EURAMMON STUDENT’S DAY 2025

14. April 2025, Hochschule Karlsruhe

Hochschule Karlsruhe
University of
Applied Sciences

HKA

eurammon
Refrigerants, naturally!

Energy efficient defrosting of finned heat exchangers in plants with natural refrigerants

Emmerich Tempfli
Güntner GmbH & Co. KG

EURAMMON STUDENT’S DAY 2025

14. April 2025, Hochschule Karlsruhe

Hochschule Karlsruhe
University of Applied Sciences
HKA

eurammon
Refrigerants, naturally!

- Measures for more sustainability
- Evaporators in frosty conditions
- Frost formation
- Defrosting
- Optimization

KEY STATISTICS

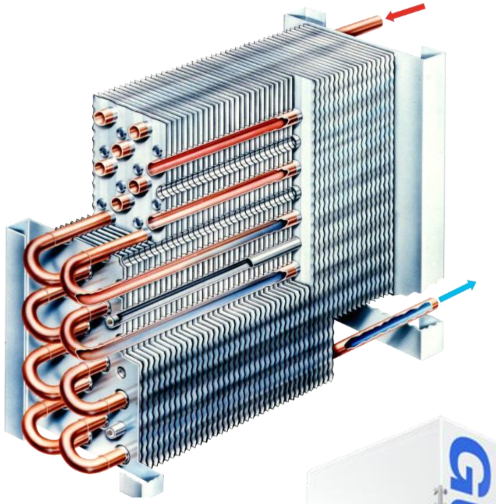
Refrigeration, Heating and Cooling

- Heating and cooling account for **50 %** of total energy consumption in the EU (where 60% is still originate from fossil sources).
- Cooling (air conditioning and refrigeration) accounts for **17 %** of global energy consumption.
- Refrigeration and air conditioning contribute **10 %** of global green house gas emissions.

→ by addressing efficiency and adopting sustainable technologies like natural refrigerants, we can play a pivotal role in reducing the industry's carbon footprint and supporting global climate goals

MEASURES FOR MORE SUSTAINABILITY

Heat pumps and **chillers** are key applications for energy efficiency



Evaporators – key components of these systems - play a critical role in determining operational efficiency especially under frosty conditions

1. Step: Life-Cycle Analysis
Before improving environmental impact, analyze the entire product life cycle & identify the phases with the most significant potential for improvement

Production of Raw Materials → Manufacturing → Utillization → Disposal / Recycling

Logistics

MEASURES FOR MORE SUSTAINABILITY

Evaporators

approx. **90 %** of the total CO_2-footprint!

