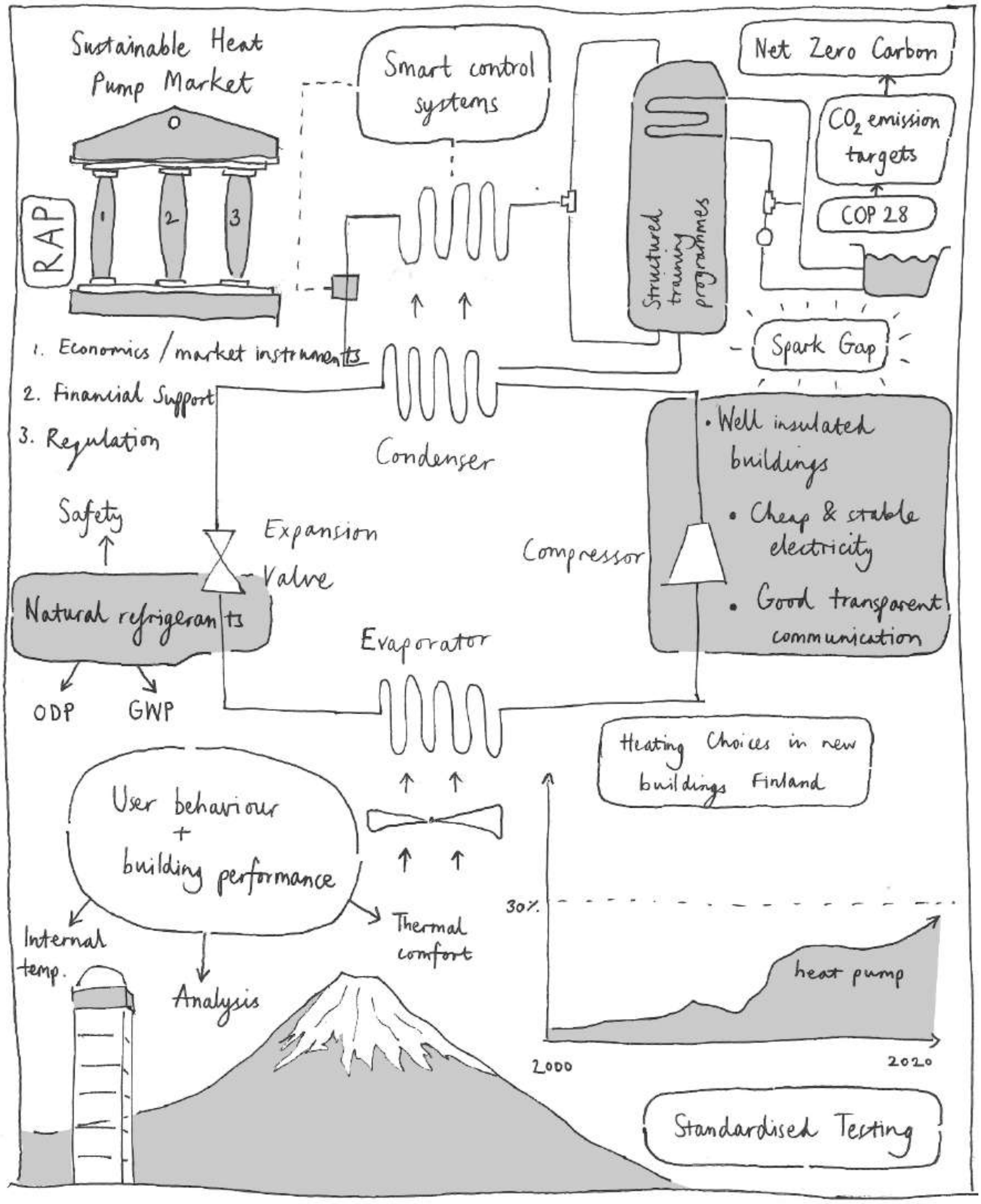
The transition to low carbon heat

A holistic investigation into the integration of heat pump technology in the built environment



William Holley

2024 CIBSE Ken Dale Travel Bursary Report
July 2025

Contents

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Throughout this research project, I have been very fortunate to receive the support from many organisations and to have met many wonderful people. Without the support and guidance of the following individuals, this report wouldn't have been possible.

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Buro Happold – since 2013, Buro Happold has given me unwavering support. As a graduate in the Bath office, I was offered german lessons and encouraged to do a transfer to Berlin. In 2021, Buro Happold supported my move to Hamburg to gain more site experience. After winning the Ken Dale Award, I was given the time out to research and write this paper. Thank you for supporting my development at every step of the way.

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In order of meetings:

Fortum: Teemu Nieminen

Gebwell: Petrus Monni

Finnish Heat Pump Association, SULPU: Jussi Hirvonen

kapacity.io: Sonja Salo

Tsinghua University - Associate Professor Baolong Wang, Professor Xianting Li

Carrier: Keiko Kanagawa, Naomi Shirai, Yasunori Chikawa

HPTCJ: Toru Asai, Mitsunobu Nakajo, Takayuki Suzuki, Shigeo Mitsuno, Masaya Shigenaga, Tomohiro Inoue, Akihiro Takeuchi, Takahide Tokuda

CRIEPI: Dr Tomohiro Higashi, Dr Tsuyoshi Ueno, Shohei Yasuda

Center for Better Living: Dr Tetsutoshi Kan

Building Research Institute: Hisashi Miura, Dr Yasuhiro Miki

National Institute for Land and Infrastructure Management: Dr. Masato Miyata, Dr Yoshihiko Akamine

Daikin: Takahiro Asahi, Masaki Nakayama

2. About the author

William Holley is a creative and outgoing chartered building services engineer leading the Buro Happold MEP team in Hamburg. His building services journey started at the University of Nottingham studying Architecture and Environmental Design (MEng). After graduating with first class honours, he started as a graduate building services engineer at the Buro Happold HQ in Bath. He spent two years in Bath working on a wide variety of cultural, sports and educational projects including the London Olympic Stadium Redevelopment, Wiltshire College, Bristol Aero Collection and St. George's Bristol. In 2013, William won the CIBSE ASHRAE Graduate of the year and visited the ASHRAE Winter conference in New York.

A 6 month secondment to the Buro Happold Berlin office turned into a 5 year transfer to the German capital. Here he gained experience on large scale international projects such as the European Investment Bank and Zalando HQ Office. After learning german, William started working on local german projects and in January 2021, he got the opportunity to move to Hamburg to work on the construction site of the Überseequartier project. Working over 4 years on the largest inner city construction project in Europe was a great challenge and significantly improved his execution knowledge and site experience.

William has been a guest tutor at the University of Nottingham and Stuttgart and really enjoys giving workshops and tutorials on the subject of building services and environmental design. William now leads the Buro Happold MEP team in Hamburg and is looking forward to applying the knowledge gained from the Ken Dale Award to effectively integrate heat pump technology in new projects in the region.

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3. Glossary

HP – Heat Pump. A heat pump is a device that can provide heating, cooling and hot water for homes, businesses and even for industry. Heat pumps take energy from the air, ground or water and turn it into heat. In reverse, they remove heat energy, like an air conditioner or refrigerator.

AAHP – Air-to-air heat pumps draw energy from outdoor air and transfer it indoors. Internal units, usually located in the common rooms, provide heating via warm air. They can function even at external temperatures of -20 °C. They can also work in reverse to provide cooling.

AWHP – Air to Water Heat Pump. Energy is taken from outdoor air and transferred to the hydronic heating system within the building. The heated water can then be distributed to radiators, underfloor heating, or fan coils.

ExHP – An Exhaust Air Source Heat Pump is a system which absorbs heat from the waste air (or exhaust air) leaving a building. Heat is extracted from the exhaust air and is upgraded into useful heat energy for space heating and domestic hot water.

GSHP – Ground Source Heat Pump (which absorbs heat from the ground using horizontal or vertical loops and transfers it to the building's heating system). These are also known as "brine-to-water" systems or geothermal systems, as a glycol mixture is typically used within the loops to prevent freezing of the fluid

COP - Co-efficient of performance is the ratio between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied to the compressor.

CHP – Combined Heat & Power. The concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy.

CRIEPI – Central Research Institute of Electrical Power Industry (https://criepi.denken.or.jp/en/index.html)

GWP - Global Warming Potential denotes the potential influence that a specific refrigerant may have on global warming – for example, if it were to escape into the atmosphere due to a leak.

HPTCJ - Heat Pump & Thermal Storage Technology Center of Japan (https://www.hptcj.or.jp/en/)

4. Abstract

It has been well publicised that heat pumps will play a key role in achieving the current global CO_2 emission targets. The main objective of this paper was to investigate the feasibility, opportunities and challenges facing heat pump technology on the quest to achieve these ambitious targets. This research project was country specific and started by analysing and comparing the heat pump markets in Finland, China, Japan, UK and Germany.

Case studies where heat pumps in large scale district heating systems in Finland and in an industrial application in Japan were analysed. Interviews at the Department of Building Science at Tsinghua University in Beijing and with kapacity.io in Helsinki were undertaken to discuss the benefits of smart control systems for heat pumps.

Future refrigerants is a big topic in the heat pump industry. This report presents some of the latest heat pump products that utilise natural refrigerants with low GWP properties. It also highlights the safety concerns of numerous stakeholders when distributing these flammable refrigerants within buildings.

Finland witnessed a 100% increase in cumulative heat pump sales between 2016 and 2024. The key factors to this success were revealed during an in-depth interview with Jussi Hirvonen, the director of the Finnish Heat Pump Association.

The results of this research paper show that there is unfortunately no silver bullet shaped heat pump that will achieve the global CO_2 emission targets. It will require a holistic approach where heat pumps are integrated across the building and industrial sector. Cheap and stable electricity prices, clear and equitable government policy, structured training programmes and secure supply chains will help the heat pump market to grow sustainably. The case studies and interviews demonstrated that analysing user behaviour and building performance is also absolutely critical to achieve optimum heat pump efficiency. Therefore, the role of the engineer in achieving the CO_2 emission targets cannot be underestimated.

5. Introduction

In December 2023, COP28* published a historic agreement to phase out fossil fuels to achieve net-zero emissions by 2050. This was the first time that the COP explicitly addressed the need to end the use of coal, oil and gas, the main drivers of the climate crisis. The agreement also called for a tripling of renewable energy capacity globally by 2030[1]. Despite this being a complex and multidimensional challenge, it has been well publicised that heat pump technology will play a key role in realising these ambitious targets. But how will this be achieved?

This research paper strives to find the answer by analysing the heat pump market and the integration of heat pumps across 5 different countries. The countries chosen for this study were Finland, China, Japan, UK and Germany. **Why were these countries chosen?**

Finland

Finland has set one of the most ambitious climate targets in the world; a legal obligation to reach carbon neutrality by 2035. It has also become a trailblazer in the adoption of heat pumps, with more installed per capita than any other European country in 2022. The Finnish Heat Pump Association (SULPU) has done an amazing job encouraging the installation of heat pumps. An inspiring conversation with Jussi Hirvonen, Director of SULPU outlined the major success factors that enabled a 100% increase in cumulative heat pump sales between 2016 and 2024. The conversation with Jussi can be found in **Chapter 6.** Fortum, a Nordic energy company** are pushing the boundaries of heat pump integration at a district heating scale. One particularly interesting project is the heat pump plants in Espoo and Kirkkonummi, close to Helsinki. This project will capture excess heat from two Microsoft data centers and the proposal is believed to be the world's largest data center heat recovery project. Further information on Fortum and two of their projects are described in **Chapter 8**.

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*COP28: The 28th United Nations Climate Change conference or Conference of the Parties of the UNFCCC. Held in 2023 in Dubai, United Arab Emirates.

** Fortum is publicly traded on the Helsinki Stock exchange but the majority owner is the Finnish state.

[1] (BECKER, 2023) 18.12.2023. *COP28 – Results, Key Findings and Summary* (online) Available from: https://dfge.de/cop28-results-key-findings-and-summary/ (Accessed 20.04.2025)

