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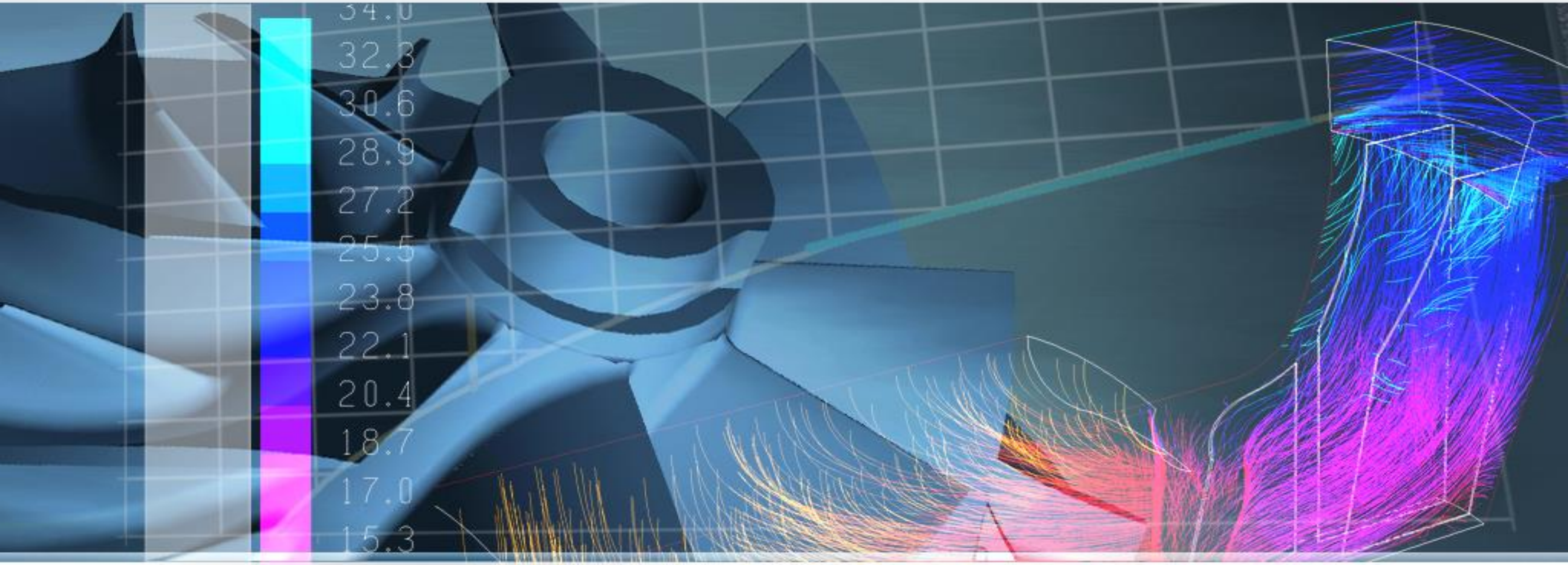


Institute of Air-handling and Refrigeration (ILK Dresden)

Power-to-Cold using vacuum ice slurry technology in the scope of German WindNODE project

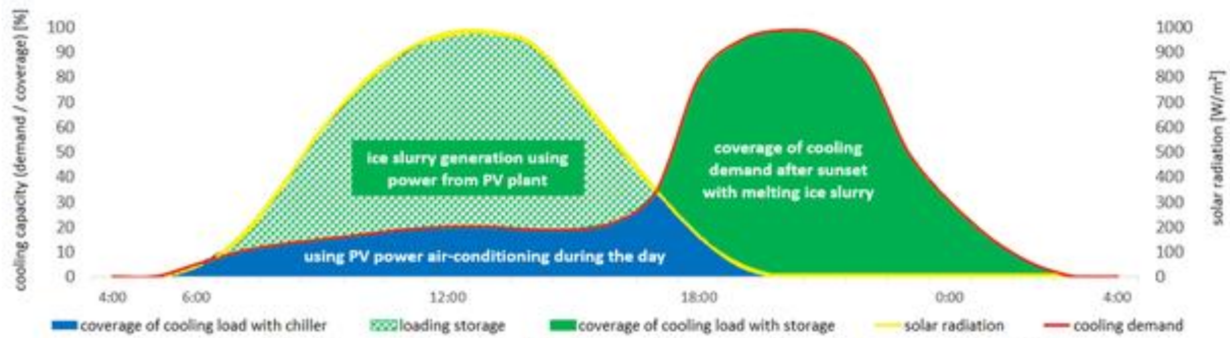
IEA SHC Task 53 Solar Cooling Workshop, 12.04.2018

Challenges in Air-Conditioning and Refrigeration

- **Phase down of HFC refrigerants**
  - → Kigali amendment of Montreal Protocol
- **Limited choice of alternative refrigerants**
- **Continuously growing energy/electricity consumption for cooling**
- **AC becoming fundamental for survival in even more regions because of climate change**
- **Urban heat island effects in cities and metropolitan areas**
- **Transition to renewable electricity generation**
  - → more volatile energy sources
  - → volatile prices (1 h, 15 min)
  - → Storage becomes crucial