Production of **Raw Materials**

Manufacturing

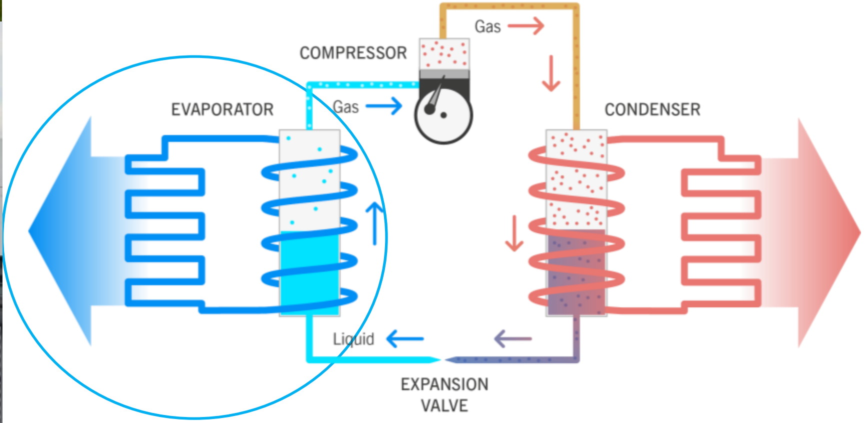
Utilization

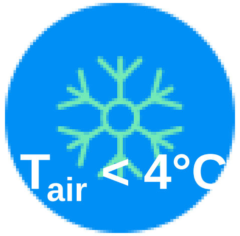
Disposal / **Recycling**

Logistics

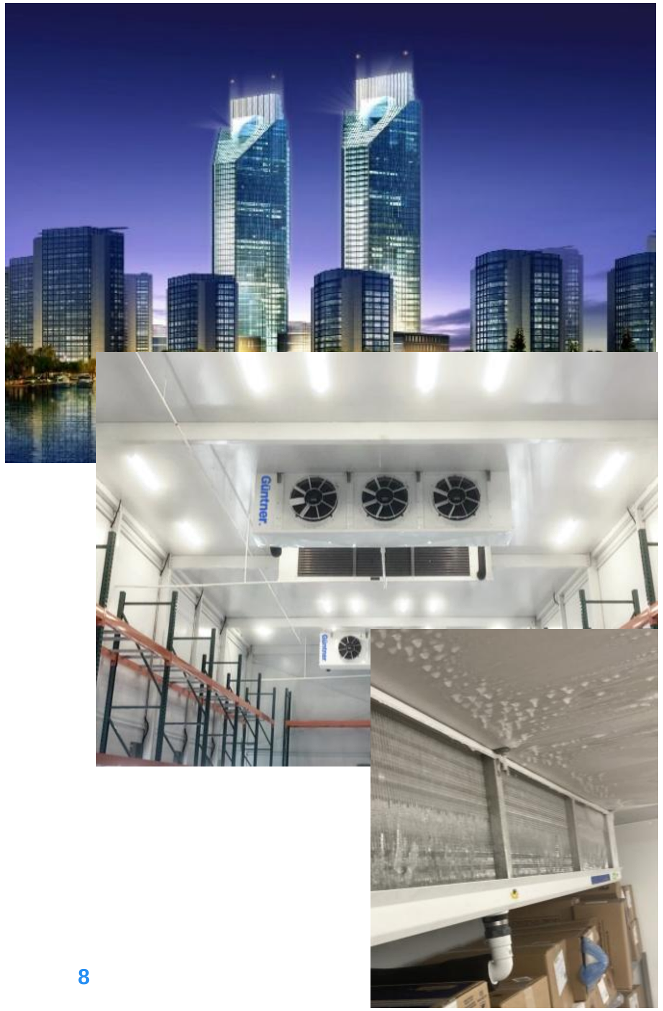
EVAPORATOR AS HEAT COLLECTOR

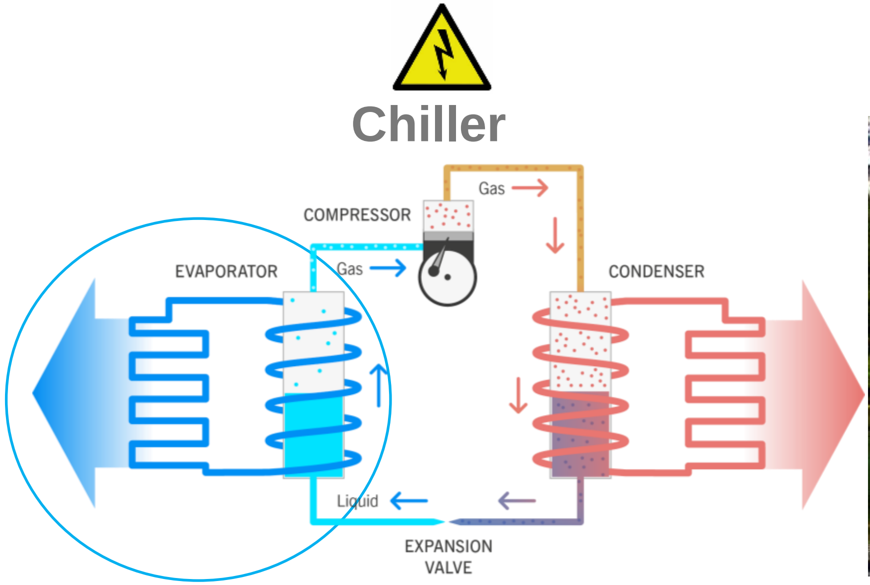
Heatpump

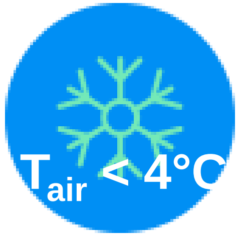




EVAPORATOR AS AIR COOLER



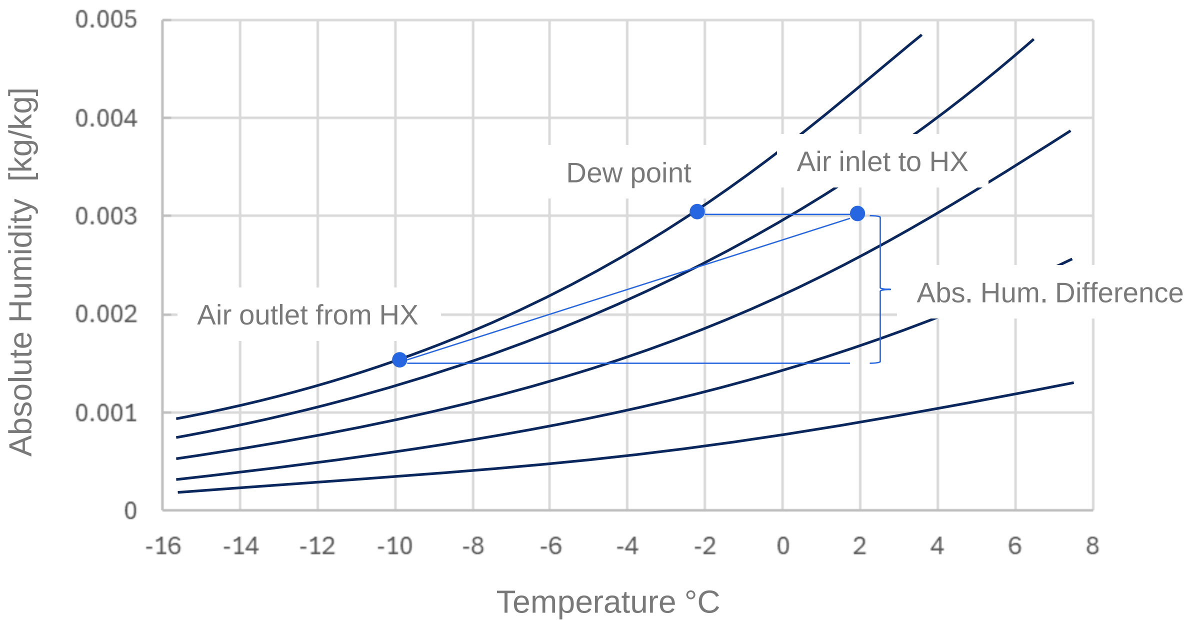




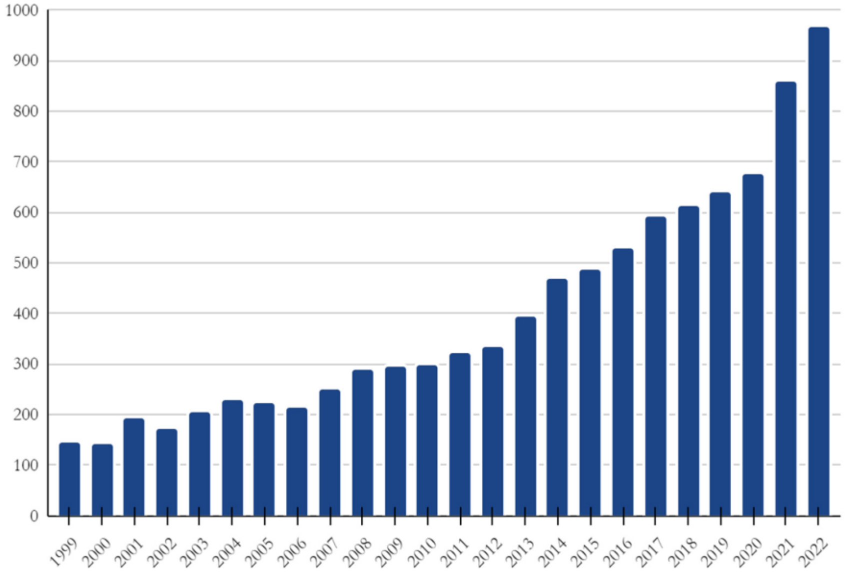
TECHNICAL BASICS

Why does frost form?

→ *Frost forms on evaporators due to condensation and subsequent freezing of moisture present in the air circulating through the evaporator coil.*

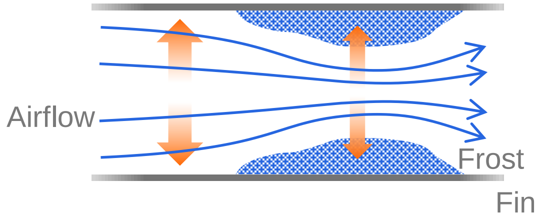


CHALLENGES OF FROSTY CONDITIONS

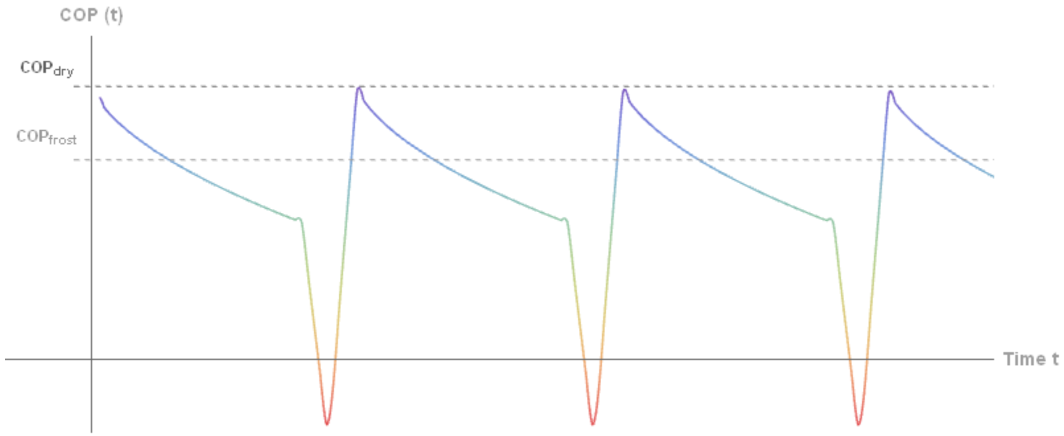


Increase in the number of articles dedicated to the topic of frost formation on the surface of heat exchanger during the time from 1999 to 2022 [1].

- Frost formation reduces **heat transfer** and **airflow** in evaporators (air coolers)



- Energy consumption increases significantly as frost builds up. (decrease system efficiency by up to 30%)