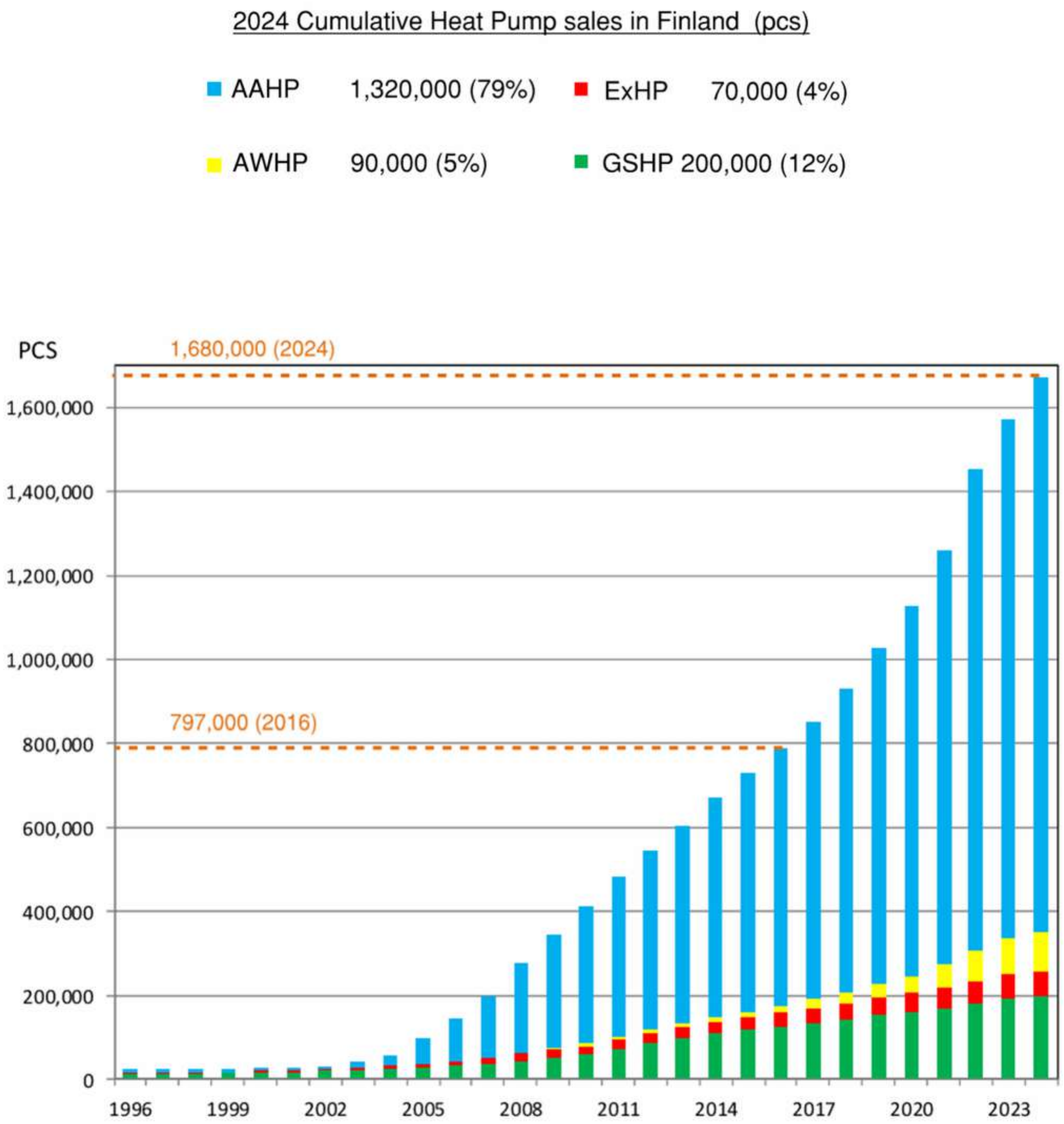

Figure 1 Cumulative Heat Pump sales in Finland (pcs) (Megawatt-size district heating / cooling, shopping center, service building, industrial HPs as well as planning, service, etc. are missing from figures below.

The People's Republic of China

The ambitious carbon reduction targets set by COP28 and individual nations set us in the right direction but there is no plausible path to limiting the global temperature rise to 1.5°C without The People's Republic of China. In September 2020, President Xi Jinping announced that China will "aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060[2]. Despite still being very reliant on coal power stations, China is pushing forward with research and development of heat pumps at an infrastructure and building level. Tsinghua University in Beijing is doing particularly interesting research in this field and my conversation with Associate Professor Baolong Wang is described in **Chapter 7.1.**

Japan

In order to push the boundaries of design, it is important to be informed of future developments and collaborate with manufacturers. Japan is well known for good quality engineering and some of the largest manufacturers of heat pumps have their headquarters in Japan. A visit to Carrier's Manufacturing plant and R&D Center in Shin Fuji as well as Daikin's solution plaza in Tokyo was organised to find the latest innovations from Japan.

One of the reasons behind good quality products is the research and testing facilities. I was fortunate enough to visit the Building Research Institute (BRI) of Japan and the Central Research Institute of Electric Power Industry (CRIEPI). A description of the facilities and their current research projects is described in **Chapter 7.3.** The Heat Pump & Thermal Storage Technology Center of Japan (HPTCJ) is at the heart of heat pump promotion in Japan and follow the motto '**Think Tomorrow's Energy through Heat Pumps'.** A visit to the HPTCJ headquarters in Tokyo was key in helping to understand the local HP market.

Figure 2 As Japan was recovering from the war, a room air conditioner development project was launched at Toshiba's Yanagimachi Factory. The RAC-7A5 was introduced to the market in 1958, the first domestically produced 1 horsepower window air conditioner. Photo by William Holley (02.04.25)

[2] (IEA, An Energy Sector Roadmap to Carbon Neutrality in China, 2021)

United Kingdom

The United Kingdom has a target to reduce carbon emissions by 68% of 1990 levels by 2030. Despite generous subsidies, the UK Heat pump market has struggled to gain momentum. In 2022, the UK had the lowest heat pump sales per 1000 households in Europe. This report strives to uncover the reasons behind this and make suggestions on how this can be improved.

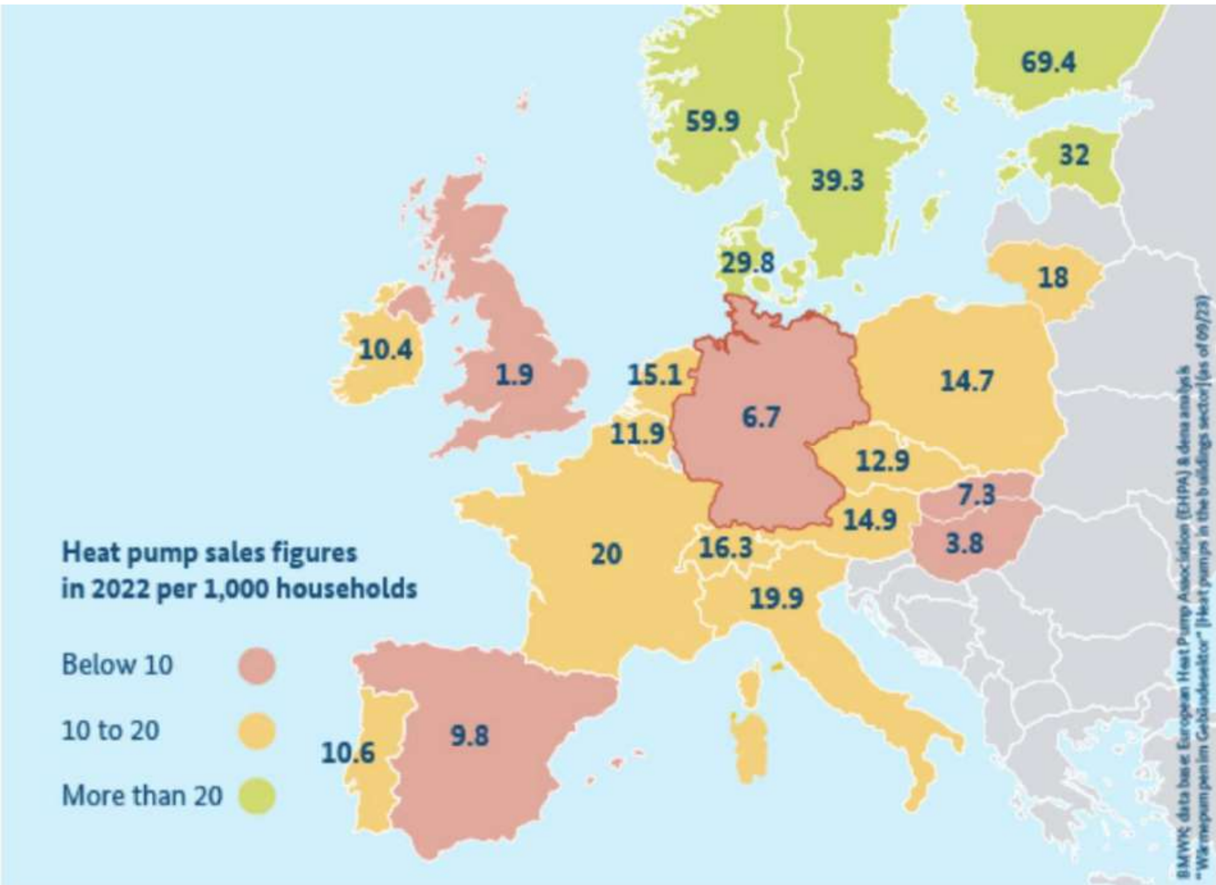

Figure 3 Heat pump sales figures in 2022 per 1000 household[3]

Germany

Similar to the UK, Germany has a target to reduce carbon emissions by 65% of 1990 levels by 2030. In addition, the new GEG (Building Energy Act) came into force in January 2024 which states that the heating energy for all new buildings must be provided by renewable energy sources. I have been living and working in Germany since 2015 and a personal objective is to apply the lessons learnt from this research and effectively integrate heat pumps into local projects.

[3] (BMWK, 2023) Data base: European Heat Pump Association (EHPA) & dena analysis 'Wärmepumpen im Gebäudesektor' (Heat pumps in the building sector) (as of 09/2023)

6. Heat Pump Market / Policy

The first objective of this report was to understand and present an overarching view of the heat pump industry in each of the chosen countries. Three comparison tables were created to reveal the political, economic and environmental aspects affecting the individual heat pump markets. **Table 1** compares the current CO_2 emission targets, the average CO_2 emissions from electricity generation and the number and type of HP installed.

	UK	Germany	Finland	China	Japan
CO_2 emission targets	68% reduction of 1990 emissions by 2030. Net zero carbon emissions by 2050.	65% reduction of 1990 emissions by 2030. Net zero carbon emissions by 2050.	Net zero carbon emissions by 2035	CO_2 emissions peak before 2030 Net zero carbon emissions before 2060.	46% reduction of 2013 emissions by 2030 73% reduction of 2013 emissions by 2040. Net zero carbon emissions by 2050. Japan's Nationally Determined Contribution (NDC)
Average CO_2 emissions from electricity generation (gCO_2 / kWh)[4] [5]	191	300	33	530	460
% HP types in the installed heat generating capacity (space heating)	AAHP – 4% AWHP – 92% GSHP – 4% ExHP - <1% [6]	AAHP – 11% AWHP – 60% GSHP – 29% ExHP - <1% [7]	AAHP – 79% AWHP – 5,4% GSHP – 11,9% ExHP 4,2% [8]	AAHP – 60% AWHP – 30% GSHP – 10% ExHP – <1% [9]	AAHP – 95% AWHP – 2% GSHP – 2% ExHP – <1%
HP Units stock per 1000 households (2024)	15	47	512	118	157

Table 1: CO_2 emission targets, % HP Types and HP Stock per 1000 households

CO_2 emission targets: Each country has the end goal of reaching net zero carbon emissions. However, the year in which this goal is achieved is significantly different; Finland has the most ambitious goal of reaching this target by 2035, whereas China aims to achieve this in 2060.

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[4] (IEA, 2025) Electricity 2025. Analysis and forecast to 2027. (February 2025)

[5] (JME, 2025) Japanese Ministry of Economy, Trade & Industry Annual Report 2023 (April 2025)

[6] (HPA, 2024) HPA Statistics 2024. Available at: https://www.heatpumps.org.uk/resources/statistics/

[7] (BWP, 2024) Branchenstudie 2024 (July 2024)

[8] (SULPU, 2025) Heat Pump market in Finland 2024 (Jan 2025)

[9] (IEA & Tsinghua Uni) Future of HP in China_P58 (March 2024)

Average CO_2 emissions from electricity generation (gCO2 / kWh): Heat pumps use electricity to provide heat. Therefore, installing heat pumps will have zero impact on achieving the emission targets unless the electricity generation is decarbonized. The top performer in this category is Finland with 33gCO_2 / kWh. As demonstrated in **Figure 4**, this is due to an impressive mix of renewables and nuclear.

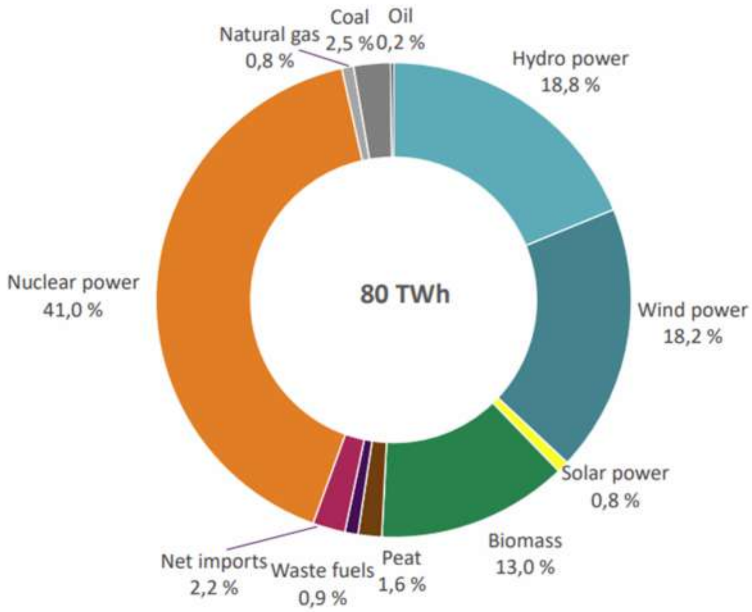

Figure 4: Finnish electricity by energy source and net imports 2023[10]

Due to its high reliance on fossil fuels, China's power sector emissions intensity in 2022 (530 gCO_2/kWh) was 22% higher than the global average of 436 gCO2/kWh.[11] The key to reducing this figure will be by shutting down the coal fired power stations and replacing with renewable energy technologies, such as solar and wind.

% HP types in the installed heat generating capacity (space heating): The most significant and interesting difference in the heat pump markets is that UK and Germany is dominated by Air to Water Heat Pumps. This is because most houses have hydronic heating systems and there is a greater focus on heating rather than cooling. Finland, China and Japan however, use mostly Air to Air Heat Pumps for heating. Internal split units used for space heating arguably create an inferior thermal comfort compared to radiators or underfloor heating. They are however, much cheaper and easier to build (refrigerant pipework and split units are much cheaper than water pipework and radiators) and have the advantage of one system being able to heat in winter and cool in summer.

HP Units stock per 1000 households (2024): these figures show that the UK has the least installed HP per 1000 households in our study. Finland has an impressive installed capacity of 512 HP per 1000 households. This value is reinforced by Figure 5 which shows that heat pumps are now the most popular space heating method after district heating.

