating temperature is **comparable** to R454B
- Seasonal energy **efficiency increases**

Higher cost of overall unit, but overall efficiency +19%!

Thermodynamic analysis



R454B unit – heat pump envelope

R290 unit – heat pump envelope

Due to **lower operating pressures, lower dP**, and lower **discharge temperature** the compressor could work at higher condensing temperatures, and lower evaporating temperatures. **Wide range** of application permitted

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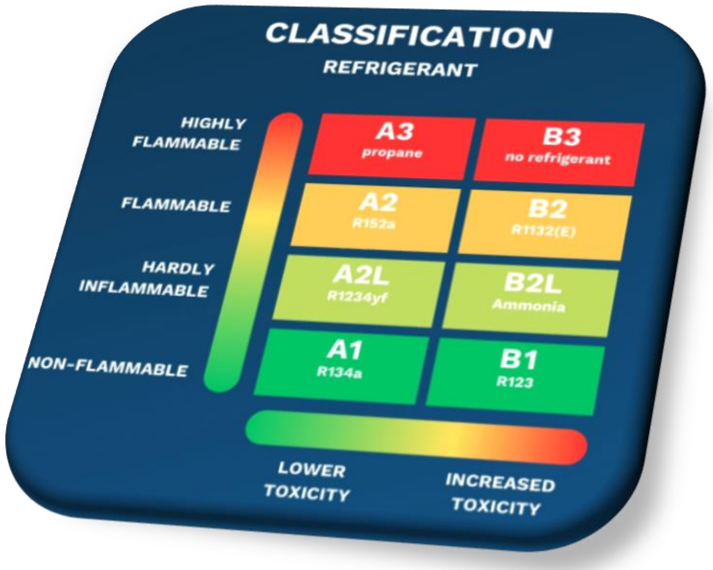
Issues – Safety management

- R290 is classified as **A3**, so non toxic, **highly flammable**
- R290 density is **higher than air**
- A **leakage** of refrigerant generate **ATEX** classified zones.