→ **addressing frost is key to maintaining performance**

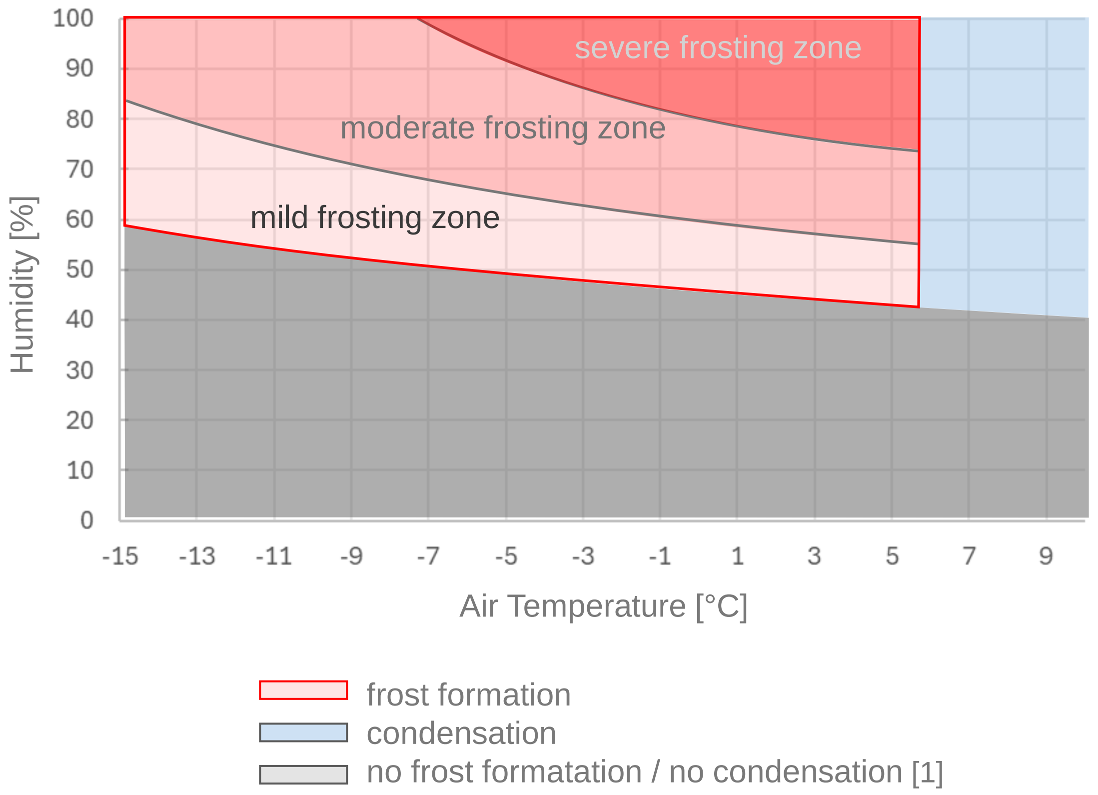
[1] Krasota, D.; Błasiak, P.; Kolasi ´nski, P. Literature Review of Frost Formation Phenomena on Domestic Refrigerators Evaporators. Energies 2023, 16, 2945

COMPLEXITY OF FROST FORMATION

Influencing Factors:

- humidity
- air temperature
- airflow
- surface temperature
- surface geometry

→ all impact the rate of frost formation and physical properties (thermal conductivity and frost density)

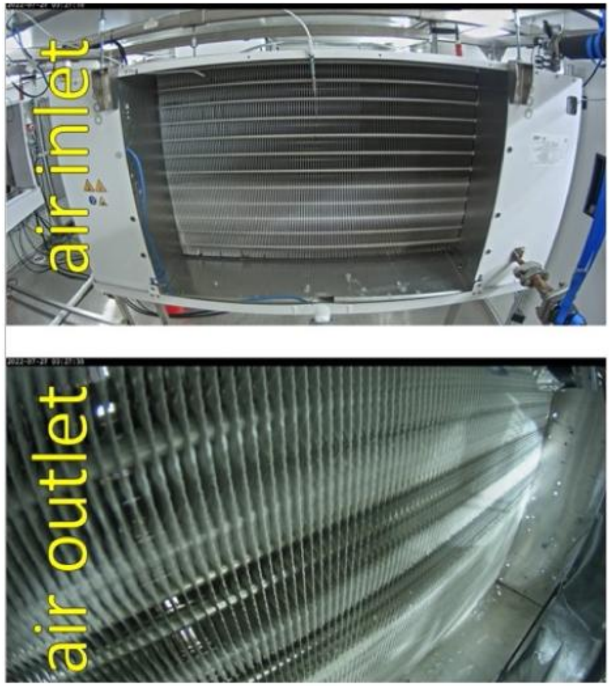


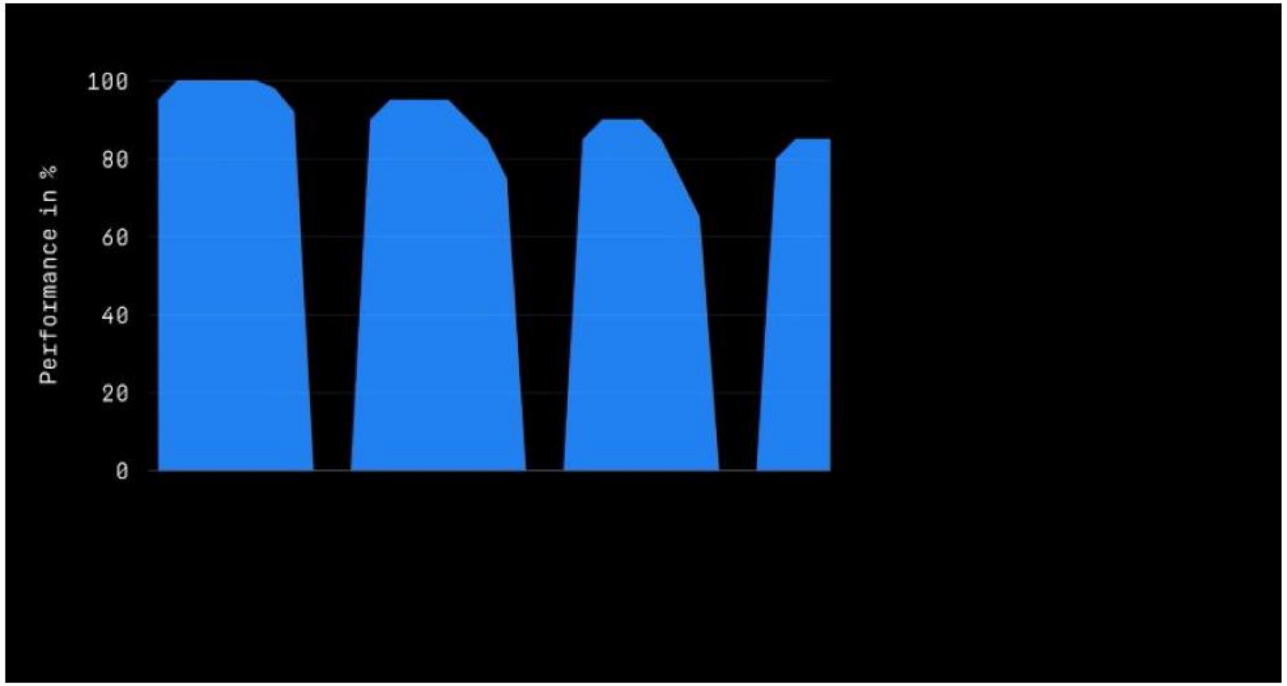
[1] H. Zhao, Z. Liu, Y. Sang, J. Chang, X. Zheng, J. Jurasz, W. Zheng,"A visual defrosting control method for air source heat pump system based on machine vision", Energy 302, p. 131778, 2024.

WHAT HAPPENS WHEN FROST IS IGNORED?

Consequences of Uncontrolled Frost Formation:

