SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Radar for Solar Energy Buildings

IEA SHC TASK 66 | SOLAR ENERGY BUILDINGS

Technology Collaboration Programme
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Technology Radar for Solar Energy Buildings

This is a report from SHC Task 66: Solar Energy Buildings and work performed in Subtask D: Current and future technologies and components

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Cover photo credit Jenni Energietechnik AG, 100% solar-heated multi-family building in Oberburg, Switzerland

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Solar Heating & Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46, 71)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

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- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
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Contents

1 Executive Summary

This report delves into the transformative potential of Solar Energy Buildings[1] (SEBs) as a credible solution for mitigating carbon emissions within the building sector. Focused on advancing technologies in this field, the report offers a comprehensive overview of promising innovations, evaluates existing technologies, and conducts a survey encompassing 150 cases to understand current practices and system integrations.

A main aspect of this report is the market potential analysis derived from the amassed data. By synthesizing information from the technology evaluations, case studies, and expert knowledge, the report provides strategic insights into the growth prospects of individual technologies. The market potential analysis not only identifies key opportunities but also highlights challenges and areas.

The research also focuses on the markets of four specific countries, providing an examination of the solar technology landscape within each. The depth of this investigation is essential for understanding the global applicability and regional nuances influencing the adoption of solar energy in building structures.

To enhance accessibility and comprehension, the report employs a visual representation of results through a technology radar. This tool serves as a comprehensive guide for stakeholders, offering a clear visualization of technological trends, their current usage, and future potential. For the most widely adopted technologies, the report goes a step further by providing additional information on their application, benefits, and potential drawbacks.

In conclusion, this research report serves as a valuable resource for industry stakeholders, policymakers, and investors seeking to navigate the evolving landscape of SEBs. By providing a detailed analysis of current technologies, market dynamics, and potential future trends, the report equips its audience with the insights needed to make informed decisions in fostering sustainable and low-carbon building practices.

2 Market potential of technologies

2.1 Method

To evaluate the market potential of a technology using the six main pillars of entry barriers, political environment, internal environment, size of the market, growth rate of the market, and the probability of occurrence a comprehensive approach has been taken, as outlined below:

Entry Barriers: First, the potential barriers to entry into the market need to be assessed. This includes identifying existing competitors and analyzing their strengths and weaknesses, as well as any regulatory or legal restrictions that may affect market entry. Are there any real barriers to entry into the existing market and in marked within the next three years (till 2026)? For example: very high investment cost, high operational costs; to low technical readiness level (TRL) at the moment, to complex, etc.

Political Environment: The political environment in which the technology will be marketed must also be considered. This involves analysing regulations, laws, and policies that may impact the technology's entry into the market, as well as any international (or national) regulations (initiatives) support or hinder a specific technology or activity (like energy communities) have been considered.

Internal Environment: The internal environment must also be evaluated to ensure that the technology has the necessary resources and capabilities to successfully enter the market. This includes assessing potential risks or challenges that may arise during market entry. Overall, the market potential may be very good, but the question arises is the technology "strong enough" to compete in the market with suitable offerings, cost, and competition?

[1] Solar energy buildings, in a central European climate, aim to achieve solar energy fractions of at least 85% for heating, 100% for cooling, and 60% for electricity requirements, which includes household use and e-mobility.

Size of the Market: The size of the market is a critical factor in determining the potential for the success of existing or new technology. This involves analysing the total addressable market, as well as any specific target markets that the technology may be intended for. Market research can be used to determine the size and scope of the market, as well as any potential opportunities or gaps in the market that the technology could fill.

Growth Rate of the Market: Finally, the growth rate of the market must be considered to determine the potential for long-term success. This involves analysing trends and projections for the market, as well as any potential disruptors or market shifts that may affect the technology's success in the future.

Probability of occurrence: The likelihood that a particular technology will be a relevant option for SEBs by 2025 was determined using quantitative bases, such as TRL levels, as well as qualitative bases, such as the instincts and experience of the experts.

By considering these six main pillars, a comprehensive evaluation of the market potential for the technologies has been conducted, providing valuable insights that inform key strategic decisions regarding market entry and growth.

Each of the analyzed technologies was evaluated based on the rating as seen in the following table.

Market Potential				
Entry Barriers	Political Environment	Internal Environment	Market Size and growth rate	Probability of occurrence
rating from 1 to 3 3 = low barriers, 1 = high barriers	rating (1 to 3) 3 = good environment, 1 = bad environment	rating (1 to 3) 3 = good environment, 1 = bad environment	rating (1 to 3) 3 = big market, 1 = small market	rating (1 to 3) 3 = high relevance, 1 = low relevance

2.2 Analysed technologies

In recent years, there have been significant technological advancements in the fields of solar energy, renewable energy, and building services. These advancements have led to the development of new approaches at both the technology and energy system levels, including sector coupling. To systematically evaluate these technologies and approaches, four main categories have been established.

The first category, generation technologies, includes solar conversion technologies like PV, ST, and PVT, as well as heat pump technologies and other technologies for heat, cold, and power generation such as biomass, green gas, and cogeneration.

The second category, storage technologies, comprises various thermal and electrical energy storage technologies, including activation of thermal masses, water storage with vacuum insulation, sorption storage, and stationary and mobile battery storage.

Categories three and four, thermal grids and buildings and communities, are further divided into sub-categories that focus on technological aspects as well as integration, operation, and optimization.

An overview of the analysed technologies is provided in the following figure. Detailed information and technological trends will be discussed in the subsequent chapters.

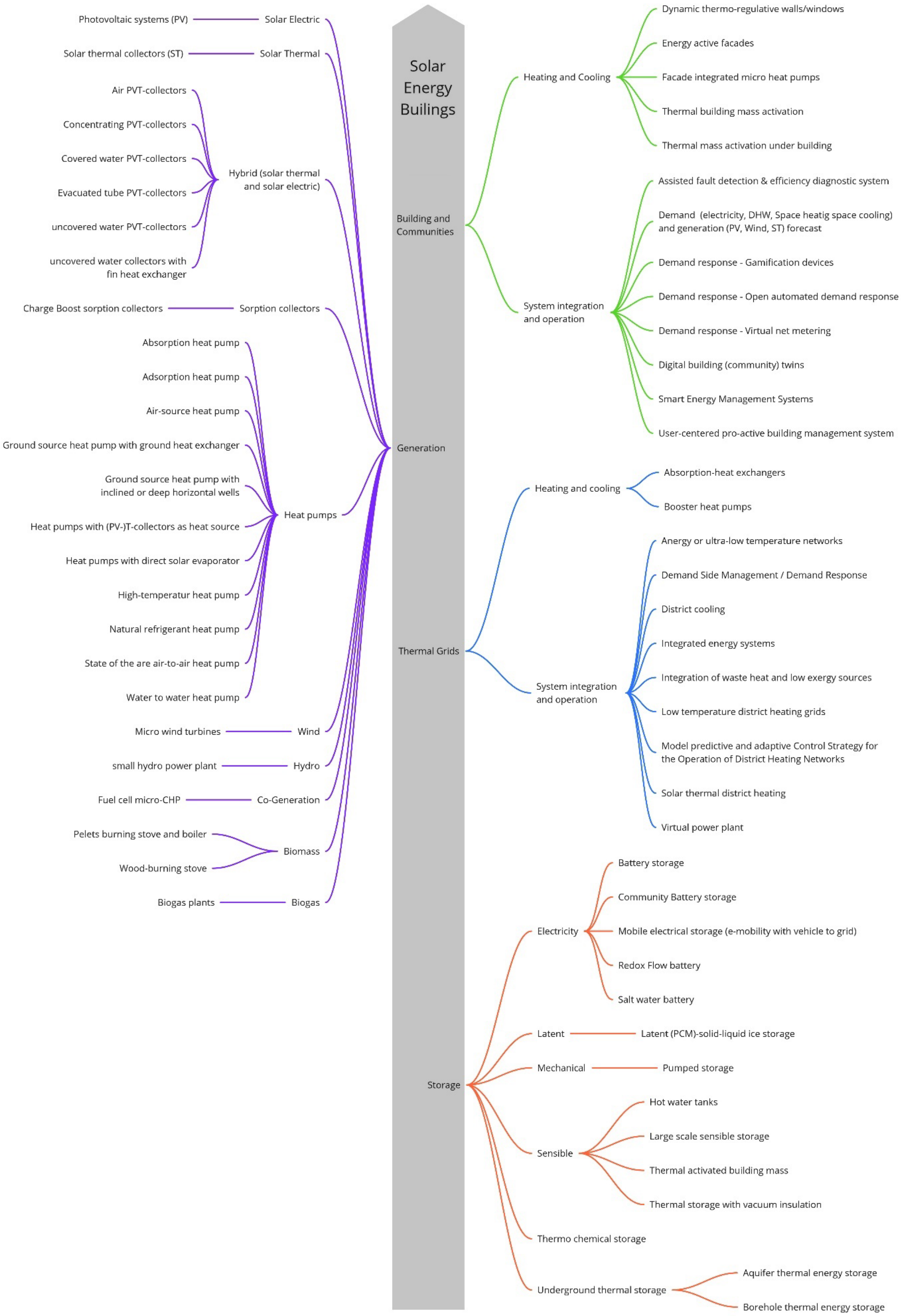

Figure 1: Categorization of reviewed technologies

2.2.1 Generation technologies and energy sources

2.2.1.1 Solar electric

Photovoltaics (PV) convert solar radiation into electricity using semi-conducting technologies. There are several types of PV technologies available. Today, the vast majority of PV modules are based on wafer-based crystalline silicon (c-Si). Modules use silicon as single- (sc-Si) with conversion efficiency of around 16 to 24% or multi- (mc-Si) crystalline modules with lower efficiencies, but they are less expensive. Thin-film solar cells are made by depositing one or more thin layers, or thin film of photovoltaic material on a substrate, such as glass, metal or polymeric materials. Organic thin-film PV use organic semiconductors. Despite the low production costs, stable products are not yet available for the market. Thin-film PV technologies based on perovskite has so far achieved efficiencies of 28 % but only with small cell areas in the laboratory. Perovskite solar cells also suffer from a short durability.

PV can be integrated in several parts of the building envelope. Building-integrated PV integrated in façade can replace the entire external layer (as opaque façade - usually added as a cladding element) or the whole façade system as semi-transparent facades. As roof system, PV modules can be added on the external surface, substitute the external layer, or the entire technological system. PV can for example also be integrated into balconies, car ports or as floating PV systems mounted on a structure that floats on a water surface.

2.2.1.2 Solar thermal

Solar thermal (ST) technologies harness solar energy and convert it into heat. Solar thermal systems use different types of solar collectors with varying characteristics, especially in terms of the temperature level they can achieve and their cost intensity. They can be categorised as unglazed absorbers, flat plate collectors, air heater solar collectors and evacuated tube collectors.

Unglazed absorbers are the simplest type of solar collector, and are frequently used for heating swimming pools or powering heat pumps. In 2020 evacuated tube collectors represented 60% of the newly installed capacity, followed by flat plate collectors with 34%. In a global context, this breakdown is mainly driven by the dominance of the Chinese market, where around 72% of all newly installed collectors in 2020 were evacuated tube collectors. In Europe, the situation is almost the opposite of that in China, with 71% of all solar thermal collectors installed in 2020 being flat plate collectors. In the medium-term perspective, however, the share of flat plate collectors decreased in Europe from 81% in 2011 to 71% in 2020. Overall, the share of evacuated tube collectors in Europe increased between 2011 and 2020 from 16% to 28%.[2]

Solar thermal technologies can provide high fractions of water heating demand at low capital cost, even in cold climates. They can be used stand-alone or integrated into virtually any type of heating system, regardless of the primary heat source (direct electricity, heat pumps, district heating, biomass, or clean fuels).

On building surfaces, solar thermal collectors can also be integrated as part of a layer of the building envelope facing the surroundings. Apart from their possible contribution to passive building design, building envelopes will need to become solar collectors themselves, so both the performance of collectors and their direct integration into buildings needs to be improved. This should lead to the development of multifunctional building components which act as elements of the building envelope and as solar collectors.

2.2.1.3 Hybrid technologies (PVT)

Hybrid solar collectors, known as photovoltaic thermal solar collectors or PVT collectors for short, are a type of power generation technology that harnesses solar radiation to produce both thermal and electrical energy. PVT collectors combine photovoltaic solar cells, which convert sunlight into electricity, with a solar thermal collector that captures and transfers the unused waste heat from the PV module to a heat transfer fluid. By integrating electricity and heat generation in a single component, PVT technology can achieve higher overall efficiency than conventional solar photovoltaic or solar thermal systems.

There are a multitude of technical possibilities to combine PV cells and solar thermal collectors. PVT products can be divided into PVT liquid collectors, and PVT air collector according to their basic design and heat transfer fluid. In

[2] IEA Solar Heat World Wide - Global Market Development and Trends 2021; Detailed Market Figures 2020, 2022

addition to the classification by heat transfer fluid, PVT collectors can also be categorized according to the presence of a secondary glazing to reduce heat losses and the presence of a device to concentrate solar irradiation: Uncovered PVT collector (WISC PVT), Covered PVT collector, Concentrating PVT collector (CPVT). Moreover, PVT collectors can be classified according to their design, such as cell technology, type of fluid, heat exchanger material and geometry, type of contact between fluid and PV module, fixation of heat exchanger, or level of building integration (building integrated PVT (BIPVT) collectors).

The design and type of PVT collectors always implies a certain adaption to operating temperatures, applications, and giving priority to either heat or electricity generation. For instance, operating the PVT collector at low temperatures leads to a cooling effect of PV cells compared to PV modules and therefore results in an increase of electric power. However, the heat also must be utilized at low temperatures.[3]

Designing and implementing PVT systems pose complex challenges that span material selection, system modelling, industry influence, market awareness, and sales strategies. Choosing the appropriate materials for a PVT collector is intricate, primarily due to the thermal constraints imposed by the PV subcomponents. Thermal system modelling and yield prediction become entangled when considering both electricity and heat production, complicating the optimization process. Installing a complete PVT system demands more effort and a higher skill set from technicians compared to PV generators which also lifts prices well above those of pure PV or solar thermal systems. Additionally, the big variance in system demo cases and specific usages for low temperature heat hinders suppliers in quantifying and generalizing the advantages of PVT systems, limiting the industry's ability to influence standards and policies favourably. Hence the general awareness of PVT remains limited across stakeholders, ranging from homeowners and planners to policymakers, utilities, and investors.[4]

2.2.1.4 Sorption collectors

To enable seasonal storage for solar heat, an exothermic and fully reversible sorption process is employed, storing energy through a thermochemical reaction to eliminate losses and self-discharge during storage. This technology boasts a material-level energy density 3-5 times greater than that of sensible water storage. To enhance the sorption storage system, the innovative "Sorption Collector" can be incorporated to augment the charging process and increase energy density. This technology utilizes the "charge boost" technique, leveraging the pressure difference between two storages at different temperature levels for improved efficiency.

