Heat Pump Related Activities of International Institute of Refrigeration (IIR)

Chicago, May 16th, 2023

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Importance of Heat Pumps

Promotion of Electric Heat Pumps

- The U.S. Department of Energy (DOE) announced a **$250 million funding** opportunity to accelerate **electric heat pump manufacturing** in America (April 18, 2023)

*"**Electric heat pumps** offer a cheaper, more reliable option for heating and cooling that isn't prone to dramatic price swings and helps to **strengthen the nation's energy independence**.,"* U.S. Secretary of Energy Jennifer M. Granholm.

Source: www.energy.gov/articles/biden-harris-administration-announces-250-million-accelerate-electric-heat-pump
Source: www.intgas.com/ko/energy-efficiency_program/residential-energy-efficiency/

Roadmap to Net Zero by 2050 (IEA)

- **50% of heating demand** will be covered by heat pumps in 2045

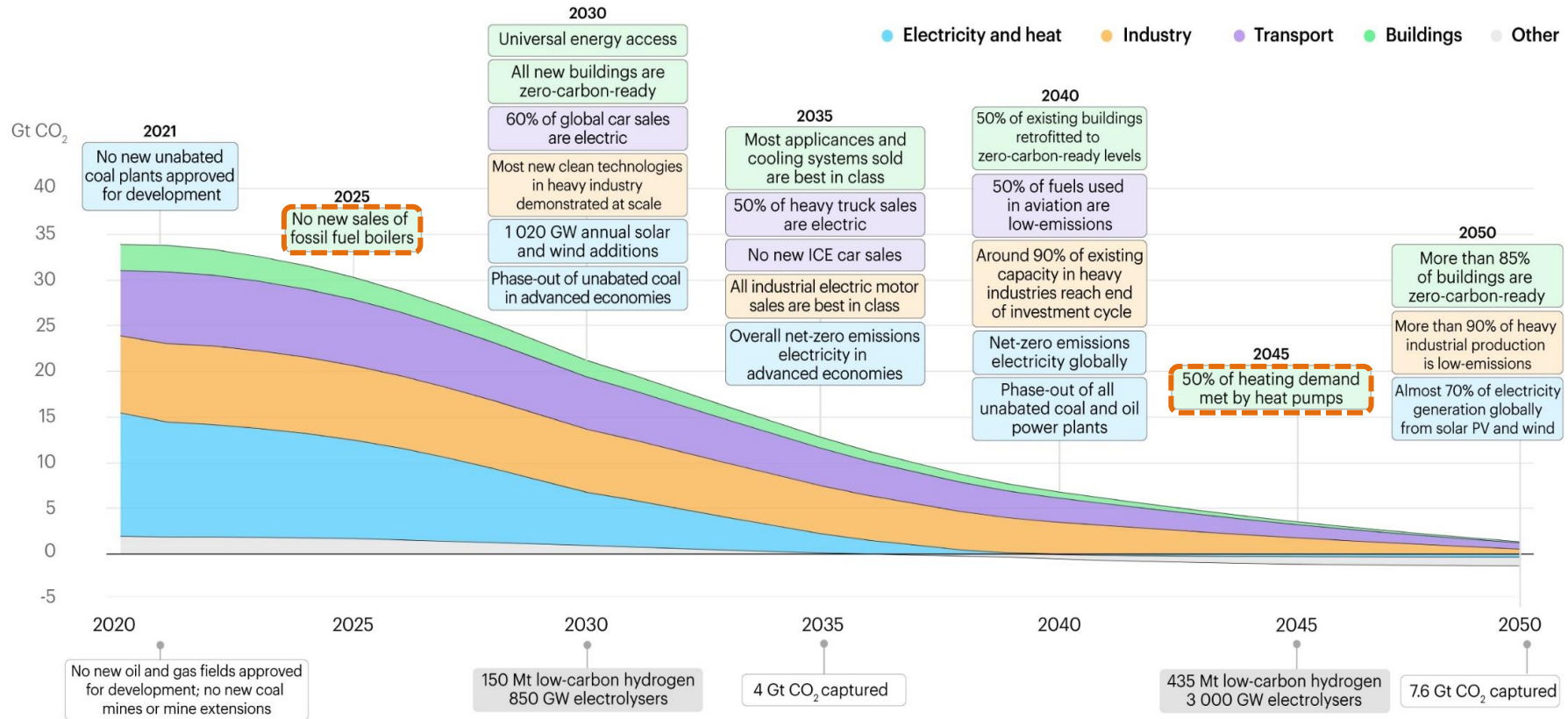


Fig. IEA Roadmap for 2050 Net zero

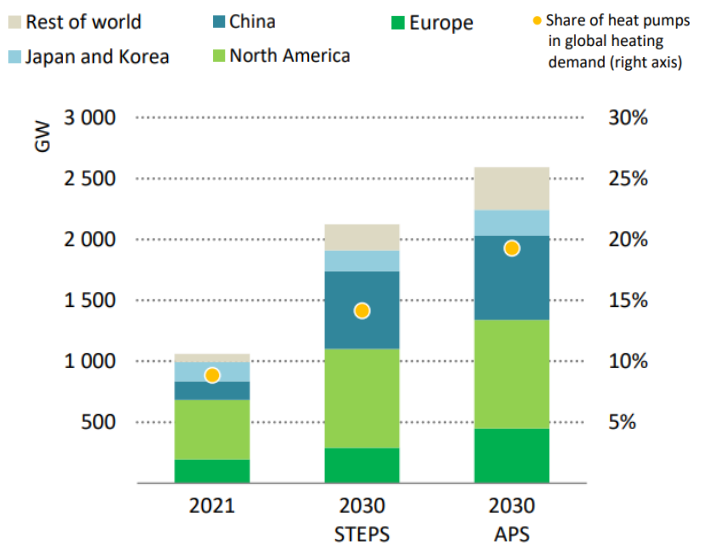
*IEA: International Energy Agency

Source: International Energy Agency's (IEA) Net Zero by 2050 report.

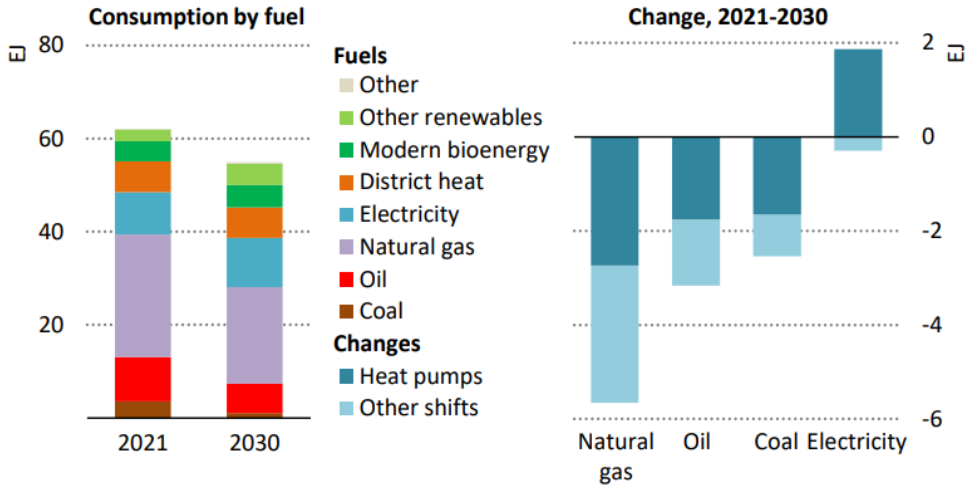
Heat Pump Energy Coverage

- The **heat pump coverage** is on the rise and expected to continue growing

Global heat pump capacity



Energy consumption by fuel and change (APS)