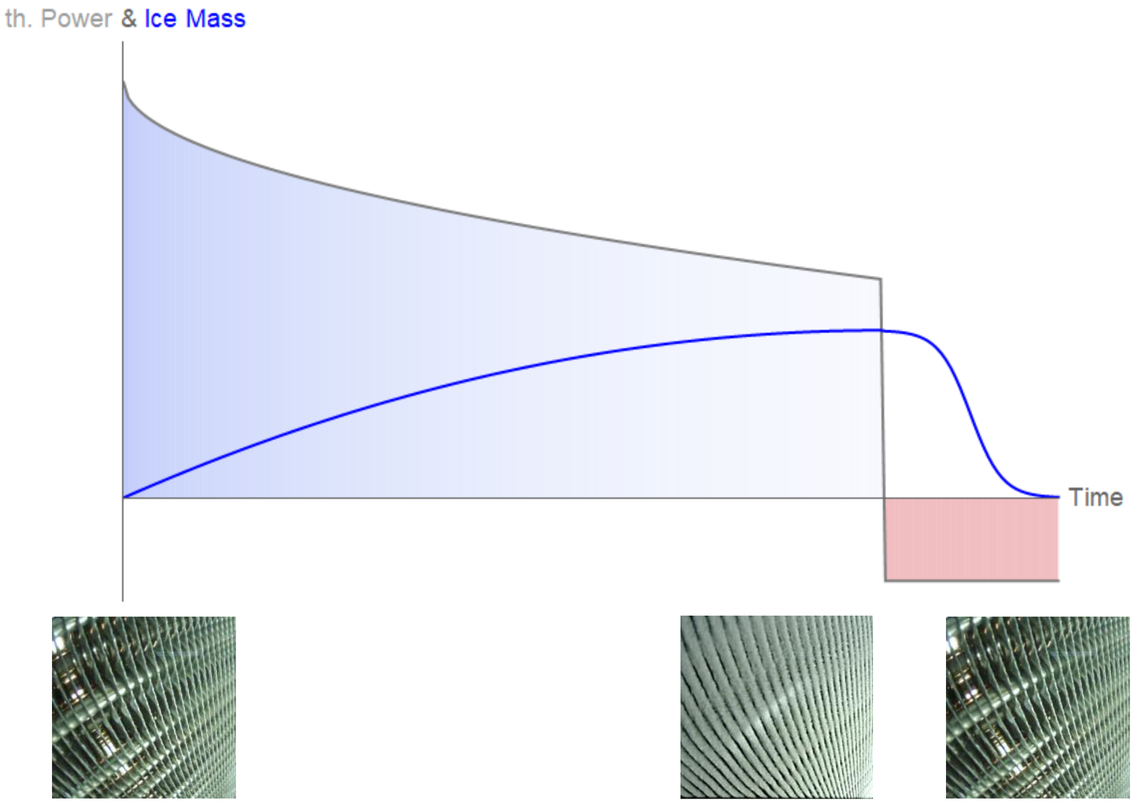
- **Reduced cooling capacity:** Ice buildup restricts airflow and increases thermal resistance
- **Higher energy consumption:** The refrigeration system consumes more energy to compensate for reduced efficiency
- **Poor defrosting strategies:** either too late (leading to ice clusters and airflow blockages) or too early (wasting energy and causing frequent downtime)

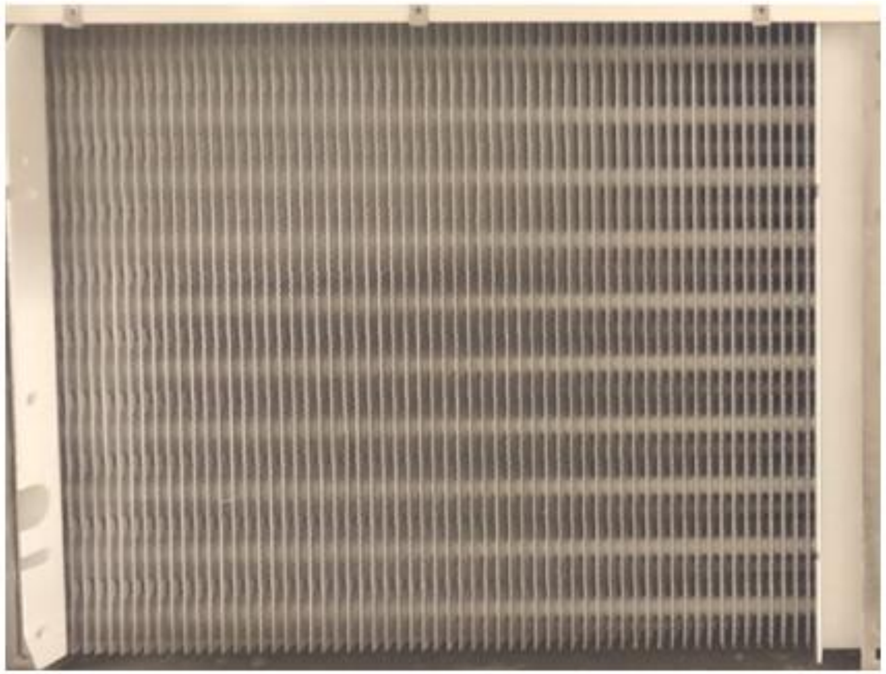




THE FROSTING-DEFROSTING CYCLE – A SIMPLE ILLUSTRATION

- Every evaporator goes through a **cooling phase (frost formation) and a defrosting phase (recovery)**
- The more frost accumulates, the lower the cooling capacity
- Defrosting restores performance, but at the cost of **downtime and energy input**





HOW WE QUANTIFY AND OPTIMIZE FROST-OPERATION

RGB & IR

Chamber size: ~100 m³

Refrigerants: R449A | R744

Therm. capacity: up to 25 kW

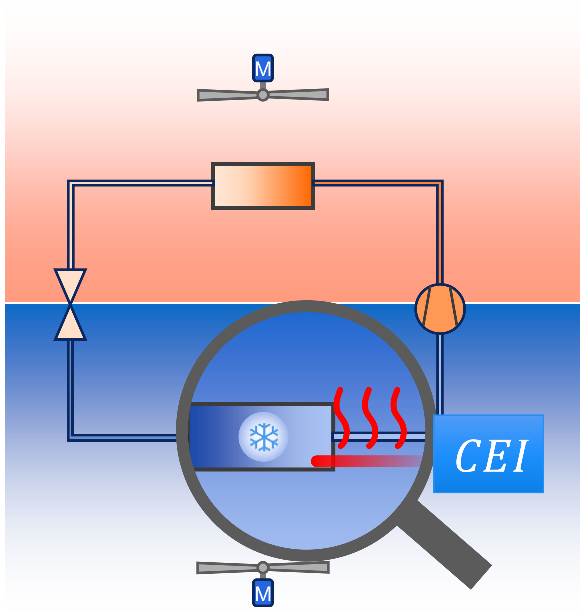
QUANTIFYING FROST IMPACT ON PERFORMANCE (CEI)

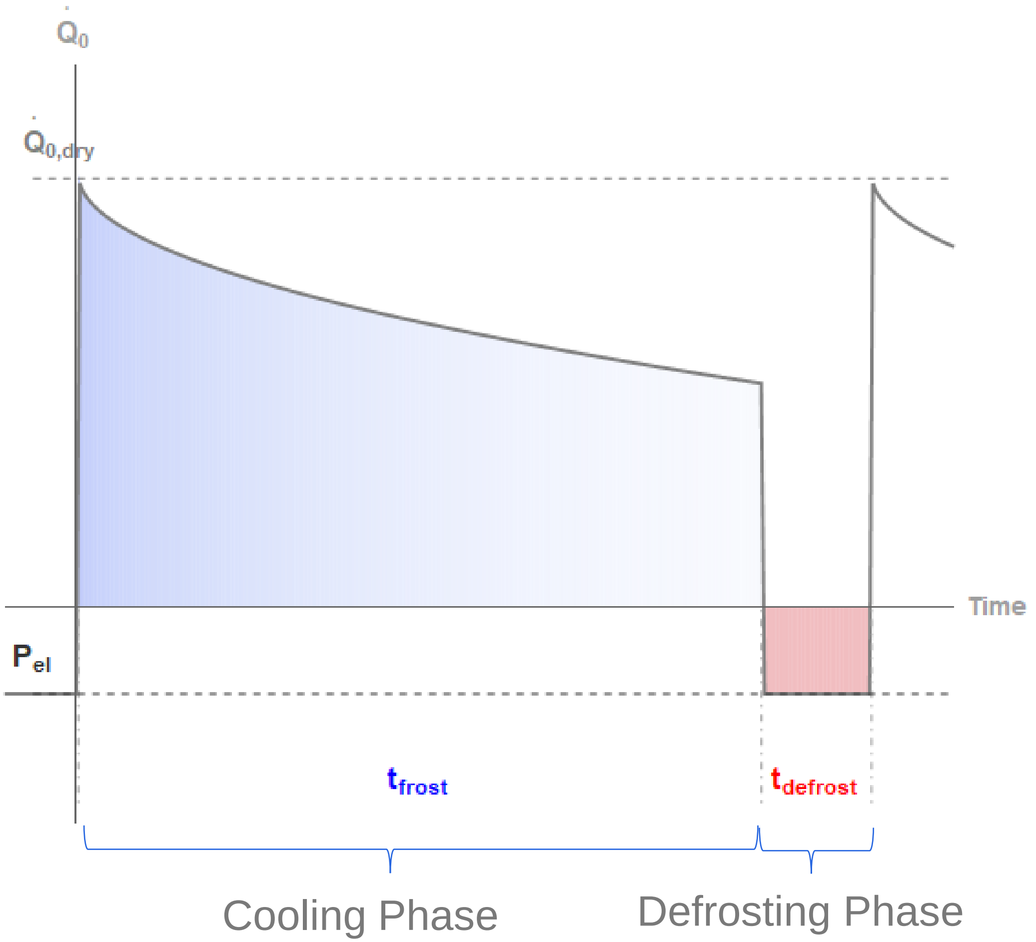
Refrigeration **Cycle Efficiency Index (CEI)**

