Description of Available Technology Portfolio

IEA SHC TASK 66 | SOLAR ENERGY BUILDINGS

Technology Collaboration Programme
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Description of Available Technology

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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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)
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1 Executive Summary

This report has been completed through international collaboration under the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme Task 66 on Solar Energy Buildings[1] (SEB). Specifically, the work contributes to Task 66 Subtask D on Current and Future Technologies and Components by identifying and discussing existing technical solutions with high Technical Readiness Levels as well as emerging technologies with the potential to be successfully applied in SEBs.

Special focus has been placed on identifying SEBs, but also nearly-zero energy buildings[2] (NZEB), plus energy buildings[3] (PEB), and the application of high share renewables in different climate zones across Europe. The report presents a collection of SEBs, discusses which technologies are being deployed in different climates, classifies them into four main categories: generation technologies, storage technologies, thermal grids, and additional energy features, and presents real cases. The 126 case studies presented in this report were identified based on the stocktaking exercise. In addition, 25 case studies were provided by Task 66 participants, showing a variety of building uses (residential, commercial, public, mixed-use), building sizes, new construction and renovation projects, and R&D approaches.

This report aims to foster the utilization of renewable technologies in solar buildings by identifying the technologies and possible combinations of technologies already in use.

2 Stocktaking of Solar Energy Buildings

2.1 Methodology

The primary goal of Subtask D activity D1 is to give an overview of various technology options and the available technology portfolio, taking into account existing and emerging technologies with the potential to be successfully applied within the context of this Task. Demo case studies from Task 66 Subtask BC[4] and other sources were revised to create an inventory of the different technologies applied in SEBs or buildings approaching SEB status.

Desk research led to the identification of 126 SEBs in total, with a highly geographically diversified data set, which offers the chance to conduct a more robust analysis and is documented in the following subchapters. The information was found online by conducting country-specific research using commonly used descriptive terms for SEBs and examining academic literature. The greatest challenge is the information availability of the implemented technologies.

The most useful resource was the Smart Cities Marketplace, which merges the two former Commission projects, “Marketplace of the European Innovation Partnership on Smart Cities and Communities” (EIP-SCC) and the “Smart Cities Information System” (SCIS), into one single platform. Further online resources that helped the identification of SEBs and implemented technologies included the Austrian accompanying research project “Demoprojekt Solarhaus,” which is one of the reasons why Austrian cases are very well represented in the dataset, the H2020-EXCESS project website as well as inputs from the IEA Task members.

[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.
[2] A building that has a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. http://data.europa.eu/eli/dir/2010/31/2018-12-24
[3] Energy efficient building that produces more energy than it uses via renewable sources, with high self-consumption rate and high energy flexibility, over a time span of one year. https://positive-energy-buildings.eu/fileadmin/user_upload/Materials/EXCESS_D1.1_PEB_definition_and_concept.pdf
[4] D.BC1 Summary of demonstration cases (case studies), https://task66.iea-shc.org/

2.2 Introducing the Solar Energy Buildings

In the context of the stocktaking exercise, 126 SEBs across Europe were identified, and this chapter provides a brief overview of these. The sample has been limited as far as possible to SEBs but also includes NZEBs, PEBs, and realization with a high share of renewables.

It should be noted that this analysis is based on a small sample and limited qualitative and quantitative data. Observations, therefore, should be seen as a starting point for further research. The table below provides an overview of the SEBs identified in four climate zones with different heating degree days (HDD). The SEB numbers do not rank the SEBs but denote the alphabetic order. Further information on the clime zone is given in the following chapter.

The stocktaking exercise identified most SEBs in France, with 25% of SEBs located in the country. Austria takes second place with 22%, followed by Germany, Sweden and Netherlands (11%, 7% and 6%). The list is not exhaustive. A further list of solar buildings can be found here: https://www.sonnenhaus-institut.de/solararchitektur/solarhaeuser.html (only in German).