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[10] (Finnish Energy, 2024) Electricity Year 2023 (Feb 2024)

[11] (EMBER, 2023) Analysis of the ten largest power sector emitters in 2022. Accessed on 30.04.25. Available at: https://ember-energy.org/latest-insights/global-electricity-review-2023/country-and-region-deep-dives/#china

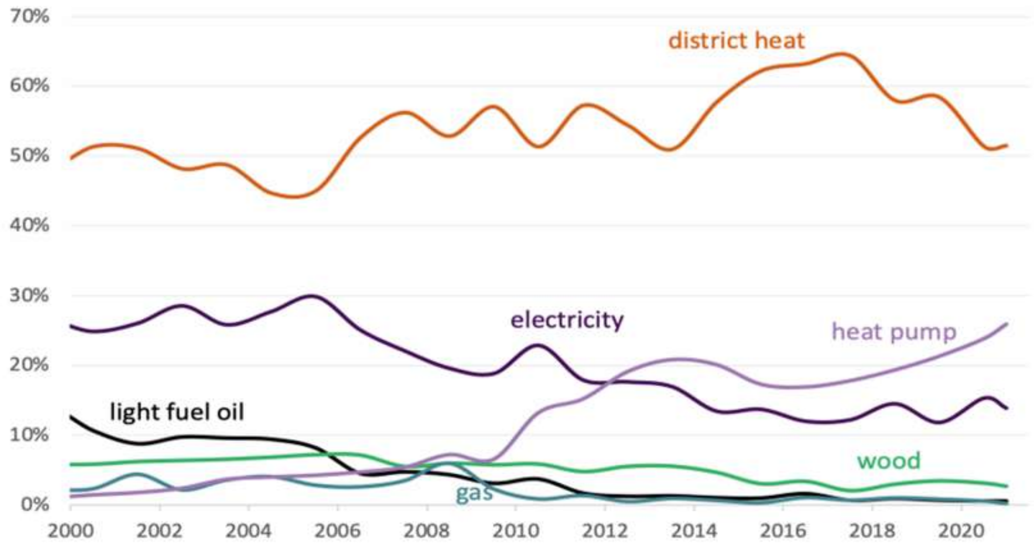

Figure 5: Heating choices in new buildings (Finland)[12]

Table 2 looks at the economic aspects affecting the HP market and offers an answer to why the UK and Germany has not seen the success of other European countries.

	UK	Germany	Finland	China	Japan
2024 average electricity price per kWh (€)[13]	0,32	0,31	0,16	0,07	0,19
2024 average natural gas price per kWh (€)	0,07	0,10	0,10	0,04	0,07
Spark Gap (Ratio between the price of electricity and gas per kWh)	4,6	3,0	1,6	1,6	2,8

Table 2: Average electricity & gas prices 2024 and Spark gap

As written in the excellent **Policy toolkit for global mass heat pump deployment** by the Regulatory Assistance Project and Rosenow 'Without a strong economic framework on both upfront heat pump costs and running costs, heat pump deployment is expected to be far slower than needed to reach net-zero emissions targets. The main running costs (associated with electricity used by the heat pump) will be determined by the cost of electricity, the efficiency of the heat pump and the overall heat demand of the

[12] (IEA & Statistics Finland, Granted building permits, 2022)

[13] (World Population Review, 2025) Cost of Electricity by Country 2025. Accessed on 24.06.25. Available at: https://worldpopulationreview.com/country-rankings/cost-of-electricity-by-country

building. If fossil fuels such as oil, gas and coal are cheaper to use per unit of heat delivered, there is a disincentive for customers to switch to heat pumps.'[14]

This is one of the main factors why the HP Market in the UK and Germany has not seen the success of other European countries. Why should the consumer invest in heat pumps when electricity is expensive and gas is cheap? To shift the economics towards clean heating, a combination of carbon pricing and environmental taxation could be considered at government level. In addition, policy makers need to ensure an equitable transition to clean energy and protect low income families, who generally spend the greatest share of their incomes on energy.

A clear indicator of the economic viability of switching to a heat pump is known as the **Spark gap**. This is the ratio between the price of electricity and gas per kWh. Back in 2022, the UK had the highest spark gap in Europe. If the UK Government is serious about increasing the deployment of heat pumps, this issue needs to be prioritised.

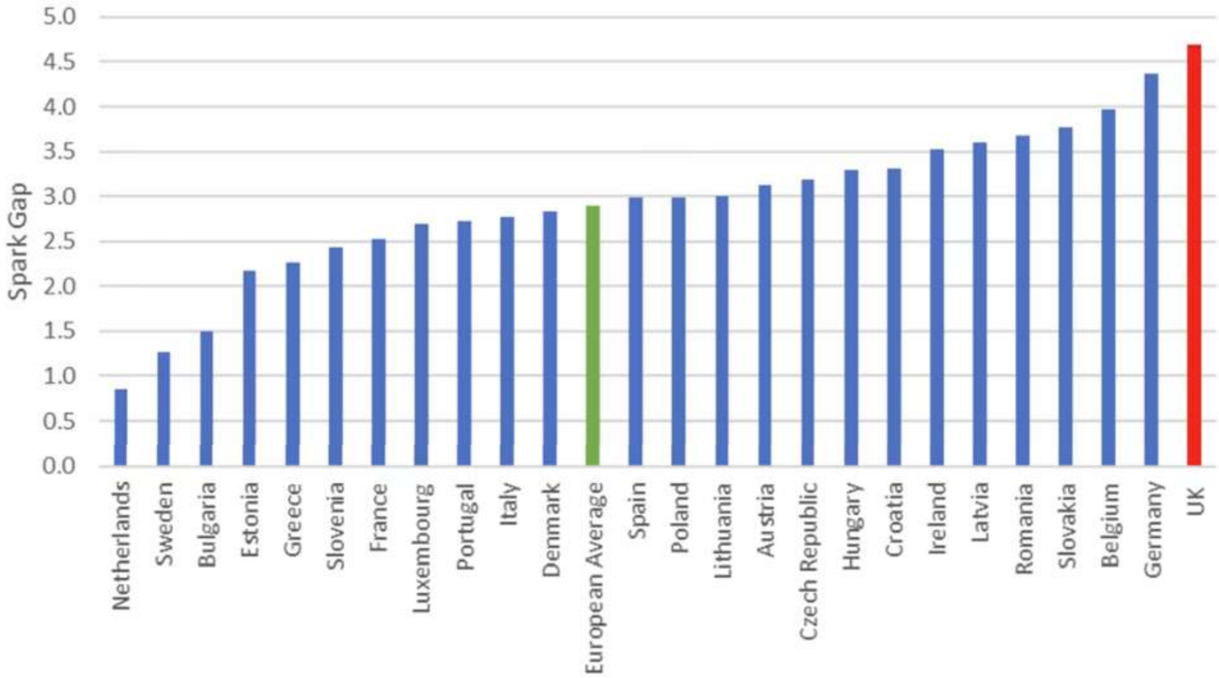

Figure 6 Comparison of spark gaps in European countries – July '21 to June '22[15]

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[14] (RAP, 2022) A policy toolkit for global mass heat pump deployment (Nov 2022)

[15] (Warren, 2023) The Price Cap and the Spark Gap (May 2023) Accessed on 30.04.2025. Available at: https://www.linkedin.com/pulse/price-cap-spark-gap-richard-warren/

Table 3 compares the current government incentives and design regulations affecting the heat pump industry. These are important tools to support and encourage the heat pump market but cannot be applied in isolation. As illustrated in **Figure 7**, all three pillars are vital to create a sustainable heat pump market[16].

	UK	Germany	Finland	China	Japan
Government incentives (carbon pricing and environmental taxation, taxes and levies on energy and obligations to develop markets)	£7,500 grant for air source (approx. 40%) or ground source heat pump. £5,000 off the cost and installation of a biomass boiler.	Subsidy of up to 70%. Max €21.000 Goal – 500.000 HP installed per year	Up to €4000 subsidy available	Up to €4000 subsidy available	Subsidies for HP are available, for example, €345 subsidy for Ecocute product (Heat pump for hot water generation).
Current Regulations affecting the HP sector	**Future Homes & Future Buildings Standard.** The UK Government has recently backtracked on plans to ban the installation of boilers in new buildings. This was a blow to the heat pump market. Future Homes Standard – <75% carbon emissions from previous standard.	**GEG 2024 (Building Energy Act)** From January 2024, all new buildings must provide 65% of the heating energy with renewable energy sources. **European Green Deal**	**2025 Construction Act** Focus on renewables and district heating in line with Carbon Neutral Targets	**2025 Energy Law** First ever Energy Law mandates minimum renewable energy consumption targets.	**Building Energy Efficiency Act** Energy calculation to be submitted. Compulsory since April 2025. Webpro. Building Energy code. U Value and insulation requirement. Manufacturer Standard: Annual Performance Factor (APF). Housing Quality Assurance act

Table 3 Government Incentives and Current regulations

In the last two years, the regulations across all countries are demanding more sustainable design solutions. For example, the new building energy act in Germany (GEG 2024) that came into force in 2024, states that all new buildings must provide 65% of the heating energy with renewable energy sources. With this new regulation, the Government are hoping to kickstart the heat pump market; 500,000 new heat pumps are to be installed nationwide every year, totaling six million by 2030[17].

The European Green Deal aims to progressively eliminate boilers powered by fossil fuels. Member States are required to implement measures for phasing out fossil fuel-based heating and cooling, with the goal of completely removing these boilers by 2040.

[16] (RAP, 2022) A policy toolkit for global mass heat pump deployment (Nov 2022)

[17] (Spiegel, 2023) Operation Wärmepumpe_May 2023. Accessed 01.05.2025. Available at: https://www.spiegel.de/panorama/wahnsinn-waermewende-ein-land-in-panik-a-9ee7e594-e5b3-4c16-a96c-0d25f5f8f217?context=issue

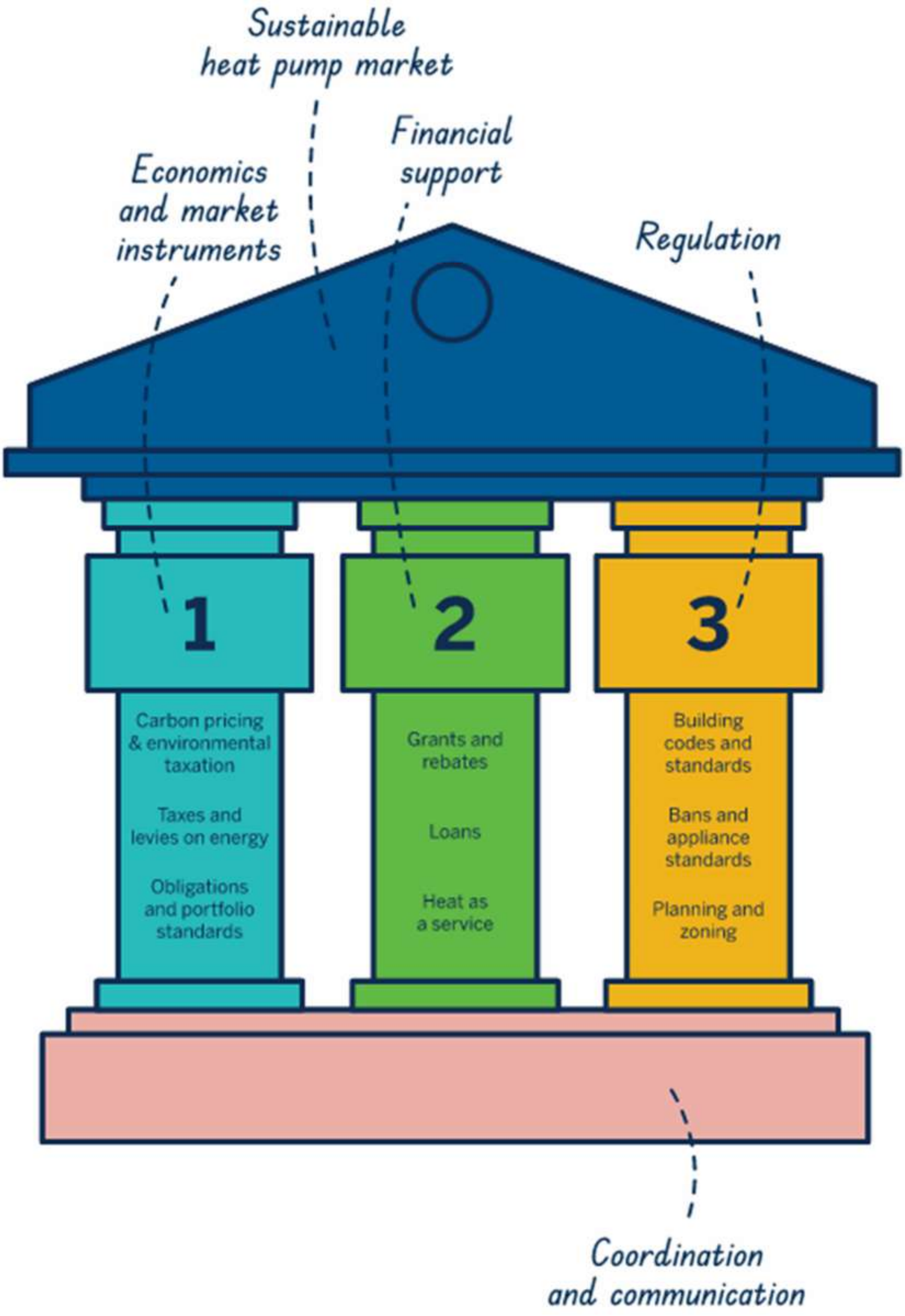

Figure 7: The Heat Pump Policy Toolkit framework[18]

[18] (RAP, 2022) A policy toolkit for global mass heat pump deployment (Nov 2022)

Finnish Heat Pump Association

In October 2024, I was very fortunate to speak to **Jussi Hirvonen, Executive Director of the Finnish Heat Pump Association, SULPU**. It was inspiring to hear about his journey and the development of the Finnish Heat Pump market. In 1992, Jussi imported the first Air to Air Heat Pump (AAHP) from Sweden. As illustrated in **Figure 3,** in 2022 Finland sold the most heat pumps per capita in Europe!