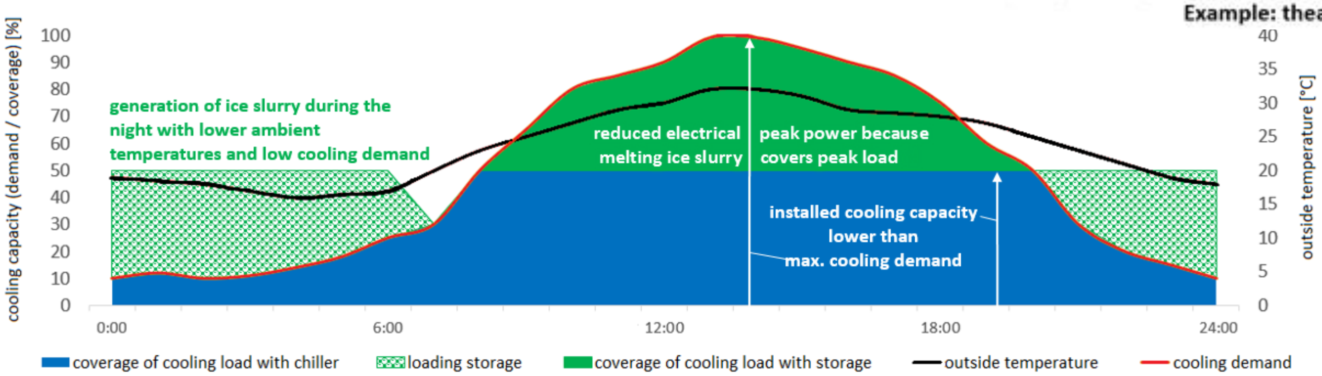
Why cold thermal energy storage?

- Cooling/Refrigeration mostly driven by electricity
- ~16 % of electricity consumption in Germany for cooling
- 40…60 % of electricity consumption in warmer climates
- Cold thermal stores useful energy
- Integration of renewables needs storage, “Power-to-Cold”



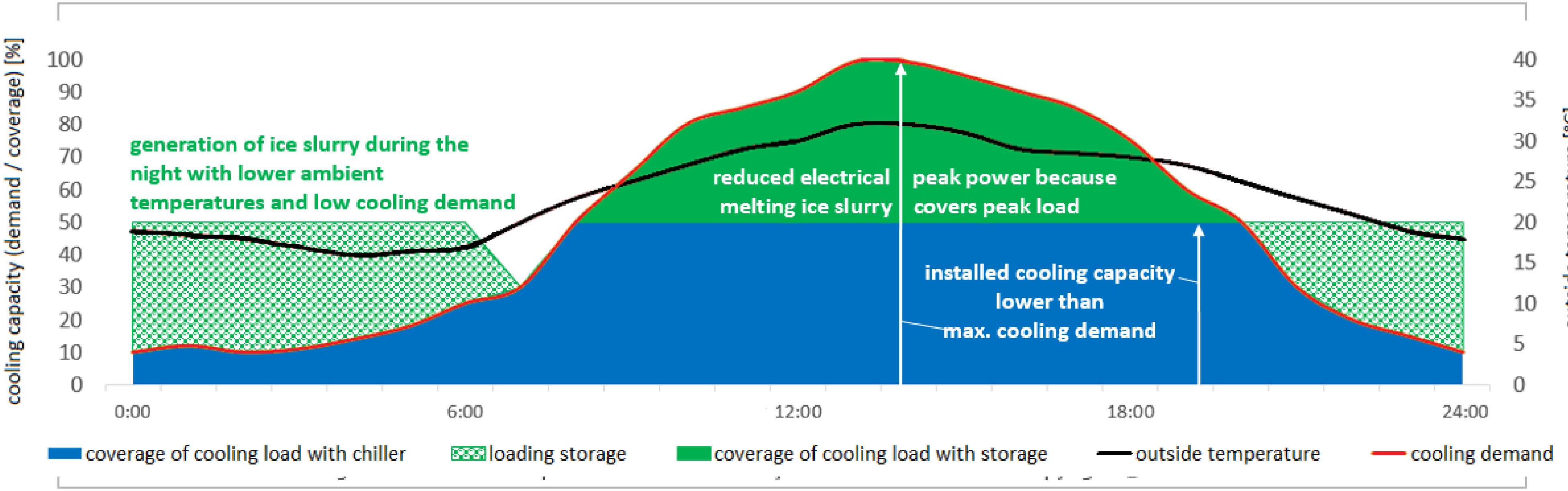
Decoupling of cold generation and cooling demand increasing the self-consumption of PV power

Example: theater with performance in the evening



Cold thermal energy storage … why?