*APS: Announced pledges scenario *STEPS: Stated policies scenario

- **Global heat pump capacity** will increase, mainly replacing that of natural gas boilers
- Heat pumps contribute over half of the 29% decrease in demand for fossil fuels in space and water heating in the APS by 2030, **reducing natural gas demand** the most

Source: IEA (2022), *The Future of Heat Pumps*, IEA, Paris www.iea.org/reports/the-future-of-heat-pumps, License: CC BY 4.0

International Institute of Refrigeration and Heat Pump Related Activities

International Institute of Refrigeration

- **IIR** has engaged in **activities related with** (1) Refrigeration, (2) Air-conditioning, **(3) Heat pump** (4) Alternative Refrigerants, (5) Climate change, (6) Others

59
Member Countries

364
Experts

109 760
References in FRIDOC

- **International Institute of Refrigeration (IIR)**, an intergovernmental organization, gathers global scientific and technical knowledge in all refrigeration sectors, with 59 member countries
- IIR is committed to advancing refrigeration knowledge for sustainable development worldwide

Source: iifiir.org/, en.wikipedia.org/wiki/International_Institute_of_Refrigeration

Organization

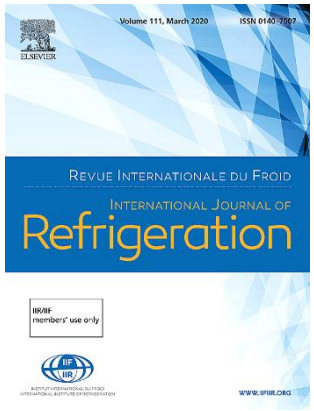
General Conference | Science and Technology Council | Management Committee | Executive Committee | Head Office

Section A Cryogenics and liquified gases	**A1** Cryophysics and cryoengineering **A2** Liquefaction and separation of gases
Section B Thermodynamics, equipment and systems	**B1** Thermodynamics and transfer processes **B2** Refrigerating equipment
Section C Biology and food technology	**C1** Cryobiology, cryomedicine and health products **C2** Food science and engineering
Section D Storage and transport	**D1** Refrigerated storage **D2** Refrigerated transport
Section E Air conditioning, heat pumps and energy recovery	**E1** Air conditioning **E2** Heat pumps and energy recovery

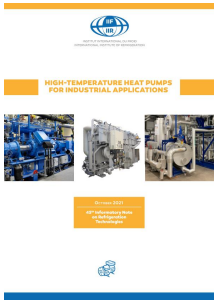
Heat Pump Related Activities by IIR

Publications

❖ International Journal



❖ Informatory Notes

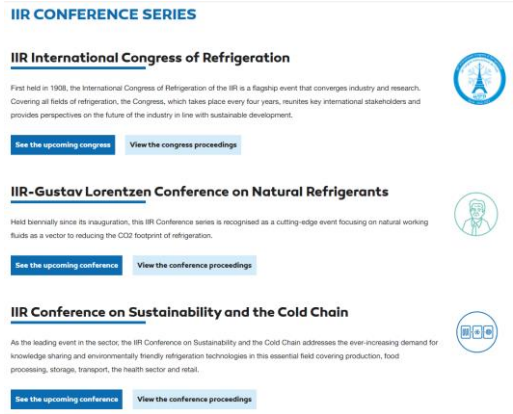


Air-source Heat pumps

High-temperature Heat pumps

Conferences

❖ International conferences



❖ Sponsored conferences

14th IEA HEAT PUMP CONFERENCE
RENAISSANCE CHICAGO DOWNTOWN HOTEL
MAY 15 – 18, 2023 | CHICAGO, IL

PURDUE UNIVERSITY

Projects

❖ Energy efficient cold chain

CoolFish

ENOUGH
EUROPEAN FOOD CHAIN SUPPLY TO REDUCE GHG EMISSIONS BY 2050

❖ Off-grid solution

SOPHIA

❖ Refrigeration/AC

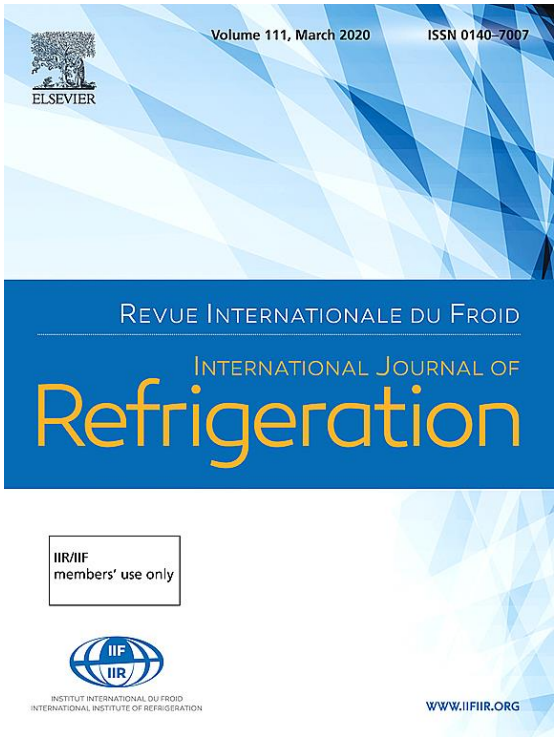
INDEE

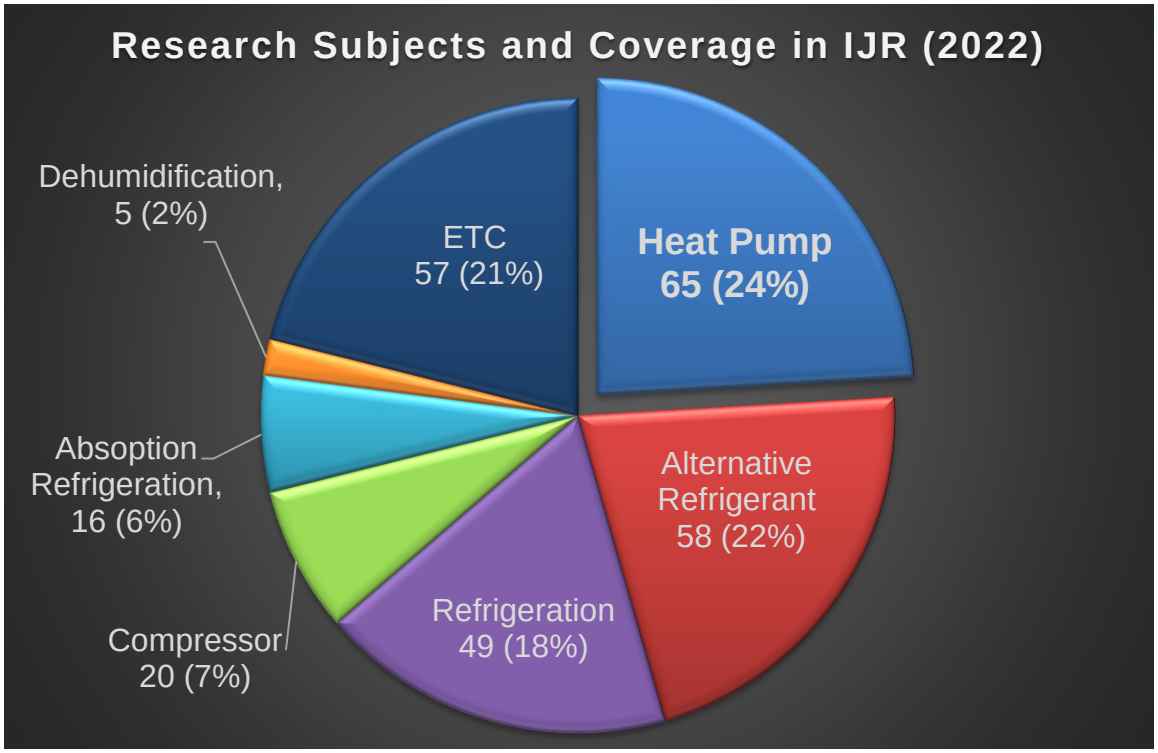
CLIM'ECO

Source: iifiir.org/

International Journal of Refrigeration (IJR)