What are the key success factors that have allowed the Finnish heat pump market to flourish?

There are a number of factors that have contributed but well insulated buildings, cheap and stable electricity prices and affordable, easy drilling for bore holes are the key points. Political and historical factors should also not be ignored. Finland shares a complicated history and long border with Russia. Installing heat pumps offered an attractive energy independence away from Russian gas imports. The key factors mentioned above are unfortunately not so simple for other countries to achieve quickly. However, one easy lesson I think other countries can take from the Finnish Heat Pump Association is the **vital role of good communication:** sharing the facts, possible benefits and dispelling myths regarding heat pumps. Jussi has worked tirelessly throughout his career to provide clear, regular and transparent communication which has helped to build consumer confidence.

Figure 8: Jussi Hirvonen, Executive Director of the Finnish Heat Pump Association (SULPU).

Photo by William Holley (10.10.24)

Regular and transparent communication on heat pumps is not just the responsibility of the heat pump associations. The government and the media have a huge role to play. A key factor that hasn't helped the HP Market in Germany and the UK is the confusing and contradicting messaging regarding heat pumps.

In 2023 Robert Habeck, ex vice chancellor and joint leader of the green party made headlines by announcing the new energy act (Gebäude Energiegesetz) with very ambitious sustainability targets and clear support for the installation of heat pumps. Many would argue that such a significant change in policy was necessary to meet the carbon emission targets and 68% of the german population support the energy transition[19]. However, what caused confusion and anger was the lack of guidance on how the new energy act should be implemented. Many didn't understand the new regulations and installers, of whom there are far too few, lacked the expertise to install a heat pump. This created headlines such as:

'Expensive and controversial. With green overeagerness into chaos'

Figure 9 Spiegel magazine 'Operation Heat pump' (20.05.23)[20]

[19] (Wolf, Ebersbuch, & Huttarsch, 2023) Soziales Nachhaltigkeitsbarometer 2023

[20] (Spiegel, 2023) Operation Wärmepumpe_May 2023. Accessed 01.05.2025. Available at: https://www.spiegel.de/panorama/wahnsinn-waermewende-ein-land-in-panik-a-9ee7e594-e5b3-4c16-a96c-0d25f5f8f217?context=issue

Ill-conceived government policy and contradicting headlines in the media reduced consumer confidence and were incredibly damaging to the HP market. **So how can national government improve their approach on supporting the heat pump industry?** In addition to the policy toolkit illustrated in Figure 7, this research has highlighted the importance of the following points:

- **Straight forward regulations** that are easy to understand for industry and non-technical consumers

- **Accurate and transparent communication** on the pros and cons of installing heat pumps

- **Incentives for phasing out fossil fuels.** Patrick Crombez, (Deputy) General Manager at Daikin Europe's Environment Research Centre, stressed the importance of such policy measures, stating, *"Decisive action, including phasing out incentives for fossil fuels, stronger new-build regulations, and implementing renewable heating standards, will increase the replacement rates of fossil-fuel-based solutions by low-carbon heat pumps. Adopting the right policies and incentives today will bring the path to full decarbonization by 2050 within reach[21]."*

- **Explicit guidance for designers** – case studies showing successful HP integration in new and existing buildings. For example, in an existing building, what are the recommended minimum fabric efficiencies and system temperatures to ensure an effective HP installation.

- **Certified training programmes for installers**

The German Central Association for Sanitary, Heating and Air Conditioning estimates that around 60,000 installers alone will be needed to realise the government's targets. And the Institute for Labour Market and Occupational Research predicts that 400,000 additional skilled workers will be needed from 2025 onwards in order to implement all the projects in the coalition agreement on climate protection and building renovation[22].

The UK Government has just announced further support for the heat pump sector by expanding the Boiler Upgrade Schema (BUS), boosting training and offering consumers more flexible purchase options. There are plans to build a 'clean power army' with up to 18,000 professionals to be trained to retrofit homes and install heat pumps, insulation, solar panels and heat networks. An extra £5m will be provided to continue the Heat Training Grant until March 2026, supporting a further 5,500 heat pump installers and 3,500 heat network professionals.

The Boiler Upgrade Scheme – which currently offers up to £7,500 off the cost of a heat pump install, enjoyed its best month ever in March 2025, with 4,028 applications received – an increase of 88% on the same month last year[23].

- **Clear strategy for manufacturing and supply chain to meet the demand**

- **Subsidies and affordable running costs.** It is vital that low income families are supported in the energy transition.

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[21] (Refindustry, 2025) Daikin Highlights Heat Pump Market Potential and Refrigerant Strategy at ISH 2025. Available at: https://refindustry.com/news/market-news/daikin-highlights-heat-pump-market-potential-and-refrigerant-strategy-at-ish-2025/

[22] (Spiegel, 2023) Operation Wärmepumpe_May 2023. Accessed 01.05.2025. Available at: https://www.spiegel.de/panorama/wahnsinn-waermewende-ein-land-in-panik-a-9ee7e594-e5b3-4c16-a96c-0d25f5f8f217?context=issue

[23] (Cooling Post, 2025) Cooling Post_Government looks to expand boiler upgrade scheme_April 2025. Accessed 02.05.2025. Available at: https://www.coolingpost.com/uk-news/government-looks-to-expand-boiler-upgrade-scheme/

7. Challenges / Opportunities

The following chapter describes five of the biggest challenges and opportunities facing the current heat pump market.

7.1 Controls

My first meeting in Beijing, China was with Associate Professor Baolong Wang at the Institute of Built Environment at Tsinghua University. Tsinghua University is one of the highest ranking universities in the world hosting approximately 50,000 students.

One of Professor Wang's research projects investigated model based optimisation control of heat pump systems. This study analysed multiple parameters simultaneously to provide optimal performance. For example, internal and external condition monitoring, predicted demand, comfort parameters, compressor performance and cost of electricity.

How do we optimise heat pump performance and save money for the consumer?

During this meeting, we discussed how heat pumps; including the internal cycle and components such as the compressor, have already been optimised under the rated working conditions to a very high efficiency level. Professor Wang explained that the biggest potential to optimise heat pump performance is through controls oriented to real field conditions. Going forward, control systems that learn behaviour, monitor climate conditions and track dynamic pricing should be a standard component of a heat pump system.

Figure 10: Tsinghua University, Department of Building Science with Associate Professor Baolong Wang (19.03.25)

Industry Example: kapacity.io

Kapacity.io are a Finnish based company building smart power grids for heat pumps with a cloud based demand response platform. They have a vision to connect all heat pumps into a single platform, or Virtual Power Plant. They believe that leveraging the power of millions of devices by centrally adjusting their consumption will result in cost reductions, a decrease in grid emissions, and the prevention of rolling blackouts.[24] Smart control systems are particularly relevant in the Nordic countries as many consumers have a dynamic pricing tariff, meaning the price of electricity changes throughout the day. This can be beneficial for heat pump users in Finland, as there are certain parts of the day when electricity prices are close to 0.

In the following example, the price of electricity and external conditions are predicted and monitored to optimise performance and cost saving.

1. The heat pump is operated during the night to take advantage of cheaper electricity. This energy can then be stored in a buffer tank
2. The red bars indicate the high electricity prices between 8:00 and 9:00 AM.
3. The external temperature rises from -10°C in the morning to approximately 0°C in the evening
4. The estimated saving in heating energy costs due to the control system is 20%

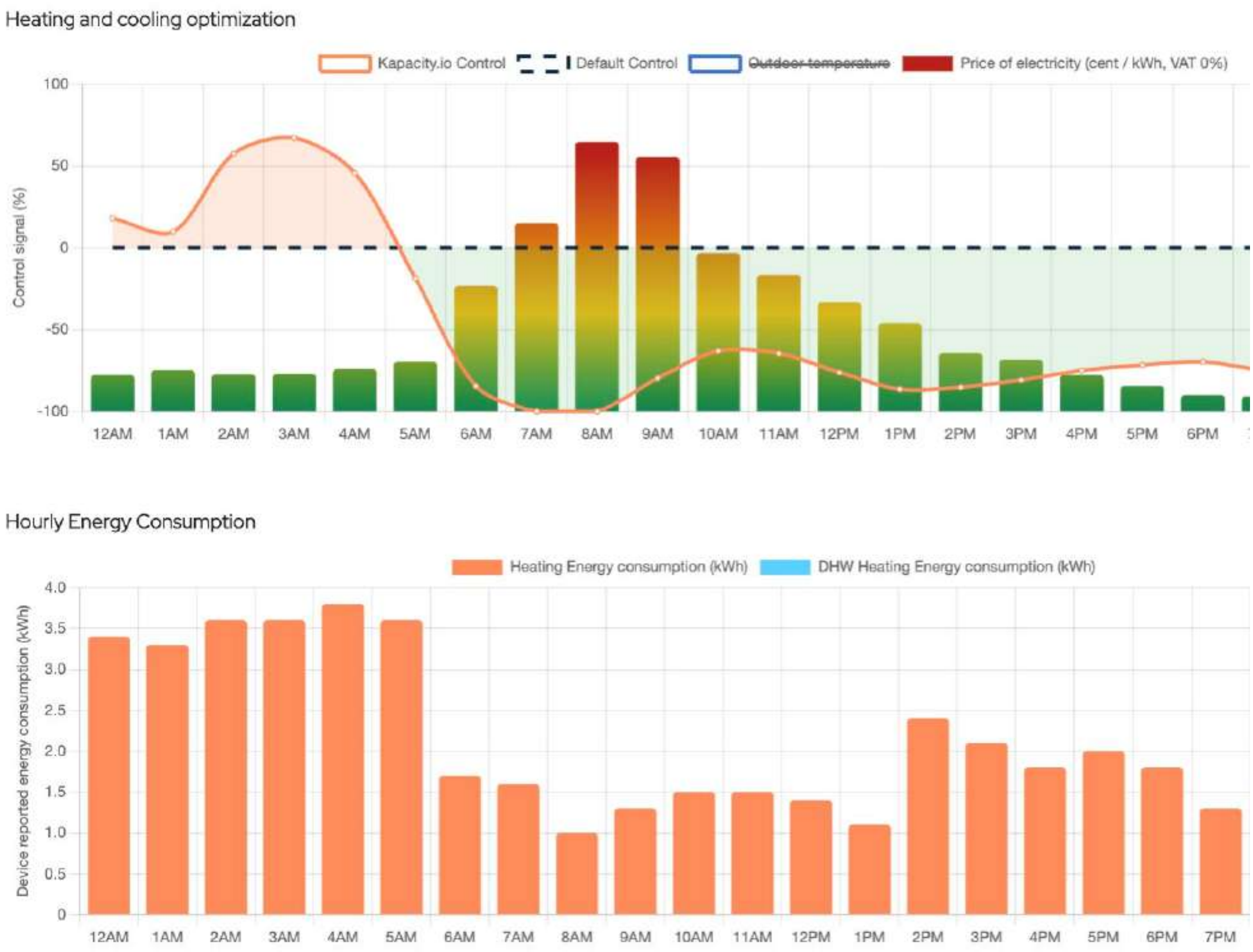

Figure 11: Heating optimisation of a heat pump using the smart control system from kapacity.io

[24] (kapacity.io, 2025) Mission: 100% decarbonized electricity grids. Accessed on 10.05.25. Available at: https://www.kapacity.io/about

7.2 Refrigerants

Refrigerant selection in a heat pump is crucial to achieve optimal performance for heating, cooling and hot water production. As can be seen in **Table 4,** various refrigerants exist, each with their own characteristics, advantages, and limitations.[25] An overview explaining the different refrigerant properties including Ozone Depleting Potential (ODP), Global Warming Potential (GWP), toxicity and flammability can be found in the **Appendix**.

Thanks to the latest F Gas Regulations[26] and the Kigali Amendment to the Montreal Protocol[27] we are on the path to the use of more climate friendly refrigerants. Due to the very low GWP, natural refrigerants would easily fulfil these requirements. However, safety issues and different performance properties hasn't allowed for an easy incorporation into the industry.