Operated in a day/night cycle, the sorption collector heats the main storage during the day by transferring heat via a hydraulic system and a fixed bed heat exchanger in the sorption storage module. Simultaneously, the sorption material in the collector is heated, releasing water vapor that is condensed at the condenser heat exchanger. The collector's sorption material is directly desorbed, reaching the highest temperature without requiring extra containment, allowing for a compact system design. During the night, the charge boost mode is employed, utilizing the collector's high radiation losses to cool down the sorption material and induce a pressure drop. This pressure difference is then utilized to desorb water vapor from the hot main storage to the cold sorption collector. This process shifts vapor to the collector and releases heat to the ambient, providing an advantage by allowing the main storage to be desorbed to a higher state of charge without increasing the desorption temperature.

The sorption collector provides the ideal boundary conditions for applying as charge boost storage because it enables the highest and lowest temperatures in a day/night cycle. However, it's important to note that the technology is still in the prototype stage.

2.2.1.5 Wind

Small wind turbines operate relatively close to the ground as compared with the larger, modern multi-megawatt machines now operating in wind farms onshore and offshore, and the methods to assess the wind resource are different. Small wind turbines can be installed in a wide variety of locations, ranging from unobstructed flat terrain to land with varying combinations of natural and manmade obstructions, forests and complex landforms. In addition, because of their size, small wind turbine installations are often located within and atop urban buildings (known as "rooftop wind").

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[3] IEA Task 60/ Report D5Basic concepts of PVT collector technologies, applications and markets;2020
4 IEA Task 60/Technology Position Paper - PVT Collectors and Systems, 2020, https://task60.iea-shc.org/

Rooftop and complex terrain sites are the most challenging because of high turbulence, wind shear, vertical velocity and the influence of atmospheric stability. While rooftop projects do not meet energy production estimates, the owners may view the installation as successful because of the perceived marketing benefits (i.e., the installation boosts the project owner's "green" image). Urban sites are attractive for using small wind turbines to demonstrate opportunity for distributed, low-carbon generation combined with highly visible statements on sustainability.

Suburban or rural sites are often ideal locations for good energy production. Many rural sites have open terrain and farming operations. There is still a need to assess the site and understand the site characteristics, topography, location of grid interconnection and obstacles.

2.2.1.6 Hydro

Hydropower facilities vary in size, with some being large power plants that supply electricity to numerous consumers, while others are small and even 'micro' plants operated by individuals to meet their own energy needs or sell excess power to utilities. The size of a hydropower plant determines its category, which includes pico-power (generating less than 20 kW), micro-hydro (generating from 20 kW to 500 kW), mini power plants (generating from 500 kW to 2 MW), and small power plants (generating from 2 MW to 10 MW). In Europe, hydropower constitutes approximately 80% of electricity generated from renewable sources and 19% of total electricity generated. The contribution of small hydropower to Europe's electricity generation amounts to around 3%[5].

2.2.1.7 Biomass

Central heating system providing heat and hot water for multiple rooms, automatically (i.e. independently from the loading) and generally using wood pellets, wood chips, chopped logs, cereal plants, or a combination of them.

2.2.1.8 Biogas

Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The precise composition of biogas depends on the type of feedstock and the production pathway (Biodigesters, landfill gas recovery systems, wastewater treatment plants). The development of biogas has been uneven across the world, as it depends not only on the availability of feedstocks but also on policies that encourage its production and use. Almost two-thirds of biogas production was used to generate electricity and heat (with an approximately equal split between electricity-only facilities and co-generation facilities). Around 30% was consumed in buildings, mainly in the residential sector for cooking and heating, with the remainder upgraded to biomethane and blended into the gas networks or used as a transport fuel.[6]

2.2.1.9 Heat pumps

By leveraging electricity to harness ambient heat from the ground, water or air, heat pumps can supply useful heat with one-third to one-fifth of the electricity used by conventional electric equipment. The heat pump system typically consists of a compressor that circulates a refrigerant through a refrigeration cycle and a heat exchanger that extracts heat from the source and transfers it to a heat sink. Heat can be delivered in buildings using either forced air or hydronic systems, such as radiators or under-floor heating. Heat pumps can also be connected to a tank to produce hot water or to provide flexibility in hydronic systems. In addition to meeting space heating needs in winter, many heat pumps can also provide space cooling in summer. Large-scale heat pumps in district heating networks require higher input temperatures than in residential applications, which can be sourced from the waste heat of industrial processes, data centres, or wastewater. Heat pumps are considered large if they exceed capacities of 100 kW. Solar assisted heat pumps can reduce the temperature lift that the heat pump will have to bridge, thus improving their performances. In the case of ground source heat pumps injecting solar heat into the ground, these can also

[5] https://www.energy.gov/eere/water/types-hydropower-plants [access on: 30.03.2023]
[6] IEA 2020: Outlook for biogas and biomethane; Perspective for organic growth. 2020

help in balancing the underground temperature in cases where the borehole is somewhat shorter than needed or when there is more heat extraction in winter than recharge from cooling in summer.

2.2.1.10 Co-generation

Fuel Cell micro-Cogeneration is a technology that uses a single fuel (hydrogen, natural gas or LPG) to produce both heat and electricity for a building. Compared to other micro-Cogeneration technologies the Fuel Cell micro-Cogeneration has a low 'heat-to-power ratio' (meaning it produces a relatively low amount of heat and a relatively high amount of electricity compared to other micro-Cogeneration technologies) – so is well suited to the evolving trend in buildings towards higher electricity use and low space heating demand. There is growing potential for the use of these micro-cogeneration systems in the residential sector since they have the ability to efficiently produce both useful thermal energy and electricity from a single source of fuel.[7]

2.2.2 Storage technologies

To bridge temporal differences between renewable and fluctuating electricity and heat generation and electricity and heat demand, different storage technologies for electrical and thermal energy storage are briefly described below.

2.2.2.1 Electrical storage

Purely electrical storage systems include capacitors and superconducting coils that are currently being developed, but which, from today's perspective, are reserved for special applications, at least in the medium term. They are therefore not considered further here. However, electrochemical storage systems, which include various types of accumulators, i.e., rechargeable batteries, are much more relevant for applications in buildings, districts, and communities. Electrochemical storage systems can be used to increase the consumption of self-produced electricity, improve the grid integration of renewable energies, and stabilize the electricity grid. In principle, electricity is converted into chemical energy during the charging process and converted back into electricity during the discharging process.

For these stationary applications, **lead-acid batteries**, with a service life of five to seven years, have been used most frequently to date due to their cost-effectiveness and commercial availability. Much more cost-intensive are lithium-ion batteries, which, however, have higher efficiencies, higher numbers of cycles and thus a longer service life than lead-acid batteries and represent the state of the art for mobile applications (notebooks, cell phones, electro mobility, etc.). Since the term **lithium-ion battery** covers a large number of battery systems with different anhydrous, organic electrolytes, as well as different combinations of electrode materials, a wide range of applications can be covered. For stationary applications, lithium-ion technology is still at an early stage of development. Since 2020, the focus has also increasingly been on more cost-effective and longer-lasting **lithium-iron-phosphate batteri**es instead of lithium-ion batteries. In addition, a change in the battery market towards batteries without lithium as a resource has been observed in recent years. Great progress has been made in the research, development, and demonstration of sodium-ion batteries with inorganic, aqueous electrolyte, the so-called **salt-water batteries**, of high-temperature batteries, such as sodium-sulfur batteries, and of **redox-flow batteries**. The latter are based on the circulation of two circuits of positively and negatively charged electrolyte, separated by a membrane. Whereas the two electrolyte circuits are stored in two separate tanks. Compared to other accumulators, this design, with the separate storage of the electrolyte, allows a problem-free scaling of capacity and power up to the megawatt range, as well as a problem-free deep discharge, which may also persist over a longer period of time without causing significant aging effects. This also increases the service life. Salt-water batteries, on the other hand, correspond to the classic design of the batteries most commonly used to date. Their service life and efficiencies lie between those of lead-acid batteries and batteries with lithium. However, salt-water batteries are characterized by components with low environmental impact in terms of their life cycle and high

[7] Fuel Cell micro-Cogeneration, http://pace-energy.eu/micro-cogeneration/ [access on: 30.03.2023]

resource availability compared to the other types of accumulators, which means that this type of design could assume increasing importance in future energy supply systems[8,9].

Several mobile accumulators in electric vehicles and decentralized stationary accumulators (so-called home stores), which are connected to a common electricity grid in addition to an interconnection of prosumers, renewable energy producers and consumers in combination with a corresponding energy management system, are referred to as a so-called smart grid. Prosumers can be, for example, electric vehicles, which, according to the so-called **vehicle to grid** (V2G) concept, bi-directionally feed electricity, which they have stored in the mobile accumulators via the electricity grid at a time x, back into the electricity grid from the mobile accumulators at a different time y. Instead of small-scale home store units, larger-scale **community energy storage** (CES) units can also be used in the smart grid at the district or community level. Community energy storage is currently one of the most advanced smart grid technologies, providing services based on balancing strategies for the described interconnection. In this context, the CESs are usually located at the edge of the electrical grids, instead of distribution stations, close to prosumers, consumers and generators of the interconnection. Due to the size of the accumulators and centralized control, community energy storage offers many advantages over distributed electrical energy storage in terms of stability, reliability, quality, and control. Balancing strategies may include peak shaving, power shifting or leveling, power quality improvement through voltage and reactive power support, frequency control, and even islanding during outages. In addition to balancing strategies, certain operational strategies, such as those aimed at either maximizing the captive power consumption of all interconnected participants or increasing the profits of the shareholders in the power markets, must be pursued[8,10,11,12].

2.2.2.2 Mechanical storage

Pumped storage power plants are one type of mechanical stores that stores electrical energy in the form of potential energy with almost no losses. Modern pumped storage power plants have a high efficiency of about 80 %, taking into account the conversion losses of the energy forms into each other, i.e. electrical energy into potential energy and vice versa. This storage technology has been established and proven over decades, but its expansion potential is limited from a technical, ecological, and topographical point of view. Among other things, since pumped storage power plants are usually implemented as large-scale plants, many of the suitable sites for the corresponding dams are located in protected areas, where the construction of the dam has a significant impact on the ecosystem. In flat regions, underground pumped storage power plants still seem to be a promising alternative, but are still in the development or demonstration phase. Other types of mechanical storage include compressed air storage, liquid air energy storage or flywheels. However, these are currently also still in an early research and development phase and are reserved for special applications, at least in the medium term. They are not considered in the further analysis[8,9].

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[8] Fraunhofer-Institut für Solare Energiesysteme (ISE); Institut für Gebäude- und Solartechnik der Technischen Universität Braunschweig, Solar- und Wärmetechnik Stuttgart (SWT): Gemeinschaftlicher Abschlussbericht SolSys Analyse und Optimierung solarer Energieversorgungssysteme (Wärme/Strom) für Gebäude, Förderkennzeichen 0325558A/B, 2019

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2.2.2.3 Latent storage

Latent heat is stored by increasing the temperature of a storage medium beyond the phase change. With the phase change of a storage medium at a constant temperature level, the energy storage density of the store is significantly increased compared to the sensible stores with the same storage medium explained below. Energy storage densities of 50 to 120 kWh/m³ can be achieved depending on material combinations[8]. The higher the energy storage density, the less volume or even space is required for the insertion of the store. This can be a decisive criterion, especially in urban, densely built-up areas.

Latent stores, just like the sensible stores explained below, are used to store thermal energy. Charging with electrical energy via heating rods or other electric boilers is conceivable, e.g., for electricity grid stabilization in the form of negative balancing energy and power for sector coupling. Usually charging also takes place with thermal energy, which is supplied to the storage medium via heat exchangers. For loading a latent store, a phase change can take place from the solid aggregate state of the storage medium to a liquid aggregate state (solid-liquid), as well as from the liquid to the gaseous aggregate state. During loading, heat is supplied. For a discharge, a heat dissipation, the phase changes take place correspondingly vice versa. A suitable storage medium for an application is selected based on the temperature range in which both the heat storage and the phase change are to take place. Proven storage media for the most frequently investigated solid-liquid phase change are various paraffin waxes, salt hydrates and water. Water as a storage medium offers many advantages in addition to a high specific heat capacity and enthalpy of fusion, as well as ecological harmlessness. So-called **ice stores**, with a phase change temperature of around 0 °C, are thus particularly suitable for use in cold district heating networks, also known as anergy networks, or so-called fifth generation of district heating and cooling (5GDHC) networks with operating temperatures between - 10 and + 20 °C, for example.

2.2.2.4 Sensible storage

Examples of the most widely used sensible heat stores with a liquid storage medium at the building level are so-called **hot water, buffer or combined stores for storing domestic hot water and/or water for space heating**. If the district or community level is considered, the sensible heat stores with the liquid storage medium water can be scaled almost arbitrarily with regard to their volume and thus with regard to their thermal storage capacity. While the heat transfer medium must be separated from the storage medium by a heat exchanger in the area of domestic hot water for hygienic reasons or in hydraulic circuits with a risk of frost, e.g. when integrating a solar thermal system, heat transfer is not required for the pure storage of water for space heating. Compared to a sensible heat store with heat exchanger, the main advantage is that the heat transfer medium can be used for heat input and output into the store as well as for distribution and storage, thus eliminating heat transfer losses. If certain heat exchangers, loading and unloading lances or heat insulation concepts are required according to the use of the sensible heat store, there are a large number of designs of these, which are already highly developed and tested, as well as those which are still in research and development. **Vacuum-insulated heat stores** are one such development. Vacuum-insulated domestic hot water stores, as well as other vacuum-insulated sensible heat stores in the appropriate temperature range, can achieve heat losses up to 10 times lower than conventionally insulated domestic hot water stores. In addition, they are particularly suitable for outdoor installation due to the high insulation performance and the good weather resistance of the thermal insulation[13].

Compared to the storage of latent heat, the storage of sensible heat takes place by means of a temperature increase or decrease of a storage medium within an aggregate state (liquid, solid or gaseous) without phase change. The storage densities of sensible heat stores with gases as storage medium are low, therefore they are hardly realized. In existing sensible heat stores with solids as storage medium, the soil or rock layers in the soil often form the solid. This type of sensible heat store is therefore described in chapter 2.2.2.6, for underground thermal storage. Another type of sensible heat store with solids is the so-called **thermal activated building mass**. This is used in particular in the building sector. Here, by means of electrical elements or hydraulic piping in combination with the heating system, the building structure, in particular solid floors and ceilings, is heated at a low temperature level. Due to the usually high specific heat capacity and mass of the building structure, especially in the case of a massive construction, the heat can be stored there and released to the room for space heating or cooling with a time delay. Thermal activated building mass can be used together with intelligent operating and control strategies (e.g. demand-side management) for sector coupling.