Table 1: Overview of the SEBs included in the stocktaking (HDD=heating degree days)

SEB No.	Name of SEB Example	Country	HDD Zone	Link
1	EXCESS	Austria	High HDD	Link
2	Green Solar Cities	Austria	High HDD	Link
3	MGG[22] Residential Development	Austria	Moderate - High HDD	Link
4	Plus-Energie-Bürohochhaus,	Austria	Moderate - High HDD	Link
5	SINFONIA	Austria	High HDD	Link
6	SMARTER TOGETHER	Austria	Moderate - High HDD	Link
7	Solarhaus Achatz	Austria	Moderate - High HDD	Link
8	Solarhaus Anzberger	Austria	Moderate - High HDD	Link
9	Solarhaus Bader	Austria	High HDD	Link
10	Solarhaus Braun-Doppelhofer	Austria	High HDD	Link
11	Solarhaus Degenfellner	Austria	High HDD	Link
12	Solarhaus Dicklhuber	Austria	Moderate - High HDD	Link
13	Solarhaus Felsch	Austria	High HDD	Link
14	Solarhaus Höfferer	Austria	High HDD	Link
15	Solarhaus Inschlag	Austria	Moderate - High HDD	Link
16	Solarhaus Jung	Austria	Moderate - High HDD	Link
17	Solarhaus Krug	Austria	High HDD	Link
18	Solarhaus Lindenberger	Austria	High HDD	Link
19	Solarhaus Miksche	Austria	Low - Moderate HDD	Link
20	Solarhaus Rattenberger	Austria	High HDD	Link
21	Solarhaus Salchinger	Austria	Moderate - High HDD	Link
22	Solarhaus Schindl	Austria	High HDD	Link
23	Solarhaus Schirnhofer	Austria	Moderate - High HDD	Link
24	Solarhaus Tischler	Austria	Moderate - High HDD	Link
25	Solarhaus Westreicher	Austria	High HDD	Link
26	Solarhaus Wieder	Austria	Moderate - High HDD	Link
27	Solarhaus Zuendt	Austria	High HDD	Link
28	Sunlighthouse Pressbaum	Austria	Moderate - High HDD	Link
29	ECO-Life	Belgium	Low - Moderate HDD	Link

30	NEED4B	Belgium	Low - Moderate HDD	Link
31	Student Dormitory Varazdin	Croatia	Moderate - High HDD	Link
32	ECO-Life	Denmark	Moderate - High HDD	Link
33	Green Solar Cities	Denmark	Moderate - High HDD	Link
34	Ready	Denmark	Moderate - High HDD	Link
35	SIB ZERO+ House	Denmark	Moderate - High HDD	Link
36	The Home for Life	Denmark	Moderate - High HDD	Link
37	Lantti-talo	Finland	High HDD	Link
38	SOLUTION	Finland	High HDD	Link
39	Act2	France	Low HDD	Link
40	Aerem factory	France	Low HDD	Link
41	BEEM-UP	France	Low - Moderate HDD	Link
42	CITY-ZEN	France	Low HDD	Link
43	Concert or Conference Hall "The House for All"	France	Moderate - High HDD	Link
44	Eco-Renovation of KTR France HQ	France	no information on exact location	Link
45	Education and Leisure Hub	France	Low - Moderate HDD	Link
46	Elithis Tower	France	Low - Moderate HDD	Link
47	Energy Positive Social Housing and Offices	France	Low HDD	Link
48	Green Office® Châtenay	France	Low - Moderate HDD	Link
49	Green Office® Link	France	Low - Moderate HDD	Link
50	Green Office® Meudon	France	Low - Moderate HDD	Link
51	Green Office® Rueil	France	Low - Moderate HDD	Link
52	Green Office® Spring	France	Low - Moderate HDD	Link
53	Gustave André School Extension	France	Low HDD	Link
54	Head office of the Caisse d'Epargne Bank	France	Low HDD	Link
55	Hikari Complex	France	Moderate - High HDD	Link
56	L6 - L'OREAL Group Research Laboratory	France	Low - Moderate HDD	Link
57	Le Parc de l'Ensoleillée	France	Low HDD	Link
58	Maison Air et Lumière	France	Low - Moderate HDD	Link
59	Mauges Public High School	France	Low HDD	Link
60	New HQ of GA Group	France	Low HDD	Link
61	NEXT-BUILDINGS	France	Moderate - High HDD	Link
62	P.A.T.H Turnkey House	France	Low - Moderate HDD	Link
63	Positive Energy High School	France	no information on exact location	Link
64	PRD Office	France	Low - Moderate HDD	Link
65	Residence Esperia	France	no information on exact location	Link
66	Residence etudiant arc en Meyran	France	Low HDD	Link
67	Residence Ma. Curie 2	France	Moderate - High HDD	Link
68	SMARTER TOGETHER	France	Moderate - High HDD	Link
69	Student Residences	France	no information on the exact location	Link
70	Act2	Germany	Moderate - High HDD	Link
71	AquaTurm Water Tower Hotel	Germany	High HDD	Link