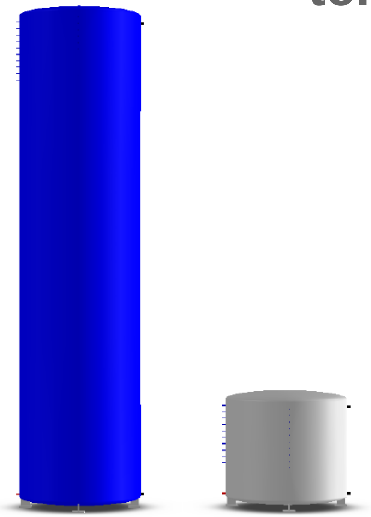
- **Thermal storage for decoupling of cooling demand & cooling generation**
- **Efficiency increase of cold generation at favorable re-cooling / condensation conditions** (day-night temperature difference)



Comparison of cold storage technologies

Sensible heat storage

- Uses temperature difference (6/12 °C → 25 kJ/kg ~ 7 kWh/m³)
- Very small difference usable
- Leads to very big tanks
- Stratification issues



© T.Urbaneck

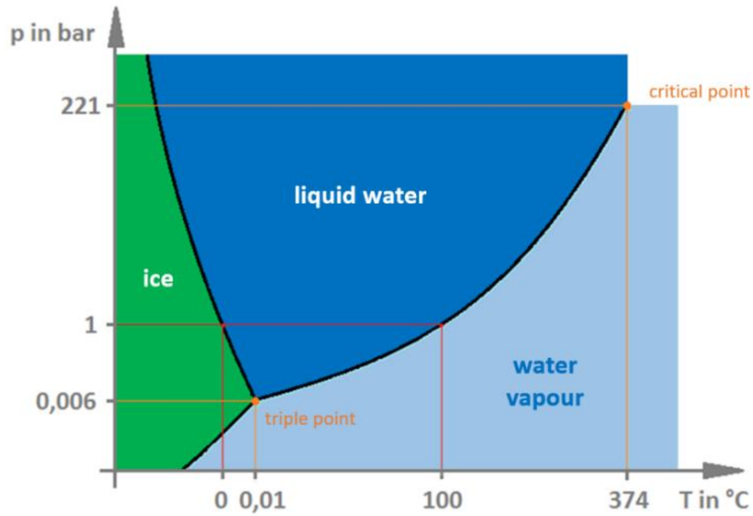
Latent heat storage

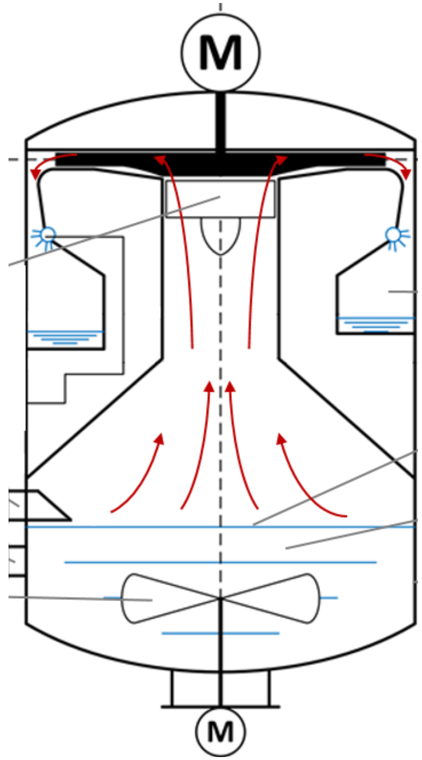
- Uses latent heat of fusion Water / Ice (333 kJ/kg ~ 93 kWh/m³)
- High storage density
- Melting point close to application temperature

© Calmac

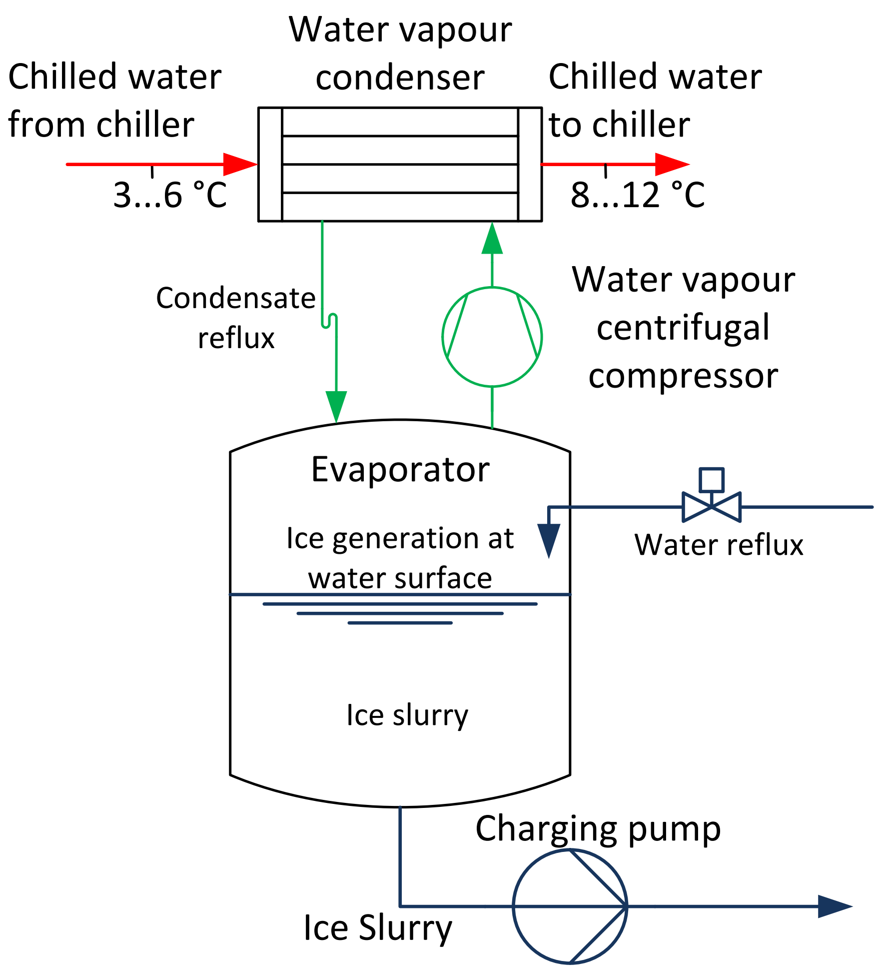
Ice slurry generation by direct evaporation
How does it work?