[13] AEE - Arbeitsgemeinschaft ERNEUERBARE ENERGIE – Dachverband: Phasenwechselmaterialien, Zeitschrift Erneuerbare Energien, 2005, https://www.aee.at/zeitschrift-erneuerbare-energie?id=870, retrieved on 03/31/2023

The model for long-term or seasonal heat storage is the **large-scale sensible heat store** according to the Danish examples, which can hold up to several hundred thousand cubic meters of water. Seasonal heat storage is often used in combination with local or district heating networks fed by renewable heat sources such as solar or geothermal energy. The high storage capacity can be used for the temporal decoupling of heat generation and heat demand and for optimized operating strategies of all components in the system. To further increase the usable storage capacity of these seasonal heat stores, by means of reducing the lower usable temperature level, they can also be used as a heat source for large-scale heat pumps, thus offering further opportunities for sector coupling. This also applies to the seasonal borehole thermal energy storage described in chapter 2.2.2.6. Seasonal heat stores have already been implemented dozens of times for more than 30 years, at least in the European region, mainly in the form of pit thermal energy stores. They are currently spreading, among other things, due to the increasing requirements for decarbonization of heat supply, as well as for security of supply in times of crisis[8],[14],[15].

Based on the temperature range of the liquid phase of water and the temperature of cold water from the water supply, these sensible heat stores are operated in the temperature range between about 10 °C and 95 °C. The minimum operating temperatures of pit thermal energy stores are often limited to about 40 °C due to their seasonal use. The maximum operating temperatures of this type of store are limited to temperatures of about 85 °C due to the materials used. At a usable temperature difference of 50 K, an energy density of 60 kWh/m³ can be achieved with sensible heat stores using water as the storage medium. In order to keep the exergy of the stored sensible heat high or, for example, to achieve an efficient operating point of a connected solar thermal system, a temperature stratification, i.e. high temperatures at the top and low temperatures at the bottom, is aimed at.

Tank- thermal energy storage (TTES) systems are mainly designed as buried reinforced concrete tanks. The concrete tank is made on site from in-situ concrete. More recent research projects use precast concrete elements that are prestressed on site. This allows for higher load application or even internal pressurization. Inside, the tank is sealed with stainless steel or black steel plates. Recently, UHPC (Ultra High Performance Concrete) has also been used, which is so diffusion-tight that no internal coating is required. Novel GRP constructions can also be considered as a replacement for stainless steel linings and concrete constructions. The heat storage tanks are insulated on the bottom, walls and lid to prevent heat loss. Depending on the load case, foam glass gravel for the floor and expanded glass granulate in a membrane formwork for the walls and roof are used as insulation materials.

Pit thermal energy storage (PTES) are buried underground. Typical depths are 4 to 16 meters. The sidewalls are naturally sloped (possible up to a certain angle) or supported by spraying concrete (shotcrete) for greater slopes. The achievable angle of inclination and the depth of the reservoir will depend on the ground conditions. Careful insulation of the tank is also very important. Tanks are insulated at the bottom, sides and top. Various techniques have been tried for the top cover. So far, floating, cantilevered or overlying covers have been realized. The geometry Pit thermal energy storage is rather flat compared to tank heat storage tanks. The resulting large surface area is a disadvantage. The maximum temperatures of the earth storage tank depend in particular on the temperature stability of the inner sealing foil. Optionally, a water-gravel mixture is used as the storage material where the gravel content is approximately 60-70% (corresponding to the void ratio of random fill). The construction with naturally sloping pit walls and a solid water filling eliminates the need for a complex concrete support structure. The gravel/water design is preferable where structural considerations are important, e.g. where car parking or playground can be located above the reservoir. The upper cover of the tank is also structurally simple. Due to the lower specific heat capacity of rock in relation to water, the gravel pit store must have a larger volume than a pure hot water storage tank for the same heat storage capacity. This is the reason why today more water-filled PTES are built than gravel water PTES. In combination with a floating cover, storage tanks of almost any size can be built.

2.2.2.5 Thermo-chemical storage

Thermochemical heat storage is still a relatively new discipline within thermal energy storage. Due to its physical properties, it is considered to have great potential to take on heat storage tasks in the future that previously could not be taken on, or only to a limited extent, by hot water storage systems, for example. On the other hand, this discipline is still much less researched than sensible or latent heat storage. At this point it should also be pointed

[14] Steinbeis Innovation gGmbH (SIZ EGS), Universität Stuttgart IGTE, Bayerisches Zentrum für Angewandte Energieforschung (ZAE): Abschlussbericht futureSuN - Analyse, Bewertung und Entwicklung zukunftsfähiger Anlagenkonzepte für solare Nahwärmeanlagen mit saisonaler Wärmespeicherung, Förderkennzeichen 0325897A, 0325897B, 0325897C, 2020

[15] AEE - Arbeitsgemeinschaft ERNEUERBARE ENERGIE – Dachverband: Phasenwechselmaterialien, Zeitschrift Erneuerbare Energien, 2005, https://www.aee.at/zeitschrift-erneuerbare-energie?id=870, retrieved on 03/31/2023

out that there are currently no commercial storage systems on the market. However, in a growing international research environment, some promising demonstration systems have been realized and successfully tested, so that the status of a proof of concept has been exceeded.

Thermochemical energy storage is characterized by the fact that a significantly higher volumetric storage capacity (compared to hot water storage) can be achieved and the storage is almost loss-free. The term thermochemical heat storage covers mechanisms based on reversible chemical reactions, mostly gas-solid reactions, chemisorption (e.g. salt hydration) and physisorption (adsorption processes). The range of possible reaction systems is very wide and accordingly, very intensive research has been carried out over the last 20 years to find the most suitable reaction systems for heat storage.

The subject of intensive research on thermochemical energy storage are hygroscopic materials, such as silica gel, zeolites or salts on highly porous carrier materials. Heat storage is based on a reversible process in which water vapour is absorbed by the storage material with the release of heat (discharging the storage material) and desorbed again by adding heat (charging the storage material). If the sorption material is desorbed (dried) and then hermetically separated from any water vapour or moist air, the energetic state can be maintained for any length of time. The storage system is only discharged when moisture is added. This means that no heat losses occur during the actual storage phase; heat losses only occur during the loading and unloading process. This is why the technology can also be used on a small scale as a seasonal thermal storage system in single- or multifamily-houses.

The heat required for the regeneration of the materials can be provided by a solar thermal system, for example. Electric heating with PV surpluses in summer is also very possible. Depending on the storage material, relatively high regeneration temperatures are required. Especially for zeolitic storage materials, temperatures of about 150 °C are required for regeneration. Even if these temperatures can be reached by high-performance collectors with acceptable efficiencies, the high regeneration temperatures place certain demands on the process technology. Other materials such as silica gels or composites manage with lower temperatures. However, it can almost generally be said that the higher the charging temperature, the better the storage performance.

A distinction is generally made between open and closed adsorption. Open adsorption is much simpler in terms of equipment. Closed adsorption operates in a vacuum and is therefore more complex. However, it has the advantage that it can not only store energy for heating purposes, but can also be used as a cold store for cooling applications.

Research into thermochemical heat storage is strongly based in Europe. Research groups from Austria, Germany, Denmark, the Netherlands, France, and Poland have successfully tested demonstrators.

2.2.2.6 Underground thermal storage

Underground thermal storage can be assigned to the above-mentioned sensible heat stores with solids, such as the soil or rock layers in the ground, as storage medium. Several designs for underground thermal storage are so-called aquifer heat stores and vertical geothermal or borehole heat stores. Due to their dimensions, these are mainly used for long-term or seasonal heat storage.

Heat storage in **aquifer heat stores** works with two wells. Where one well is used to inject hot water and one well is used to extract cold water. This type of construction is locally limited by naturally occurring geological strata. Thus, there must be a rock formation saturated with water, which is horizontally permeable and vertically delimited. Depending on the geological conditions, the maximum operating temperature of the heat reservoirs ranges from about 25 to 100 °C[14].

Borehole heat stores consist of a mostly cylindrical arrangement of several geothermal probes. A borehole heat exchanger consists of one or a double U-pipe or a pipe in helix design, with a depth of 20 to 300 m on average. The pipe serves as a heat exchanger between the ground and a heat transfer fluid circuit of the heating system. In this way, the ground is used directly as a storage medium. Suitable soils for this purpose are clayey, loamy soils without groundwater flow and rock. The geological conditions determine the pipe spacing and the probe depth. As explained above, borehole heat stores are often used in combination with local solar district heating and are therefore operated in a temperature range between 40 and 80 °C without the combination with a large-scale heat pump. The heat is stored in the ground. Charging takes place by means of heat transfer fluid, an antifreeze mixture, during summer heat surpluses of the solar thermal system. Discharging takes place during high winter heat demand[8,14].

2.2.3 Thermal grids technologies

2.2.3.1 Fundamentals

The sustainable energy supply of entire quarters is increasingly coming into focus. In a traditional district heating system, the temperature of a working fluid (hot water, steam etc.) is raised to the required heating levels using a central power station and then distributed to the consumers in the district via transfer stations. High installation costs and high distribution losses due to the high temperature level are a major disadvantage of these high temperature heating systems[16]. In summer, many systems are generally operated only to meet hot water demand and the heated water has a long residence time in the grid. This can result in up to 30% of thermal energy being lost from the grid[17]. Over the last century, the development of heat grids has therefore been aimed at reducing the temperature in the grid (see Figure 2). 1st generation district heating grids use steam as the heat transfer medium and have been replaced by 2nd generation grids using pressurised hot water with inflow temperatures above 100 °C as the heat transfer medium. From the 1970s to the present day, 3rd generation grids have been used, which provide inlet flow temperatures of 100-80 °C for heat transfer to radiators (classic district heating system). These systems operate with a central heat generator and use pressurised water as the working medium. The total number of these district heating systems in Europe is estimated to be around 6,000. A disadvantage of centralised systems is the distribution loss, which ranges typically from 10-30%[18].

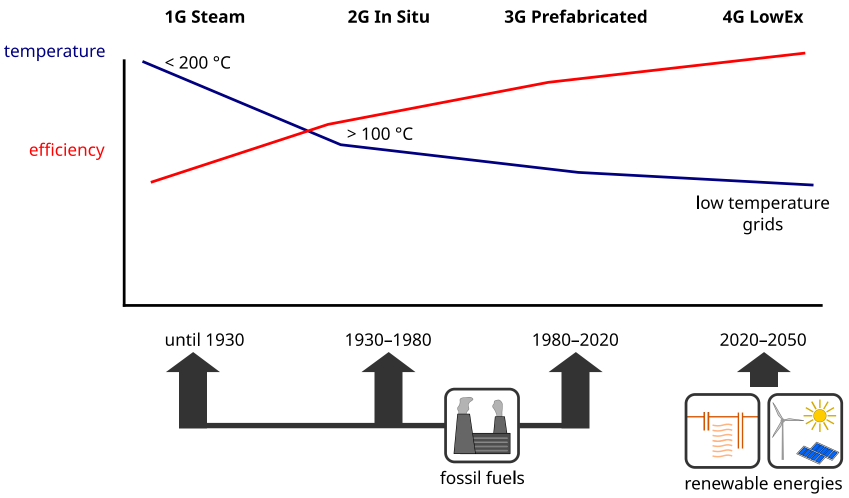

Figure 2: Qualitative representation of the development of efficiency and temperature level of heat grids (according to Pehnt19)

2.2.3.2 Integration of renewable energies

Developments in recent years have focused on low temperature grids with system temperatures below 90 °C. In most cases, even grid temperatures below 70 °C are targeted in order to integrate lower temperature renewable energy sources, such as geothermal energy[20]. These are also referred to as 4th generation grids. Higher efficiencies can be achieved due to the lower system temperatures of the grid[21].

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[16] Banks, D.: An introduction to thermogeology – Ground source heating and cooling. John Wiley & Sons Ltd, Hoboken NJ, 2012.
[17] Buffa, S.; Cozzini, M.; D'Antoni, M. et al.: 5th generation district heating and cooling systems: A review of existing cases in Europe. In: Renewable and Sustainable Energy Reviews 104 (2019), S. 504-522. https://doi.org/10.1016/j.rser.2018.12.059.
[18] Pellegrini, M.; Bianchini, A.: The Innovative Concept of Cold District Heating Networks: A Literature Review. In: Energies 11 (2018), Heft 1, S. 236. https://doi.org/10.3390/en11010236.
[19] Martin Pehnt (ifeu-Institut für Energie-und Umweltforschung Heidelberg GmbH)): Wärmenetzsysteme 4.0-Endbericht – Kurzstudie zur Umsetzung der Maßnahme „Modellvorhaben erneuerbare Energien in hocheffizienten Niedertemperaturwarmenetzen" (2014).
[20] Marco Wirtz: Wärmenetze 5. Generation / Kalte Nahwärme, https://www.mwirtz.com/5gdhc_projects.html [access on: 18.04.2022].
[21] Banks, D.: An introduction to thermogeology – Ground source heating and cooling. John Wiley & Sons Ltd, Hoboken NJ, 2012.

4th generation grids can be further subdivided into classic district heating grids (50-70 °C grid temperature) and cold district heating grids. Due to the high temperatures in the pipes, classic district heating grids cannot simultaneously supply different buildings with heating and cooling (unidirectional supply). Cold district heating grids address this challenge[22].

There are many terms for these grids. In addition to the term cold local heating grid, which will be used in the following, the terms anergy grid or heat grids 5.0 are also in use. The main characteristic of these grids is that the grid temperature, with values between 5-40 °C (mostly 10-25 °C), is not sufficient for direct heating of a building. Decentralised heat pumps have to be installed in the buildings to raise the heat from the grid to the required temperature of the building energy system. The possibility of reversing the operation of the heat pump in the heat transfer stations in the buildings has the advantage that the heating and cooling needs of the connected users can be met by the same grid (bi-directional supply). As mentioned above, cold local heating systems operate at temperatures between 5 and 40 °C, which allows the integration of a variety of renewable energy sources (e.g. mine water or ambient air). Figure 3 gives an overview of the usable temperature levels of different heat sources.

2.2.3.3 Technical implementation

Grids with a central pumping station are typically single-pipe systems. Some users utilize the heating mode, others may cool at the same time. The user draws water from the single pipe in the building, cools (heating mode) or heats (cooling mode) it and returns it to the single pipe. In practice, as the demand for hot water can occur at the same time as the demand for cooling, it can be difficult to use the same pipe for both heating and cooling.

Therefore, in cold local heating grids, two-pipe systems are most common, where some houses can be in heating mode and others in cooling mode at the same time.