- **The IIR publishes an international journal** that covers topics related to refrigeration, air conditioning, heat pumps, and other related areas





- International Journal of Refrigeration (IJR), published by Elsevier for IIR, provides updated information on research and development in refrigeration, air conditioning, heat pumps and associated fields **(IF: 4.41, JCR: 24.45%, EF: 12.04%, 2022)**

Conferences

- **IIR organizes conferences** related with various themes including heat pumps

IIR International Congress of Refrigeration

First held in 1908, the International Congress of Refrigeration of the IIR is a flagship event that converges industry and research. Covering all fields of refrigeration, the Congress, which takes place every four years, reunites key international stakeholders and provides perspectives on the future of the industry in line with sustainable development.

26th IIR International Congress of Refrigeration (ICR 2023)
August 21-25, 2023
Paris Congress Center | Paris, France

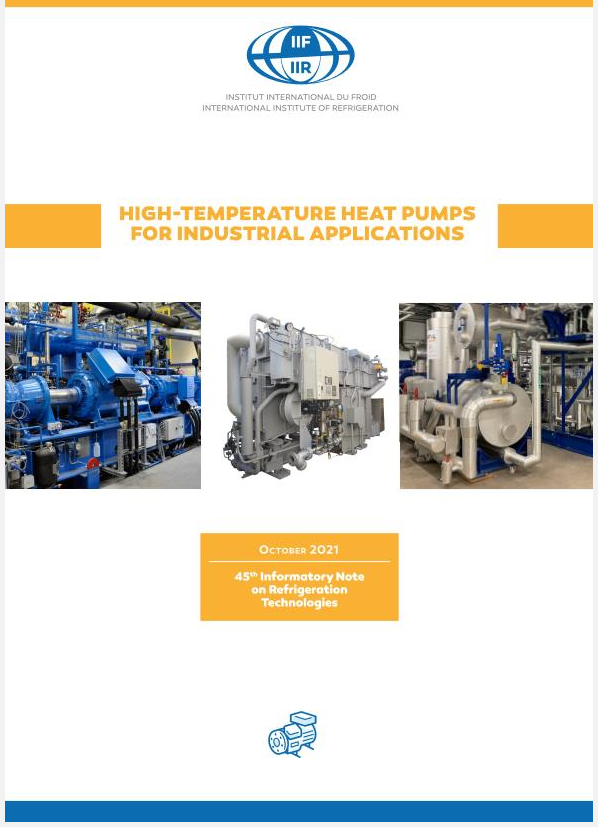
Source: iifiir.org/
Source: www.icr2023.org/

Informatory Notes

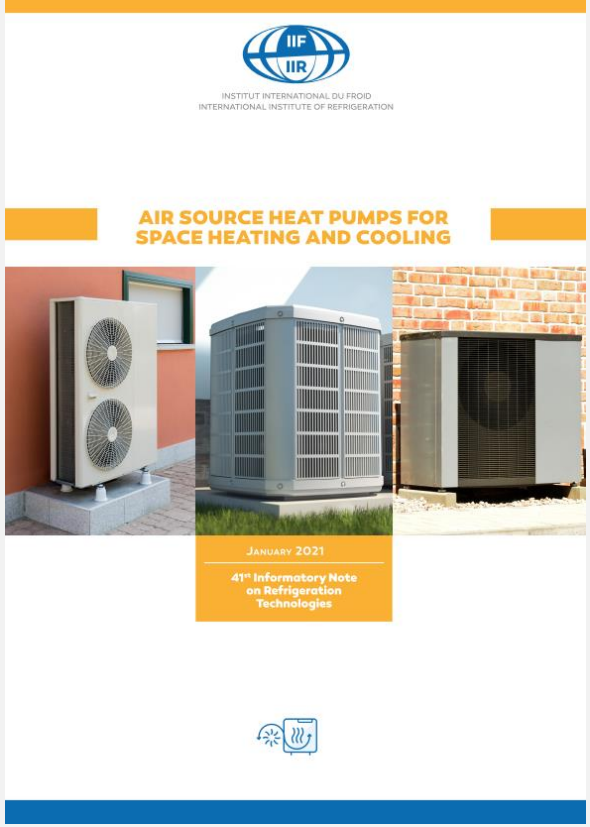
- **IIR periodically publishes Informatory Notes** as part of its official publications