- Method to generate ice & to create a pumpable water/ice mixture by direct evaporation of the refrigerant water under vacuum conditions
- Evaporation near triple point of water (611 Pa, 0 °C)
- Evaporation at low temperature difference
- Storage as a single substance
  binary mixture of water / water ice





Ice generation by direct evaporation

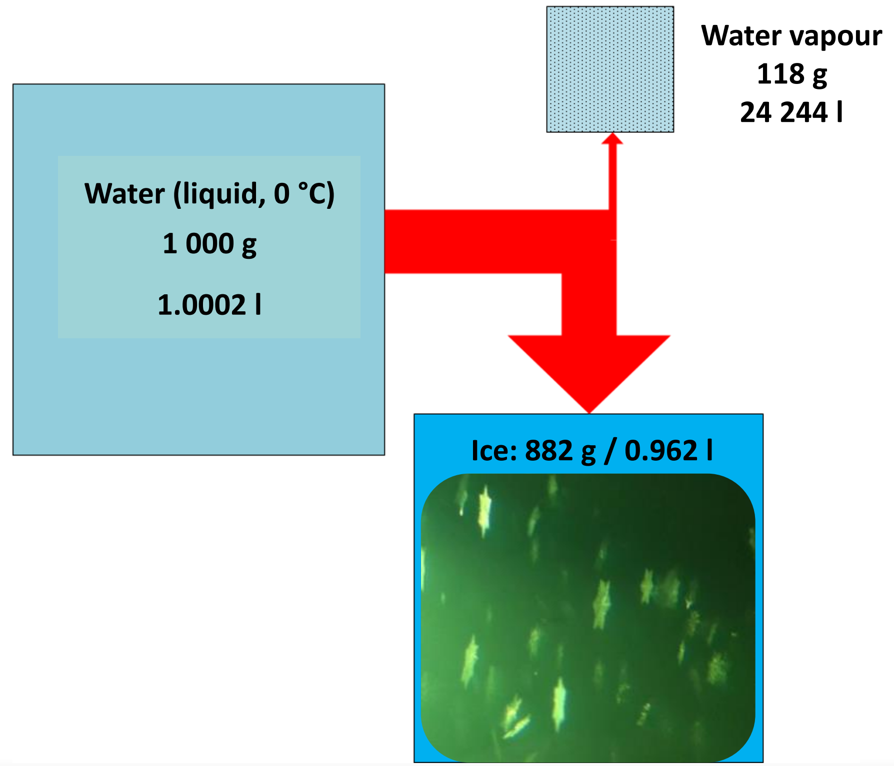


Heat of evaporation (6.1 mbar; 0.01 °C)

