ENGINEERING TOMORROW

Article | Danfoss Climate Solutions — District Energy

Fast track to **sustainable** energy

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Over seven years since the Paris Agreement was widely adopted at COP 21, the complexities involved in limiting global warming continue to impede substantial progress. If we are to realize the goal of limiting the global temperature increase to 1.5°C above pre-industrial levels, time is at a premium and radical changes are required. However, many countries are struggling to turn their commitment to the Paris Agreement into action. This article outlines why decarbonizing heating and cooling in the building sector should be prioritized to kick-start the transition to sustainable energy. Additionally, it argues that district energy can fast-track this process with existing proven technology, utilizing its flexible and resilient infrastructure to support and balance other energy sectors.

Parisian complexity continues to frustrate green energy transition

On the 12th of December 2015, the Paris Agreement was adopted by 196 parties, including 193 UN member countries, at COP 21, setting the goal of limiting global warming to well below 2°C compared to pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. The agreement came into force on the 4th of November 2016, after 55 parties to the COP 21 convention, representing 55% of global greenhouse gas (GHG) emissions, ratified the agreement. As of 2023, 194 of the 198 parties to the convention have ratified the agreement, accounting for close to 98% of the world's GHG emissions.

According to the IPCC's Sixth Assessment Report (AR6) of Working Group I from 2021, the path for realizing the goal of 1.5°C is still possible if stringent measures are applied to reach net zero GHG emissions by 2050. As the energy sector (power, heat and transport) is a major GHG emitter, accounting for 73.2% of global GHG emissions[1], significant and radical changes to how we generate energy will be required. The energy sector needs to transition from fossil fuels to renewable energy sources in a sustainable way and with the minimum environmental impact. One of the solutions that can truly fast-track the transition to a sustainable energy system is **district energy.**

While the Paris Agreement is a groundbreaking agreement, the complexities inherent to the tasks required are enormous.

This is strongly emphasized by the fact that subsequent COP meetings have addressed parts of the agreement for facilitating the implementation.

- **COP 22** (2016) had a primary focus on the financial side for facilitating the implementation of the agreement.
- **COP 23** (2017) had a primary focus on land sector emissions (agriculture, forestry and other land use). The Powering Past Coal Alliance was also launched at COP 23, which is an alliance between countries aiming to phase out coal in the energy sector.
- **COP 24** (2018) had a primary focus on negotiating how the Paris Agreement would be implemented transparently and fairly, which led to the Paris Agreement Rulebook. During the convention, it was also recognized that countries should take more adaptive, active, and determined steps to enforce and reach the climate plans they had submitted.

[1] Source: *https://ourworldindata.org/emissions-by-sector*

- **COP 25** (2019) had the primary focus of developing guidelines for how international carbon markets should work and how to compensate countries already suffering from the impacts of climate change. Neither goal was achieved.
- **COP 26** (2021) had the primary focus of reviewing the Paris Agreement and Kyoto Protocol and adopting decisions to further develop and implement these instruments. During the conference, the Paris Agreement Rulebook was completed and parties to the conference signed the Glasgow Climate Pact, which is an agreement to accelerate efforts to close the 2030 emission climate gap.
- **COP 27** (2022) had the primary focus of achieving an agreement to provide "loss and damage" funding for vulnerable countries hit hard by climate disasters. Parties to the conference further delivered a package of decisions that reaffirmed their commitment to limit the global temperature rise to 1.5°C.

As the above review of the latest COPs shows, the task and complexity of realizing the goal of the Paris Agreement is extensive. While many countries have entered the implementation phase, the overall lack of progress shows that there is a gap between commitment and actual policies in many countries due to the complexity of the transition.

Since most countries are operating their energy systems on a commercial basis, the role of policies and a general political will to guide the market in the direction of energy efficiency solutions becomes important.

Decarbonizing heating and cooling

Of all GHG emitting sectors, the building sector is the one that is easiest to decarbonize, as mature and well-proven technologies already exist for both urban and rural areas. Not only is the building sector the simplest sector to decarbonize, it is also a major energy consumer. The building sector's share of the total energy consumption varies between regions: in Europe it accounts for about 40%, in the Asia-Pacific region around 30% due to more energy intensive industry. In general, space heating/cooling and hot water account for 60-80% of building energy consumption.

Globally, heating and cooling is expected to remain the largest energy sector, even in 2050 decarbonization scenarios[2]. Clearly, if we want to achieve the energy transition, we need to decarbonize heating and cooling.