INFORMATORY NOTES

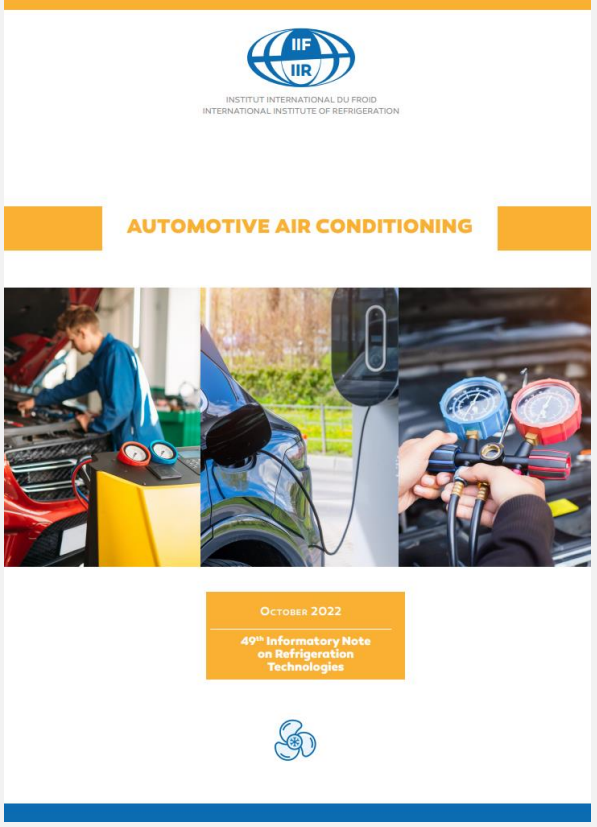
High Temperature Heat Pumps



Air Source Heat Pumps



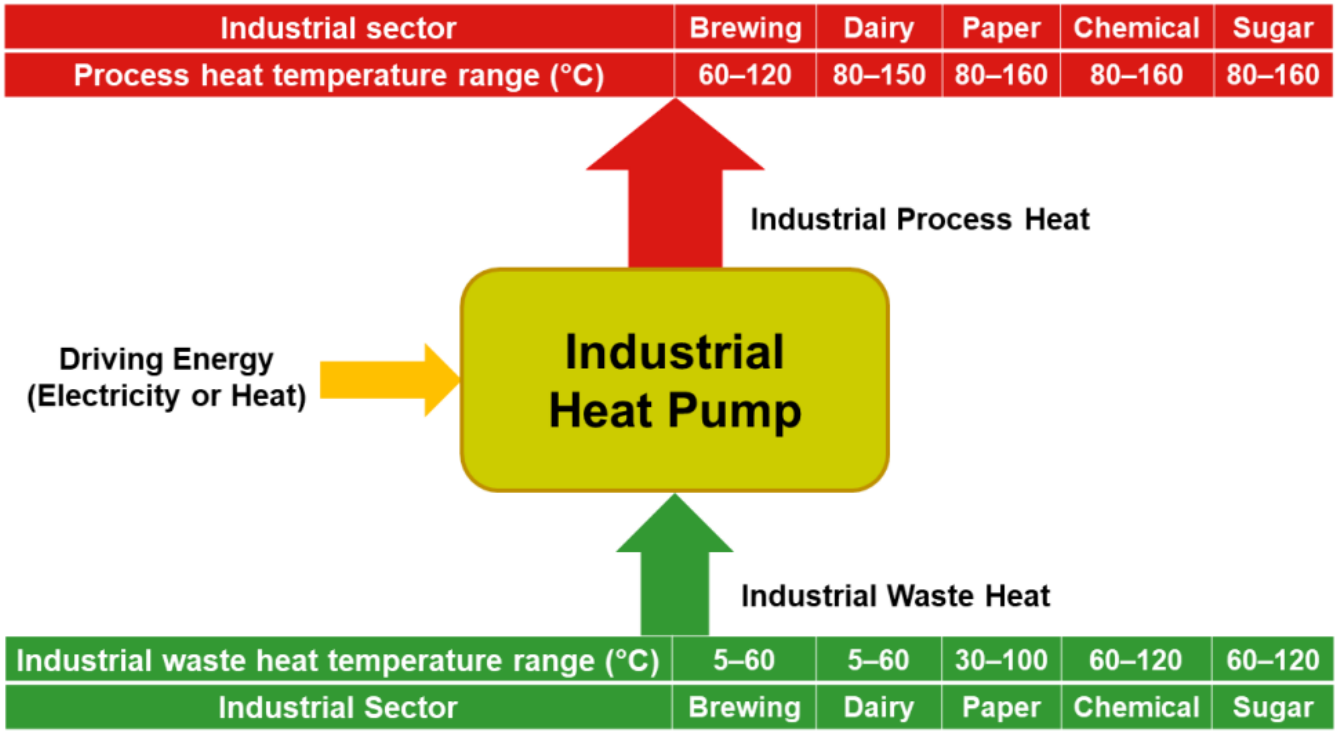
Automotive Air Conditioning



Source: iifiir.org/

Informatory Note 1: High Temperature Heat Pumps

*"**High-temperature heat pumps** are a key technology in the decarbonization of process industries." by Ayou D. S., Corberan J. M., Coronas A. (2021)*



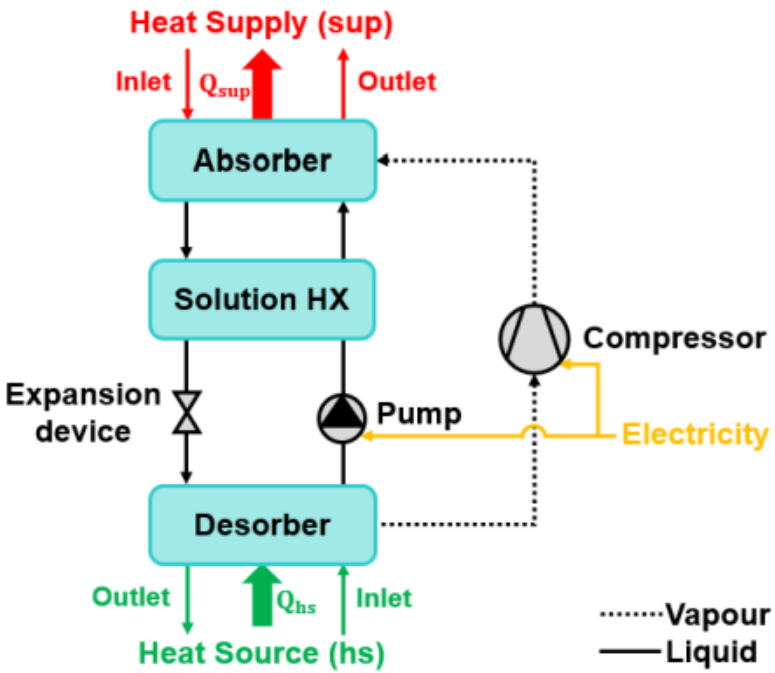
- **Industrial heat consumption accounts for about 20%** of total global energy consumption and the vast majority of it is obtained from the combustion of fossil fuels (IEA, 2018)
- Industries have a strong **need for sustainable energy transition** to **high-temperature heat pumps**

Source: "HIGH-TEMPERATURE HEAT PUMPS FOR INDUSTRIAL APPLICATIONS", October 2021, 45th Informatory Note on Refrigeration Technologies

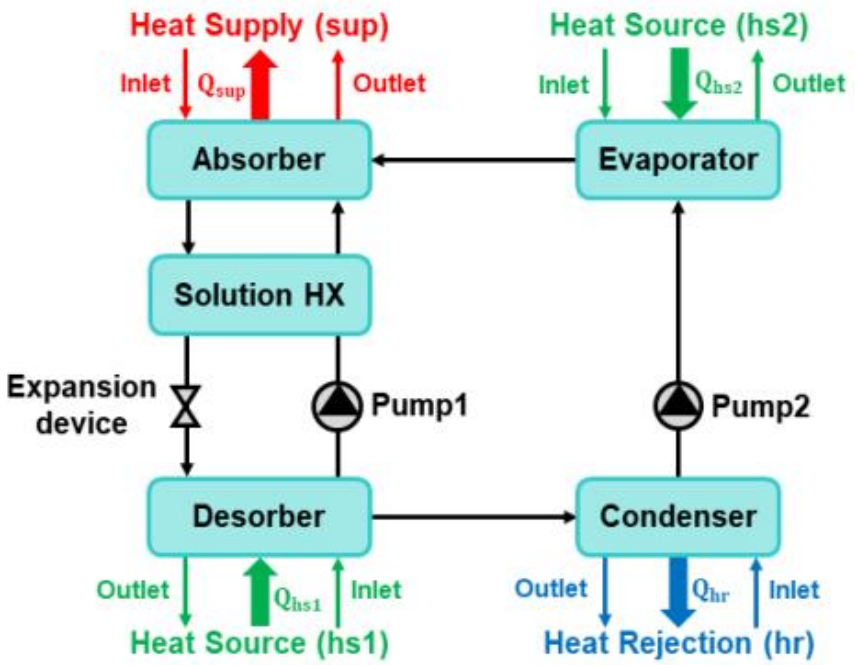
Informatory Note 1: High Temperature Heat Pumps