h_V = 2500 kJ/kg

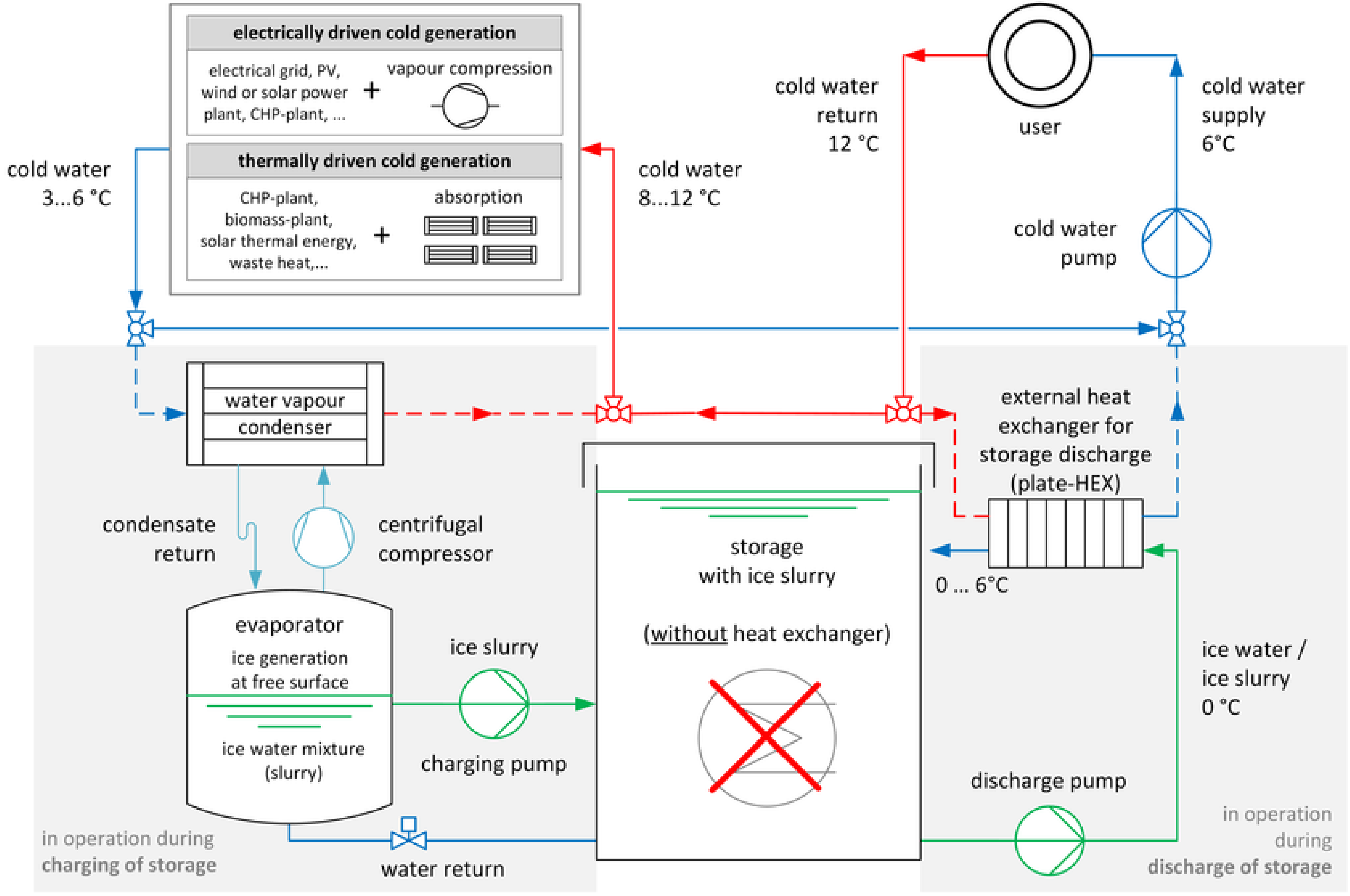
Heat of fusion

h_{fus} = 333.5 kJ/kg

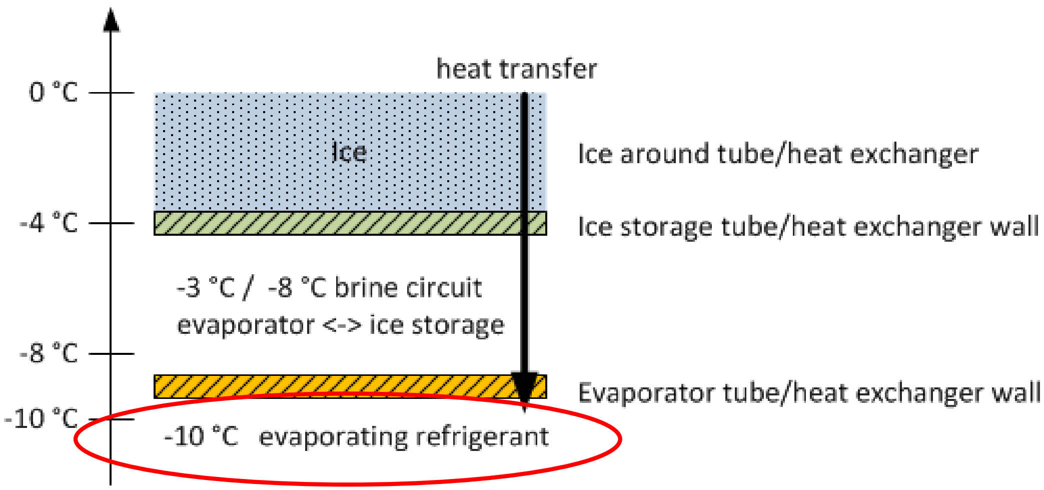


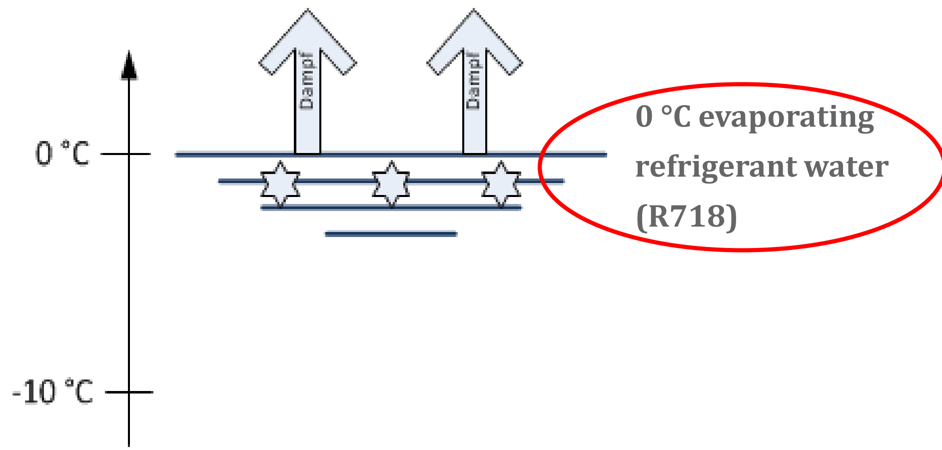
Pumpable Ice Slurry generated by vacuum freezing

Integration of vacuum ice cold thermal storage in chilled water system



Comparison of ice generation technologies





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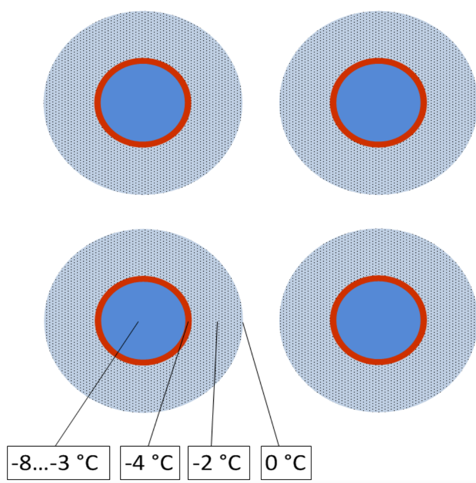
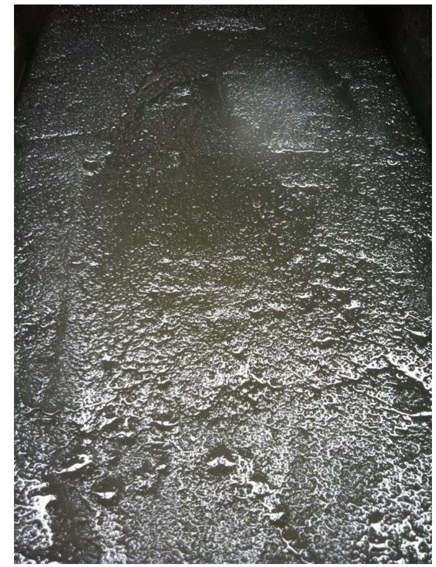




Installations – Vacuum ice slurry cold storage

Zwickau, Germany

- Charging capacity: 50 kW