= Ratio of ***net useful cooling energy*** over an entire frost-defrost cycle to ***dry-condition cooling energy***

This metric enables:

- an objective comparison of different evaporator designs
- and defrost strategies/ methods





IMPROVING CEI: REFRIGERATION PHASE

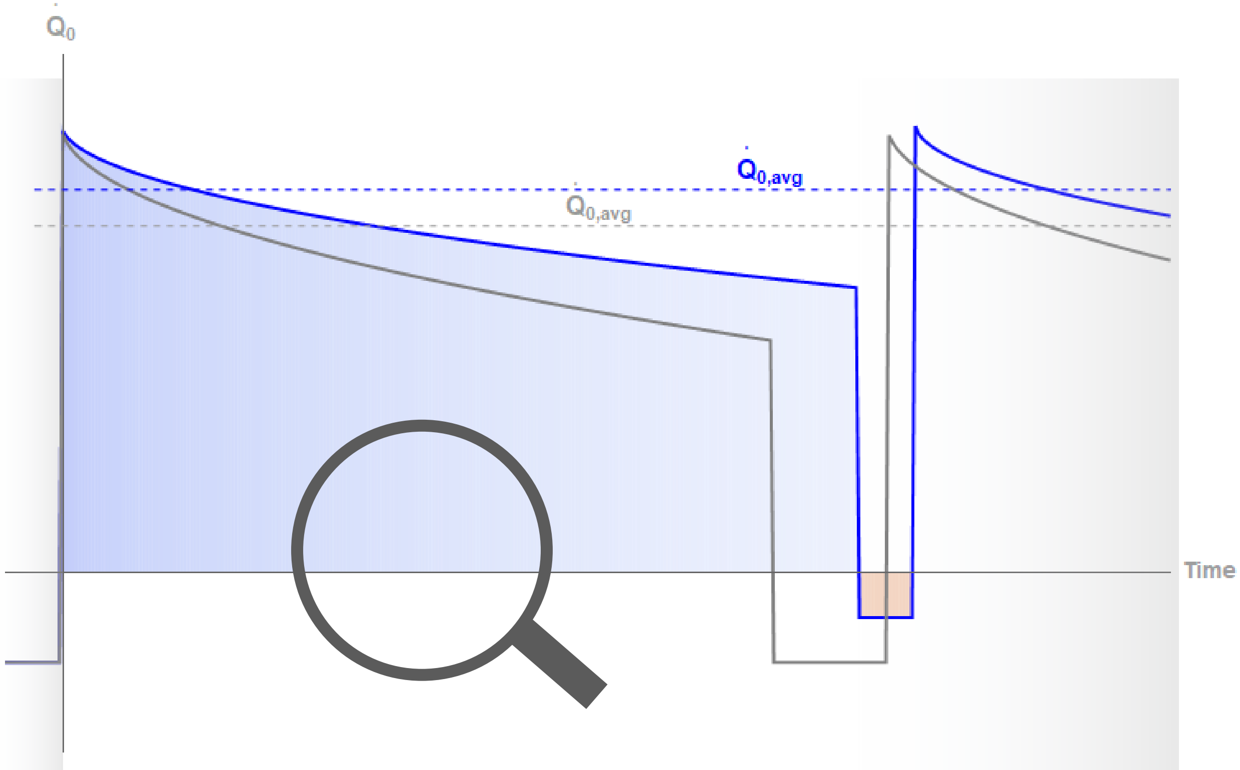
Passive Methods:

- Optimizing fin design (spacing, shape)
- Surface treatment (hydrophobic coatings)
- Altering heat exchanger structure

Active Methods:

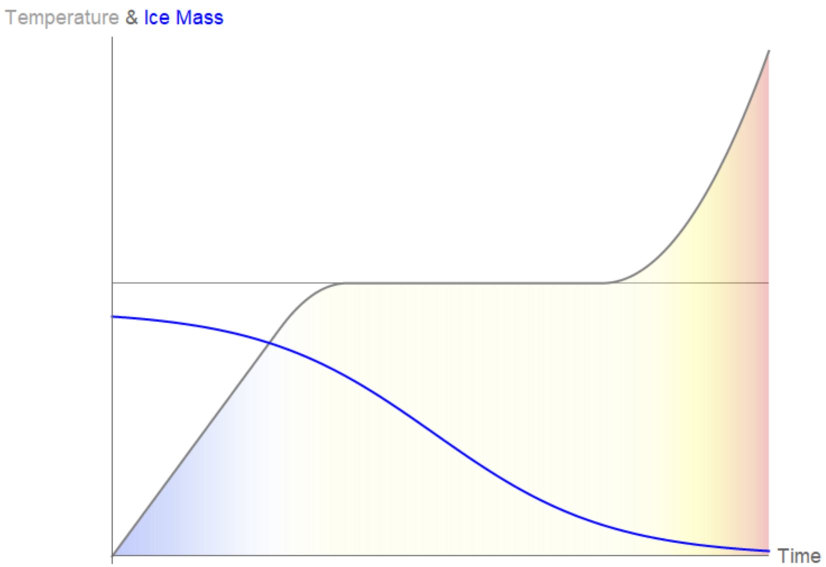
- Dehumidification using desiccants
- Electric and magnetic fields
- Ultrasonic vibration

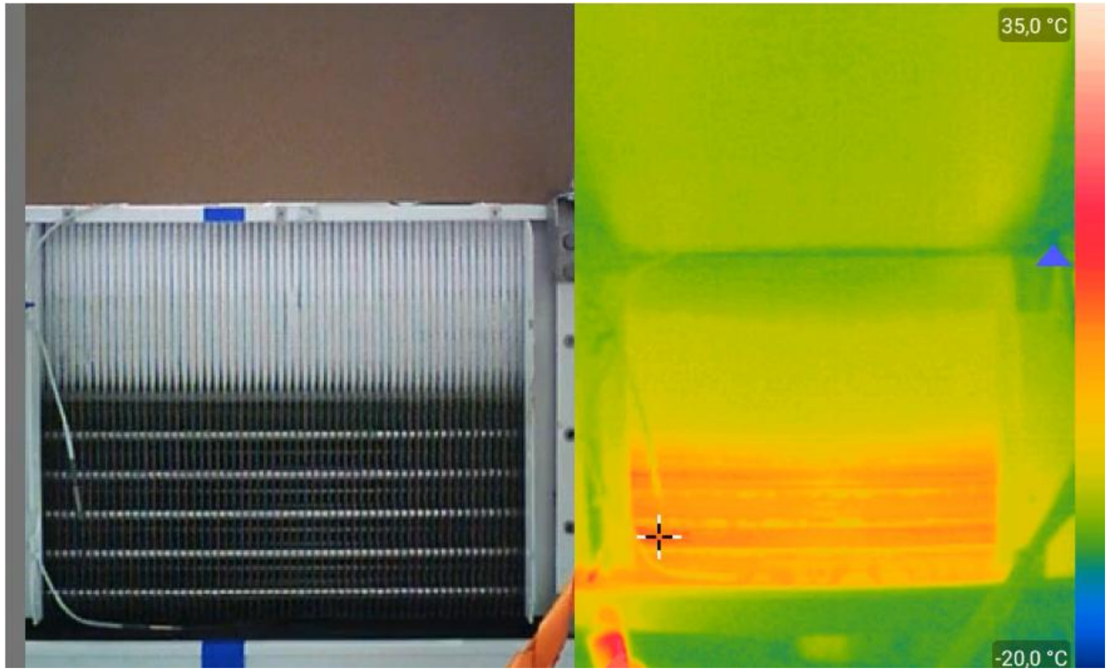
- Smart detection



WHAT IS DEFROSTING ABOUT?