- **Reduction of leakage possibility**

  Solder connections and **hermetic components**

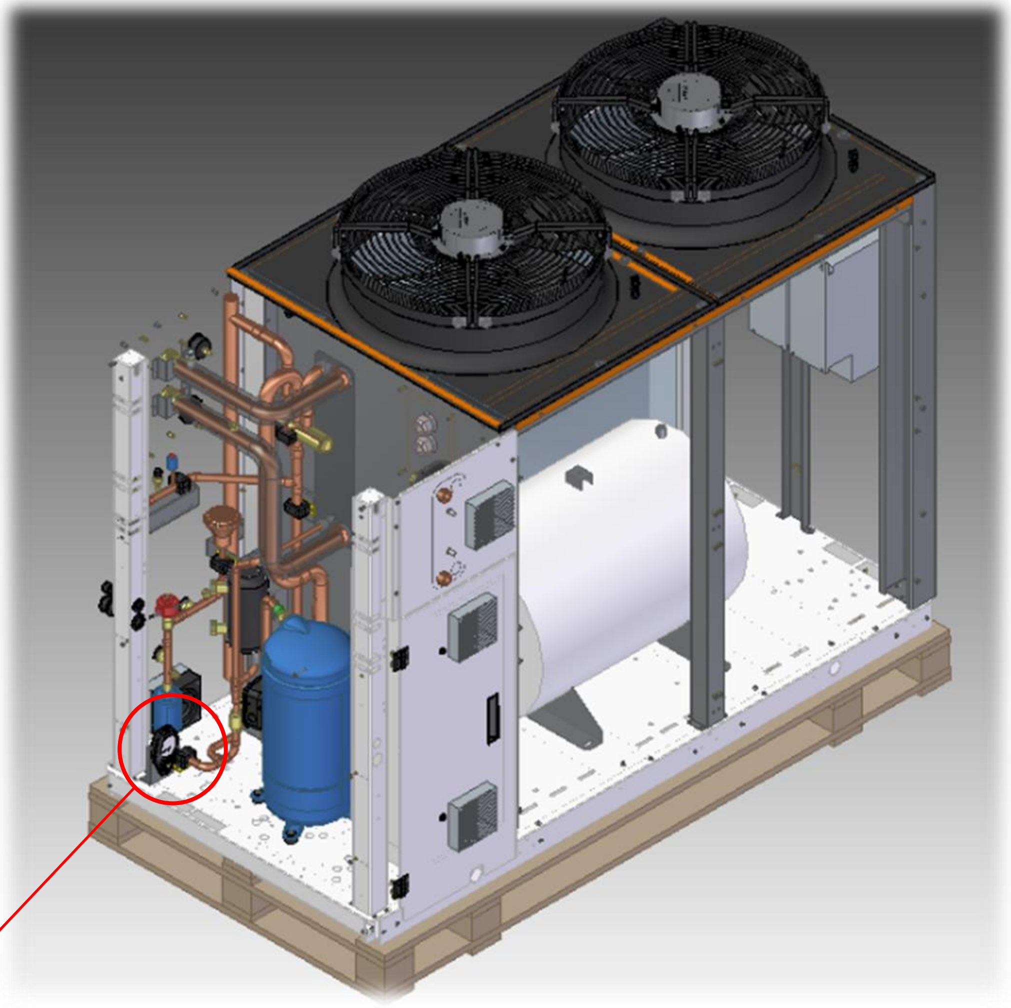
- **Reduction of refrigerant charge**

  Minichannel coil, asymmetric plate heat exchanger, optimized gas piping

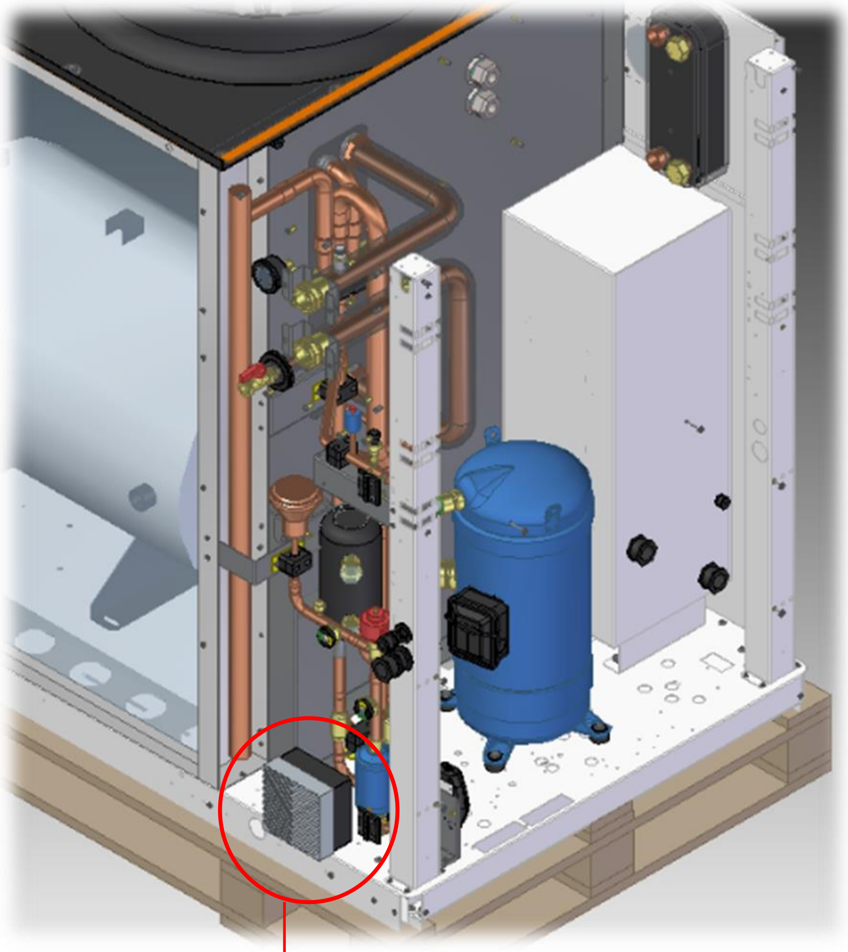
- **Reduction of risk in case of leakage**

  Leakage sensor (**30% LFL**), extraction fan, safety interlocks

Issues – Safety management



Gas detector



ATEX extraction fan

Issues – Safety management

- Safety logic of the unit: **continuos communication with the plant**. Overall risk minimization

Leak Detection
20% LFL

Switch to **external 230 V supply**

Unit **OFF**

Feedback to **external BMS**

Extraction Fans **ON**

Gas detection **ON**

Main 400 V supply **OFF**

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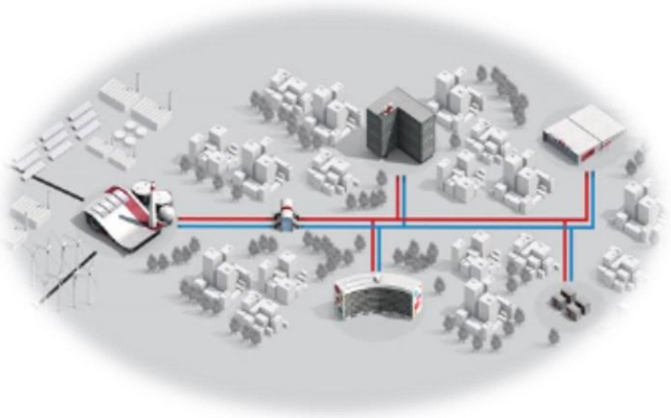
Possible developements

Air conditioning:

- Boiler replacement
- DHW production during the whole year with Anti-Legionella treatment
- District heating system



Process cooling:

- Low temperature applications down to -20°C glycol production (es. ice rinks, distillery, food conservation)

Process heating:

- High temperature applications up to 80°C water production (es. sterilization, pastorization)

Possible developements

Modular units for big capacity plants and reduction of leakage risks

- Compact units with **small footprint** and with **low refrigerant charge** (max 5 kg)
- Two or more units can be paralleled via LAN to **increase the overall unit capacity**

Thank you!