- Storage capacity: 350 kWh
- Discharging capacity: 100 kW
- Load management at local chilled water network

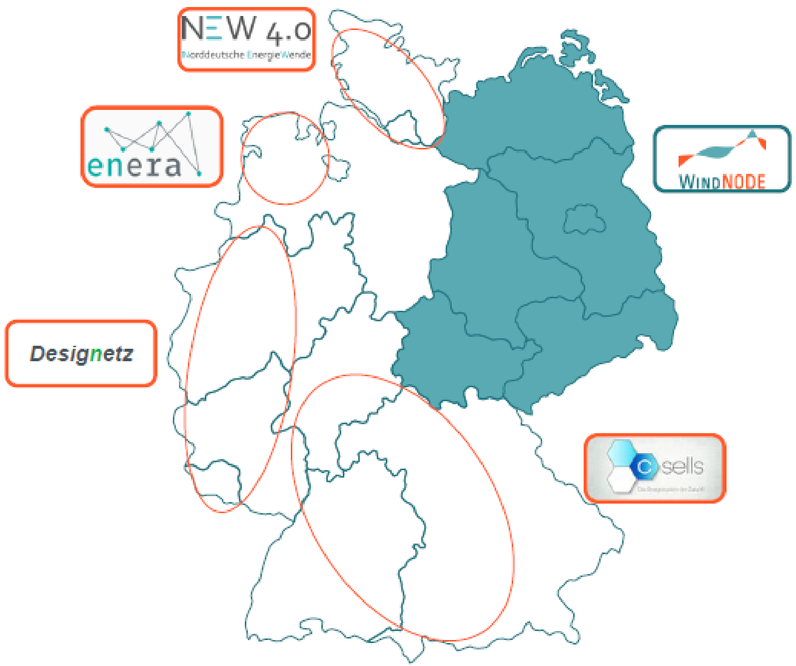
Göttingen, Germany

- Charging capacity: 180 kW
  Storage capacity: 1 MWh
- Discharging capacity: 350 kW
- Load management at local chilled water network

Ice slurry storage within SINTEG showcase WindNODE

BMWi Funding program "Smart Energy Showcases - Digital Agenda for the Energy Transition" (SINTEG)

- **Showcases demonstrating the future of energy provision & management**
- **5 showcases (model regions) in Germany**