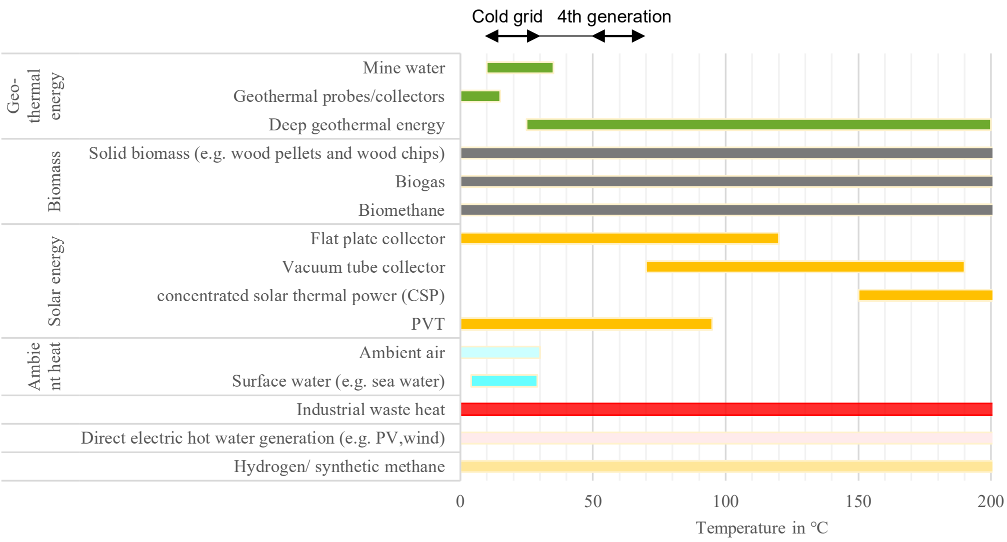

Figure 3: An overview of the usable temperatures of the various renewable energy sources[23,24,25,26]

[22] Lund, H.; Østergaard, P.A.; Nielsen, T.B. et al.: Perspectives on fourth and fifth generation district heating. In: Energy 227 (2021), S. 120520. https://doi.org/10.1016/j.energy.2021.120520.
[23] Agentur für Erneuerbare Energien: Erneuerbare Energie für die Industrie. Prozesswärme aus Bioenergie sorgt für Unabhängigkeit und Klimaschutz. In: Renews kompakt (2017), Ausgabe 38.
[24] Dr. Martin Pehnt, ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH: Wärmenetzsysteme 4.0-Endbericht Kurzstudie zur Umsetzung der Maßnahme „Modellvorhaben erneuerbare Energien in hocheffizienten Niedertemperaturwarmenetzen“ (BMWi) (2017).
[25] Johansen, K.; Werner, S.: Something is sustainable in the state of Denmark: A review of the Danish district heating sector. In: Renewable and Sustainable Energy Reviews 158 (2022), S. 112117. https://doi.org/10.1016/j.rser.2022.112117.
[26] L. Oppelt, T. Grab, S. Pose, T. Storch, T. Fieback: *Mine water geothermal energy as a regenerative energy source - status quo and results from five years of monitoring*, Oil Gas EUROPEAN MAGAZINE, 47. Edition, 1/2021, S 15-19, März 2021, DOI: 10.19225/2103054

The temperature level in the grid can vary seasonally or be kept constant. Constant operation is most often used for passive cooling of buildings, which requires temperatures below the cooling circuit temperature in each building at all times[27].

In this case, there is a hot and a cold pipe, usually with a temperature difference of 5-10 K. In the case of heating, the building's heat pump takes water from the hot pipe, cools it by a few Kelvin in the evaporator, and returns it to the cold pipe. In the case of cooling, the building takes water from the cold pipe and returns heated water to the hot pipe[28,29].

This is illustrated in Figure 4 for mine water, where a user (A) is heating, drawing heat from the warmer pipe (dark blue) and raising the temperature level in the heat pump, while the user (B) is simultaneously cooling his house with the colder pipe (light blue). The different operating modes for cold local heating grids are summarized in Table 1.

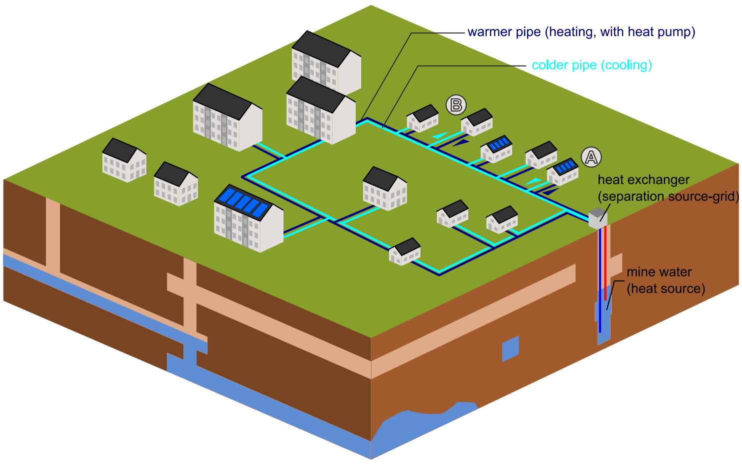

Figure 4: Principle of a cold local heating grid using mine water heat, according to Oppelt[30,31]

Table 1: Types of cold local heating grids, according to Pellegrini[32]

Type of grids	Description
Pure cold operation: (approx. 5-20 °C)	Pure use of ambient heat inflexible Often not economical due to high energy demand in existing buildings If necessary, cooling of the return flow using a heat pump before returning it to the grid.

[27] Pellegrini, M.; Bianchini, A.: The Innovative Concept of Cold District Heating Networks: A Literature Review. In: Energies 11 (2018), Heft 1, S. 236. https://doi.org/10.3390/en11010236.
[28] Buffa, S.; Cozzini, M.; D'Antoni, M. et al.: 5th generation district heating and cooling systems: A review of existing cases in Europe. In: Renewable and Sustainable Energy Reviews 104 (2019), S. 504-522. https://doi.org/10.1016/j.rser.2018.12.059.
[29] Lund, H.; Østergaard, P.A.; Nielsen, T.B. et al.: Perspectives on fourth and fifth generation district heating. In: Energy 227 (2021), S. 120520. https://doi.org/10.1016/j.energy.2021.120520.
[30] L. Oppelt, T. Grab, S. Pose, T. Storch, T. Fieback: *Mine water geothermal energy as a regenerative energy source - status quo and results from five years of monitoring*, Oil Gas EUROPEAN MAGAZINE, 47. Edition, 1/2021, S 15-19, März 2021, DOI: 10.19225/2103054
[31] L. Oppelt, T. Grab, T. Wunderlich, T. Storch, T. Fieback: *Mine Water Geothermal Energy - Abandoned Mines As A Green Energy Source*, CLIMA 2022-Proceedings, Rotterdam, 2022, DOI: 10.34641/clima.2022.55
[32] Pellegrini, M.; Bianchini, A.: The Innovative Concept of Cold District Heating Networks: A Literature Review. In: Energies 11 (2018), Heft 1, S. 236. https://doi.org/10.3390/en11010236.

Alternation between warmer (60-85 °C) and cold (10-30 °C) operation	Suitable for new and existing buildings Cooling mode depending on the season, e.g. above 22 °C outdoor temperature. Hot water and residual heating loads covered by decentralised heat pump in buildings
Sliding operation (approx. 10-50 °C)	Mainly suitable for new buildings Use of decentralized heat pumps

2.2.3.4 System optimisation

In existing heating networks - based on already installed piping, which means that the diameters of the pipes are also fixed - the maximum possible mass flow ($\dot{m}$) is limited and thus also the maximum possible heat capacity ($\dot{Q}$) of the network is limited. The limitation of $\dot{m}$ in existing pipes is based on cavitation avoidance reasons, where the flow velocity cannot be increased so that the local static pressure in the pipe does not fall below that of the saturation pressure. Thus, an increase in heat capacity could be only achieved if larger pipes would be installed. But this causes high investment costs and long periods for the renewal of the entire grid. To overcome this situation, the (primary) return temperature has to be lowered by a higher value than the (primary) supply temperature, in order to achieve a bigger temperature-spread and thus ensure an increase of the heat capacity of the existing DH-grid. With a sufficiently high reduction of the return temperature, the supply temperature could also be reduced at a high value, resulting in a reduction of losses and significantly increasing the possibility to integrate renewables, such as deep geothermal or industrial waste heat.

Absorption heat exchanger (AHX) is one of the most commonly used technologies to improve the performance of district heating grids[33]. Compared to a conventional heat exchanger (HX) an AHX can use the exergetic potential based on the temperature difference between the supply temperature to subcool the return temperature of the primary circuit below the return temperature of the secondary circuit, which is the inlet temperature on the secondary side of the transfer substation. This subcooling allows the DH grid to be improved, as already mentioned above, and is the reason for using an AHX[34]

Another trend is the hybridization of heat supply based on two networks, the thermal and the electrical. Through the power-to-heat approach, excess electricity is converted into heat and directly fed into heat networks or stored. The use of the thermal inertia of buildings through thermal component activation has enormous potential to cost-effectively compensate for peak loads and will gain significant importance. In particular, large-scale heat storage systems have the potential to store volatile energy short-term as well as seasonally, acting as a kind of "heat sponge". Predictive controls based on current measurement data, weather data or energy prices enable a forward-looking and resource-efficient operation with the help of model-based system considerations, offering the possibility to use the network itself as a thermal storage and to integrate spatially and temporally distributed prosumers and storage (keyword "virtual heating plant")

2.2.4 Building and community technologies

Even though the building sector poses technical and non-technical challenges for decarbonization, a building stock with a continuously increasing rate of energy efficient and energy active buildings via new construction and holistic refurbishment also provides unique opportunities for the overall energy system. Buildings that can interact as energy active prosumers with overarching grid infrastructures (thermal, electrical) can become an indispensable pillar for the energy climate-neutral volatile energy system of the future through key qualities:

Low temperature levels for building thermal energy supply

[33] Hu, J,, Xie , X., Jiang, Yi, 2020: Design and experimental study of a second type absorption heat exchanger: *International Journal of Refrigeration* 118 (2020) 50–60
[34] Zotter, et. Al., 2023: An energetical, exergetical and experimental analysis of an absorption heat exchanger used as transfer substation in an already existing district heating grid: 14th IEA Heat Pump

Typically, buildings required energy at temperature levels of up to 70°C for space heating and hot water. Modern, high area heat dissipation systems like floor or wall heating can further decrease the required temperature level for space heating, enabling low overall operating temperatures in conjunction with suitable booster technologies for hot water preparation and legionella protection. These low supply temperatures can be provided at high conversion efficiencies by renewable based technologies such as solar thermal, heat pumps, geothermal or excess heat. The usage of highly exergetic energy sources like fossil fuels can easily be avoided for these applications, given the appropriate design of the energy supply system in the building.

Local renewable conversion and consumption

Especially in urban areas, space for renewable energy generation is limited and costly. Technologies like large solar thermal or PV collector fields and pit-thermal energy storages need to be complemented by conversion technologies that are embedded in the city structures themselves. Given economically and technically feasible integration concepts, buildings offer so far untapped potential through façade and roof integrated solar conversion technologies (Solarthermal, PV, PVT, **dynamic thermo-regulative walls/windows**), integration of **micro heat pumps** in the facades and the usage of common and open spaces for geothermal boreholes (e.g. patios, garages or parks). Digitalised, **smart and predictive control algorithms** can enable a maximized self-consumption on site, reducing the stress on overarching grid architectures and enabling the establishment of local energy communities at neighbourhood or quarter scale.

Digitalisation as enabler of efficient and energy active buildings

Digital building (community) twin-based solutions gain increasing track for optimized operation of buildings, coupling a continuously self-learning simulation model of the building to the building management software for predictive, automated control. Additionally, recent research shows that decentralized and data secure agent-based algorithms can predict flexibilities in the building and offer them on the energy market without the need for user involvement or negative influence on the user comfort[35].

Even though an autonomous building operation with no need of interaction and constant high comfort for its residents is desirable, digitalisation also offers opportunities for **user involvement** aside from just inputs to the control system. Energy flows, consumption and current CO_2 footprint as well as energy cost can be displayed on smart devices, **offering incentives** for the users to engage with their own energy system, creating increased awareness for energy and the connected environmental impact. Through transparency, **gamification** and a paradigm shift from being just a consumer, societal change can be triggered on an end-user level.

Storage capacity for overarching grid infrastructures and sector coupling

Energy supply grids enable the intelligent integration and combination of renewable energies, storage, energy consumers and the coupling of different sectors and infrastructure, leading to an increase in overall efficiency and cost-effectiveness as well as CO_2-emissions reduction. As the share of volatile renewables in both electrical and thermal energy grids increases, the need for innovate ways to manage supply and demand in energy grids has become clear, as it is less possible (as in traditional fossil based energy grids) to freely adjust supply to meet demand. Through thermal inertia of the building masses and to a lesser extent the storage potential in decentralized hot water buffers and battery storages, buildings can act as storages (thermal building mass activation) for overarching thermal and electricity girds, including power-to-heat sector coupling via heat pumps. Through overcharging or withholding energy supply in defined boundaries, so called demand response (DR) provides the ability for consumption to follow production without negative influence on user comfort, health and privacy. Work has been done on the use of thermal inertia for demand response[36], and attempts have been made to characterise the response of buildings of different construction types to varying magnitude and duration of heat input adjustments. Kepplinger[37] and Nik and Mozami[38] describe methods for autonomous DSM, in which consumers devices are provided with information to make decisions about how to vary their consumption independently, or in collaboration with each other.

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[35] https://cordis.europa.eu/project/id/101033683, project COLLECTiEF
[36] Johan Kensby, „Buildings as Thermal Energy Storage", o. J., 48.
[37] Peter Kepplinger, „Autonomous Demand Side Management of Domestic Hot Water Heaters" (2018), https://www.researchgate.net/publication/332834319_Autonomous_Demand_Side_Management_of_Domestic_Hot_Water_Heaters.
[38] Vahid M. Nik and Amin Moazami, 'Using Collective Intelligence to Enhance Demand Flexibility and Climate Resilience in Urban Areas', *Applied Energy* 281 (January 2021): 116106, https://doi.org/10.1016/j.apenergy.2020.116106.

2.3 Analysis from Austria, Denmark, Portugal, and China

The method described in section 2 was used to analyse each technology in four countries (Austria, Denmark, Portugal, and China), which have different climatic conditions. The results are presented in greater detail for each country and as aggregated results in the following chapters.

2.3.1 Analysis from Austria

The factors that influence the diffusion of renewable energy sources in Austria are varied. Although the impact of the Covid crisis was not significant, the prices of fossil fuels have sharply increased in the past three years and are expected to remain above average in 2024. Some issues in supply chains and the high demand for renewable energy technologies have also caused hindrances in certain areas. Nevertheless, the energy policy framework has created new incentives in some sectors.