72	DIRECTION	Germany	Moderate - High HDD	Link
73	Efficiency House Plus	Germany	High HDD	Link
74	EnergyPlus Primary School	Germany	Moderate - High HDD	Link
75	Family Center Sandhäuschen	Germany	Low - Moderate HDD	Link
76	Freiburg's New City Hall	Germany	High HDD	Link
77	Green Building Kirstein & Sauer	Germany	Low - Moderate HDD	Link
78	Heliotrope Solar Home	Germany	High HDD	Link
79	NEWTONPROJEKT Haus 1	Germany	Moderate - High HDD	Link
80	SMARTER TOGETHER	Germany	High HDD	Link
81	Sobek’s Aktivhaus B10	Germany	High HDD	Link
82	SolSys	Germany	Moderate - High HDD	Link
83	Willibald-Gluck-High School	Germany	Moderate - High HDD	Link
84	Passivistas - the house project	Greece	Low HDD	Link
85	PIME'S	Hungary	Low - Moderate HDD	Link
86	ileeid house	Ireland	no information on the exact location	Link
87	Concerto AL Piano	Italy	Low HDD	Link
88	NEED4B	Italy	Low HDD	Link
89	Passive House in Sicily	Italy	Low HDD	Link
90	SINFONIA	Italy	Low - Moderate HDD	Link
91	Technical High School for Health Professionals	Luxembourg	Low - Moderate HDD	Link
92	IRIS	Monaco	Low HDD	Link
93	BEEM-UP	Netherlands	Low - Moderate HDD	Link
94	CITY-ZEN	Netherlands	Low - Moderate HDD	Link
95	Energy Positive Dwelling	Netherlands	Low - Moderate HDD	Link
96	IRIS	Netherlands	Low - Moderate HDD	Link
97	NEXT-BUILDINGS	Netherlands	Low - Moderate HDD	Link
98	OVG’s TNT Centre	Netherlands	Low - Moderate HDD	Link
99	REMINING-LOWEX	Netherlands	Moderate - High HDD	Link
100	Venlo City Hall	Netherlands	Low - Moderate HDD	Link
101	New Montessori School	Norway	High HDD	Link
102	Powerhouse Brattørkaia	Norway	High HDD	Link
103	Powerhouse Kjørbo	Norway	High HDD	Link
104	Svart Hotel [Arctic Circle]	Norway	High HDD	Link
105	Solace (Demo) House	Poland	Moderate - High HDD	Link
106	GEOCOM	Slovakia	Low - Moderate HDD	Link
107	Commercial Building Kobra	Slovenia	Moderate - High HDD	Link
108	EE-HIGHRISE	Slovenia	Moderate - High HDD	Link
109	REMINING-LOWEX	Slovenia	Moderate - High HDD	Link
110	DIRECTION	Spain	Low HDD	Link
111	GrowSmarter	Spain	Low HDD	Link
112	PIME'S	Spain	Low HDD	Link
113	SOLARHAUS	Spain	no information on the exact location	Link
114	BEEM-UP	Sweden	High HDD	Link

115	BUILDSMART	Sweden	High HDD	Link
116	CITyFiED	Sweden	High HDD	Link
117	CLASS1	Sweden	High HDD	Link
118	Energy in Minds!	Sweden	High HDD	Link
119	IRIS	Sweden	High HDD	Link
120	NEED4B	Sweden	High HDD	Link
121	NEXT-BUILDINGS	Sweden	High HDD	Link
122	Ready	Sweden	High HDD	Link
123	SOLUTION	Switzerland	High HDD	Link
124	CITyFiED	Turkey	Low HDD	Link
125	NEED4B	Turkey	Low HDD	Link
126	Active office	United Kingdom	Low - Moderate HDD	Link

2.3 SEB distribution across four climate zones

A zoning approach based on heating degree days (HDD) at NUTS-3 (Nomenclature of territorial units for statistics, level 3) creates four main climate zones (Eurostat) (see Figure 1). As this zoning approach is tailored to buildings, the SEBs were also categorized according to this classification. Interestingly, when SEBs are categorized according to this classification (as shown in Figure 2), there is no clear majority of buildings in a specific HDD zone. 31% of the buildings are in the High HDD zone. 52% are evenly distributed between Moderate – High HDD and Low – Moderate HDD. The remaining percentage (17%) of the buildings are in the category Low HDD.