To decarbonize in a cost optimal way, taking a holistic approach is crucial. Two things go hand in hand: improving energy efficiency and ensuring the remaining energy demand is covered by carbon neutral energy sources. It is therefore important to look at the entire energy system, from energy production, energy conversion, and energy distribution to final energy use, and identify energy efficiency potentials. For example, a simple, cost effective, and often neglected measure is the optimization of heating and cooling installation in buildings, which reduces energy consumption by up to 28%[3]. Such no-regret measures can significantly reduce the overall cost for decarbonization.

While the decarbonization of heating is often seen as one of the biggest challenges of the energy transition today, the solution is closer than one might think. The key is the largely disregarded fact that **the required energy quality for space heating and cooling is very low.** In fact, it is so low that there is an abundance of suitable energy sources around us that can easily fulfil our space heating and cooling demand. Even so, the demand is today primarily met by high quality energy in the form of gas, oil or electricity—for different historical, logistical and financial reasons. Instead, we should use renewable sources, such as geothermal and solar thermal, as well as excess heat from industry and the tertiary sector (e.g. data centers, supermarkets). Amory Lovins, the American ecologist got it right when he said that the use of nuclear-powered electricity or fossil fuels to provide space heating and cooling or hot water is like "using a chainsaw to cut butter".

Today, we have the knowhow, the experience, and the technology to tap into these sustainable energy sources and supply heating and cooling to the building stock in an efficient manner. In rural areas, the long-term sustainable decarbonization solution is electrification via heat pumps. In urban areas, the most promising and sustainable decarbonization solutions are district energy systems. District energy systems are water-based distribution networks that connect the building stock to a wide range of renewable and sustainable thermal sources.

[2] Source: Review of available information - Accompanying the document: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling. *https://ec.europa.eu/energy/content/winter-package-heating-and-cooling_en?redir=1*
[3] Source: Optimising the energy use of technical building systems – unleashing the power of the EPBD's Article 8. Ecofys Germany GmbH, 2017

District energy and the green transition

District energy systems are local infrastructures connecting buildings across districts or cities with central thermal generation plants, as well as various low temperature and renewable waste energy sources. As the thermal energy is supplied by water at directly usable temperature levels, no energy conversion process is required for end-users, and district energy systems consequently create a unique opportunity to utilize local resources and harvest synergies with other sectors. In terms of fast tracking the energy transition, district energy systems possess the following key abilities:

- **Multi-source nature:** As the energy carrier is water, there are essentially no limitations on the type and number of thermal sources the network can include. This allows for fast conversion of existing fossil fuel-based systems to renewable energy sources and the realization of new systems using local resources.

- **Fuel independent:** As the thermal generation is centralized, the type of fuel used is irrelevant for end-users, which enables fast and uncomplicated transition from one fuel to another for all connected thermal users.

- **Load shifting and sector integration potential:** With large scale and efficient thermal energy storages, district energy systems enable the decoupling of energy consumption and generation. When supported by modern digital solutions, district energy systems become a backbone in the integrated energy system by offering large-scale flexibility that is vital for maximizing the utilization of renewable energy sources and balancing the power grid.

- **Cost-efficient and low maintenance requirements:** The interface units connecting buildings to district energy systems are simple, efficient and low cost; the thermal energy generation is optimized and professionally operated, and system maintenance is carried out on a continuous basis by professionals.

Combining these abilities creates the framework for fast tracking the energy transition from fossil fuels to renewables for building thermal demands.

Best practice examples are showing the way

The share of district energy in the heating and cooling supply varies at a national and regional level. In the European Union, district heating has an average market share of only 12%, although in some champion countries such as Denmark, Sweden and Latvia, district heating covers between 50% and 66% of the heat demand and is growing. The feasible share of district heating in the EU has been estimated to be around 50%[4]. The market share of district heating outside Europe is not particularly well documented. Examples of strong markets are South Korea and northern China, with 15% and 55% market share, respectively. While district cooling has been applied since the 1960s, it has developed at a slower rate than district heating, but recent years have shown strong uptake in the Middle East and southern Asia, which are expected to be the main drivers for district cooling growth in the coming decades. In Europe, district cooling is expected to have moderate growth, driven by increasingly warm summers, better insulated building stock, strong focus on decarbonization of the energy sector and exploitable synergies with the well-developed European district heating market. The development stage, as well as efficiency of district energy systems, varies significantly between regions, and today the most advanced and efficient systems are found in Scandinavia, where district heating systems and building heating installation are complementing each other, leading to the high overall energy efficiency of the building heating sector.