- **Absorption heat transformers** and **absorption-compression heat pumps**

Heat pump with a solution circuit



Absorption heat transformer

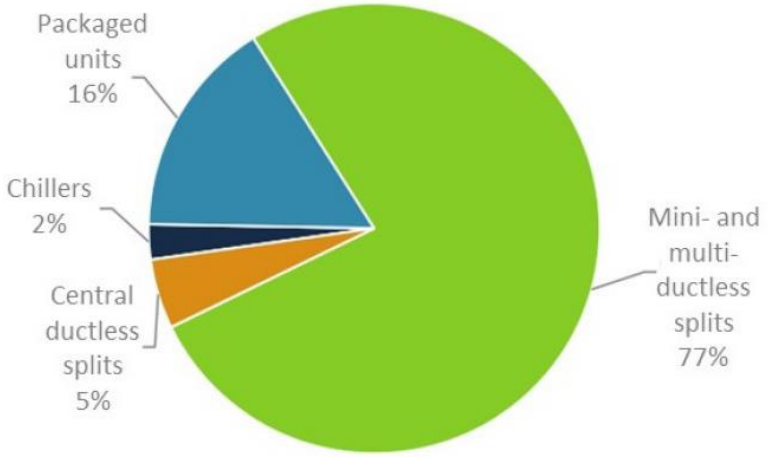


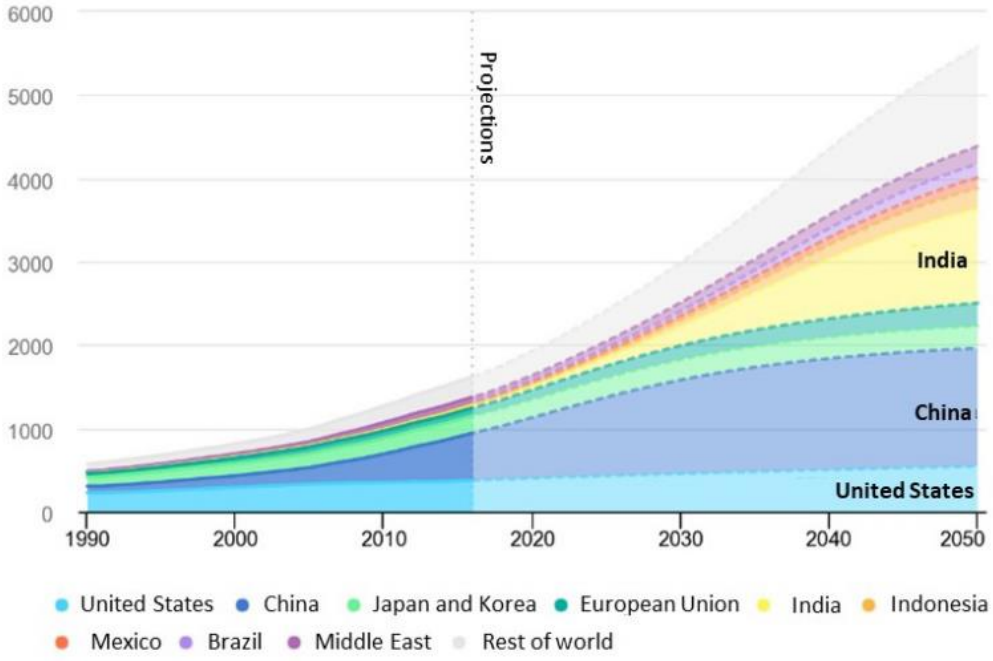
- **High temperature heat supply** with heat pump can be achieved by **integrating** solution circuit with waste heat utilization

Source: "HIGH-TEMPERATURE HEAT PUMPS FOR INDUSTRIAL APPLICATIONS", October 2021, 45th Informatory Note on Refrigeration Technologies

Informatory Note 2: Air Source Heat Pumps (ASHP)

*"**Heat pumps can play an important role** in meeting global targets for energy savings and low carbon emissions." by Li X., Wang B. (2021)*





- **Room air conditioners and VRF systems** account for the majority of air-conditioning system
- In order to combat air pollution from traditional boilers, **ASHP plays an increasingly important role** in cases where **both heating and cooling** are required

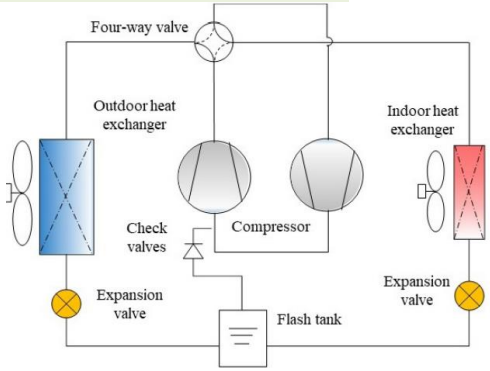
Source: "AIR SOURCE HEAT PUMPS FOR SPACE HEATING AND COOLING", January 2021, 41st Informatory Note on Refrigeration Technologies

Informatory Note 2: Air Source Heat Pumps (ASHP)

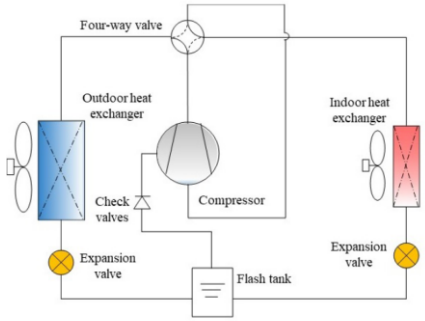
- This Informatory Note suggests **the state of the art of ASHP** technologies, along with **defrosting strategies** and alternative refrigerants

Multi-stage heat pumps

Two-stage heat pump

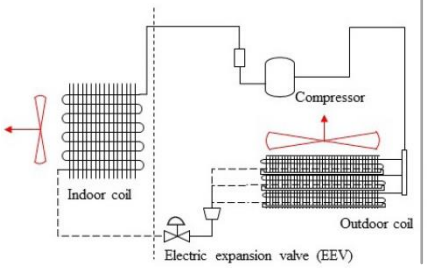


Quasi two-stage heat pump

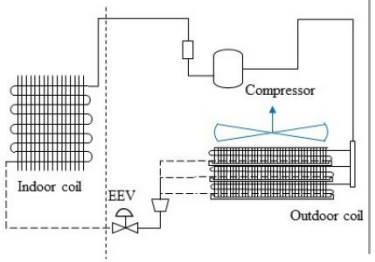


Defrosting strategies

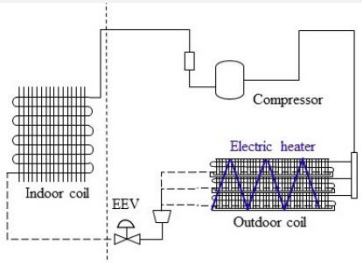
(a) Heating mode



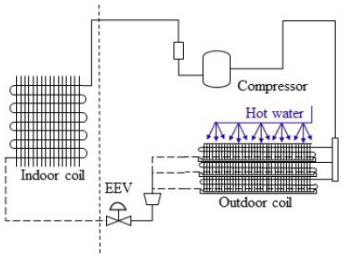
(b) Compressor shutdown



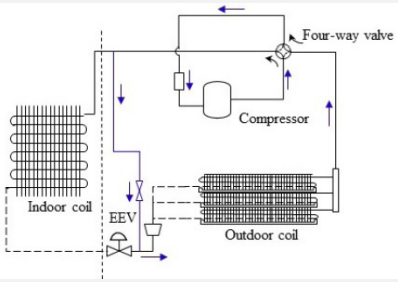
(c) Electric heating



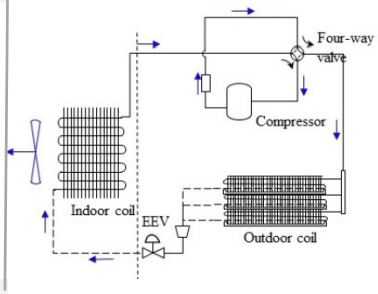
(d) Hot water spray



(e) Hot gas bypass



(f) Reverse cycle



Source: “AIR SOURCE HEAT PUMPS FOR SPACE HEATING AND COOLING”, January 2021, 41st Informatory Note on Refrigeration Technologies

Measures to Mitigate Climate Change

Low-GWP Refrigerants: Status and Outlook

- **The IIR** published a Informatory Note, evaluating the **cycle performance of low-GWP refrigerants** (by Domanski P., Motta S. Y.)