Quelle: BMWi, WindNODE, Websites der anderen Konsortien

SINTEG
SCHAUFENSTER INTELLIGENTE ENERGIE

Federal Ministry for Economic Affairs and Energy

Vacuum ice slurry project within SINTEG/WindNODE

- **Demonstrating vacuum ice slurry technology for Power-to-Cold applications**

Main goals

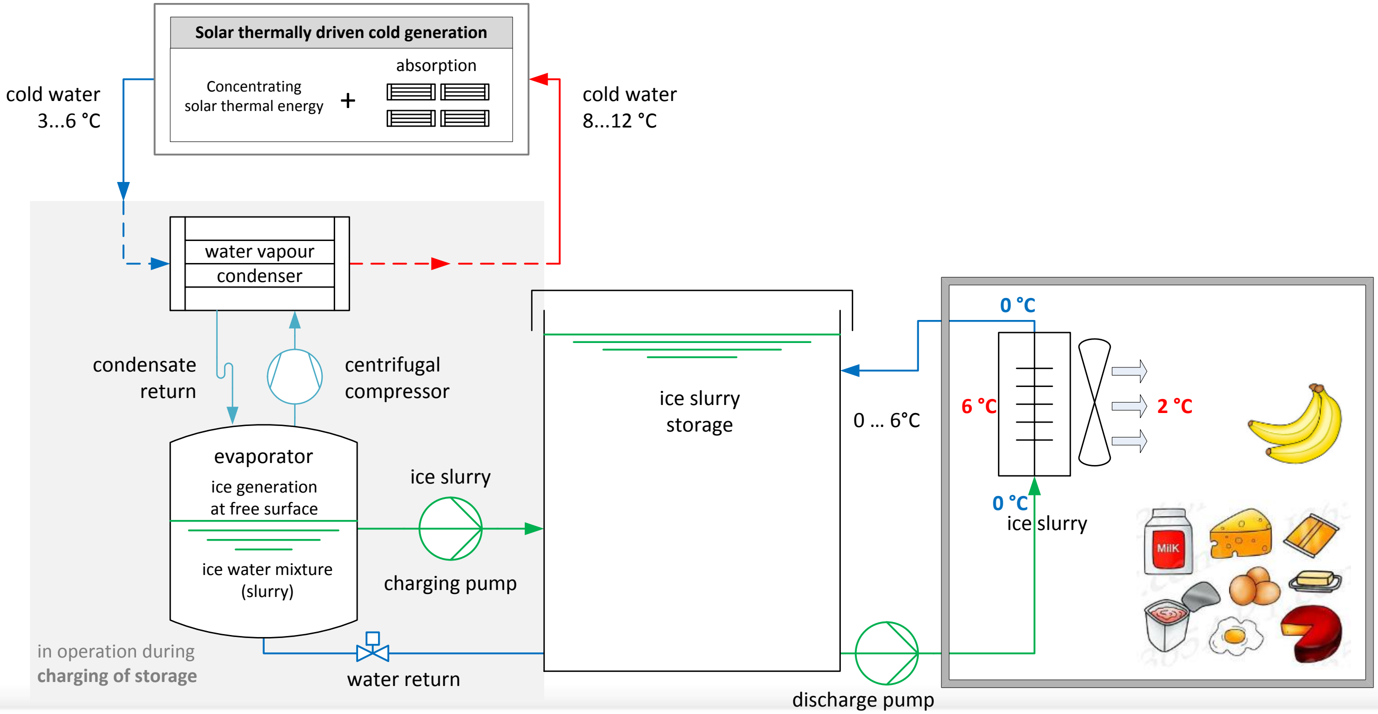
1. **High capacity demonstrator: 500 kW_0 (@ 0 °C)**
2. **Lower ice temperature (-5 °C) for easier integration into industrial cooling systems e.g. food processing and refrigerated storage**
3. **Integration in ICT platform**
   a. coordinating flexibility options
   b. securing grid stability with high shares of volatile renewables

Applications of vacuum ice slurry technology

- **Energy storage in direct / indirect combination with volatile renewables**
- **Cooling of industrial processes / food processing / batch processes**
  (breweries, diaries, bakeries, cheese maturing, dehumidification of air)
- **Enhanced district cooling systems**
  – **decentralised** storage for higher peak capacity (without changing tubes or installing additional chillers)
  – **centralised** storage → use of off-peak electricity
  – **ice slurry for cold transportation** → reduced pipe size and pumping power
- **Cold storage for demand side management or for integration of higher shares of renewable electricity**
- **Open new applications for thermally driven chillers** (co- / trigeneration, concentrated solar)
- **Combined desalination and cold generation**
- **High efficiency snow generation at any ambient temperature (sport events and facilities)**