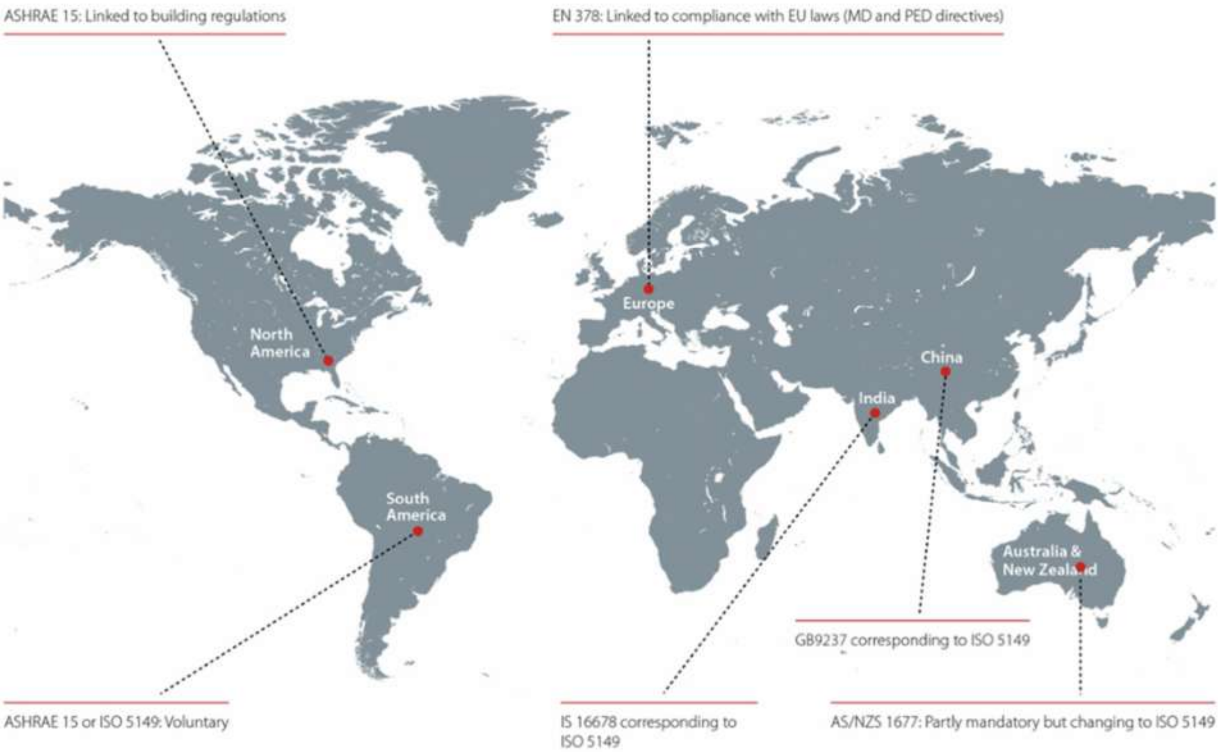

Figure 12: Global overview of standards affecting refrigerants

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[25] (HVAC Informed, 2025) Daikin at ISH25. March 2025 (Accessed 02.05.25). Available at: https://www.hvacinformed.com/docs/opdf/news/daikin-ish25-exhibiting-low-carbon-heat-solutions-co-1570611277-ga.1742376278.pdf

[26] **The latest F-gas regulations**, outlined in Regulation (EU) 2024/573, were adopted on February 7, 2024, and came into effect on March 11, 2024. The regulation introduces a steeper reduction in the amounts of HFCs that can be placed on the EU market, aiming for a complete phase-out by 2050. For more information, see the **Appendix.** (European Commission, 2024) *F-gas legisalation. March 2024 (Accessed (05.05.2025) Available at***:** https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/f-gas-legislation_en

[27] **The Kigali Amendment to the Montreal protocol** will reduce the production and consumption of hydrofluorocarbons (HFCs) by more than 80 per cent over the next 30 years. If fully implemented, the amendment can avoid up to 0.4°C of global warming by the end of this century. The Kigali Amendment came into effect on 1st January 2019. (UNDP, 2022) K*igali Amendment. Jan 2022 (Accessed 05.05.2025) Available at:* https://www.undp.org/chemicals-waste/montreal-protocol/kigali-amendment#:~:text=The%20Kigali%20Amendment%20to%20the,the%20end%20of%20this%20century.

Refrigerant	GWP	ODP	Flammability*	Saturation Pressure @25° (kPa)	Boiling Point	Critical Point**	Benefits	Drawbacks
R410a	2088	0	A1 - Non flammable	1650	-52	73	- High system efficiency - A1 refrigerant	- High GWP - Price will increase - Long term availability limited
R134a	1430	0	A1 - Non flammable	567	-26	102	- High system efficiency - A1 refrigerant	- High GWP - Price will increase - Long term availability limited
R-32	675	0	A2L - Mildly flammable	1710	-52	78	- Meets F-gas regulations - High system efficiency	- A2L - mildly flammable
R454B	465	0	A2L - Mildly flammable	1571	-51	77	- Possible replacement for R410a	- A2L - mildly flammable
Propane (R290)	3	0	A3 - Highly flammable	850	-42.1	96.7	- Enables flow temperatures of up to 75 °C in heat pumps - Lower condensing pressure compared to R32 - 5% extra funding from the German BEG programme for the use of natural refrigerant	- A3 - Highly flammable
R1234ze	1,37	0	A2L - Mildly flammable	427	19	109	- Low GWP	- A2L refrigerant - 20–25% lower volumetric refrigeration capacity - Larger unit dimensions
CO_2 (R744)	1	0	A1 - Non flammable	6370	-78	31	- Environmentally compatible refrigerant - Imperviousness to pressure losses - Not subject to the F-gas Regulation - Cost-effective	- Very high working pressure - Very low critical temperature (31 °C)

Table 4: Properties of commonly used refrigerants in heat pumps and air conditioning

*What does the classification A2L and A3 mean?
A2L refrigerants need at least 1,000 times more energy to ignite than most A3-class flammable refrigerants. It means that A2L refrigerants are unlikely to ignite from a discarded cigarette or a space heater. Even naked flames struggle to ignite A2L refrigerants under test conditions. What's more, the "L" means they have a low burning velocity. So, even in the event of ignition, the flame will likely burn slowly and self-extinguish.

**The critical point of a substance is the temperature and pressure at which the gas and liquid phases of the substance become indistinguishable from each other. At this point, the substance exists as a supercritical fluid, which has properties of both a liquid and a gas. Critical Temperature: The highest temperature at which a substance can exist as a liquid, regardless of pressure. Critical Pressure: The pressure required to liquefy a gas at its critical temperature.

Utilisation of natural refrigerants in heat pumps

The second stop of the research trip was to **FinnBuild**, the largest construction and building technology trade fair in Finland. Petrus Monni, Business Director from **Gebwell** presented the new heat pump product line which utilises the natural refrigerant R290 (propane). The increasing F Gas requirements across the EU, has led Gebwell to believe that developing products using R290 with a Global Warming Potential (GWP) of 3 and an Ozone Depletion Potential (ODP) 0 is the way forward.

"Using inlet water temperatures ranging from −5 to 20°C [23 to 68°F], we can produce outlet temperatures up to 75°C [167°F] with the 40kW unit and up to 63°C [145°F] with the 120KW product," Aku Leskinen Product Manager of Gebwell. Both units incorporate inverter technology and continuous ventilation and leak detection sensors to handle the A3 refrigerant safely.[28]

G-Eco Core 40: With a propane charge of 1.8kg, the 40kW unit provides an SCOP of up to 3.9 at an outlet temperature of 35°C (95°F) and 3.2 at 55°C (131°F), with a frequency-controlled scroll compressor.

G-Eco Pro 120: With a propane charge of 4.7kg, the 120kW unit provides an SCOP of up to 4.3 at an outlet temperature of 35°C and 3.4 at 55°C, with a piston compressor.

Figure 13: Gebwell presenting the new heat pump products at FinnBuild 2024. Photo by William Holley (10.10.24)

Even though Gebwell have decided to utilise propane in their new products, it is vital that designers check local regulations when specifying certain refrigerants. My personal experience in Germany is that refrigerant attributes such as GWP, toxicity and flammability need to be carefully considered. Despite R1234ze (GWP 0)

[28] (Haroldsen, 2025) Gebwell Ground Source Water to Water Propane Heat Pump. April 2025. (Accessed on 02.05.25) Available at: https://naturalrefrigerants.com/ish-2025-gebwell-releases-ground-source-water-to-water-propane-heat-pump-to-europe/

having an A2L 'low flammability' rating, specifying this refrigerant in a recent project required a number of additional safety features in the chiller plant room compared to a refrigerant with A1 flammability rating.

Daikin Altherma 4

A further example of a heat pump using the natural refrigerant R290 (Propane) is the Daikin Altherma 4. This product arrived on the European market in Autumn 2024 and has the following properties:

- Air to water heat pump with model capacities 6 / 8 / 10 / 12 / 14kW
- Three indoor unit variations allow for different applications (Wall mounted, floor standing with integrated tank, floor standing with ECH20 tank)[29]
- Flow temperature 75° possible at external temperature -14°
- Noise Level 47dBA at 3m normal operation
- Noise Level 34dBA at 2m night operation

As already mentioned, R290 has an A3 rating. A3 stands for (A) non-toxic with high flammability. For this reason, the Altherma 4 product has the following safety features:

- The refrigerant vessel is only partly filled for transport. This reduces the risk of ignition during storage and transport. The refrigerant is then filled to 100% at the commissioning stage.
- Leak detection – if a leak is detected, ventilation is switched on automatically. With additional ventilation, ignition is not possible.
- Reduced refrigerant volume – the new aluminium microchannel heat exchanger reduces the necessary quantity of the refrigerant to 1,3kg.
- Stand by Me Certified Partner Training Program – Daikin offers a training program to ensure the safe handling of R290 during installation, maintenance and disposal.
- An AWHP has the advantage that the refrigerant is located outside of the building – reducing the risk of fire inside the building.

Figure 14 Daikin Altherma 4, Air to Water Heat Pump

[29] (Daikin, 2024) DAIKIN Altherma 4. März 2024. (Accessed on 09.05.25) Available at: https://www.daikin.eu/en_us/press-releases/daikin-altherma-4-unveiled.html

Carl Lievens, General Manager Residential SBU at Daikin Europe expressed the following thoughts on future refrigerants at the recent ISH 2025:

"We are committed to supporting Europe's 2030 climate goals and believe in long-term heat pump growth despite the current market slowdown. With a projected market growth of 250% by 2030, Daikin will be at the forefront of heat pump adoption in the coming years.

By carefully selecting the most balanced refrigerant for each application, we prioritize energy efficiency, affordability and safety throughout the entire product lifecycle, from production and installation to maintenance and decommissioning. Meanwhile, we consider the European regulations on F-gases. We are committed to advocate for the flexibility of refrigerant choices: there is no one-size-fits-all solution to help decarbonize heating[30]*."*

What are the views of China & Japan on the use of natural refrigerants?

The Central Research Institute of Electric Power Industry (CRIEPI) in Japan started investigating the use of **natural refrigerants** in heat pumps in 1993. The initial studies showed that CO_2 had a large potential as a working fluid for heat pumps, especially for a heat pump water heater[31]. This research led to a successful collaboration between CRIEPI, DENSO CORPORATION and Tokyo Electric Power Company (TEPCO). In 2001 the **'Eco Cute'** heat pump for hot water was introduced to the Japanese market[32]. This product has been extremely successful and cumulative sales surpassed 10 million units in 2024.

- **Refrigerant:** CO_2 (R744) with a GWP 1
- **Components:** A typical HP capacity of 4.5kW is combined with a hot water tank of 300 litres. Both the HP and tank are typically placed outside
- **Hot Water Temperature:** 90°C, at -15° external temperature is possible
- **COP (Coefficient of Performance):** The initial models had a COP of around 3.5, but recent models have improved to a COP of 5.1.
- **Energy Savings:** Compared to conventional combustion-type water heaters, Eco Cute can reduce CO_2 emissions by approximately 65%.

[30] (Refindustry, 2025) Daikin Highlights Heat Pump Market Potential and Refrigerant Strategy at ISH 2025. Accessed 10.06.25. Available at: https://refindustry.com/news/market-news/daikin-highlights-heat-pump-market-potential-and-refrigerant-strategy-at-ish-2025/

[31] (CRIEPI & Saikawa, 2007) Development and Progress of CO2 Heat Pump Water Heater (Aug 2007)

[32] (HPTCJ, 2022) About Eco Cute. Accessed 09.05.25. Available at: https://www.hptcj.or.jp/en/learnings/water_heater/

Figure 15 Eco Cute Heat Pump for Hot water generation. A typical HP capacity of 4.5kW is combined with a hot water wank of 300 litres

While I was in Tokyo, I visited the Daikin Showroom in Shinjuku to get a closer look at this product. It was fascinating to see the difference between the European and Japanese products and how the Japanese bathing culture has influenced the product development of this hot water heat pump. For example, to maintain bath water temperature over time, the AWHP **'EcoCute'** product recirculates bath water to a separate heat recovery coil within the hot water storage unit. As illustrated in **Figure 16**, there is no cross contamination, just an exchange of heat.

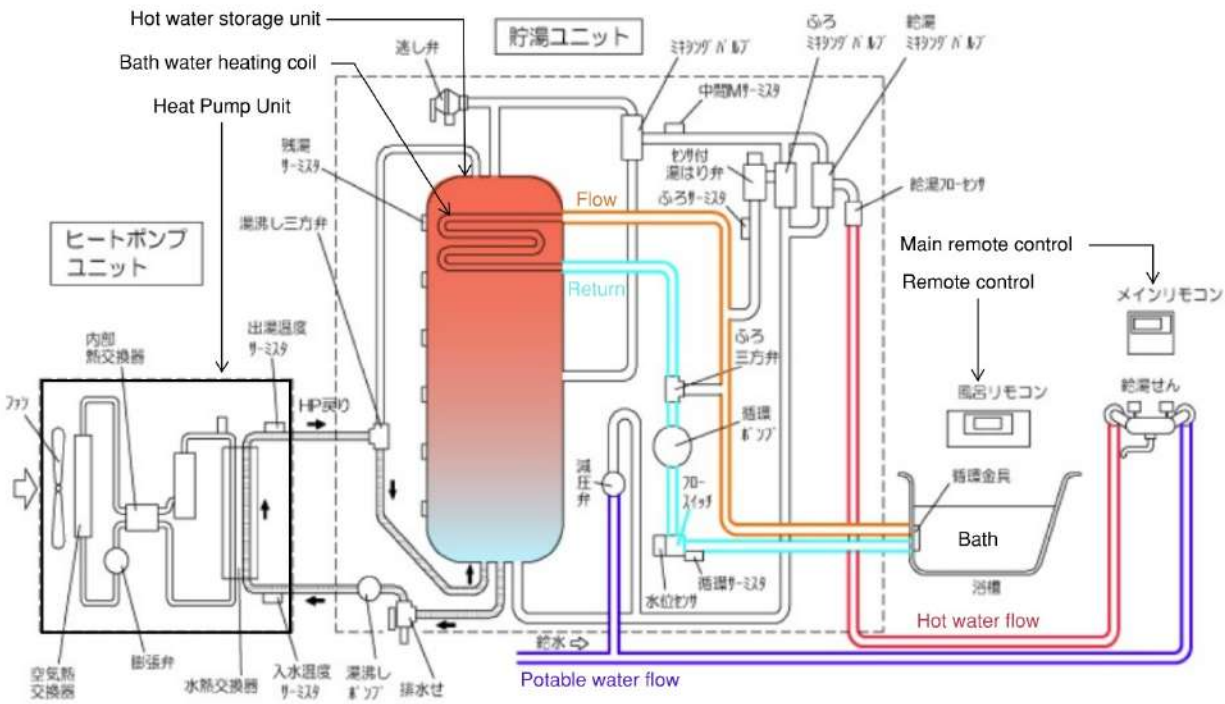

Figure 16 EcoCute Product Schematic[33]

[33] Remodel-plus. Inside Eco Cute. Accessed 15.07.25. Available at: Eco Cute Breakdown / Inside Eco Cute - Remodel Plus Nagoya

Figure 17: Daikin Showroom in Shinjuku, Tokyo (08.04.25)

One of Professor Wang's research projects at Tsinghua University is to advise the Chinese government on future refrigerants. This topic is also one of the hottest topics at the R&D Centers of Carrier and Daikin in Japan. As can be seen below, the selection of refrigerants for heat pumps, like for other equipment, requires a comprehensive consideration of multiple factors. The complexity of this task is increased as the various stakeholders (government agencies, equipment manufacturers, users, etc.) prioritise different aspects.