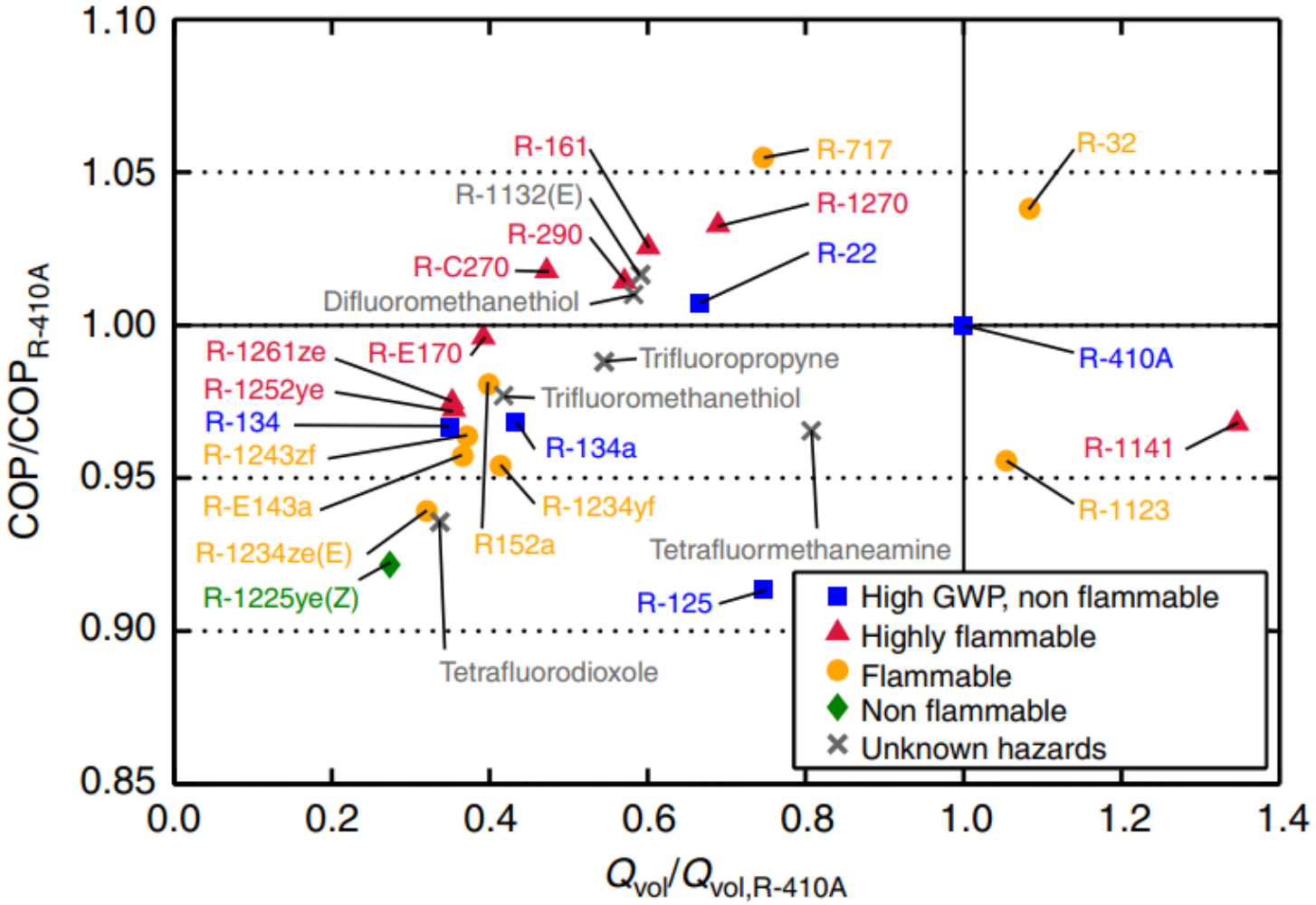
R-410A replacements for space-heating heat pumps

Refrigerant	GWP Reg. value	GWP Latest value	SafetyClass	$\frac{COP}{COP_{R-410a}}$	$\frac{Q_v}{Q_{v,R-410a}}$	$\frac{P_D}{P_S}$	Evap. Glide# (°C)	NBP (°C)
R-410A	**2088**	**2256**	**A1**	**1**	**1**	**3.1**	**-0.3**	**-50.6**
R-290	1	0.02	A3	1.006	0.57	3.0	-0.3	-42.1
R-454C	166	148	A2L	0.952	0.49	3.5	5.3	-45.8
R-455A	166	148	A2L	0.939	0.53	3.5	7.2	-52.0
R-454B	466	531	A2L	1.021	0.96	3.0	0.7	-50.7
R-32	675	771	A2L	1.044	1.08	3.0	-0.4	-51.7
R-466A	733	808	A1	1.009	0.98	3.0	0.9	-51.7

- Overall, the **existing trade-off between GWP and flammability** implies that a significant share of future equipment will use flammable refrigerants

Source: "LOW-GWP REFRIGERANTS: STATUS AND OUTLOOK", June 2022, 48st Informatory Note on Refrigeration Technologies

Performance of low-GWP Refrigerants



*Source: McLinden, Mark O. et al., "Limited options for low-global-warming-potential refrigerants." Nature Communications 8.1 (2017): 14476..

International Meetings on Climate Change

- **The IIR** participated in the Meeting of the Parties to the **MOP 32*** and **COP 27***

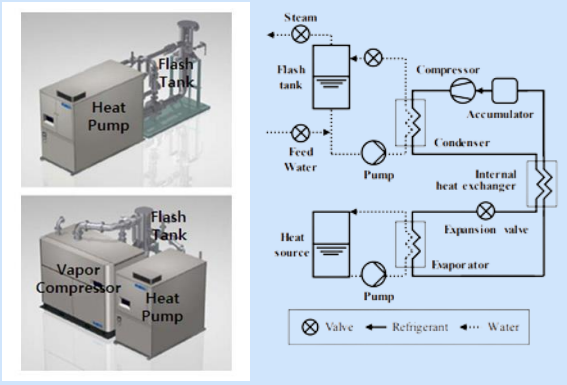
*MOP 32: Meeting of the Parties to the Montreal Protocol in Montreal *COP 27: Conference of the Parties on Climate change in Sharm Al Sheikh

Source: “The IIR at the Hear of Sustainable Development”, IIR Activity Report(2022)

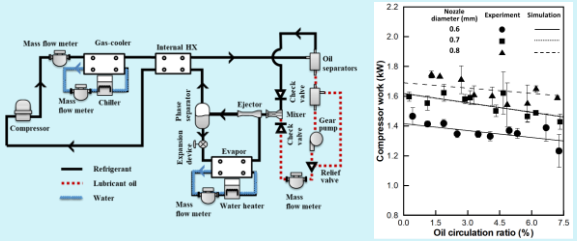
Future of Heat Pumps

Future of Heat Pumps

Industrial stream generation heat pump



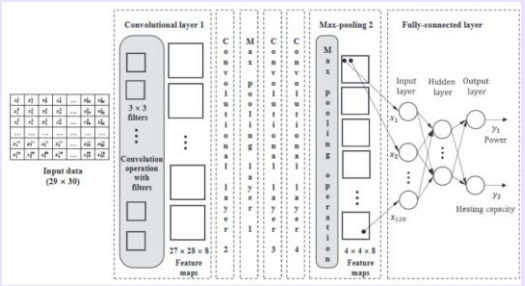
Natural refrigerant



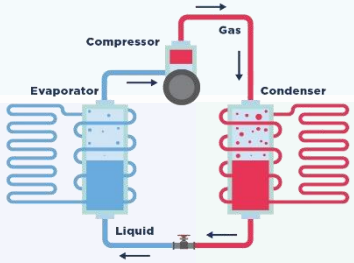
AI-based fault detection

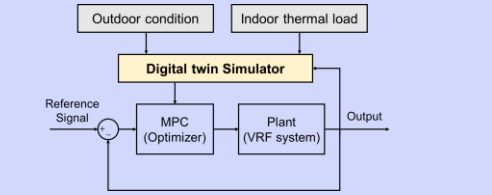
$$O_t = \sigma(W_{xo}x_t + W_{ho}h_{t-1} + W_{co}c_t + b_o)$$