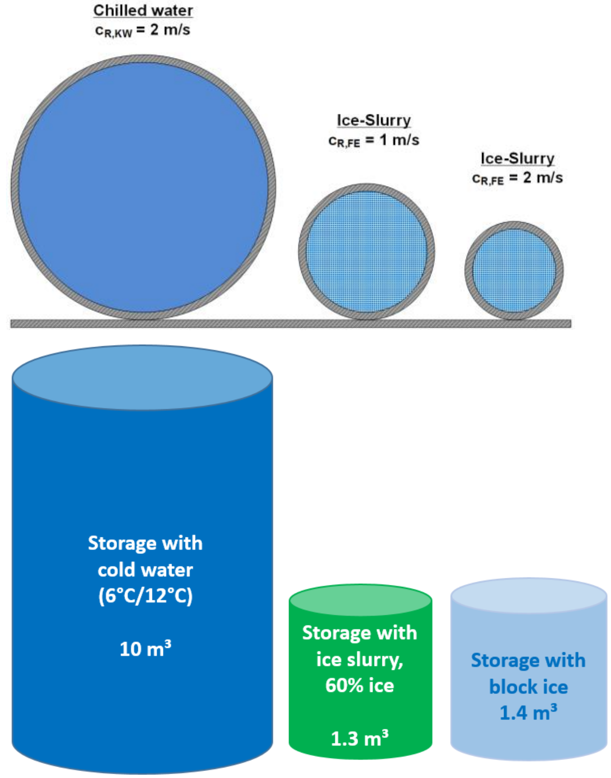
Solar thermal cooling for refrigerated warehouses

- Highly efficient cold generation with high temperature solar heat and double effect water/LiBr absorption chillers (chilled water @ 4…6 °C)
- Ice slurry generation with low electrical input (small temperature lift)
- Cooling of refrigerated warehouse using ice slurry as coolant (thermal energy carrier) with constant temperature (0 °C or down to -5 °C with using additives)



Summary

- 7 times higher energy density than chilled water storage
- ~30 % higher efficiency than block ice storage
- Flexible operation; 0…100 % discharging
- Cheap storage medium (PCM)
- Pumpable storage medium
- Sustainable, using water (R718) as refrigerant



Comparison of storage volume for the same capacity

Storage with cold water	Storage with ice slurry	Storage with block ice
pumpable medium	pumpable medium	rigid medium
low energy storage density	high energy storage density	high energy storage density

Ice slurry storages combine the advantages of cold water and ice block

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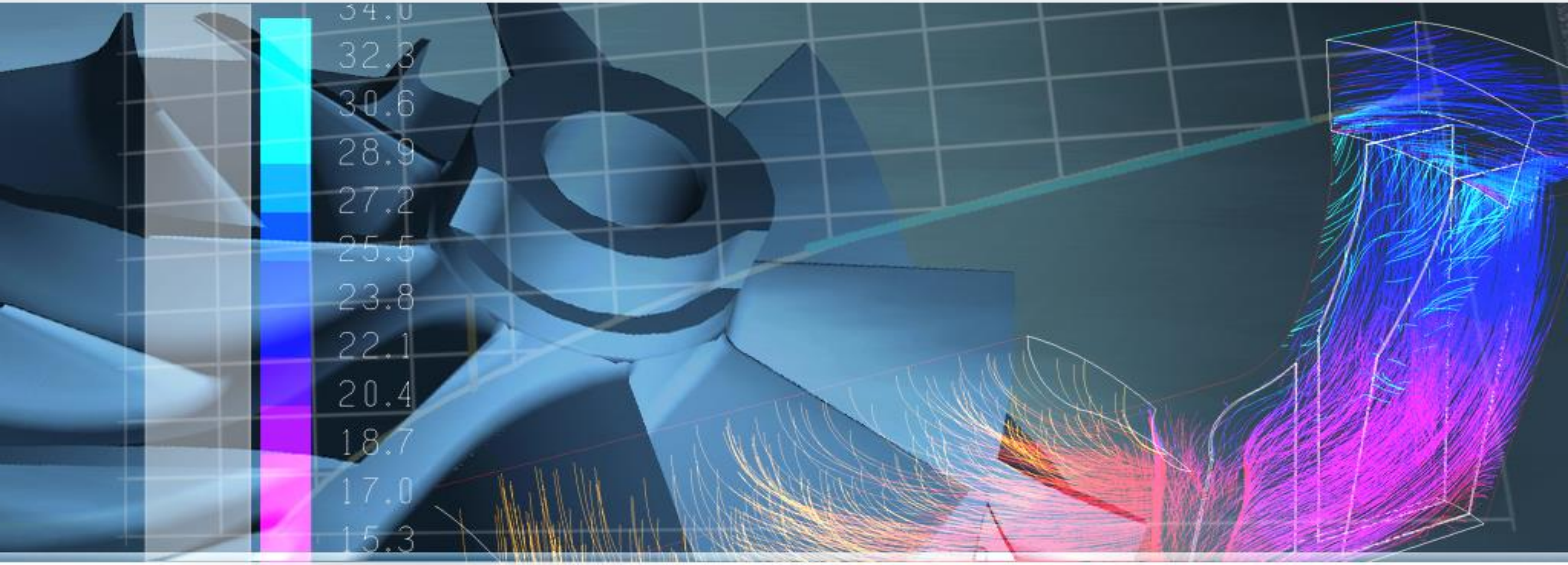

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