District energy systems have the unique feature that they allow rapid and cost efficient decarbonization of the heat supply, due to their heat/cool source neutrality. Great examples are Denmark and Sweden. The Swedish district heating sector was decarbonized by 80% between 1980 and 2006 through introduction of biofuels, waste incineration plants and large heat pumps[5]. The Danish district heating sector was decarbonized by 70% between 1990 and 2017 through introduction of biofuels, waste incineration plants and low-grade renewables[6]. The next large transformation of the Danish district heating sector is already underway and entails smart integration, and exploitation of synergies with the other energy sectors via electrification using heat pumps and electric boilers. The experience in both Sweden and Denmark shows that once district heating systems are established, decarbonization is just a matter of connecting environmentally friendly heat sources to the distribution grid.

District cooling is, in comparison to district heating, a relatively newly applied solution but built on the vast experience acquired in the district heating field. The economic competitiveness of district cooling compared to building level cooling solutions generally lead to installed schemes growing extremely fast until the cooling market in the area is saturated. Examples of successful district cooling systems in Europe are in northern Europe (e.g. Stockholm, Sweden and Helsinki, Finland), as well as southern Europe (e.g. Paris, France and Barcelona, Spain). District cooling is also widely applied across the Arabian Peninsula, the United States and in Asia.

[4] Source: Connolly, D., Mathiesen, BV., Østergaard, PA., Möller, B., Nielsen, S., Lund, H., Persson, U., Werner, S., Grözinger, J., Boermans, T., Bosquet, M., Trier, D. Heat Roadmap Europe: Second pre-study.
[5] Source: Werner, S. District heating and cooling in Sweden. Energy, 2017. *https://doi.org/10.1016/j.energy.2017.03.052*
[6] Source: Johansen, K., Werner, S. Something is sustainable in the state of Denmark: A review of the Danish district heating sector. Renewable and Sustainable Energy Reviews, 2022. *https://doi.org/10.1016/j.rser.2022.112117*

Water-based systems enable higher shares of renewable energy

Modern district energy systems act as **flexible energy infrastructure** where available energy sources can be "plugged in". The energy can then be distributed to buildings for immediate use or be stored for later use in efficient centralized thermal energy storages. The hot water can be stored for a few hours or days (e.g. in tanks), or for several months (e.g. in large pits or other storage facilities, such as old mines). District energy systems and central thermal energy storages also offer huge advantages to intermittent renewable power generators, by being exceptionally flexible power consumers and by offering balancing services.

In a decarbonized energy system, there will be a need for all kinds of available renewable and sustainable energy sources, including solar, geothermal, wind power, biomass, waste heat and ambient heat. Additionally, it is essential to fully utilize the primary energy potential and use waste heat and cold sources when possible. The main challenge with renewable energy sources, especially wind and solar, is their intermittent nature, which causes large challenges for the traditional energy system, which is built on a locked relationship between supply and demand. In the perspective of heating and cooling, district energy enables the decoupling of this relationship, thereby enabling an efficient use of these intermittent sources. District energy further enables cost efficient usage of low temperature heat sources, which are often located at remote locations in respect to potential heat consumers.

The well-known challenge with volatile renewable electricity is to match energy supply and energy demand. The wind might not be blowing at times when the energy is needed most, and at other times there can be more wind than is needed, leading to an oversupply of wind power – a serious strain for energy systems. To deal with excess power generation, either some wind turbines need to be stopped or new electricity usage models that do not add to the traditional demand need to be developed. The optimal solution, both in terms of cost and energy efficiency, is to channel excess electricity generation into district energy systems. At times of excess electricity production, heat can be generated using heat pumps and electric boilers. If the heat generation from excess electricity exceeds the heat demand, the energy can be stored with very high efficiency in thermal storages for later use. At periods where there is a lack of renewable power generation, the district heating system can use the already stored heat or heat generated by other means (e.g. geothermal, biomass or waste heat). In a smart energy system, district energy can act as a virtual battery, allowing fuels that would otherwise be used for heat generation to be used for power generation when there is a lack of renewable electricity generation. In the context of electrification of building thermal demands, the large thermal energy storage potential of district energy systems will become vital for decoupling power supply and demand, minimizing peak electricity demands and helping to balance the power grid.