Essential promoting factors were the improved energy-political framework conditions mostly in the area of incentive oriented instruments, the already established "phase out of fossil fuels" campaign as well as the expectation respectively the already rising prices of fossil energy sources. Further promoting effects are contributed to the consequences of the Corona crisis and the Ukraine war. Growing uncertainties in regard to security of supply, the stability of energy prices as well as inflation respectively currency stability are a great incentive for private investments in technologies for the use of renewable energy and energy storage technologies.As a result, there has been a notable growth in the domestic market for photovoltaics, all kind of heat pumps, biomass boilers and stoves, and wind power in general, although the market potential at the building or community level is estimated to be low. Solar thermal energy sales figures have declined, but there is a vast potential for SEBs. The use of covered and uncovered PVT collectors with finned heat exchangers for direct coupling with heat pumps are currently in focus around hybrid technologies.

Austria has a rich history in energy storage, with hydraulic storages and pumped-storage power plants being established on a large scale. Water-based storages for local heating and district heating systems were also introduced before 2000, allowing for the optimization of boiler operations. Large water pits used in district heating systems have a high potential. The use of electric battery storages has been growing for the past decade, driven mainly by the desire to maximize private consumption but has also a high potential due to the high and variable electricity costs. On community level battery storages become more important to reduce grid loads. The thermal activation of building parts has become more perceptible in recent years, thanks to the introduction of corresponding smart grid interfaces for thermal heat pump units and the possibility to increase self-consumption of local produced renewables.

However, the market diffusion of innovative energy storage technologies such as mobile electrical storages (V2G, V2H), latent heat storage systems, and thermochemical storage systems is still in its early stages or undergoing research and development. Therefore, the state of the innovation diffusion processes for storage technologies varies significantly in Austria, as does their possible short- to medium-term contribution to the energy transition. The necessary energy and research political framework for the further acceleration of market diffusion also varies accordingly.

The achievement of mid- and long-term international and national climate goals is a major challenge, in which consequently flexible and sustainable DH systems play a central role. Our current heat supply and the supply quality and robustness of DH systems is guaranteed by the versatility and ease-of-use of fossil fuels. In a future sustainable and fully decarbonized DH system, the same supply standard must be maintained in an affordable way in an even more complex system (storage, renewables, volatility, prosumers, etc.) without fossil fuels. This can be only achieved by increased flexibility of the overall system and a smart interaction of all its technical (e.g., supply units, storage, control) components which is reflected in the high market potential for the different aspects of DH systems.

DH systems allow for integration of renewable energy sources and are highly suitable for measures to increase flexibility in terms of renewable supply sources, advanced operation strategies and application of thermal storage. These benefits could be further increased if system-wide and holistic approaches as well as scientific methods such as simulation and optimization during conceptualization, implementation and operation would be applied. For implementation of flexible and sustainable DH systems further research and demonstration is needed for flexibility measures such as thermal storage, Absorption heat exchanger, booster heat pumps, smart control, sector coupling with electricity and wastewater infrastructure in combination with increased share of renewable heat and holistic system and planning/operation approaches.

Energy-efficient buildings are a crucial aspect of sustainable development. The integration of renewable energy sources, such as BIPV and BIST, can be achieved through prefabricated energy-active facade elements in new construction and renovation which shows a high potential. These elements can also provide heat and weather protection, as well as building technology for heating, cooling, and ventilation. Low-temperature heat distribution and delivery systems can also be integrated into existing buildings to maximize their thermal capacity (thermal building mass activation). Efficient building operation can be achieved using model predictive control systems ensuring optimized performance. The use of game elements and user-centred pro-active building management can improve customer participation in demand management programs, contributing to the reduction of energy consumption but this is in an early stage.

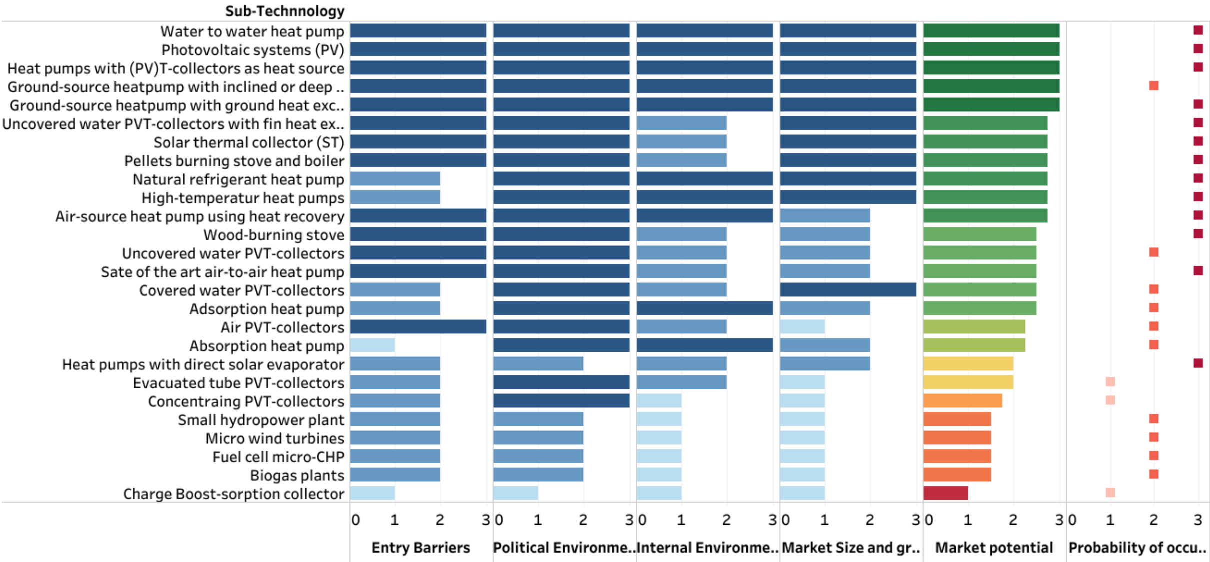

Figure 5: Market potential for renewable generation technologies in Austria

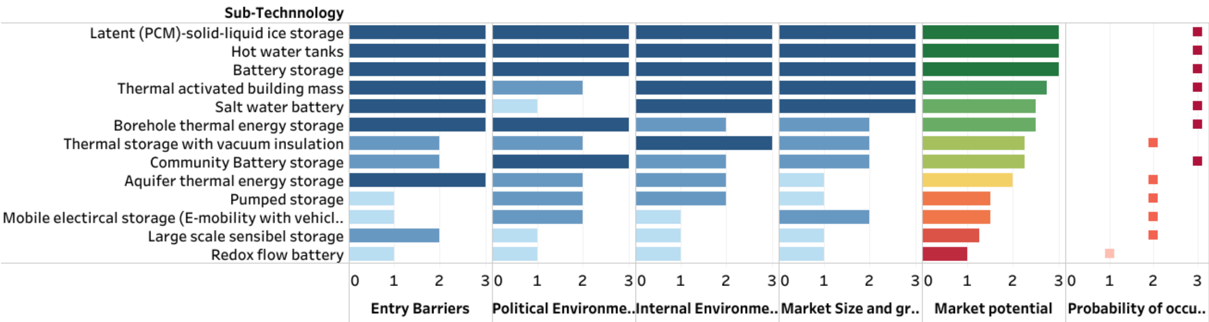

Figure 6: Market potential for storage technologies in Austria

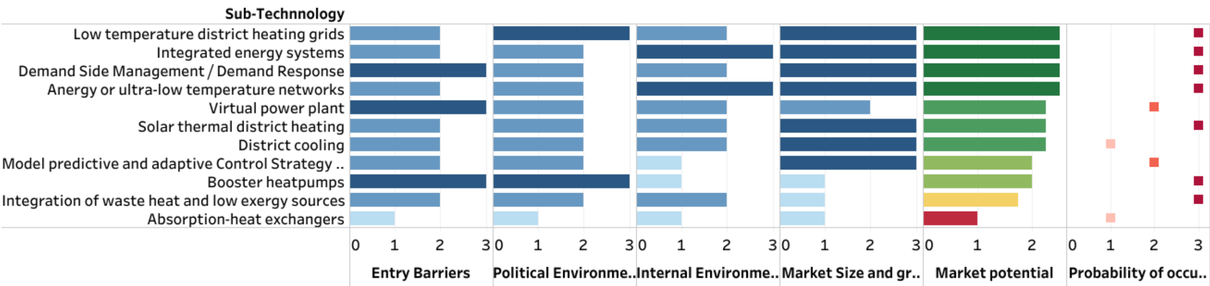

Figure 7: Market potential for thermal grid technologies in Austria

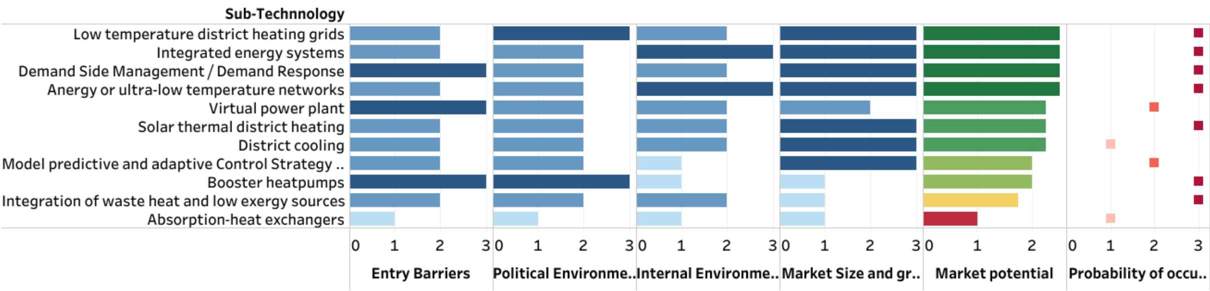

Figure 8: Market potential for building and community technologies in Austria

2.3.2 Analysis from Denmark

The estimated potential for renewable generation technologies in Denmark are shown in Figure 9.

PV systems and heat pump solutions, especially the inexpensive solutions, have the highest potentials. Due to the high and variable electricity costs, PV systems are economically attractive. Subsidy schemes are available for heat pump systems.

The estimated potential for energy storage technologies in Denmark are shown in Figure 10.

Electric batteries have a high potential due to the high and variable electricity costs. In addition, hot water tanks have a high potential due to relative cheap costs and relative high heat storage capacity. Finally, large water pits used in district heating systems have a high potential since these heat storages are relatively inexpensive and offer both short- and long-term heat storage. Use of water pits can further secure a good interplay between thermal grids and electricity grids and make a flexible energy system with different energy producing technologies possible, resulting in low energy costs.

The estimated potential for thermal grid technologies in Denmark are shown in Figure 11.

Solar district heating plants have a high potential, since these relatively inexpensive plants have high thermal performances, long lifetimes and low operation and maintenance costs. The estimated potential for building and community technologies in Denmark are shown in Figure 12. Use of thermal storage in the building mass has a high potential due to simplicity and due to low costs.