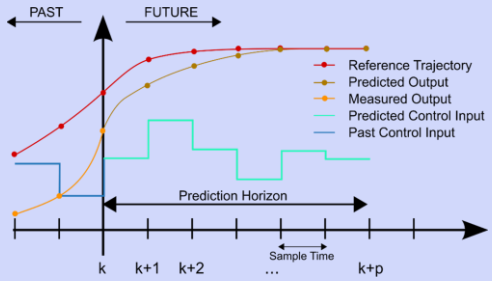
$$h_t = o_t \odot \tanh(c_t), y_t = W_{hy}h_t + b_y$$

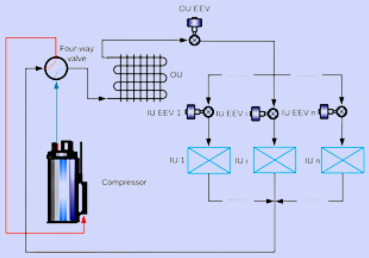


Future of Heat Pumps

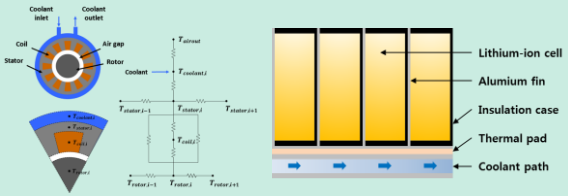


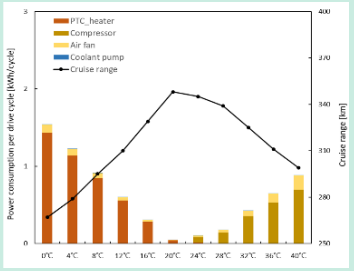


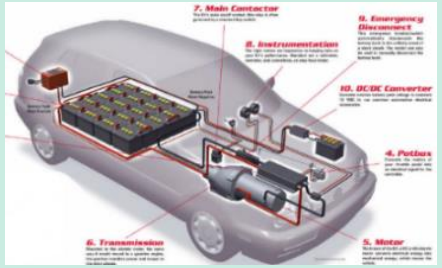




Digital Twin based control and operation







Heat pumps for Electric Vehicles

Digital Twin Based Control

*ROR: refrigerant flow on ratio

- **Digital Twin** was developed to estimate the dynamic performance of heat pump

$$* \text{ ROR} = \frac{\Delta t_{on}}{\Delta t_{on} + \Delta t_{off}}$$

Fig. Experimental apparatus for variable refrigerant flow (VFR) heat pump

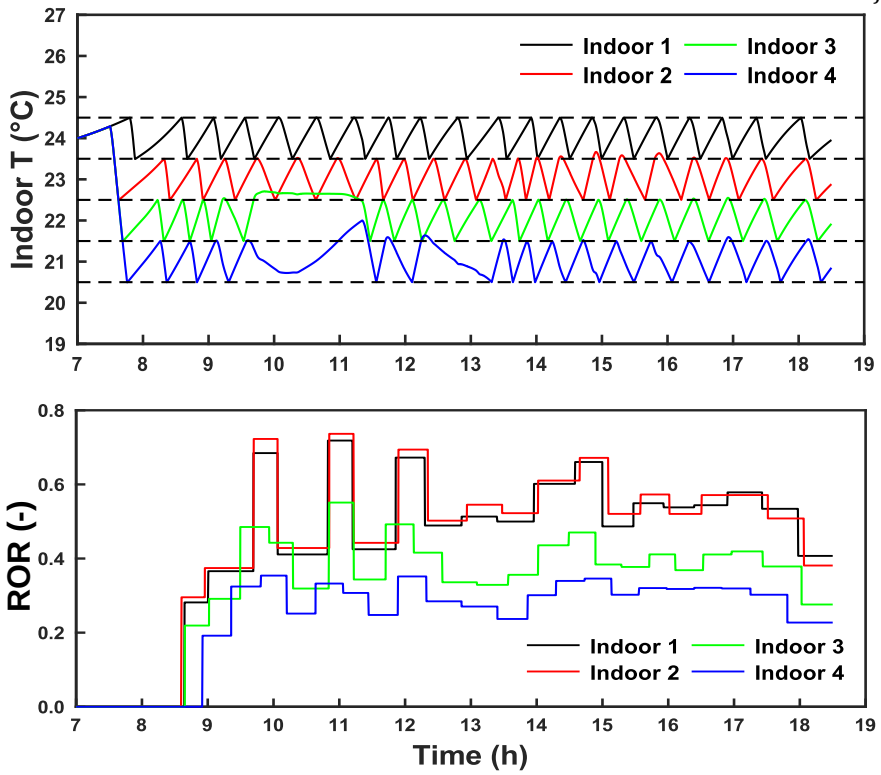


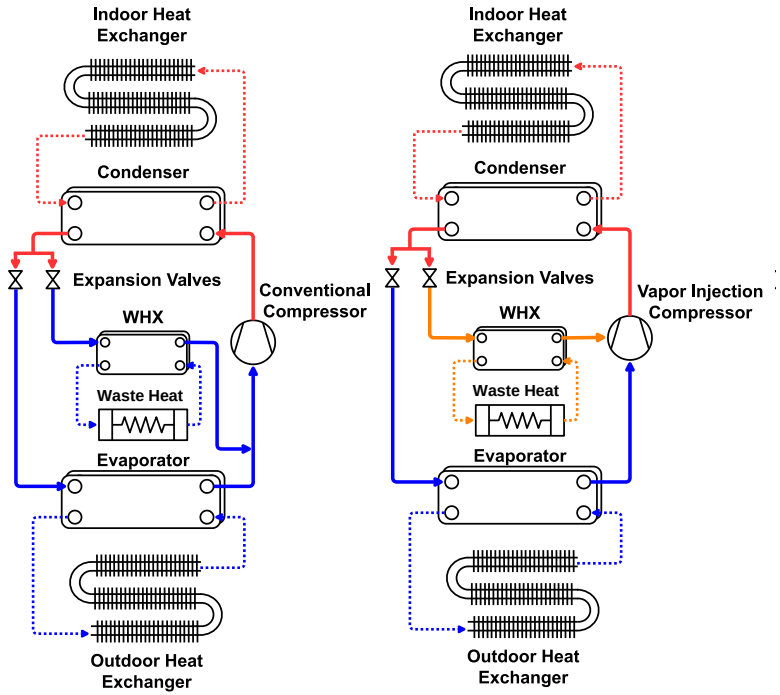
Fig. Dynamic performance of VRF system

- A dynamic heat pump model with moving boundary layer approach was established to find **optimal operating strategy** reducing the thermal on-off of system

Electric Vehicle Heat Pump

- **Vapor injection technique** increased heating capacity in winter

*WHR: waste heat recovery
*CWHR: conventional WHR
*MWHR: multi-level WHR using vapor injection



(a) CWHR (b) MWHR

Fig. Schematic of (a) conventional and (b) multi-level waste heat recovery system