By coupling the electricity, electrofuels (PtX) and thermal sectors via district energy systems, extensive synergies between the sectors can be harvested. The coupling of the sectors will not only contribute to the decarbonization of the heating and cooling sector but significantly advance, as well as reduce the cost of, the energy transition. In Denmark, one of the countries with the highest shares of renewable energy, district energy is considered as the backbone of the future fully renewable energy system, not least because of its ability to compensate the fluctuating nature of wind and solar.

To facilitate this role, district energy systems are undergoing a transformation to so-called 4th generation district heating (4GDH)[7] and cooling (4GDC)[8]. 4GDH networks run on low temperatures to enable efficient utilization of a wide range of low-temperature energy sources, at the same time as achieving low distribution losses. 4GDC are advanced district cooling systems that facilitate smart connection with the electricity sector using large thermal energy storages, and exploit synergies with the heating sector and industries. With their advanced control functionalities, they are perfectly suited to connecting different parts of the energy system—electricity, heating, cooling, buildings, industry—and flexibly using different renewable energy sources. In this context, digitalization brings interesting opportunities for gathering and evaluating data, which can be used to improve the accuracy of energy consumption prediction, to optimize operational temperatures, temporarily shift loads from challenging peak periods by utilizing the building thermal mass, as well as utilizing the storage capacities of district energy infrastructure.

[7] Source: Lund, H., Werner, S., Wiltshire, R., Svendsen ,S., Thorsen, JE., Hvelplund ,F., Mathiesen, BV. 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. Energy, 2014. *https://doi.org/10.1016/j.energy.2014.02.089*
[8] Source: Østergaard, PA., Werner, S., Dyrelund, A., Lund, H., Arabkoohsar, A., Sorknæs, P., Gudmundsson, O., Thorsen, JE., Mathiesen, BV. The four generations of district cooling - A categorization of the development in district cooling from origin to future prospect, Energy, 2022. *https://doi.org/10.1016/j.energy.2022.124098*

Exceptionally resilient infrastructure

With more extremes in the world, climate as well as political, it is becoming clear that nations need to pay extra attention towards building energy systems that are exceptionally reliable, robust, as well as resilient towards external disruptions. District energy is unique, as it not only possesses all these essential characteristics[9], but it is also a solution that embraces the ideology of "low-tech", as the basic principle of district energy is simple local infrastructure, which is easy and simple to repair and made for fulfilling basic needs of urban areas using locally available sources. Although the underlying philosophy of district energy is "low-tech", it is nonetheless complemented by "high-tech" solutions, which maximize its efficiency and exploit synergies with other sectors.

The reliability of district energy is commonly in the region of 99.99% and above. Additionally, in rare instances of no thermal delivery, it is usually due to planned maintenance activities that only affect a small number of connected consumers for a short period of time.

The robustness of district energy is seen in the ability of the infrastructure to endure a wide range of environmental impacts, such as earthquakes, floods, and extreme cold, hot, or windy weather. These systems are also exceptionally adaptable to changing demands, both due to seasonal variations, as well as changes in building usage. Further, as with other water-born systems, district energy can operate for an extended period of time with leakages, which enables utilities to optimize the repair process.

The resilience of district energy to withstand disruptions is a result of the different properties and abilities of the infrastructure, such as its fuel agnostic nature, multi-heat source operation, meshed network design, "low-tech" foundation, and robust technologies. Examples of how district energy deals with disruptions are:

1. Heat plant breaks down (malfunction, sabotage, …)
   — The utility brings another plant online.
2. Pipeline breaks (catastrophic malfunction, sabotage, …)
   — The utility closes off impacted section of the network and continues normal operation for unaffected section, while repairing the pipeline.
3. Fuel supply chain breaks down (import/export ban on fuels, shortages, …)
   — The utility operates existing plants using different fuels.

Ready to fast-track the **energy transition?**

With all its characteristics, district energy can truly fast-track the energy transition and contribute significantly to both mitigating climate change and minimizing the environmental footprint of renewable energy generation, as significantly lower generation capacity is needed for district energy systems compared to individual building solutions. It allows grand utilization of renewable energy sources at feasible cost levels and is the only means to utilize excess heat from industry and commercial activities for large scale heating of buildings, thereby significantly increasing the overall efficiency of the energy system. In combination with thermal energy storages, district energy systems allow for larger penetration of fluctuating renewable power sources, such as wind and solar, with significantly lower generation capacity, compared to electrified heating at a building level. In hard to electrify sectors (e.g. high temperature industry processes, heavy transport and aviation), the production of electrofuels has an interesting synergy with district heating, where district heating can remove the waste heat from the PtX processes, resulting in more cost efficient manufacturing of electrofuels. In short, district energy increases the flexibility and the efficiency of the entire energy infrastructure.