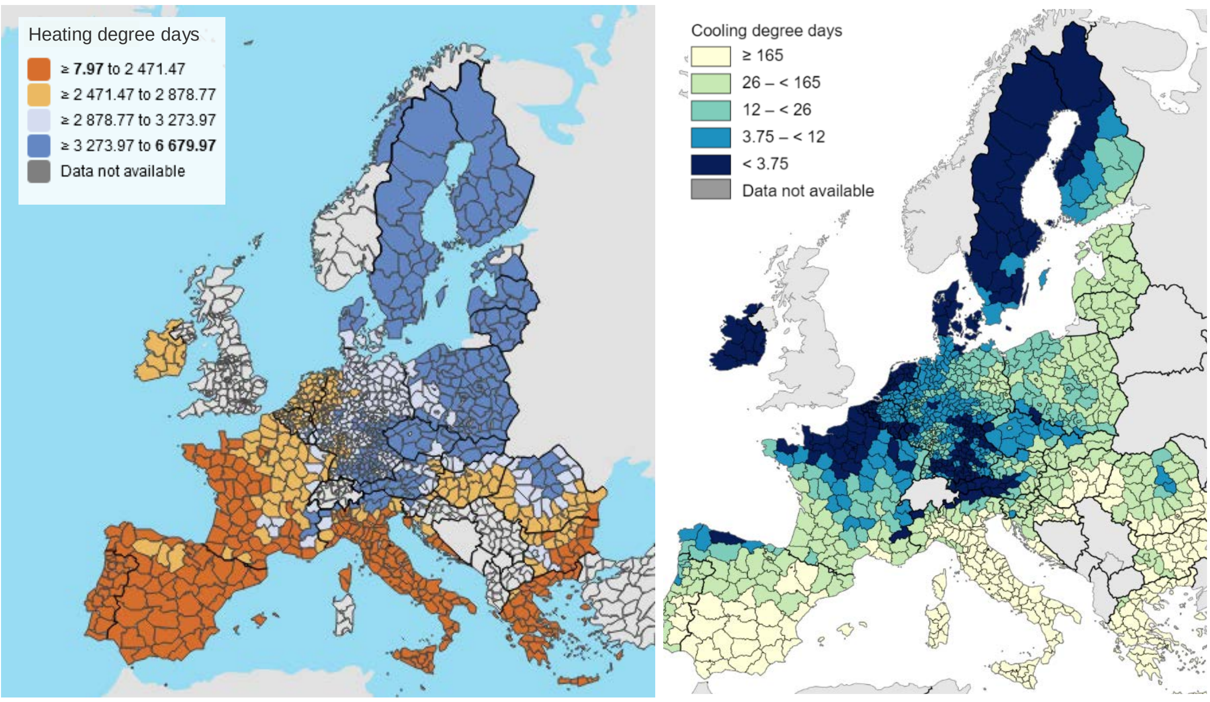

Figure 1: Heating degree days (left), Cooling Degree days (right) by NUTS-3 regions – annual data (Source: Eurobase Cooling and Heating degree days)