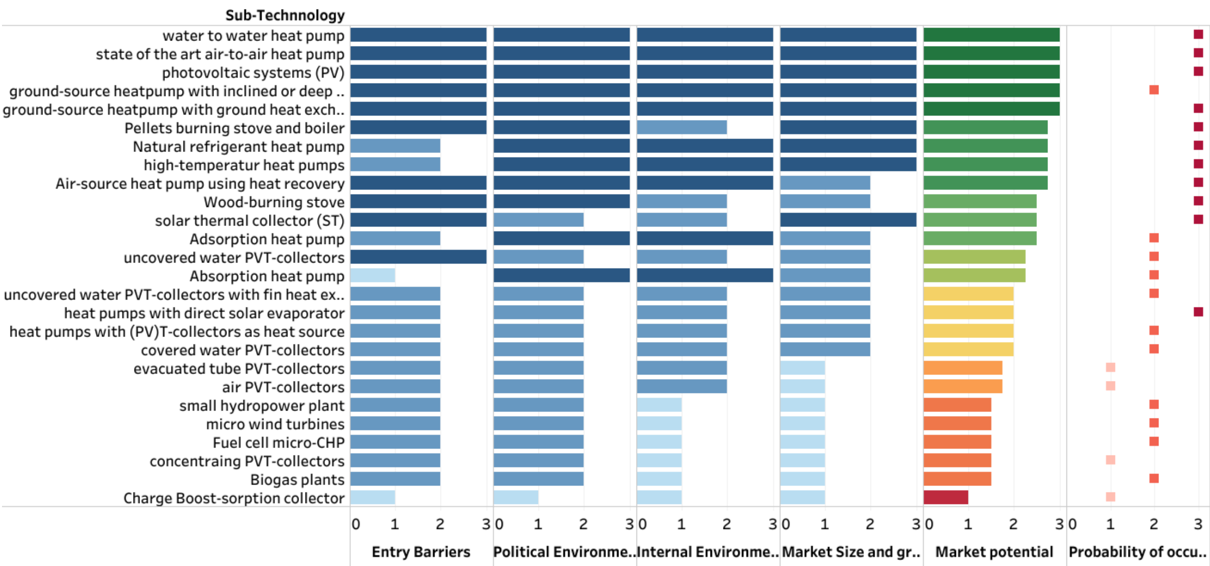

Figure 9: Market potential for renewable generation technologies in Denmark

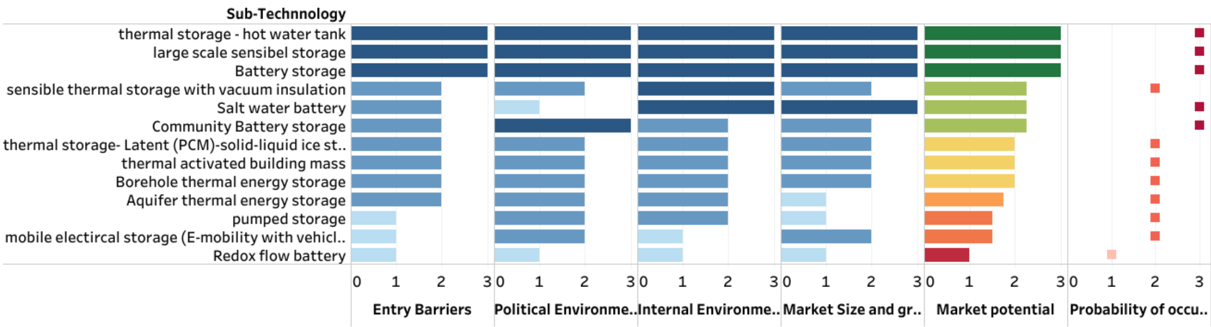

Figure 10: Market potential for storage technologies in Denmark

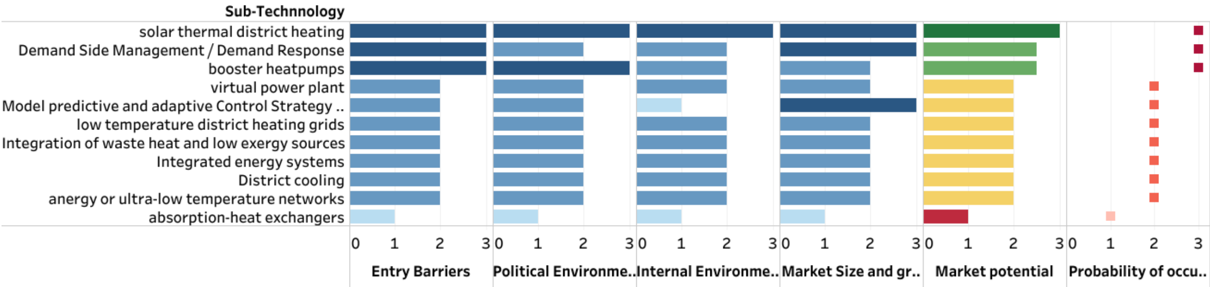

Figure 11: Market potential for thermal grid technologies in Denmark

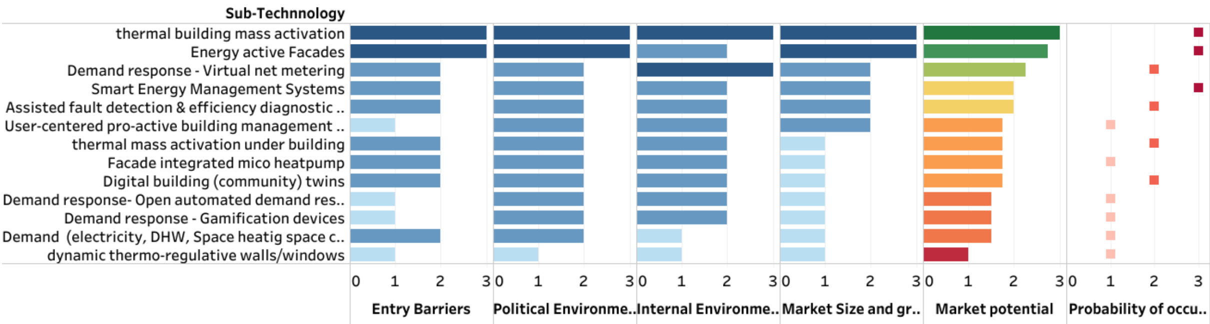

Figure 12: Market potential for building and community technologies in Denmark

2.3.3 Analysis from Portugal

In Portugal, the technologies with the highest growth potential in recent years have been photovoltaic electricity production and the use of heat pumps. However, the solar thermal generation of domestic hot water has shown a decreased installation rate in recent times. The renewable electricity generation was in 2022 around 66,9%. The total PV electricity produced reached 3 137 GWh, which represents about 7,3 % of the total electricity produced in Portugal in 2022. In 2021 was 4,5% it indicates that this technology is in fast-growing.

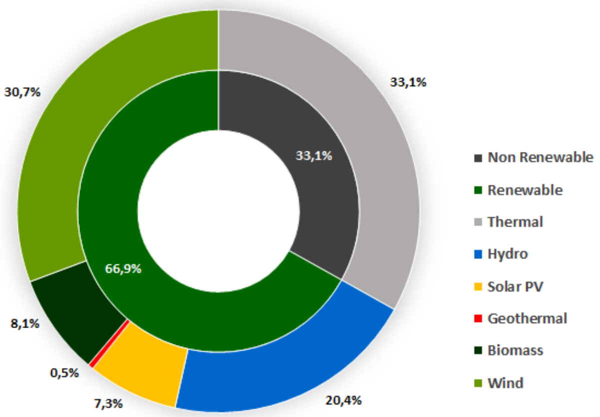

Figure 13 Renewable energy sources in electricity production in Portugal in 2022

According to Solar Heat Markets in Europe - Trends and Market Statistics 2021, SHE, December 2022, Portugal has around 1.314 million m^2 of thermal collectors, with an increase of 1.1% in 2021 related to 2020. In 2020 was 5.34% related to 2019, which means that the installation rate is decreasing. In 2021, Portugal recorded 33,000 heat pumps sold - six thousand more than in 2020. And, within the most sold typologies, the Portuguese market shows a preference: more than three quarters of sales refer to air-to-air units. From 2020 to 2022 the program "Programa de Apoio a Edifícios Mais Sustentáveis (PAE+S)," aimed to support more sustainable buildings. This program, supported for installing solar thermal systems and other energy efficiency measures such as efficient windows, insulation, PV systems and heat pumps, as well as water efficiency use. This situation allows to conclude the market potential for the listed renewable generation technologies in Portugal in Figure 14.

Portugal has an important capacity of pumped-storage hydroelectricity allowing energy from intermittent sources (such as solar, wind) to be saved for periods of higher demand. Additionally, the widespread use of battery storage systems seems likely to occur in the near future based on market potential for Storages listed in Figure 15. There is no tradition for thermal grids – district heating. However, there is a small community in Lisbon (Climaespaço) that has a distribution of hot water for space heating, domestic hot water and cold water for space cooling, through a

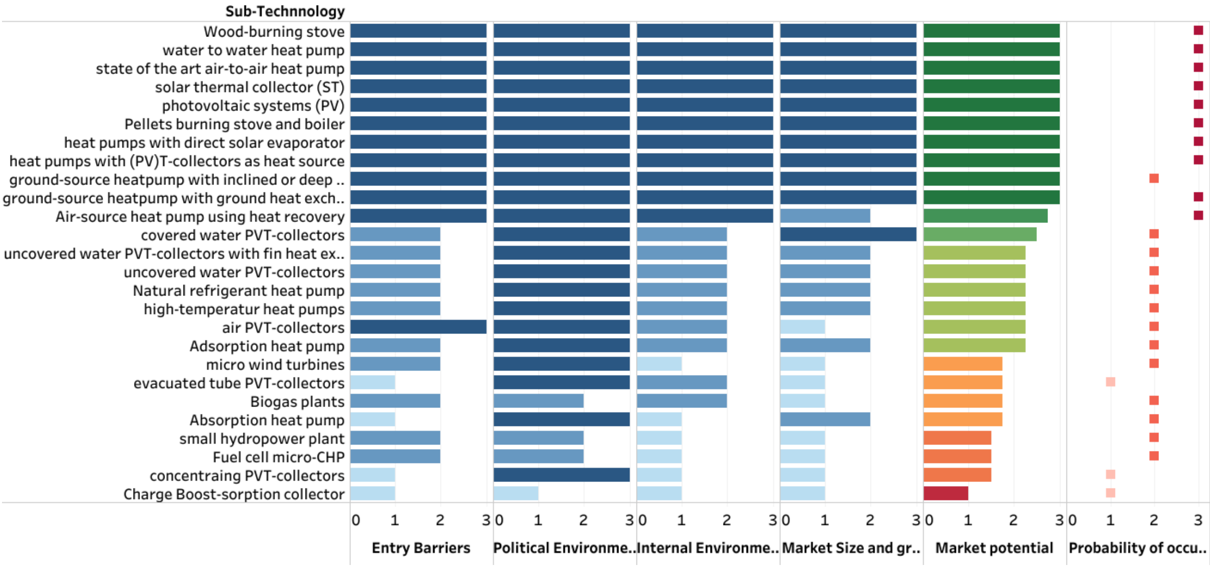

Figure 14: Market potential for renewable generation technologies in Portugal

trigeneration combined heat, cold and power system with a gas turbine and absorption chillers, which provides a proof of feasibility to further implement such technologies. The market outlook in Figure 16 also shows large potential, despite the currently scarce realizations. In terms of building technology, the two most promising future features in the list (Figure 17) are thermal building mass activation and energy active façade refurbishments.

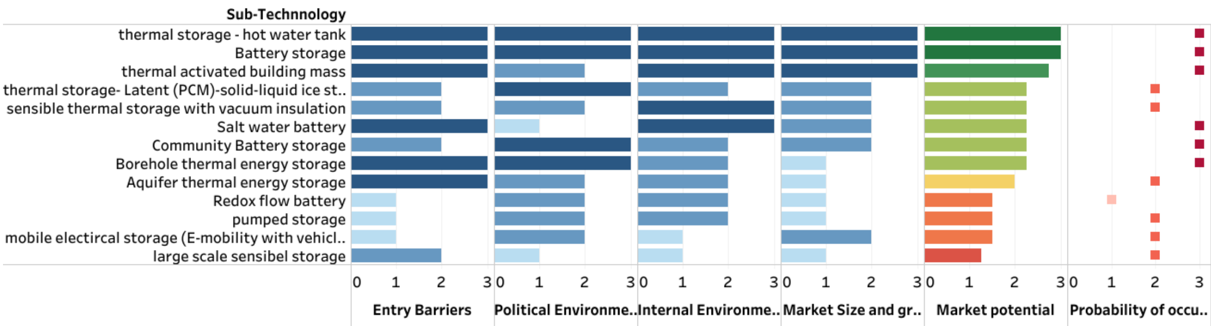

Figure 15: Market potential for storage technologies in Portugal

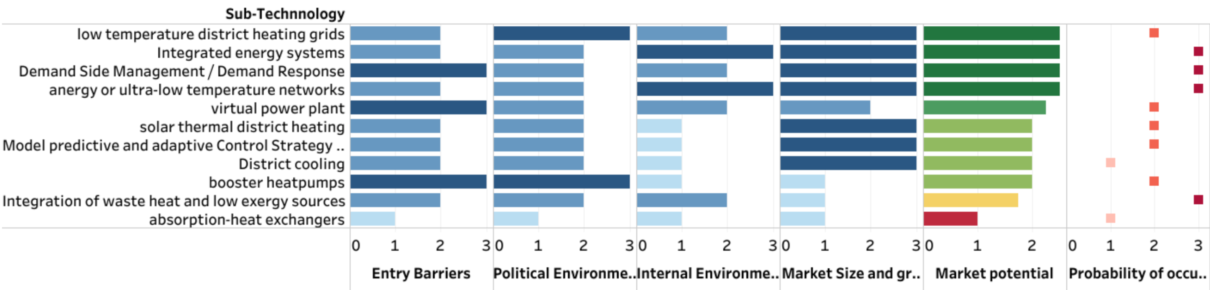

Figure 16: Market potential for thermal grid technologies in Portugal

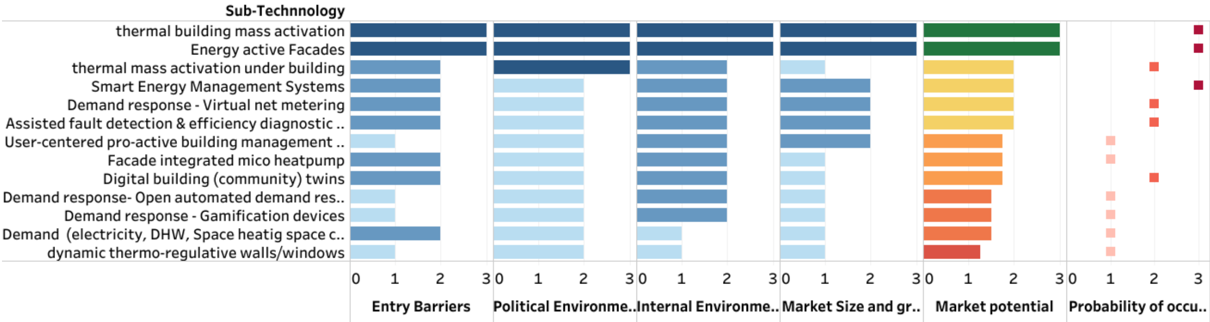

Figure 17: Market potential for building and community technologies in Portugal

2.3.4 Analysis from China

In September 2020, China put forward the "carbon peaking and carbon neutrality goals", which lead the country to build a green, low-carbon and circular economic development system from the structure of energy source industry, technologies, and standards, related regulatory policies and etc aspects. In new development stage, China pursues a philosophy that development must be innovative, coordinated, green, open, and shared and accelerates the pace in creating a new development dynamic. China follows the current technological revolution and industrial trends, and seizes the opportunities created by green transition, transforms and upgrades its economic and industrial structure and energy mix by innovation, and boosts China's sustainable economic and social development.

With the continuous improvement of the national innovation system and targeted support from relative industrial policies, the technological level and industrial competitiveness of wind electricity, photovoltaic electricity and power battery have made obvious progress. In 2022, there were 152 GW newly installed capacity of renewable energy in China, accounted for 76.2% of newly installed power generation capacity. Among them, 37.63 GW for wind power, 87.41 GW for photovoltaic power, 3.34 GW for biomass power, 15.07 GW for hydropower and 8.8 GW for pumped storage. So far, the renewable energy installed capacity come to 1,213 GW, accounts for 47.3% of total installed power generation capacity in China. This massive pace leads to great market prospects for all kinds of generation technologies as presented in Figure 18.

In the field of energy storage technology, the state issued several relative policies, built national big data platform for new energy storage, established national industrial management system, coordinated and promoted pilot and demonstration projects nationwide to lay the foundation for innovative application of new energy storage technologies and high-quality development of the industry. Up to 2022, the installed capacity of new energy storage projects in China has reached 8.7 GW, and the average energy storage time reached 2.1 hr. From the installed capacity technology proportion, the lithium ion battery technology takes the predominance, reaches 94.5%. The compressed-air energy storage, flow battery, and lead-acid battery take for 2%, 1.6% and 1.7% respectively. In addition, flywheel, gravity, and sodium ion and other energy storage technologies have entered the engineering demonstration stage in China. The diversified development trend of new energy storage technologies is remarkable. Additionally, the market prospects for hot water tank storages and latent heat ice storages are very promising (Figure 19).

Urban and rural development is an important prerequisite and guarantee for the high-quality development of the national economy and other industries in China. The policy systems and institutional mechanisms is gradually establishing for green and low-carbon development in construction. Promoting the application of solar energy, and variety of electrical heat pump technologies such as ASHP, GSHP in buildings to optimize the energy structure and improve the green level of buildings according to local conditions. Encouraging the application of BIM technology, Internet of Things, cloud computing, big data, artificial intelligence and other technologies in design, construction, property management, building operation and maintenance phases to greatly improved the degree of smart buildings/cities. This boom in property development and the drive towards smart and flexible solutions shows itself also in market prospects for several technologies listed in Figure 20 and Figure 21.