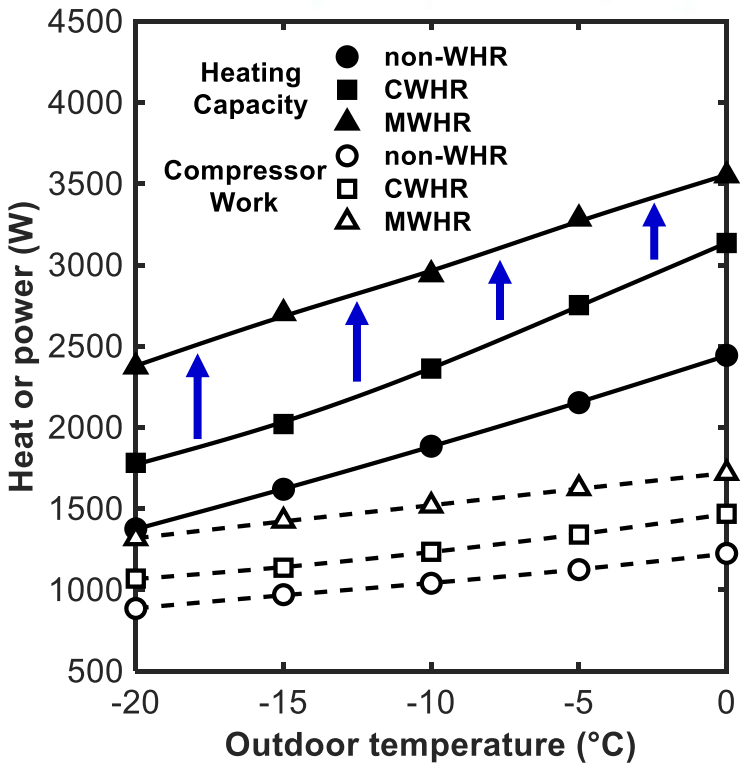


Fig. Heating capacity and compressor work of the non-WHR, CWHR, MWHR system

- The waste heat from electric devices was absorbed at intermediate temperature, using vapor injection technique showing **increased heating capacity in winter**

Source: Lee, Sangwook et al. "Experimental study on an electric vehicle heat pump system with multi-level waste heat recovery using a vapor injection technique at low ambient temperatures." *Energy Conversion and Management* 267 (2022): 115935.

Frost Formation Prediction with Neural Network

*FCDNN: fully-connected deep neural network

- Heat pump performance was well-predicted using **neural network**

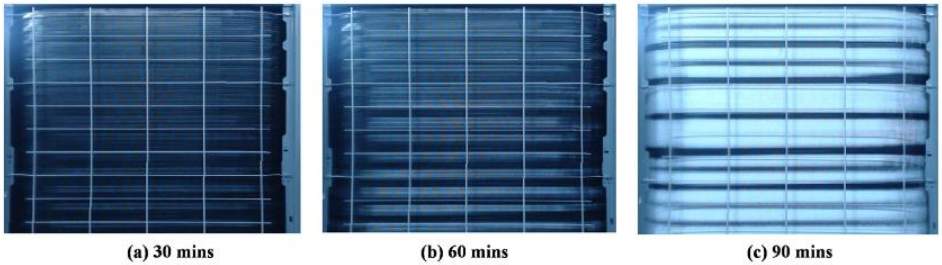


Fig. Frost accumulation

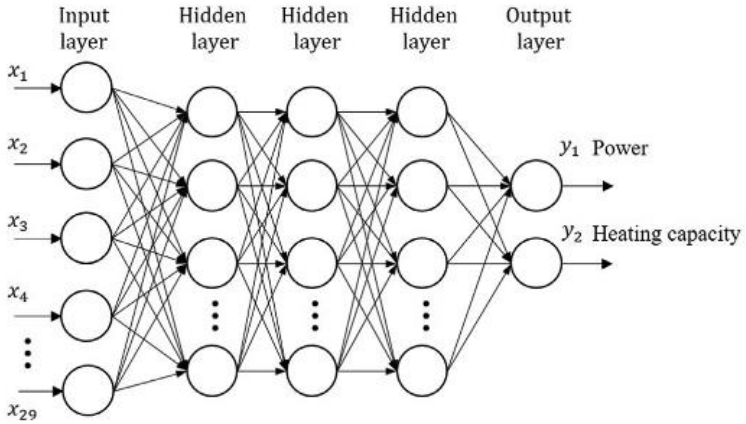


Fig. The architecture of a FCDNN*-based model

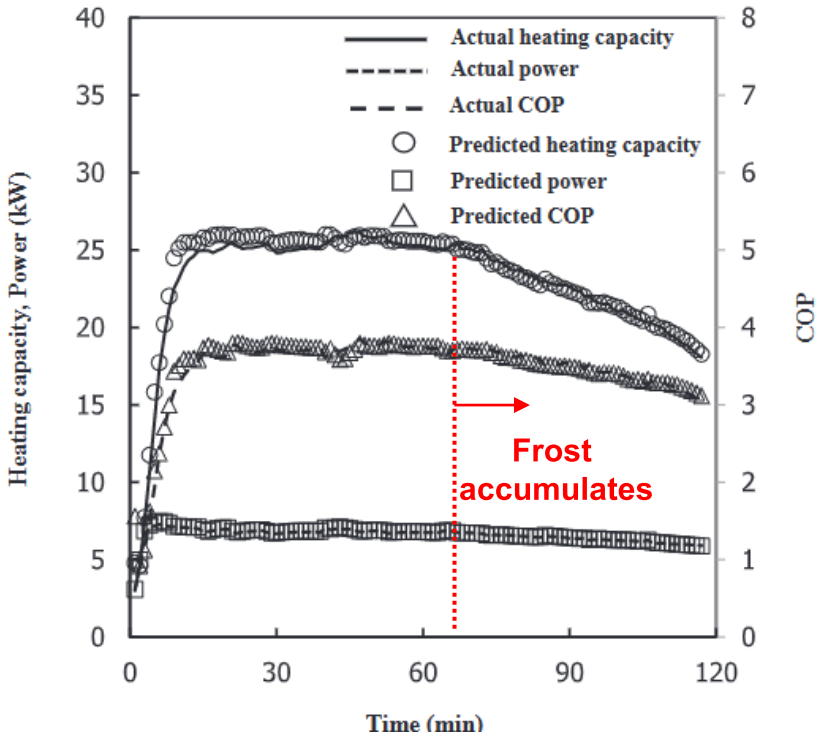
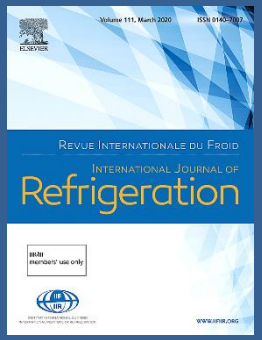


Fig. Heat pump performance prediction under frost growth

- Using a single **model based on deep learning**, the **performance** of heat pump **under frost growth** can be **accurately predicted**, and optimal defrosting strategy was derived

Source: Eom, Yong Hwan et al. "Deep learning-based prediction method on performance change of air source heat pump system under frosting conditions." Energy 228 (2021): 120542.



Publications

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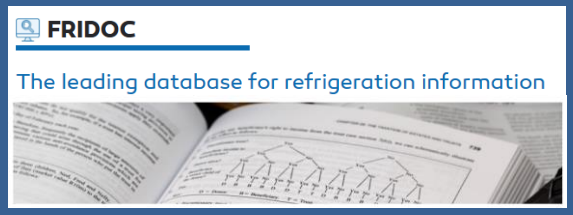
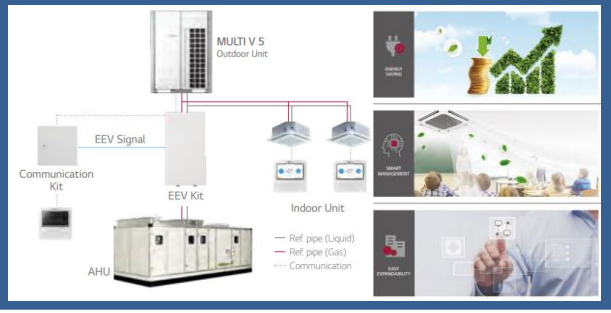


Future Heat Pumps



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Thank you