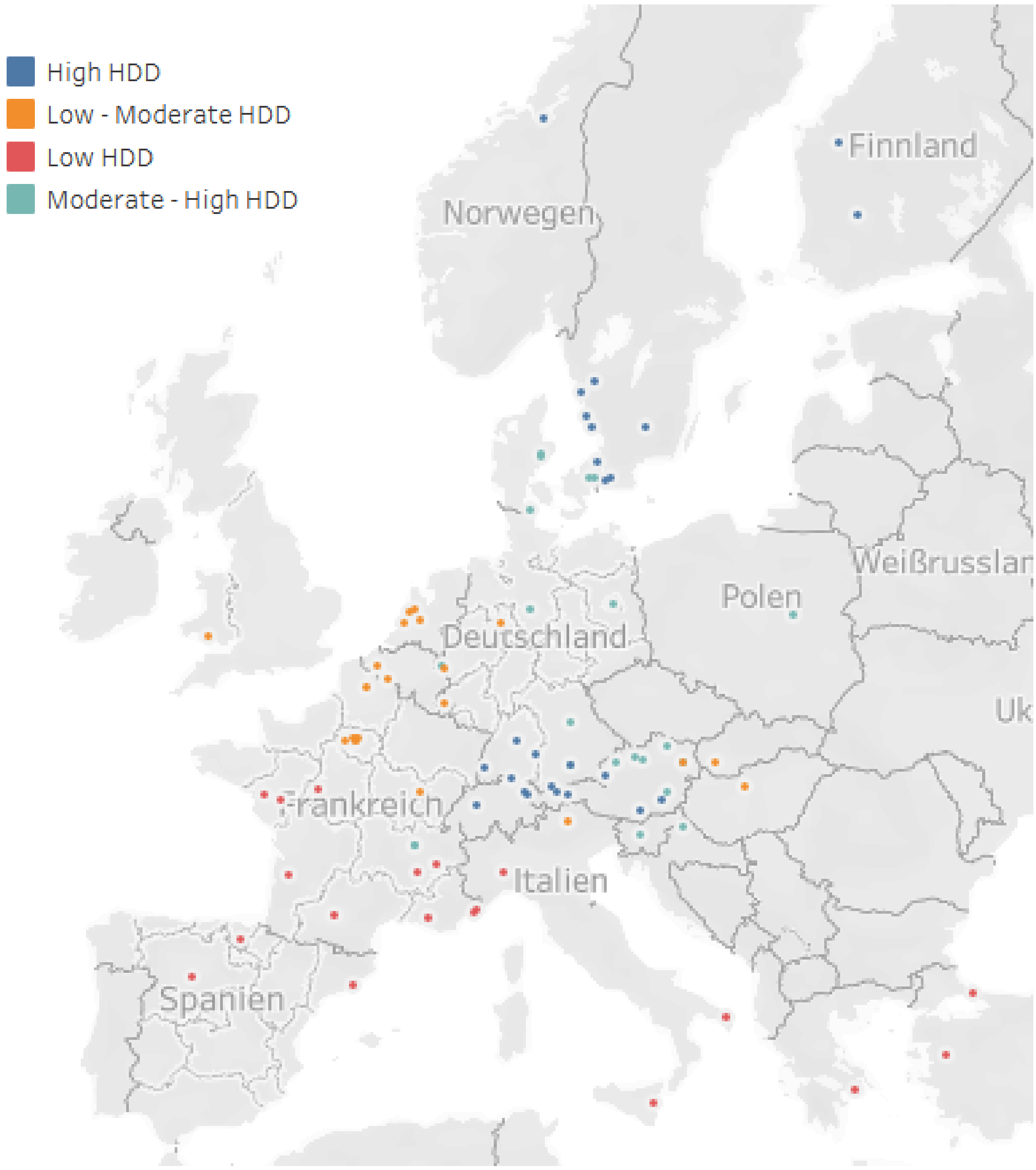

Figure 2: Map showcasing SEBs identified (Source: AEE INTEC)

3 Technologies in SEBs

3.1 Common technologies integrated in SEBs from the stocktaking exercise

One of the most important aspects of offering opportunities for a wide roll-out of SEBs is the availability of a large selection of existing technical solutions with a high Technical Readiness Level. This chapter provides an overview of the technologies integrated in the SEBs from the Stocktaking exercise. With regard to the building technologies analysis presented in this chapter, it should be noted that it was impossible to find complete information for many of the individual cases. Therefore, it is highly likely that figures and percentages attributed to specific technologies presented in this subchapter are, in reality, much higher. Nevertheless, the analysis of the SEBs from the stocktaking exercise does provide some insights into potential trends that could be further explored by conducting more in-depth research.

Technologies were clustered into four main categories: energy generation, storage technologies, thermal grids, and other SEB energy features. The subcategories are based on the identified technologies, which does not mean there are no other technologies on the market. The category "energy generation" includes solar thermal technologies (conventional collectors, photovoltaic thermal (PVT) hybrid collectors), photovoltaic (PV) technologies, different heat pump technologies, and other technologies for heat, cold and power generation (biomass, biogas, and waste heat recovery). Different thermal and electrical energy storage technologies (e.g., activation of thermal masses, water storage, ice storage, stationary and mobile battery storage) are included in "storage technologies." "Thermal grids" represent systems with connection to a district heating network, and the category "Other SEB Energy Features" gives additional insight into the SEBs.