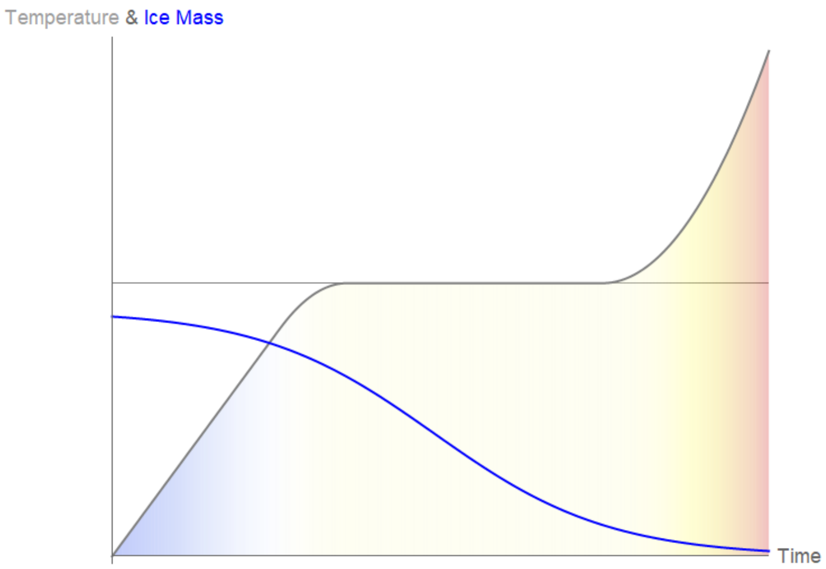
- **Heat Transfer:** Defrosting removes frost by applying heat, either through conduction, convection, or radiation, to raise the surface temperature and melt the ice.
- **Ideal Two Phases:** Initial heating phase raises the temperature of the frost layer, followed by the melting phase, where latent heat is used to convert ice to water.
- **Challenges:** Complete melting is necessary to avoid ice buildup, but inefficiencies such as re-freezing or excessive heating can reduce performance.

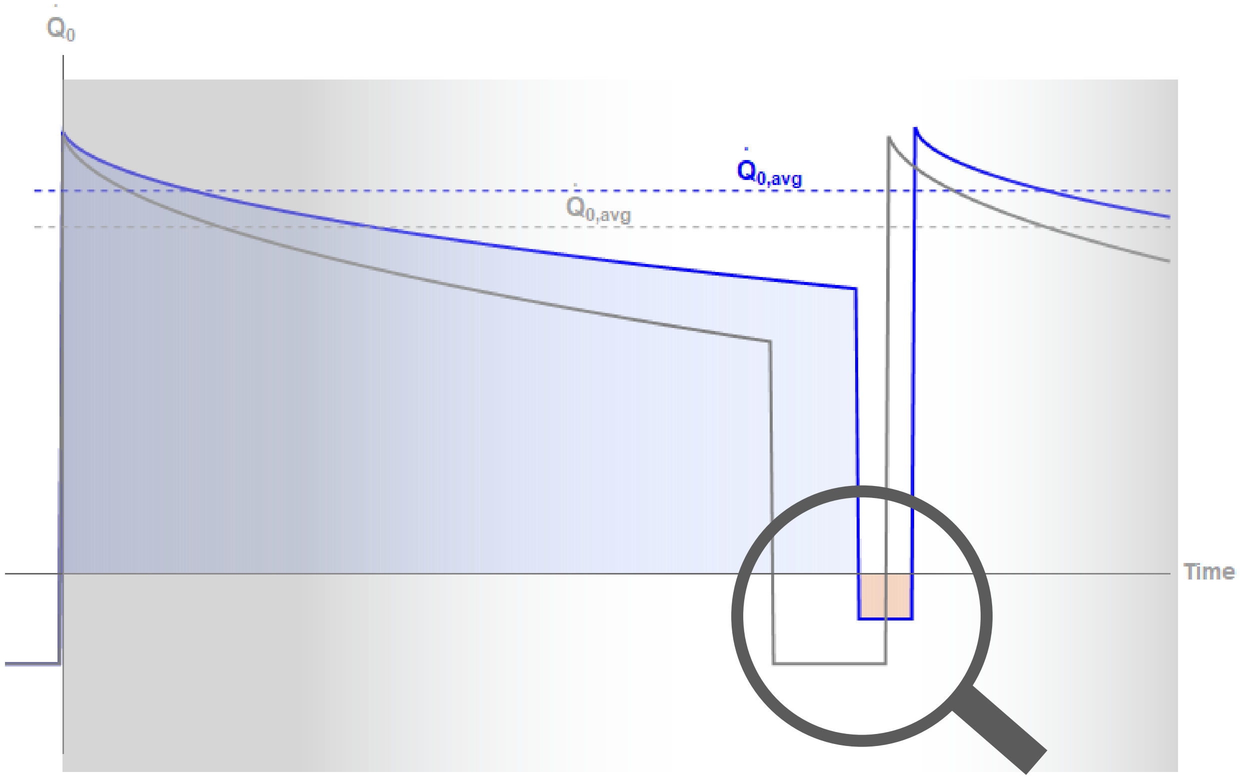




IMPORTANCE OF DEFROSTING

- Thermal capacity restoration
- Reducing the need to operate in extreme conditions
- Prevention of unwanted stoppage