- **Safety** - This is being viewed as an incredibly important factor for both countries. Air to Air Heat Pumps (AAHP), which dominate the market in China and Japan, distribute the refrigerant within the building to the internal units. Therefore, the risk of installing flammable natural refrigerants is higher than circulating the refrigerant in the external unit only (Air to Water Heat Pump). In this case, manufacturers are still exploring different options to find the most effective and safest solution.

- **Sustainability** – as future products are developed, manufacturers are forced to follow the ever increasing requirements, such as the carbon emission targets, European regulations on F-gases and the UN Montreal Protocol Kigali Amendment regulations. Accurate consideration of comprehensive emissions is increasingly becoming a key criterion in refrigerant selection.

- **Cost –** cost of refrigerant will of course have a big impact on the final price of the product and profitability. In low-charge heat pumps, natural refrigerants, including R290, represent the future trend, though the pace of adoption varies across regions. The use of flammable refrigerants requires corresponding safety measures, which increases equipment costs. Thus, addressing cost challenges is actually one of the primary issues for the development of flammable refrigerants.

- **Performance –** a major challenge is that many of the new refrigerants have very different performance characteristics. For example CO_2 has a significantly higher saturation pressure than previously used refrigerants. R1234ze has a lower volumetric capacity resulting in larger unit dimensions.

- **Domestic manufacturing and stock security** - By focusing on local production, the countries seek to reduce reliance on imports and enhance national energy security.

7.3 Research & Standardised Testing

Research and standardised testing are crucial for the advancement and reliability of heat pump technology.

Standardised testing provides consistent benchmarks to evaluate the performance and efficiency of heat pumps. This helps manufacturers improve their products and ensures consumers receive reliable and effective systems. During my visit to the **Building Research Institute of Japan**, I learnt the importance of standardised testing including the actual performance of heat pumps. Recent investigations by Dr Masato Miyata (National Institute for Land and Infrastructure Management, NILIM) revealed that the actual performance of heat pumps had differed from the standard testing results. This means that many systems are not performing to their full potential in the real world. His investigations simulate the performance of heat pumps and air conditioning equipment at a wide range of climate and load conditions. For example, the external unit can be tested at a dry-bulb temperature of -20°C to 45°C and relative humidity of 30-80%.

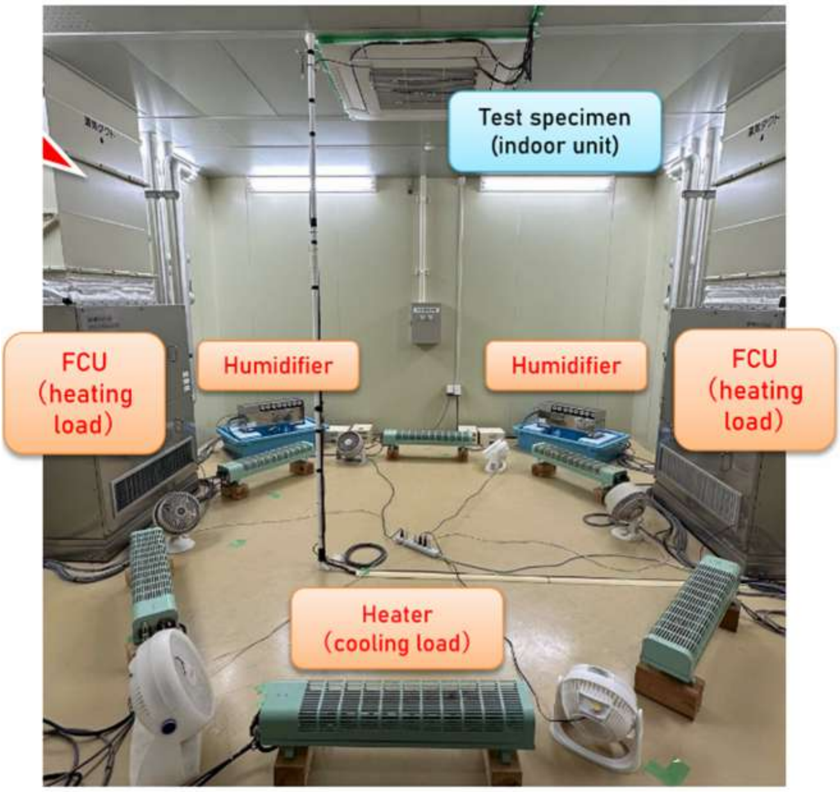

Figure 18: Indoor Chamber Testing Facility at the BRI of Japan, Tsukuba

Here are four takeaways on how the industry can improve in this area:

- Standardised testing needs to be consistent across the globe. The IEA revealed the disturbing findings that a great number of test methods for heat pump water heaters had major differences between them[34]. For example, product configuration, temperature conditions in the test room, tapping profiles and calculation procedures.

[34] (IEA, 2019) IEA_Test Procedures and Quality Labels for Heat Pump Water Heaters (Sept 2019)

- Standardised testing needs to reflect actual energy consumption characteristics. This means including a wider range of test criteria, for example, part-load performance and differing internal and external climate conditions. This will force manufacturers to improve energy efficiency of products during part-load conditions.
- Results should be published and explained clearly
- The testing facilities at CRIEPI, BRI and NILIM were very impressive and I found it particularly interesting how these private and publicly funded research institutions worked together. The close collaboration with manufacturers was also highlighted as a key to success. I believe other countries could benefit from adopting the testing culture and meticulous quality control found in Japan.

Figure 19: Building Research Institute of Japan in Tsukuba with colleagues from BRI, HPTCJ & NILIM. As you can see from the background, I was very fortunate to be in Japan during the cherry blossom (Sakura) season. (07.04.25)

Research and innovation are vital in the development of more efficient and environmentally friendly heat pumps. As mentioned in **Figure 15**, research at the CRIEPI led to the development of the incredibly successful Eco Cute Air to Water Heat Pump. CRIEPI is a privately funded institute that has a mission to deepen technological knowledge and contribute to the electrical industry by conducting research and testing. The research campus in Yokosuka has an extensive range of testing facilities including an Industrial & Commercial Heat Pump Performance Evaluation Facility, Air Conditioning Equipment Performance Evaluation Lab and an Air Heat Exchanger Testing Facility. During my visit, I learnt about two of their latest research projects:

1. **Development of a Climate Chamber Reproducing Real and Simulated Heating Spaces for Thermal Comfort Evaluation by S. Yasuda.**

Understandably, there is currently a huge focus on how to reduce CO_2 emissions in the built environment. However, we must not forget the importance of thermal comfort. CRIEPI are developing a climate chamber that can simulate a non-uniform thermal environment that is close to the thermal environment in an actual home, and investigating methods for evaluating comfort during heating and cooling. I was really impressed to see the level of detail of this experiment and believe that it is imperative that manufacturers and designers keep thermal comfort of the user as a top priority.

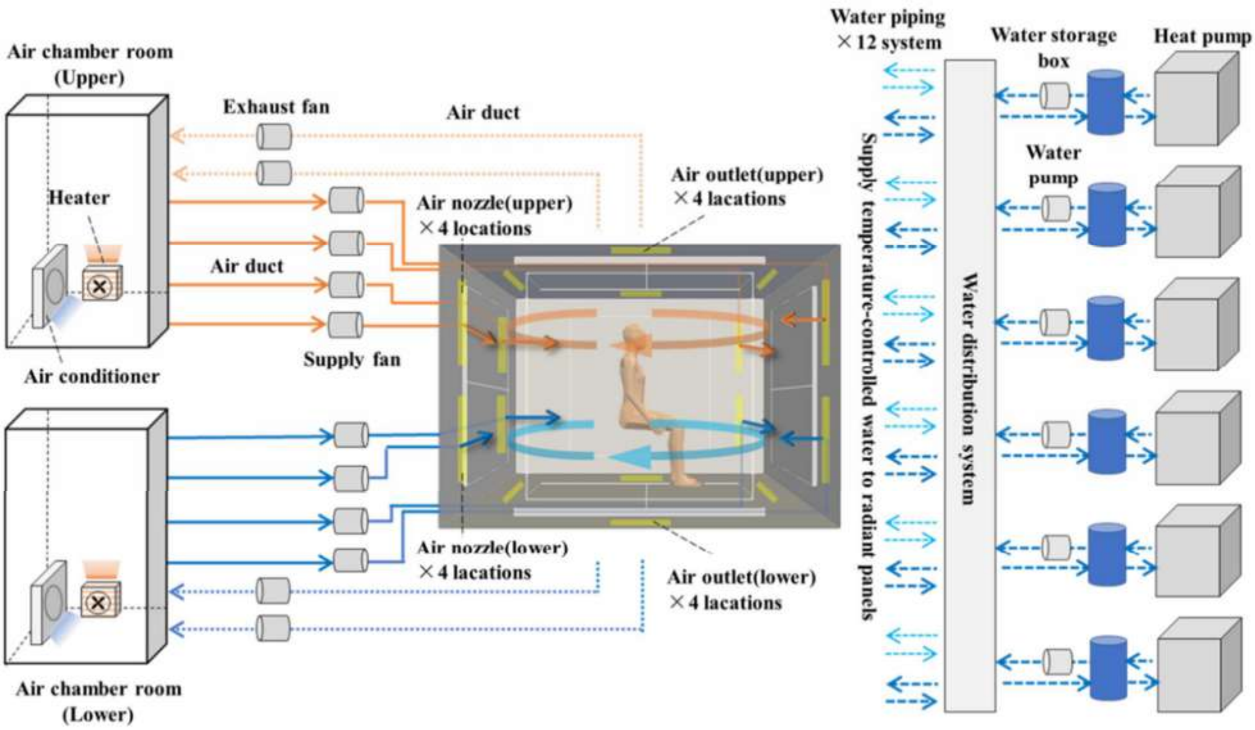

Figure 20: Climate chamber study to simulate thermal comfort

2. **Experimental Investigation of Hybrid Air-Conditioning System with Desiccant-Coated Heat Exchanger Using CO2 Refrigerant.** Tomohiro HIGASHI, Kohei TOKUNAGA , Li ZHANG , Michiyuki SAIKAWA , Chaobin Dang , Eiji HIHARA

The refrigeration cycle can include cooling dehumidification, which involves eliminating airborne water vapor by condensing it on the evaporator surface. However, this operation may cause refrigeration cycle efficiency to decline and require a condensate drain. Moreover, the humidification process requires an additional humidifier and a water supply. The scope for controlling humidity by desiccant is attracting increasing attention as a means of overcoming these issues. The desiccant can absorb the water vapor directly from the air and this can reduce the energy consumption required to control humidity[35]. This particular research project investigated the use of a hybrid heat pump system with a desiccant heat exchanger and CO_2 refrigerant.

[35] (Higashi, Tokunaga, Zhang, Saikawa, & Dang, 2022) Experimental Investigation of Hybrid Air-Conditioning System with Desiccant-Coated Heat Exchanger Using CO2 Refrigerant. (July 2022)

What future innovations will we see in the heat pump industry?

Summer conditions in certain areas of Japan can be very hot, humid and uncomfortable. Being able to control the temperature and humidity of the air is therefore vitally important. The two research projects at CRIEPI showed that humidity control using desiccant heat exchanges could be a future development in air conditioning and heat pump products. This is because utilising desiccant heat exchanges to dehumidify rather than cooling dehumidification has a great potential of saving energy and reducing CO_2 emissions. This also has the important benefit of improving thermal comfort.

Figure 21: CRIEPI Heat Pump Testing Building B with Tomohiro Higashi & Dr Tsuyoshi Ueno (04.04.25)

Figure 22: CRIEPI Testing Facility, external VRV unit test. This laboratory can simulate an external environment (-20 to 50°C).

Photo by William Holley (04.04.25)

7.4 User behaviour and building performance

A major challenge facing effective heat pump integration is that all buildings are unique and a one size fits all approach will not work. Hugely contrasting building fabric efficiency, wide ranging flow and return temperatures and differing consumer behaviours need to be considered by designers.

Figure 23 illustrates some major differences of user behaviour across the world. For example, a typical Japanese household consumes by far the least amount of energy for heating. This is not due to a very warm climate. On the contrary, Hokkaido, the northernmost of Japan's main islands experiences harsh winters with heavy snowfall and minimum winter temperatures of -12°C. Tokyo has milder winters compared to Hokkaido but still experiences minimum winter temperatures of 2°C.