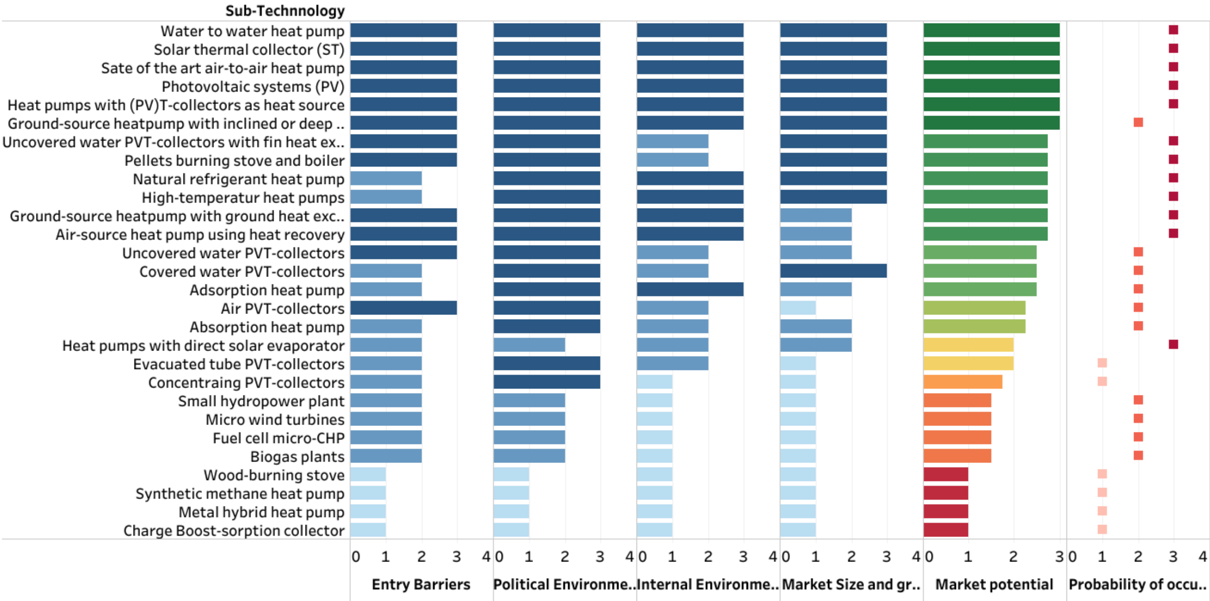

Figure 18: Market potential for renewable generation technologies in China

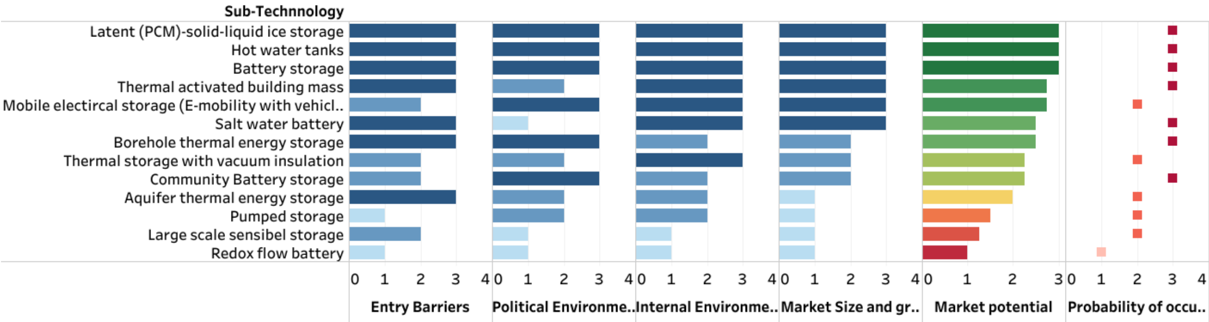

Figure 19: Market potential for storage technologies in China

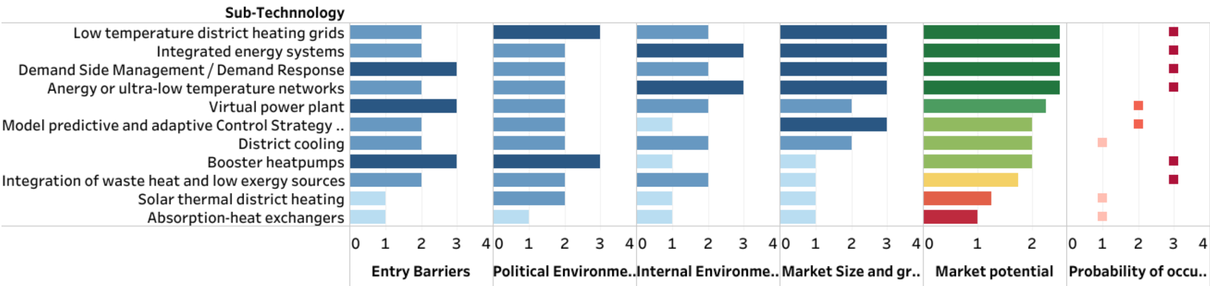

Figure 20: Market potential for thermal grid technologies in China

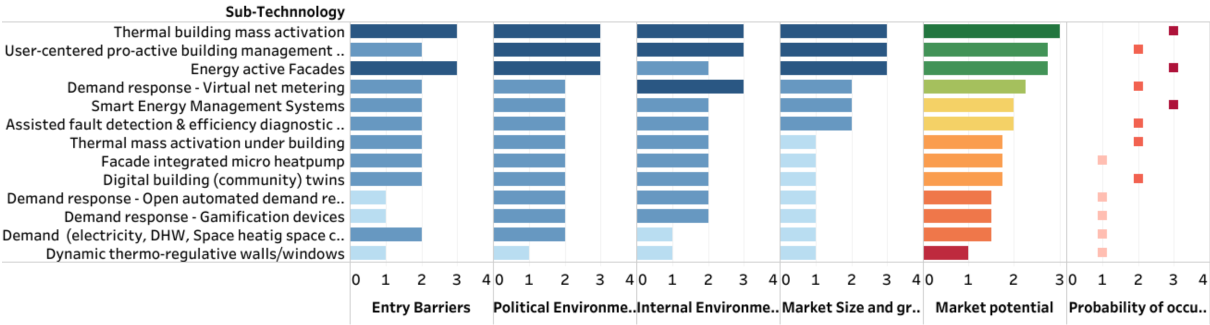

Figure 21: Market potential for building and community technologies in China

2.3.5 Aggregated results

As shown in Figure 22 listed, the overall market potential for generation technologies in the context of SEBs is very high for PV and heat pumps in general. This of course follows the general trend of electrification in the heat sector and is amplified even more by prevailing subsidies and policies. However, on a global level solar thermal technology and PVT is ranked among the most relevant generation technologies. Biomass still plays a large role in heat generation with pellet stoves being ranked very positive. Technologies with lower TRLs like sorption collectors or fuel cells are not to be expected playing large roles in the following years.

In the category of storage, the most prevalent single technology is the hot water tank as it holds an essential function in many hydronic heating systems. Followed by battery storages which are on the rise to compensate volatile renewable electricity generation in many applications. Thermal activated building mass is used for load shifting and

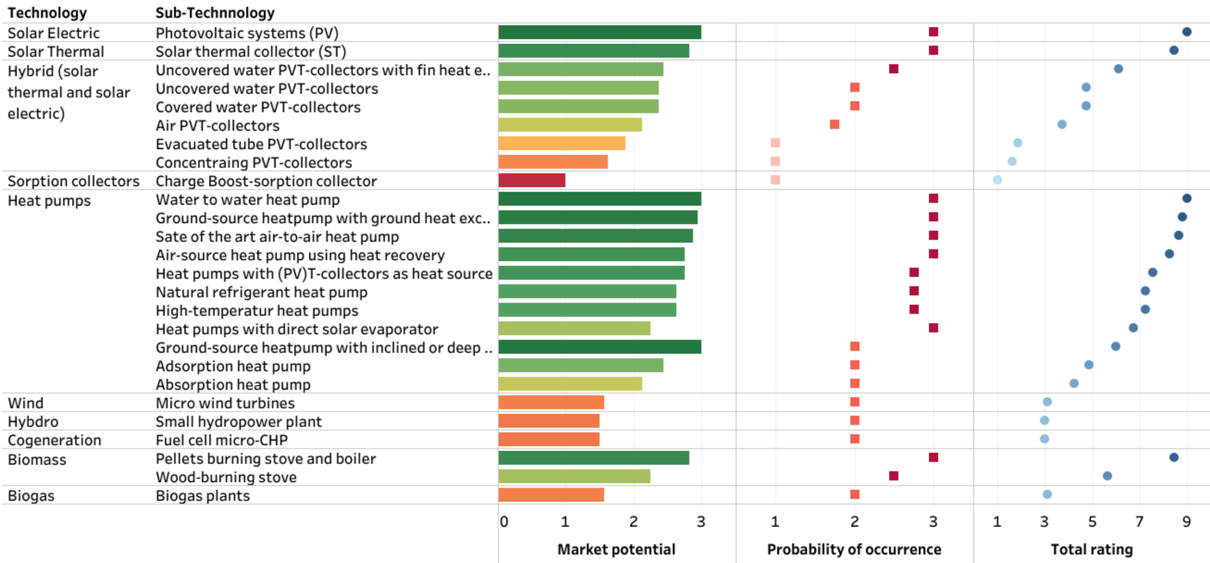

Figure 22: Aggregated results for renewable generation technologies

heat/cold dissipation in newly constructed buildings and is expected to occur more often. In the field of long-term storage, the use of latent heat ice storages is picking up.

The market potential of grid technologies is listed in Figure 24 with very good ratings for demand response systems and rising opportunities for low temperature of anergy grids. Again, low TRL technologies like absorption heat exchangers are ranked as lowest.

In the category of Buildings/Communities the highest potential shown thermal building mass activation and the renovation concept of energy active facades. These rank especially positive as the demand for quick renovation across the building sector is of international scale. Typical system integration and data driven control methods are showing low market potential which is surprising in the current upwind of digitalization. The complexity of the methods and maybe also cost benefit doubts are probably one of the pitfalls here.