To leverage the potential of district energy, it is crucial that policies support an **integrated approach** where district energy systems are analyzed together with the buildings that need to be supplied, all available energy sources are considered, and heating, cooling and electricity are connected. We need ambitious policies that support the take-up of innovative technologies, drive the decarbonization of heating and cooling, and the modernization of heating systems. Let's enter into action mode and fast-track our journey to a sustainable energy system!

[9] Source: Gudmundsson, O. Designing a resilient district energy infrastructure. Danfoss, 2022.

Examples of renewable and low-carbon sources that district energy can tap into:

Solar power and heat

The main challenges with solar energy are space, intermittency—both during the day and seasonal, and the low yield during the winter—when heat is most needed. This implies solar energy cannot fulfill either the entire power or heating demands throughout the year. The utilization of solar energy can be maximized in district energy systems with the utilization of large-scale thermal energy storages, which make it possible to store heat generated during the summer until the autumn or even the winter.

Wind power

The challenges with harnessing wind energy are its intermittency on a short, medium and long-term basis. Due to the nature of the wind, large fluctuations in power generation are commonly experienced within short periods of time. Variations in wind intensity during the day and at night—as well as between seasons, is a general challenge, as efficiently storing excess power is both difficult and expensive. By integrating power and district energy grids, district energy systems can provide both a balancing service to the power sector, as well as being an extreme flexible power user—capable of operating without power from the grid, as well as being able to quickly absorb vast amounts of excess renewable power. In essence, the district energy sector acts as an energy user that balances the power grid.

Geothermal energy

Geothermal energy is a stable and secure renewable energy source that can be used on a large scale through district heating networks, traditionally as a base load heat supply. It is estimated that over 25% of the EU population lives in areas directly suitable for geothermal district heating[10]. In the case of low temperature geothermal sources, heat pumps can be used to lift the temperature to suitable levels. Paris hosts a great example of geothermal-based district heating, where the total installed geothermal capacity is 270 MWth, supplying heat to 250,000 residential units[11].

Biomass

In the transition period from a fossil-based energy system to a renewable energy system, it is expected that biomass will be used as a transition fuel, due to the relatively simple process of retrofitting existing coal power plants to biomass. However, due to the generally lower power generation efficiency of plants operating on biomass, it will be more important than before to operate the plants in a combined heat and power mode and use the waste heat efficiently in a district energy system.

Excess heat from industry and commercial activities

Studies show that excess heat from industry is available throughout Europe[12] and, by utilizing this "by-product", huge amounts of fossil fuels can be replaced. Excess heat from commercial activities (e.g. supermarkets, data centers and cooling of large commercial buildings) is another untapped heat resource. The main issue is that the heat can be of low temperature, which would require heat pumps to boost the temperature.

[10] Source: Report Developing geothermal district heating in Europe *https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/geodh_final_publishable_results_oriented_report.pdf*
[11] Source: Geothermal – Greater Paris area making better and better use of enormous potential *https://www.thinkgeoenergy.com/geothermal-greater-paris-area-making-better-and-better-use-of-enormous-potential/*
[12] Source: Persson, U. Cycle de Formation Énergie – Environnement, Séminaire 2012-2013, Université de Genève, 18th of April, 2013

Power to electrofuels
Electrofuels, or power-based synthetic fuels, are a type of replacement fuel for fossil fuels, which will be important for sectors that are hard to electrify directly, such as high temperature industry processes, aviation, sea and long-distance land transport. Due to the conversion losses in the manufacturing process of electrofuels, they are not suitable for directly replacing fossil fuels for building thermal demands[13]. However, to ensure high primary energy efficiency, it will be important to capture and utilize waste heat from the manufacturing process and for fulfilling industry or building thermal demands. As PtX plants will generally be located outside of urban centers, they will need to rely on district heating systems to transport waste heat to heat consumers.