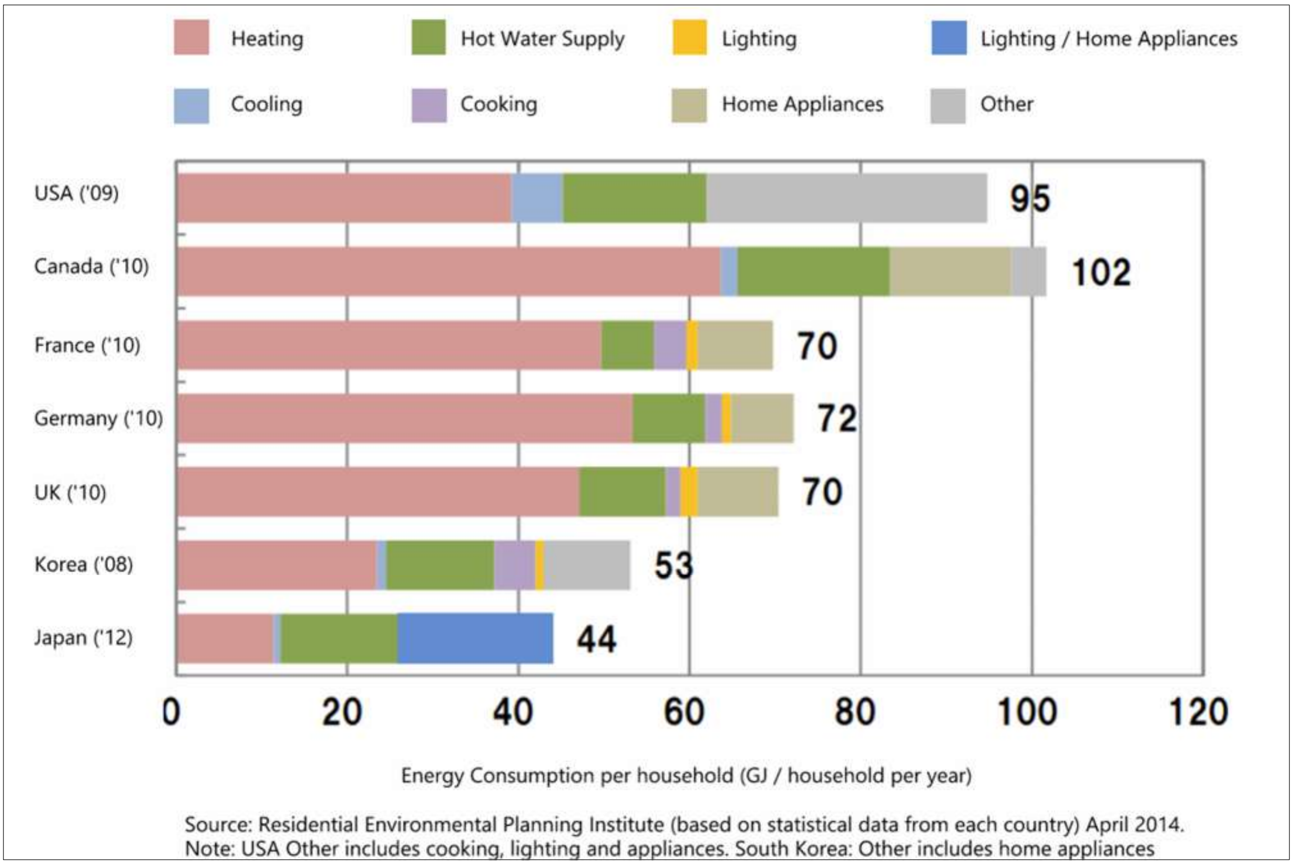

Figure 23: International comparison of household energy consumption

I learnt from the colleagues at the **Heat Pump & Thermal Storage Technology Center of Japan (HPTCJ)** that Japan's approach to heating and energy conservation is deeply rooted in both cultural practices and economic necessity.

Energy Conservation Culture

Japan has limited natural energy resources and relies heavily on imports for its energy needs. This has led to a strong cultural emphasis on energy efficiency and conservation. The concept of "**mottainai**", which means avoiding waste, is a fundamental part of Japanese culture[36]. This principle encourages people to use resources sparingly and efficiently. It is therefore not uncommon to experience internal temperatures of 10-15° in winter. In contrast, when the external temperature drops below 12° in Finland, heat pumps usually run constantly to provide a 21° internal temperature.

Heating Practices

Japanese homes often use individual room heating rather than central heating systems. This means that only the rooms in use are heated, while other areas like hallways, bathrooms, and entrances remain unheated. Traditionally, a Kotatsu; a low wooden table, covered by a futon with a heat source underneath would heat the living space. In modern apartments, the Kotatsu has been replaced by an internal split unit.

Figure 24 Traditional Japanese Kotatsu[37]

[36] (Japan Nakama, 2024) Energy Efficiency: Lessons from Japan's Success. Sept 2024. Accessed (09.05.25) Available at: https://www.japannakama.co.uk/lifestyle/energy-efficiency-lessons-japan/

[37] (Japanese Kotatsu, 2023) Futon Tokyo. Accessed (20.06.25) Available at: https://futontokyo.com/product/japanese-kotatsu-futon-reversible-organic/

Figure 25: Different indoor split unit models. Daikin showroom, Tokyo. Photo by William Holley (08.04.25)

Individual room heating with internal split units helps to reduce overall energy consumption but doesn't create a particularly pleasant thermal comfort in winter, especially from a European perspective. On my travels, I learnt that Japanese people are quite content with low internal temperatures, as long as they can spend time in the Ofuro (Bathtub).

Japanese bathing culture is rich in tradition and deeply ingrained in daily life. This is reflected in **Figure 23**, which shows that almost 30% of total energy consumption comes from hot water demand. This is by far the highest percentage of total energy consumption of any other country.

How does this affect the heat pump market?

The typical Japanese conservative heating practise and bathing culture has resulted in the following common solution:

- Heating is provided by an Air to Air Heat Pump. Internal split units are typically placed in the common spaces and bedrooms. Entrances, corridors and bathrooms are typically not heated.
- Hot water is provided by a separate Air to Water heat pump, for example, by the Eco Cute product seen in **Figure 15.**

Rather than trying to provide heating and hot water from one heat pump, it is quite common to split these systems entirely. What are the advantages of this?

- The air to air heat pump only heats the occupied rooms, using considerably less energy compared to a centralised heating system
- The refrigerants can be operated at optimum efficiency. For example, CO_2 heat pumps are more efficient for the high temperature hot water generation application.
- Despite consisting of two heat pumps, the separate heating and hot water system is cheaper than a typical centralised heating system. It is also quicker to install compared to a traditional heating network with radiators or underfloor heating commonly seen in Europe.

Figure 26: A visit to the Heat Pump & Thermal Storage Technology Center of Japan (HPTCJ) in Tokyo was key in helping to understand the differences in user behaviour and the local heat pump market (03.04.2025)

7.5 Heat Pump application in the industry sector

Fossil fuels are still extensively used in industrial processes which results in a major source of global CO_2 emissions. For example, 36% of China's total emissions comes from the industrial sector[38]. This is a huge area of potential for heat pumps, either in the form of hot water generation or utilising waste heat.

As illustrated in **Figure 27**, a heat pump can be applied in many industrial processes, such as fermentation, cleaning, drying and sterilization.

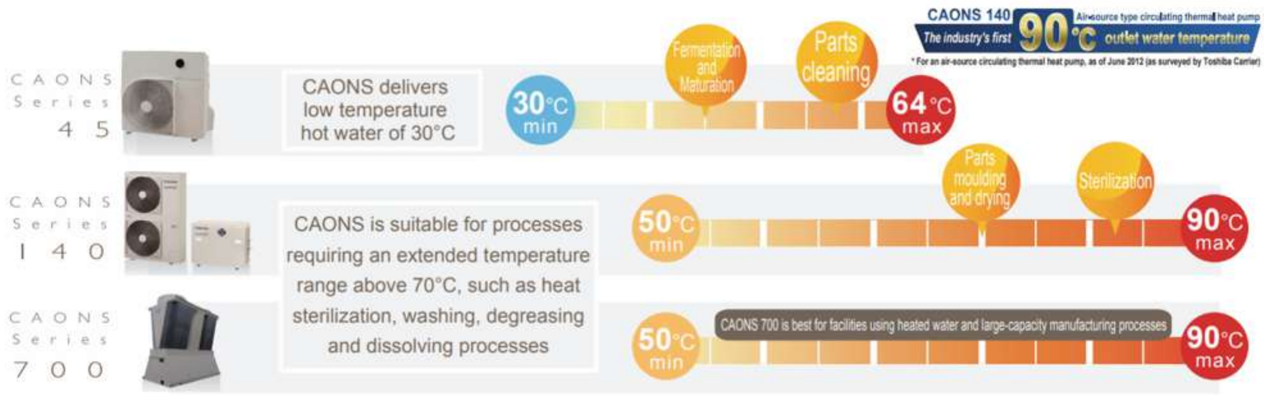

Figure 27: Industrial application of heat pumps[39]

On my visit to the Carrier factory (formerly Toshiba) in Shin Fuji, I learnt that Carrier had recently replaced a gas fired steam generator with an Air to Water Heat Pump (AWHP). The CAONS 140 AWHP was supplying hot water up to 90° as part of the compressor painting pretreatment liquid heating system. This is a fantastic example of how heat pumps can be applied in an industrial setting to significantly reduce CO_2 emissions. The CAONS 140 AWHP uses R134a refrigerant which has a GWP of 1430. A possible further improvement, from a CO_2 emission stand point, would be to use an AWHP with a natural refrigerant like CO_2 (GWP 1).

[38] (IEA, An Energy Sector Roadmap to Carbon Neutrality in China, 2021)

[39] Toshiba_Circulating Hot Water Heat Pump CAONS (July 2012)

Figure 28: Carrier Factory in Shin Fuji, Japan. This factory was built in 1951 by Toshiba. It now consists of a production line and R&D Center. In 2022, Carrier completed the acquisition of Toshiba’s global residential and light commercial HVAC business.

8. Project Case Studies

My first meeting in Finland was with Teemu Nieminen at the Fortum headquarters in Espoo to discuss how they are decarbonising energy infrastructure and the district heating network. Heat pumps are playing a key role in their projects including capturing heat from treated sewage water and sea water in the Suomenoja power plant and two new data centre heat recovery projects in collaboration with Microsoft. **Figure 29** shows the projects and timeline towards a carbon neutral heating network. What I found particularly interesting is the strategy of building small scale pilot projects. Teemu explained that this allows for testing and optimisation of the systems before making large scale changes and investments.

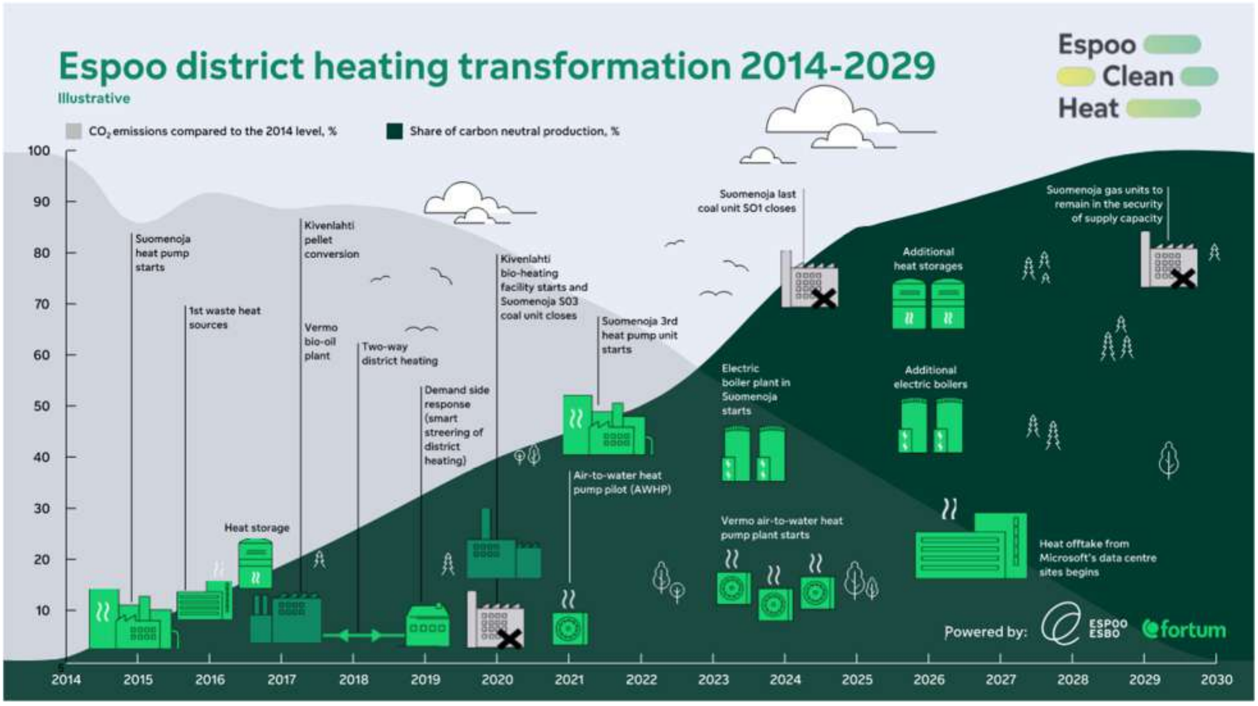

Figure 29: Espoo district heating transformation (2014-2029)

Case Study 1: Fortum Suomenoja Powerplant

Figure 30: Suomenoja Power Plant

This project is a great example of how to decarbonise a powerplant from fossil fuels using heat pumps. The Suomenoja Power Plant was transformed from using coal to using sewage water and sea water as a main heat source. 2.3 TWh of district heating were generated in 2022. The heat pumps are surprisingly 9 km from the waste water source. Sea water can also be used as a heat source (10 MW).