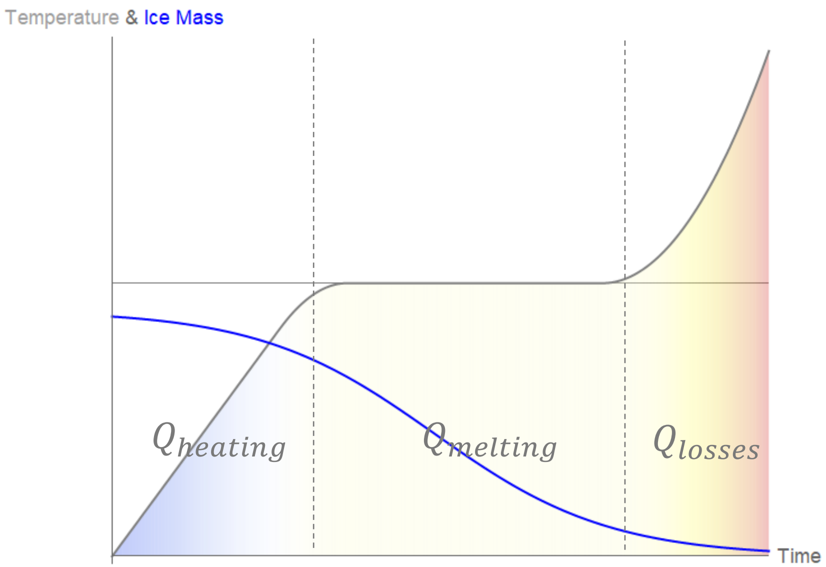


DEFROST EFFICIENCY INDEX (DEI) – MEASURING DEFROST PERFORMANCE

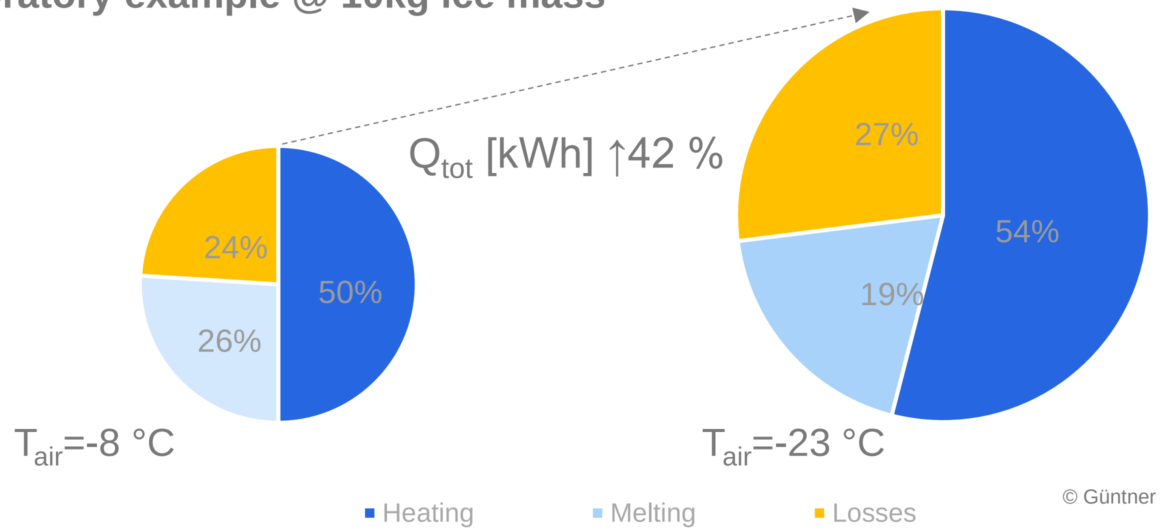
Three Phases of Defrosting:

$$DEI = \frac{Q_{melting}}{Q_{heating} + Q_{melting} + Q_{losses}}$$

in dependency of the energy parts:
$Q_{heating}$ [J] for heating the heat exchange with frost to melting temperature
$Q_{melting}$ [J] for melting frost
and Q_{losses} [J] for sensible and convective losses



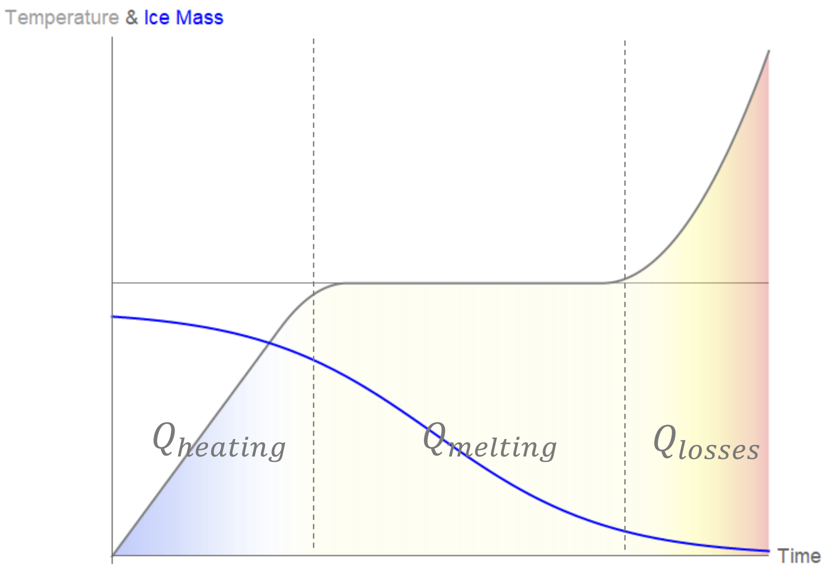
Laboratory example @ 10kg ice mass



DEFROST EFFICIENCY INDEX (DEI) – MEASURING DEFROST PERFORMANCE

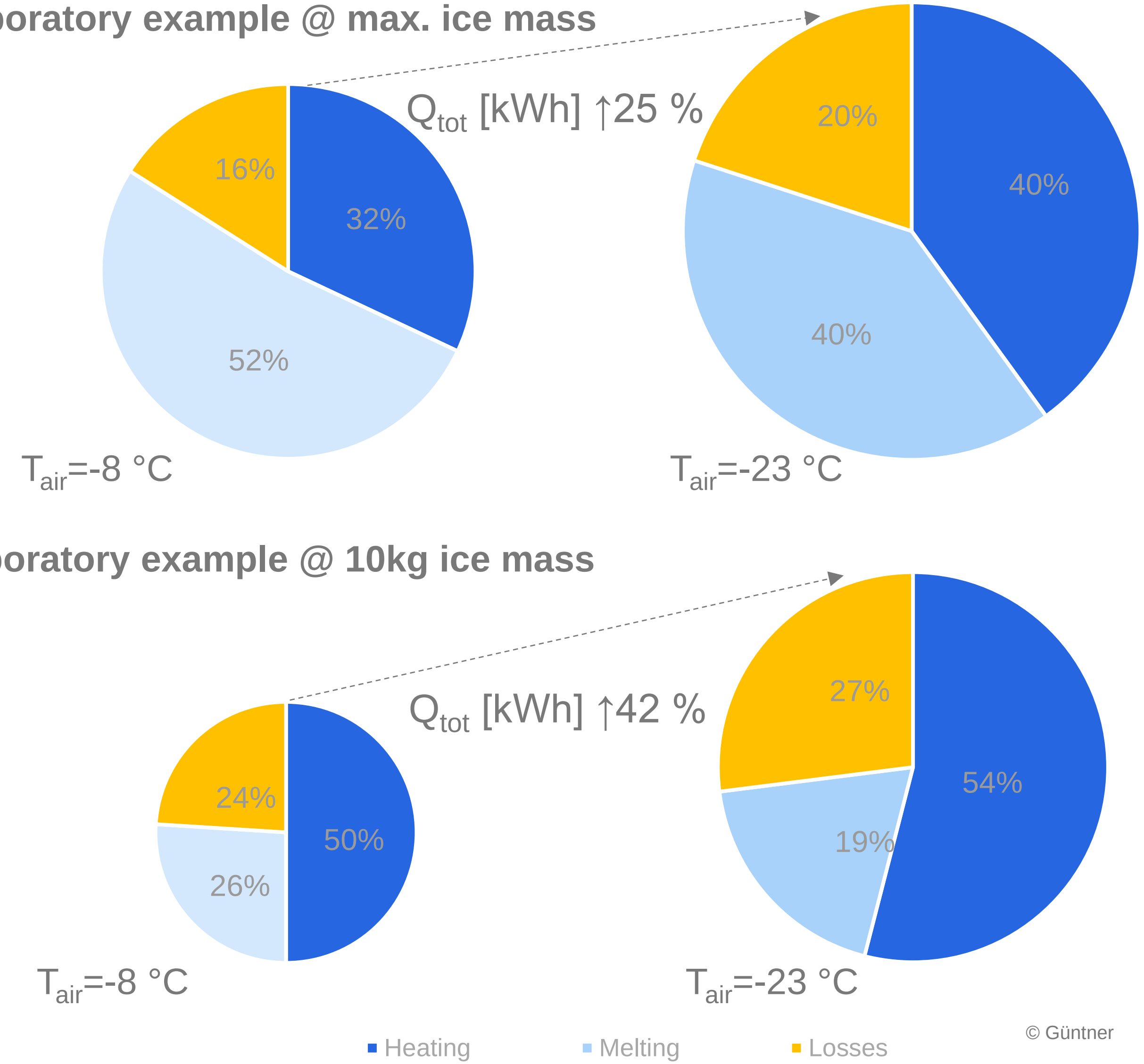
Three Phases of Defrosting:

$$DEI = \frac{Q_{melting}}{Q_{heating} + Q_{melting} + Q_{losses}}$$

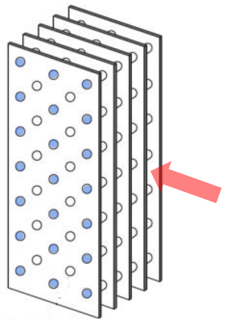


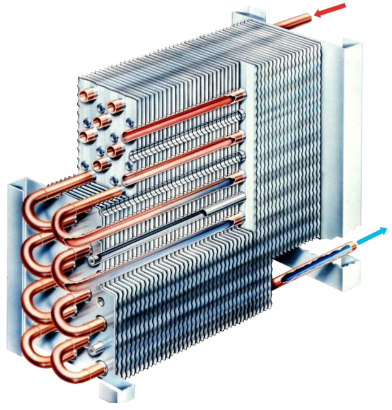
Laboratory example @ max. ice mass

Laboratory example @ 10kg ice mass

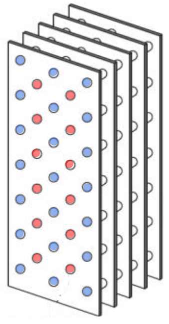


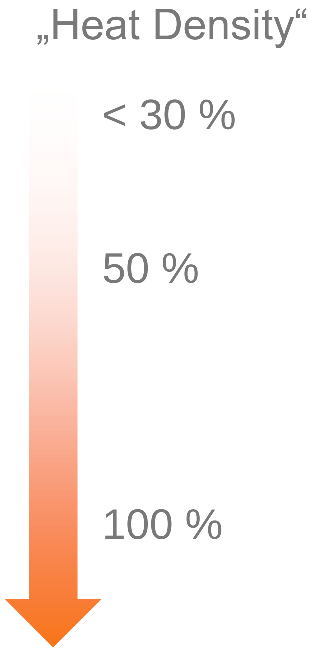
DEFROST METHODS





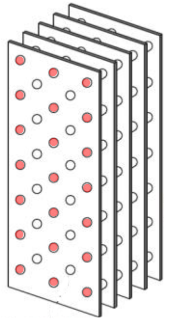
Air Defrosting: The simplest method, suitable for temperatures above 3°C, but requires long defrosting times and may cause significant droplet formation.





Electric Defrosting: Common in small refrigeration systems, with the advantage of easy installation and control but higher energy costs and heat losses.

Fluid-Based Defrosting: Utilizes warm liquid, offering fast and efficient defrosting with minimal energy loss, but suitable only for specific applications.



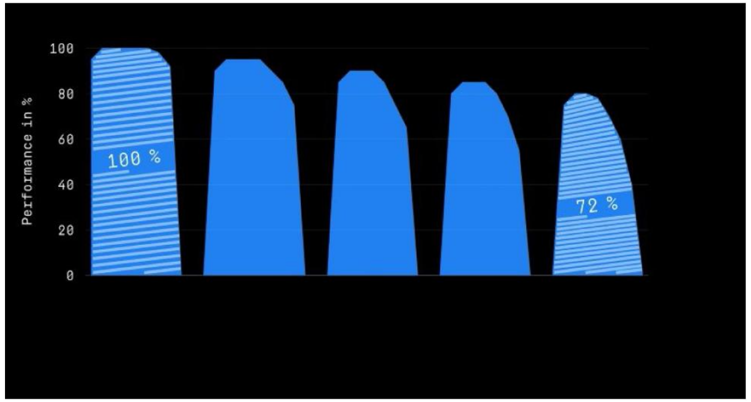
Hot Gas Defrosting: The most efficient method with high defrosting capacity and low energy consumption, ideal for large industrial systems but requiring more complex installation and control.

DEFROSTING AND EFFICIENCY

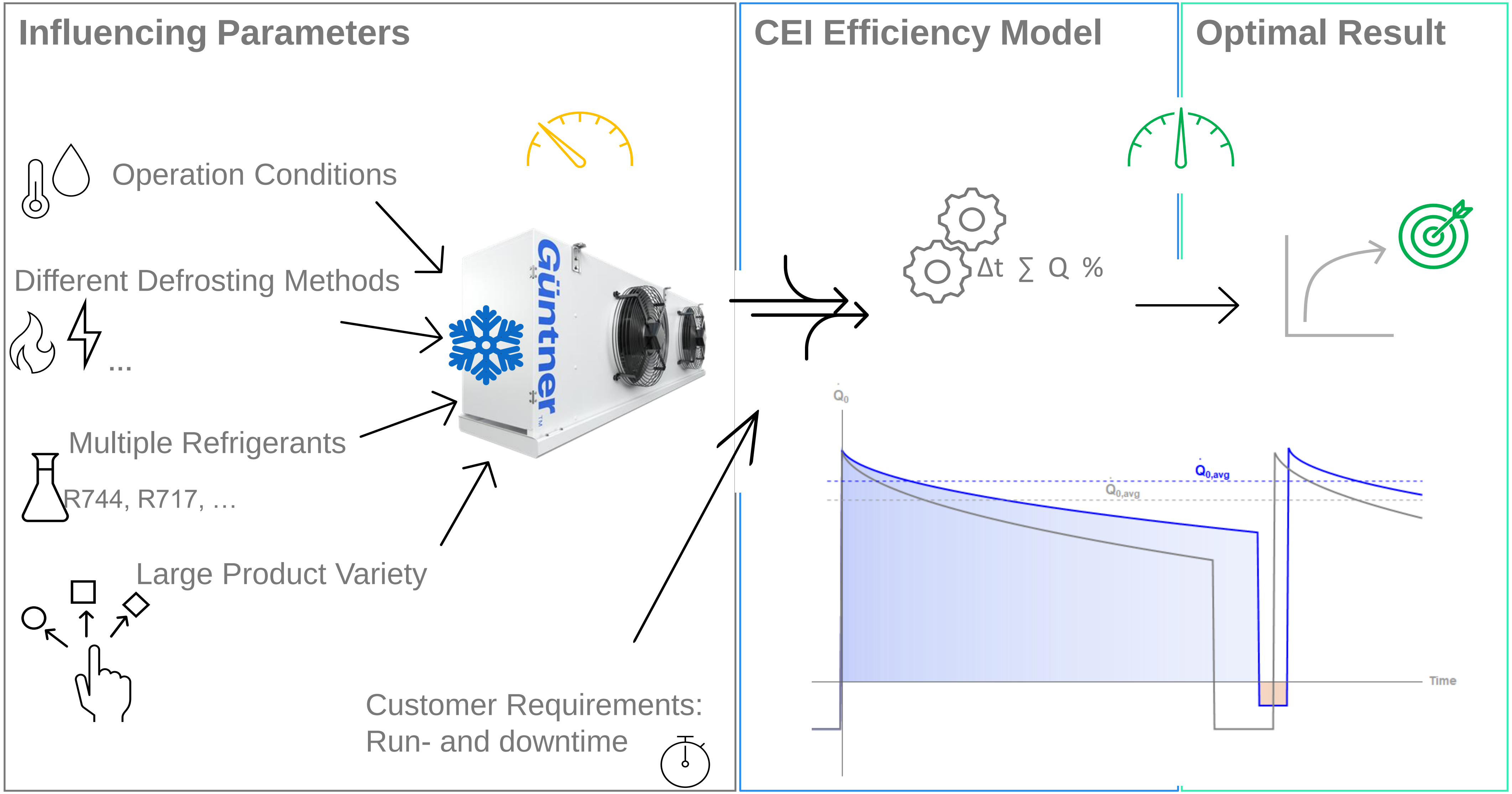
Three Common Defrosting Mistakes:

1. **Incorrect timing**
   → Too early = wasted energy
   → Too late = airflow blockage
2. **Inefficient defrost methods**
   → High energy losses (e.g. poorly designed electrical defrosting)
3. **Poor defrost strategy**
   → Ice cluster formation, negatively impacting long-term reliability (provoking unwanted stoppages)


End of defrosting



OPTIMIZATION IN THE DESIGN PHASE



SUMMARY AND CONCLUSION

- Main part of evaporators CO_2 footprint originates from utilization
- Frost formation significantly impacts efficiency – proper design is essential
- Evaluating evaporators efficiency requires analyzing the full operational cycle (not just the cooling phase)
- Defrosting plays a crucial role in the safe and efficient operation of evaporators
- Cycle Efficiency Index **CEI** and Defrost Efficiency Index **DEI** are key metrics for evaluating performance under frost conditions, which enable to find the optimal design & operation strategy

THANK YOU

Hochschule Karlsruhe
University of
Applied Sciences
HKA

eurammon
Refrigerants, naturally!