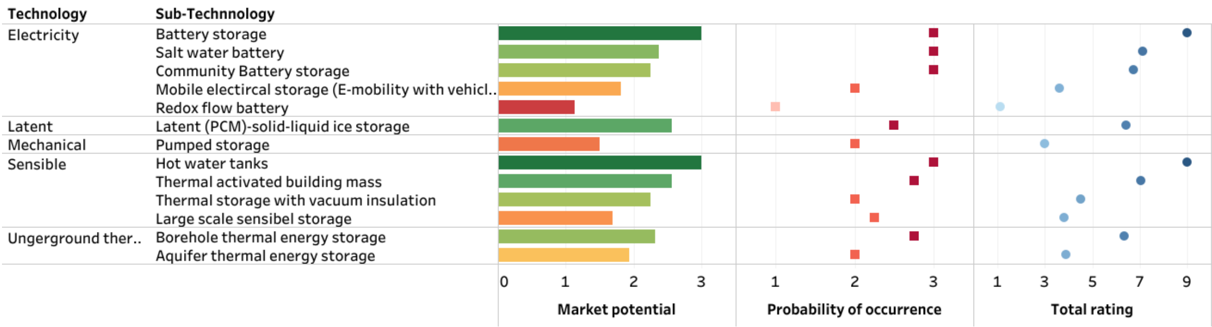

Figure 23: Aggregated results for storage technologies

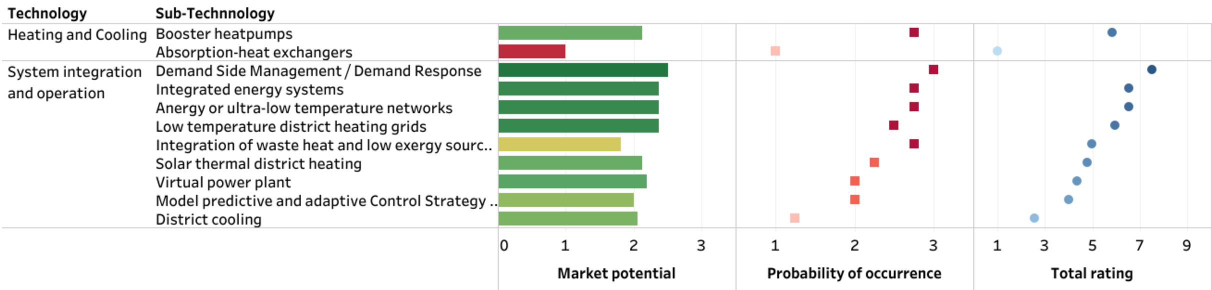

Figure 24: Aggregated results for thermal grid technologies

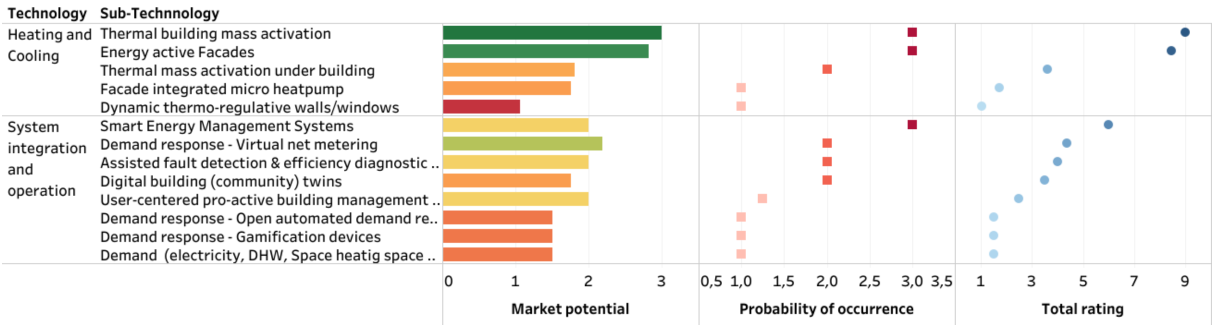

Figure 25: Aggregated results for building and community technologies

3 Technology Radar

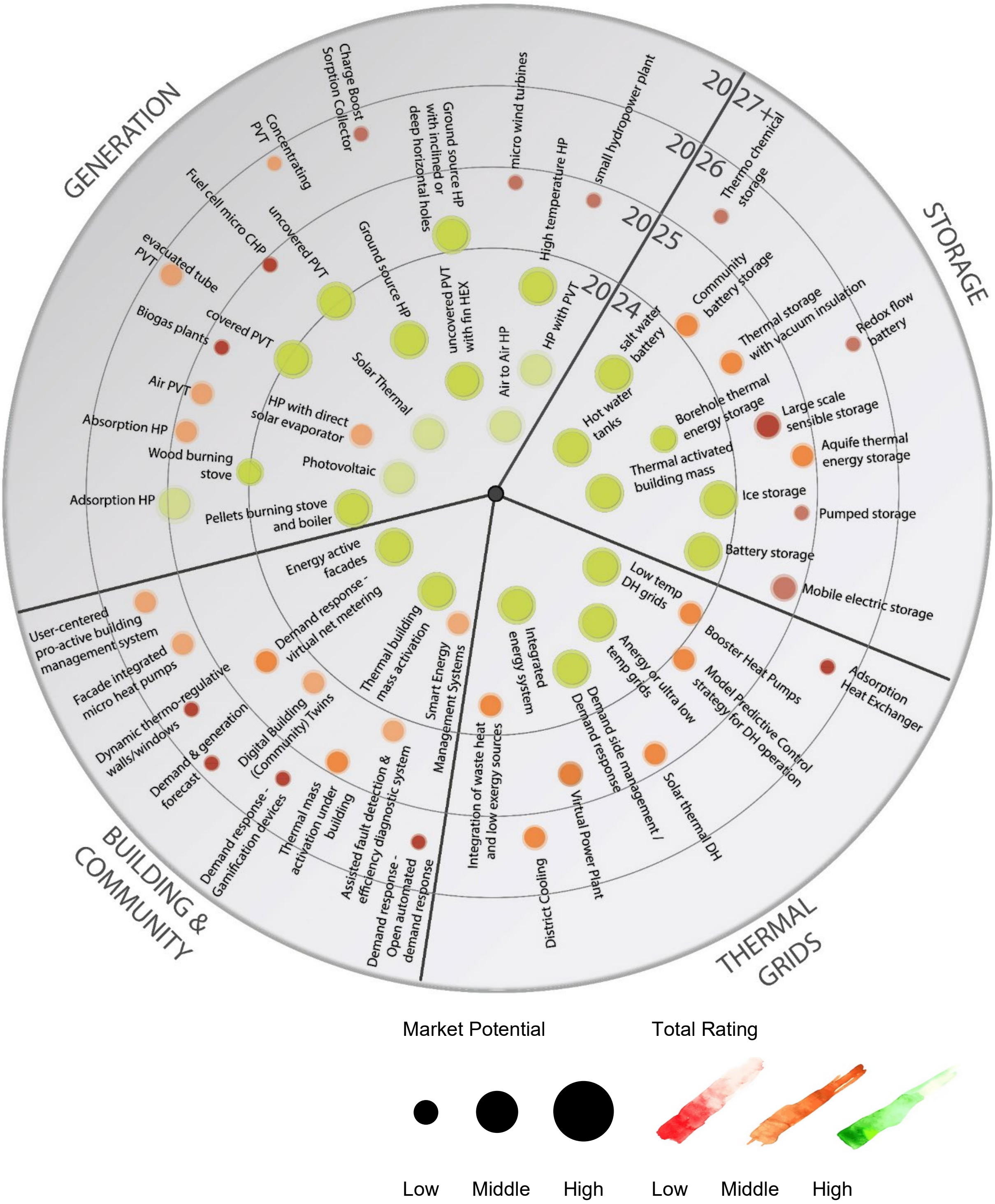

Figure 26: Technology Radar (AEE INTEC)

3.1 Generation

Renewable energy sources are quickly becoming the focus of energy generation around the world. As we move away from traditional fossil fuels, we're starting to see a wide variety of innovative new technologies that harness the power of the sun, wind, and water to create sustainable energy sources. Here's a closer look at some of the most promising renewable energy generation technologies available today:

Photovoltaic (PV) panels are one of the most well-known and popular renewable energy sources, and for good reason. These panels use solar cells to convert sunlight directly into electricity, making them a highly efficient and eco-friendly option for generating power. PV panels can be installed on a wide variety of surfaces, including rooftops, walls, and even on the ground. They can be used to power everything from homes to large-scale commercial buildings, and they're a great way to reduce your reliance on traditional energy sources.

Solar thermal systems are another popular option for generating renewable energy. These systems use the sun's energy to heat water or other fluids, which can then be used to provide heat for buildings to cover the space heating and domestic hot water demand. Solar thermal systems are highly efficient and can be used in a wide variety of applications, from small residential systems to large-scale commercial installations.

PV-thermal (PVT) collectors combine PV panels and solar thermal systems into a single unit. These collectors use the PV cells to generate electricity while also using the heat generated by the cells to heat water or other fluids. This makes PVT collectors highly efficient, and they're quickly becoming a popular choice for generating renewable energy in both residential and commercial applications. PVT-products with integrated air heat exchanger are an economically competitive, complete ready-for-connection unit for brine heat pumps without noise emissions in contrast to air-source heat pumps, and without earthworks in contrast to ground-source heat pump systems.

With the world's increasing shift towards renewable energy, the use of heat pumps as a technology for SEBs in urban areas is rapidly gaining popularity. Heat pumps are a highly efficient and sustainable alternative to traditional heating and cooling systems as they tap into different sources of ambient heat such as outdoor air, ground, groundwater, wastewater, and solar thermal systems, and transfer it to buildings for heating or cooling purposes. Moreover, they can be powered by electricity generated from renewable sources, making them an even more eco-friendly option.

The adoption of heat pumps in urban areas can bring several benefits such as reducing greenhouse gas emissions and improving air quality in areas with high air pollution levels. Buildings equipped with solar panels can generate electricity to power heat pumps, further reducing their carbon footprint. In addition, geothermal heat pumps are installed underground, and they use the constant temperature of the earth to extract heat, making them highly efficient and cost-effective. These types of heat pumps can also be used for cooling in summer months by extracting heat from the building and transferring it back into the ground.

One potential challenge with the widespread adoption of heat pumps in urban areas is the need for space to install them. However, advances in technology have led to the development of more compact and space-efficient heat pumps, also known as micro heat pumps, which can be installed in small apartments in facades or as retrofit solutions. While most building heat pumps use air as their heat source, the noise they generate can be a problem. This noise is emitted through the air and equipment housing, and it can be disturbing depending on the type and location of the installation. As the number of heat pumps installed outdoors near buildings increases, the demands on the equipment acoustics also increase, particularly in densely populated urban areas.

The choice of refrigerant is also crucial in determining the efficiency of the cooling circuit in heat pumps and technical cooling applications. Refrigerants differ in terms of their climate change effect, toxicity, and flammability. The F-gas regulation of the European Union has resulted in new developments or conversion by manufacturers of equipment and devices worldwide to reduce the use of fluorinated greenhouse gases as refrigerants.

Integrating heat pumps intelligently into the energy system is crucial to make electricity consumption more flexible and stabilize the electricity grids. This can be achieved through intelligent controls and operation management systems. With the integration of heat pumps, new business models will arise for utilities, grid operators, and system owners.

Small wind and hydro power plants are another promising option for generating renewable energy. These plants use wind or water to generate electricity, and they can be installed on a small scale for individual homes or on a larger scale for commercial applications. Small wind and hydro power plants are highly efficient and can be a great way to generate renewable energy in areas where there is a lot of wind or water.

Fuel cells are another innovative technology that are quickly gaining popularity as a renewable energy source. These cells use hydrogen and oxygen to create electricity, and they're highly efficient and eco-friendly. Fuel cells can be used in a wide variety of applications, from small residential systems to large-scale commercial installations.

Biomass and biogas are also popular options for generating renewable energy. Biomass refers to organic matter, such as wood chips or agricultural waste, that can be burned to generate heat or electricity. Biogas, on the other hand, is created by the decomposition of organic matter, such as food waste or animal manure. Both biomass and biogas are highly efficient and can be a great way to generate renewable energy in areas where there is a lot of organic waste.

3.2 Storage

Thermal energy storage is a key technology now more than ever, given the growing penetration of renewable heating systems and the need for further efficiency improvements in existing heating systems.

The particular challenge is that the required application range for thermal energy storage systems is very broad. Requirements for storage capacity, storage duration, storage temperature range, and charge/discharge performance vary widely, sometimes by orders of magnitude. In recent years, the development of thermal energy storage systems has been very successful in many respects. Not only in the international scientific field new technological approaches have been developed, but also in the industry remarkable progress has been made in terms of thermal performance on the one hand and economic improvements in the manufacturing and distribution process on the other.

In the area of sensible heat storage, water stores are by far the dominant technology. Approximately 80 to 90 % of all thermal storage systems currently in use are water storage tanks. Consequently, this technology can look back on a very high level of development. Hot water storage tanks have been and still are the subject of intensive research and development. This has resulted in a large portfolio of hot and cold water storage systems with excellent thermal performance. The development of effective storage tank insulation through to vacuum-insulated storage tanks is an example of the targeted development of the technology. The introduction of a European energy label for hot water storage tanks has also ensured a leap in development in this direction. Another intensively studied physical effect is the formation and preservation of thermal stratification in the storage tank. In many applications, good thermal stratification contributes to an increase in the storage efficiency. Furthermore, the configurability with numerous charging and discharging devices, directly or indirectly via immersed or external heat exchangers, ensures almost universal applicability in the temperature range between 0 and 100 °C.

Especially in the field of building heating, using the thermal capacity of the building itself is used as an interesting alternative to tank storage. Using the thermal capacity of e.g., concrete foundations or slabs to store any low temperature heat source such as PVT collectors is interesting especially for newly constructed buildings.

Large, seasonal heat storage projects are being planned in Denmark and Austria with storage volumes of several hundred thousand cubic meters.

Recently, there has been a rapid increase in the number of *Borehole thermal energy storage* applications in Europe and North America. However, there are still some obstacles that limit the development, such as geological conditions. The geological condition of the subsoil and the resulting maximum possible borehole depth is decisive for the feasibility. The thermal conductivity of the subsoil is an important factor, it should be as high as possible, typical values are in the range of 1.5 to 4.0 $Wm^{-1}K^{-1}$. It is particularly important to exclude groundwater flow around the boreholes.

The Netherlands is the country where *Aquifer thermal energy storage* is most widely used. It is estimated that more than 2000 systems are in use. ATES can also be found in Denmark, Norway and Belgium. There are only a few in Germany. The most prominent example is certainly the ATS of the German Bundestag. Here, two interconnected ATEs supply the government district with heat and cold.

3.3 Thermal Grids

Today and in the future, the distribution of thermal energy through the grid is essential. Over the past generations, these networks have been transformed several times as the available and required temperatures have changed.

Low-temperature networks therefore currently have a high value and market potential: they are a possible solution for the integration of renewable heat sources, such as geothermal energy, into the grid-based heat supply, which would otherwise not be possible.

The reduction in network temperatures, which is also the case with anergy or ultra-low temperature networks, allows, for example, a wider range of heat sources to be used compared to current district heating networks with flow temperatures above 80 °C. This allows, for example, the integration of waste heat from industrial plants. In this way it is also possible, for example, to integrate the waste heat from industrial plants. These technologies are already available on the market and are already being implemented.

The lower temperatures could be a problem, for example in low-temperature networks, when connecting existing buildings whose heating systems require a high flow temperature, e.g. 65 °C, or when such temperatures are required for hot water supply. The integration of a single heat pump may not be sufficient. In this case, booster heat pumps can be an option; they are already available on the market and have a medium market potential. The coming years will show whether e.g. fresh water plants (working with lower temperatures) will be used more often as a source of hot water or whether the high hot water temperatures will be maintained, thus increasing the potential of auxiliary heat pumps.

Another available technology with great potential and a high rating are integrated energy systems. By smartly linking different energy flows, losses are reduced and potential is better exploited, for example by converting surplus PV power (which otherwise could not be used) into thermal energy.

Demand-side management is also along the same lines, seeking to control energy demand through market signals to avoid peak loads and, where appropriate, to facilitate the integration of volatile renewables.

This joint consideration of energy flows and the matching of available energy flows and potential consumers is a central task in the development of thermal networks in the coming years. An important issue in the coming years will be model-based predictive control for thermal energy networks. This is also necessary to integrate the growing number of decentralised heat generators. Virtual power plants can play an increasingly important role in this context and have been identified on the technology radar as having medium potential over the next few years.

Thermal networks using solar energy as a heat source also have potential in the coming years. Local conditions are an important factor; in addition to many hours of sunshine, a correspondingly large surface area is required.

In the future, the cooling of buildings will become even more important due to climate change. One possibility is the construction of cooling networks. The potential is there, and its importance will grow significantly in the coming years.

Adsorption heat exchangers also have potential for the future. By subcooling the return temperature, more heat can be extracted at lower source temperatures. This will provide greater flexibility in the availability of energy sources and their effective use. At present, this technology is still in the early stages of development, but this may change with research over the next few years.

3.4 Building and Communities

The building stock in Europe still has a renovation requirement of 75%. With an appropriate renovation rate, all buildings could be renovated by 2050. The energy standard of the building stock must reach today's new building standard so that surface heating systems (T < 35 °C) can be introduced to increase the proportion of heat supply via heat pumps (possibly with PV) and solar thermal systems. In new buildings, component-activated facades and thermal mass activation of sealings and floors can be used as distribution systems and heat storage units, making it possible to establish demand management concepts. In addition, these can be used in conjunction with ground source heat pumps to cool buildings during the summer months without the need for primary energy (free cooling). Direct heat recovery from exhaust air or household wastewater is another way to reduce the heating demand of buildings. The same applies to nano-fluid facades with thermo-regulative behaviour. In new construction and renovation, prefabricated energy-active facade elements offer a promising, cost-effective, and often required option. In addition to providing heat and weather protection, they can also integrate building-integrated photovoltaics (BIPV) and/or building-integrated solar thermal energy (BIST) as "micro power plants," as well as building technology for heating, cooling, and ventilation.

At the same time, new low-temperature heat distribution and delivery systems can be easily integrated into existing buildings, thereby activating the thermal capacity of uninsulated walls. Photovoltaic-thermal (PVT) modules combine a PV module with a thermal collector, in which the PV is cooled and the resulting heat is made available for the building. Reducing gas demand also requires energy-efficient substitution options for widely used gas-fired boilers in multi-storey residential buildings, where decentralized micro-heat pumps offer an alternative.

In the field of optimization, model predictive control systems can help to operate buildings efficiently with weather and occupancy forecasts while maintaining the same level of comfort. In addition, the development of automated commissioning, fault detection methods, and efficiency diagnostic systems for building technical systems plays an important role in quality assurance. Interface systems (building twins) that allow for easy adaptation of building technology (plug-and-run) are becoming increasingly important. In addition, the holistic planning approach and the life cycle of buildings through Building Information Modelling (BIM) are coming into focus.

Using game elements and game design techniques as well as user-centred pro-active building management system to improve customer participation in demand management programs (e.g. demand response, energy efficiency), by competing or collaborating with others and improving upon past performance. To efficiently enable these changes, technological integration (e.g. sector coupling), demand management, as well as new services and services play an essential role. Acceptance by the population is seen as essential for this.

In addition, the development of end customers towards "prosumers" or "active consumers," who not only use but also generate energy, mobilizes additional private capital. The legal framework has already been created in Europe to strengthen the role of individuals, SMEs, public bodies, and corresponding community structures in the energy sector. In this context, energy communities have been defined as actors in the energy sector. In order to be able to integrate new technologies and approaches into new and existing buildings in a meaningful way, pilot projects need to be encouraged, in the framework of which systems are measured in detail.