Project information:

- 2 CHP and 3 Heat pumps using treated sewage water and sea water as a heat source. The last coal fired unit was closed in April 2024.
- The HP plant can utilise treated sewage water or sea water (when it is warm enough) as a heat source. The treated waste water comes from local capital area water treatment company HSY
- 15 MW of district cooling can be produced as a side product of the heat pumps; water exiting the heat pumps is cool enough to produce district cooling via a heat exchanger.
- 20,000m^3 heat accumulator that can store about 800 MWh of heat energy in water and Electric Boilers (100MW) that are used during times of cheaper electricity.
- Maximum heat output 70 MW
- Heat Pump COP 3.2 – 4.0
- Water income from 7 – 20 °C, outlet min 2 °C

Case Study 2: Fortum-Microsoft partnership, waste heat recovery of two hyperscale data center sites

Figure 31: Kirkkonummi DC heat pump plant site in October 2024

In these two new projects, Fortum will capture the excess heat generated by a new data centre region to be built by Microsoft in the Helsinki metropolitan area in Finland. The data centres will use 100% emission-free electricity, heat pumps will recover and upgrade the waste heat which will then be delivered across the 900km district heating network to 250,000 customers. The waste heat recycling concept from the data centre region will be the largest of its kind in the world. This is a unique collaboration between Microsoft and Fortum and is set to start operation in 2027.

Project Information:

- 2 Data Center Sites (Hepokorpi, Espoo und Kolabacken, Kirkkonummi)
- 87 MW Heat pump capacity + 100MW electric boilers
- Primary Side: Heat source from data center or air-to-water heat pumps 30°. Water is returned from HP at 20°
- Secondary Side: Water provided to district heating network 75-85°C. Water return 45-85°C
- Kirkkonummi site heat accumulator 20.000 m^3 = approx. 800 MWh
- 16 AWHP & 4 AWHP Multifunctional heat pumps
- District heating system (Flow temperatures between 75°-115°, return 45°)

These innovative and sustainable developments illustrate how heat pumps can be successfully integrated at an infrastructure scale and are a great example to countries around the world of how to decarbonise district heating networks.

On the journey towards digitisation and decarbonisation, **how can we foster partnerships between data centres and energy providers?** This case study highlights the enormous potential benefits and demonstrates how heat pumps can be utilised to absorb and upgrade waste heat.

Figure 32: Teemu Nieminen. Director, Project Execution at Fortum. Photo by William Holley (08.10.24)

9. Conclusion

The main objective of this paper was to analyse the feasibility, opportunities and challenges facing heat pump technology on the quest to achieve the ambitious global CO_2 emission targets. The investigations revealed that there is unfortunately no silver bullet shaped heat pump that will achieve these targets. The points below summarise the multifaceted approach that is necessary to help us achieve the targets with heat pumps:

1. The biggest opportunity to reduce CO_2 emissions with heat pumps is to utilise them in an industrial setting. The Carrier factory case study demonstrates that heat pumps can reliably provide hot water (up to 90°) and replace the use of fossil fuels.

2. Well insulated buildings, cheap and stable electricity prices and good transparent communication. These were the key factors that enabled Finland to achieve a 100% increase in cumulative heat pump sales between 2016 and 2024. Well insulated buildings allow heat pumps to run at low flow & return water temperatures. At these temperatures, heat pumps achieve their best COPs. Cheap and stable electricity prices create additional consumer motivation to switch from gas heating. Good transparent communication gives a better understanding of the technology and improves consumer confidence.

3. Smart control systems that learn behaviour, monitor climate conditions and track dynamic pricing need to be a standard component of a heat pump.

4. Research and utilisation of natural refrigerants in heat pumps should be expanded. With the necessary safety measures, there is a great potential of lowering global warming potential.

5. Analysing user behaviour and building performance before specifying a heat pump is vital. Interviews at the HPTCJ and CRIEPI revealed that buildings in Japan often have much higher hot water loads compared to Europe and use air systems for heating. Therefore, an air to water heat pumps (AWHP) using CO_2 refrigerant for hot water and a separate air to air heat pump (AAHP) for space heating is a common and efficient solution in this case.

6. Standardised testing needs to be consistent across the globe and reflect actual energy consumption characteristics. This will help manufacturers improve their products and ensures that consumers receive reliable and effective heat pump systems.

7. Equitable government policy and clear regulations are required. Offering higher subsidies to low income families and lowering the cost of electricity will ensure no one is left behind on the transition to clean energy. Clear regulations and guidance will allow engineers to design effective heat pump systems.

8. Structured training programmes and secure supply chains. The German Central Association for Sanitary, Heating and Air Conditioning estimates that around 60,000 installers alone will be needed to realise the government's targets. Training programmes are vital to avoid a skills shortage and ensure high quality installations. Local manufacturing of heat pump components is highly recommended to ensure a secure supply chain and avoid dependency on imports and price fluctuations.

10. Appendix

Refrigerant Properties:

Mitsubishi Electric have prepared the following summary of important refrigerant properties:[40]

Safety:

From a safety perspective, refrigerants can be assessed in terms of the parameters of toxicity and flammability. ISO 817 and DIN EN 378 classify refrigerants into eight safety groups according to their flammability and toxicity.

The classification of refrigerants in the various safety groups correlates to a parameter from the environmental criteria. It is generally the case for synthetic refrigerants that the higher the flammability of a refrigerant, the lower the global warming potential (GWP).

ODP:

The ODP (ozone depletion potential) is a value that clarifies the damaging effects a chemical substance has on the ozone layer in the stratosphere. It is a relative value that compares the effects of a chemical substance with the effects of trichlorofluoromethane (R11), which is assigned the ODP value 1 in the Montreal Protocol. Since the mid-1990s, the refrigeration and air conditioning industry has been striving to find alternative, environmentally friendly, efficient and safe refrigerants. For this reason, refrigerants containing chlorine, such as R22, have been banned and the focus has been placed on existing refrigerants with no ozone depletion potential.

GWP:

The GWP (global warming potential) denotes the potential influence that a specific refrigerant may have on global warming – for example, if it were to escape into the atmosphere due to a leak. It is a relative value, meaning that it compares the influence of the refrigerant in question with the influence of carbon dioxide (CO_2) over a period of 100 years. CO_2 has a defined GWP of 1. With a GWP of 675, the refrigerant R32 would therefore have a global warming impact 675 times greater than that of CO_2 in the first 100 years after its release. The lower the GWP of a refrigerant, the lower its potential global warming impact on the environment. To calculate the CO_2 equivalent of a refrigerant, take the charge quantity and multiply it by the GWP value. The next step is to use refrigerants that have no ozone depletion potential and also feature a low global warming potential (GWP). The phase-down in the F-gas Regulation additionally governs the reduction of global warming potential (GWP).

[40] (Mitsubishi Electric, 2025) Overview of Refrigerants. Jan 2025 (Accessed on 02.05.2025). Available at: https://www.mitsubishi-les.com/en-de/knowledge/overview-of-refrigerants-64.html

F-gas Regulation

Background

Having entered into force on 1 January 2015, the European F-gas Regulation (regulation no. 517/2014) was intended to gradually limit the amount of partially halogenated hydrofluorocarbons (HFCs) by 2030. The original aim was to reduce the F-gases placed on the market by 79% of the CO2-equivalent emissions as compared to 2015.

Amendment of the EU F-gas regulation 2024

The regulation (EU) No 517/2014 of the European Parliament on Fluorinated Greenhouse Gases (F-gases), which took effect on 1 January 2015, has been revised. EU institutions have been negotiating a new proposal since April 2022. The EU trilogue agreed to the amendment on 5 October 2023. The preliminary legislation was made public on 18 October 2023.

Aims

Adaptation to the European Green Deal and the European Climate Law (EU carbon neutrality by 2050 + intermediate goals such as a reduction of 55 % in total greenhouse gases by 2030 as compared to 1990 > Fit For 55 <).
Intensified reduction of emissions of fluorinated greenhouse gases. Emissions will be more tightly regulated by 2050 and should save up to 500 Mt of CO2eq.

New adaptations / measures:

1) Extension on prohibition of sale of new systems with GWP limits beginning in 2025

2) Restrictions on use of HFC refrigerants for service, repair and maintenance beginning in 2025

3) Stricter HFC phase-down (CO2eq quota mechanism) by 2050 and CO2eq beginning in 2025

4) Handling refrigerants > requirements with regard to training and certification, including for HFC and natural refrigerants

5) Stricter regulations to fight illegal imports of refrigerants into the EU

6) Optimisation of checking and monitoring of compliance with EU regulation

The amended EU F-gas regulation goes into effect during the first half of 2024, once it has been published in the EU Official Journal.

11. References

BECKER, L. (2023, 12 18). *COP28 – Results, Key Findings and Summary*. Retrieved from dfge: https://dfge.de/cop28-results-key-findings-and-summary

BMWK. (2023). *Wärmepumpen im Gebäudesektor (Heat pumps in the building sector).*

BWP. (2024). *Branchenstudie 2024.*

Cooling Post. (2025, April). *Government looks to expand boiler upgrade scheme*. Retrieved May 02, 2025, from https://www.coolingpost.com/uk-news/government-looks-to-expand-boiler-upgrade-scheme/

CRIEPI, & Saikawa. (2007). *Development and Progress of CO2 Heat Pump Water Heater.*

Daikin. (2024, May). *DAIKIN Altherma 4*. Retrieved May 09, 2025, from https://www.daikin.eu/en_us/press-releases/daikin-altherma-4-unveiled.html

EMBER. (2023). *Analysis of the ten largest power sector emitters in 2022*. Retrieved April 30, 2025, from https://ember-energy.org/latest-insights/global-electricity-review-2023/country-and-region-deep-dives/#china

European Commission. (2024, March). *F-gas legisalation*. Retrieved May 02, 2025, from https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/f-gas-legislation_en

Finnish Energy. (2024). *Electricity Year 2023.*

Haroldsen. (2025, April). *Gebwell Ground Source Water to Water Propane Heat Pump*. Retrieved May 02, 2025, from https://naturalrefrigerants.com/ish-2025-gebwell-releases-ground-source-water-to-water-propane-heat-pump-to-europe/

Higashi, Tokunaga, Zhang, Saikawa, & Dang. (2022). *Experimental Investigation of Hybrid Air-Conditioning System with Desiccant-Coated Heat Exchanger Using CO2 Refrigerant.*

HPA. (2024). *HPA Statistics 2024.* . Retrieved from https://www.heatpumps.org.uk/resources/statistics/.

HPTCJ. (2022). *About Eco Cute.* Retrieved May 09, 2025, from https://www.hptcj.or.jp/en/learnings/water_heater/

HVAC Informed. (2025, March). *Daikin at ISH25*. Retrieved May 02, 2025, from https://www.hvacinformed.com/docs/opdf/news/daikin-ish25-exhibiting-low-carbon-heat-solutions-co-1570611277-ga.1742376278.pdf

IEA. (2019). *Test Procedures and Quality Labels for Heat Pump Water Heaters.*

IEA. (2021). *An Energy Sector Roadmap to Carbon Neutrality in China.*

IEA. (February 2025). *Electricity 2025. Analysis and forecast to 2027.*

IEA, & Statistics Finland. (2022). *Granted building permits*. Retrieved July 25, 2025, from https://heatpumpingtechnologies.org/wp-content/uploads/2022/09/member-country-reportfinland-20220907jussi-hirvonen.pdf

IEA, & Tsinghua Uni. (2024). *Future of HP in China.*

Japan Nakama. (2024, September). *Energy Efficiency: Lessons from Japan's Success.* Retrieved May 09, 2025, from https://www.japannakama.co.uk/lifestyle/energy-efficiency-lessons-japan/

Japanese Kotatsu. (2023). *Futon Tokyo*. Retrieved June 20, 2025, from https://futontokyo.com/product/japanese-kotatsu-futon-reversible-organic/

JME. (2025). *(Japanese Ministry of Economy) Trade & Industry Annual Report 2023*.

kapacity.io. (2025). *Mission: 100% decarbonized electricity grids*. Retrieved May 10, 2025, from https://www.kapacity.io/about

Mitsubishi Electric. (2025, January). *Overview of Refrigerants. Jan 2025*. Retrieved May 02, 2025, from https://www.mitsubishi-les.com/en-de/knowledge/overview-of-refrigerants-64.html

RAP. (2022). *A policy toolit for global mass heat pump deployment*.

Refindustry. (2025). *Daikin Highlights Heat Pump Market Potential and Refrigerant Strategy at ISH 2025*. Retrieved June 10, 25, from https://refindustry.com/news/market-news/daikin-highlights-heat-pump-market-potential-and-refrigerant-strategy-at-ish-2025/

Spiegel. (2023). *Operation Wärmepumpe*. Retrieved May 01, 2025, from https://www.spiegel.de/panorama/wahnsinn-waermewende-ein-land-in-panik-a-9ee7e594-e5b3-4c16-a96c-0d25f5f8f217?context=issue

SULPU. (2025). *Heat Pump market in Finland 2024*.

UNDP. (2022). *Kigali Amendment*. Retrieved May 02, 2025, from https://www.undp.org/chemicals-waste/montreal-protocol/kigali-amendment#:~:text=The%20Kigali%20Amendment%20to%20the,the%20end%20of%20this%20century.

Warren. (2023). *The Price Cap and the Spark Gap*. Retrieved April 30, 2025, from https://www.linkedin.com/pulse/price-cap-spark-gap-richard-warren/

Wolf, Ebersbuch, & Huttarsch. (2023). *Soziales Nachhaltigkeitsbarometer der Energie- und Verkehswende 2023*. Kopernikus-Projekt Ariadne. Retrieved from https://ariadneprojekt.de/publikation/soziales-nachhaltigkeitsbarometer-2023/

World Population Review. (2025). *Cost of Electricity by Country 2025*. Retrieved 06 24, 2025, from https://worldpopulationreview.com/country-rankings/cost-of-electricity-by-country