Heat pumps
As fossil fuels are phased out and heating demands are electrified, it becomes essential to use electricity as efficiently as possible. Heat pumps enable the transfer of thermal energy from a low temperature source and provide it at a higher temperature for a specific use. Heat pumps can operate in a heating mode, cooling mode or cogeneration mode. In a heating mode, the heat pump extracts thermal energy from a low temperature source, for example ambient air or natural water sources, and delivers it to a building heating or domestic hot water system, or an industry process. In a cooling mode, the heat pump extracts thermal energy from (e.g. cools down) a building or an industry process, and delivers it to a heat sink (e.g. ambient air or natural water sources). In a cogeneration mode, the heat pump cools down a building or industry process and delivers heating to a building or industry process. In the perspective of district energy systems, options of heat sources and heat sinks are far greater than can be achieved on an individual "one plant, one end-user" basis, which leads to both higher efficiency and better utilization of heat pumps. Furthermore, in combination with other assets of the district energy system, particularly thermal energy storages, the heat pump can offer short and medium-term balancing services to the power sector. Additionally, the district energy operator can use the same assets to optimize heat pump operation towards periods of low-cost electricity.

Cooling supply
Large commercial buildings require cooling more or less all year. Depending on the location, free cooling from the sea, lakes or rivers can be utilized with district cooling networks. In locations where both district cooling and district heating is applied (e.g. Denmark, Sweden, and Finland), both the hot and the cold side of the heat pump can be utilized, which leads to very high power efficiency. In warmer climates, surplus heat from power generation could power absorption heat pumps for cooling purposes. The district cooling network is then used to transport the cold from the cooling source to the buildings. This can significantly reduce power consumption for cooling purposes. In a smart energy system, the district cooling network, in combination with electrical chillers and thermal storages, can decouple cooling generation and cooling demand and hence reduce the strain on the power grid during peak load periods.

Thermal energy storages
Thermal energy storage is a simple and cost-efficient technology to decouple supply and demand. The use of thermal energy storage in district energy systems minimizes the need for peak generation from heat or cool units, and helps integrate intermittent energy sources (e.g. in combination with large scale heat pumps and electric boilers to produce heat, or cool, in periods with low electricity prices). For cooling, thermal energy storages will further lead to higher efficiency of air-cooled chillers that can be fully utilized during cooler night temperatures where heat rejection is more efficient than during higher day temperatures, leading to higher chiller efficiency. Thermal energy storages in district energy systems come in various sizes, from big tanks of 5,000-30,000 m^3 at heat and power plants, to large pit storages of 200,000 m^3, such as the one at the solar thermal plant in Vojens, Denmark.

[13] Source: Gudmundsson, O. End-to-end efficiency in urban buildings: Comparing the future-proof potential of district heating and hydrogen heat sources. Danfoss, 2023. *https://assets.danfoss.com/documents/latest/239323/AC443658184607en-000101.pdf*

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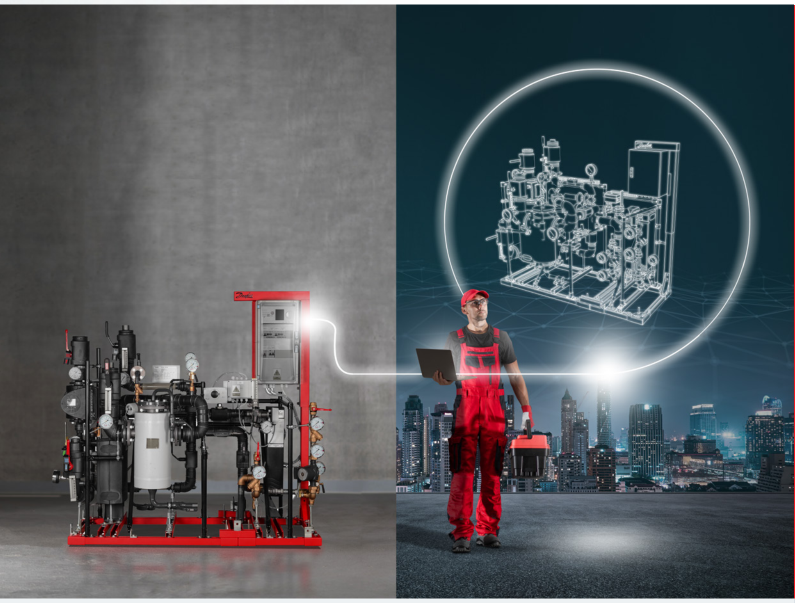

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