Examining the key technologies installed in the buildings (Figure 3), it is clear that PV panels are by far the most common, with 82% of the SEBs using these to some degree. Another frequently installed technology is conventional solar thermal collectors (53%), which are often coupled with geothermal systems. In 45% of the cases, integrating a heat pump system with different heat sources (geothermal, groundwater, etc.) was mentioned, but this figure is

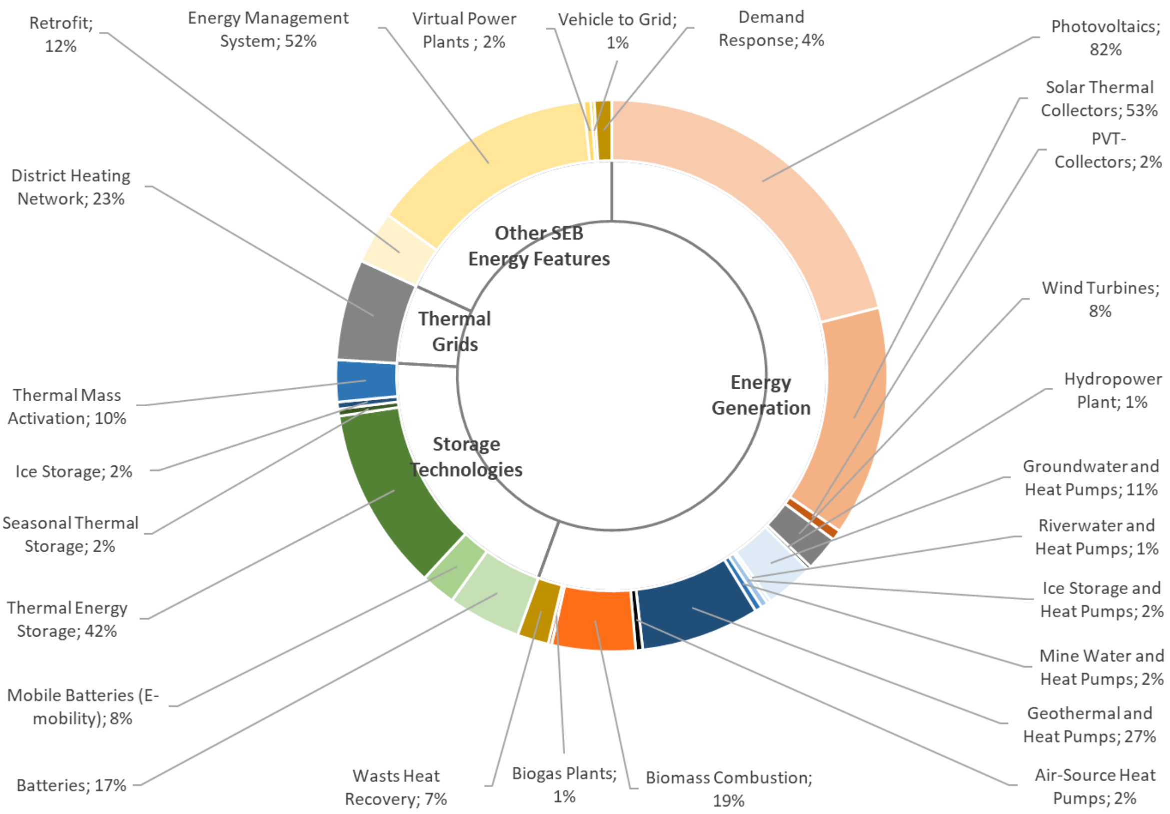

Figure 3: Visualisation of key technologies used in 126 SEBs from the stocktaking exercise

likely to be much higher. Boilers or systems using renewable fuels also feature in SEBs relatively often. They are used for energy generation, emergency backup, or to cover peak demands. Highly connected to generation is, of course, the capability to store thermal energy. Of the examined cases, 42% have a thermal storage system. However, this figure is most likely much higher (up to 100%) in reality. This technology is probably considered by default and is therefore not explicitly mentioned in the descriptions. Another way to store thermal energy is the activation of the building mass, and 10% of the considered SEBs use this technology. This is, for example, a very common technology in Austria. Storing electrical energy in stationary batteries is much less common, with only 17% of SEBs using such technology. 23% of the buildings are connected to a thermal grid (district heating network). The category "Other SEB Energy Features" illustrates that even existing buildings that are thermally refurbished can achieve SEB standard. Of the considered cases, 12% are retrofit projects. Energy efficiency and energy optimization are other common features. In 52% of the cases, the integration of an energy management system and optimization methods were mentioned.

Breaking down SEB technology integration according to the Eurostat climate zones (Figure 4), solar PV modules appear to be most popular in regions with Low HDD (94%) and Low – Moderate HDD (96%). This ratio is reduced to about half when the heating degree days increase. A contrary trend can be observed in the case of solar thermal collectors. The frequency of use increases here with increasing HDDs.

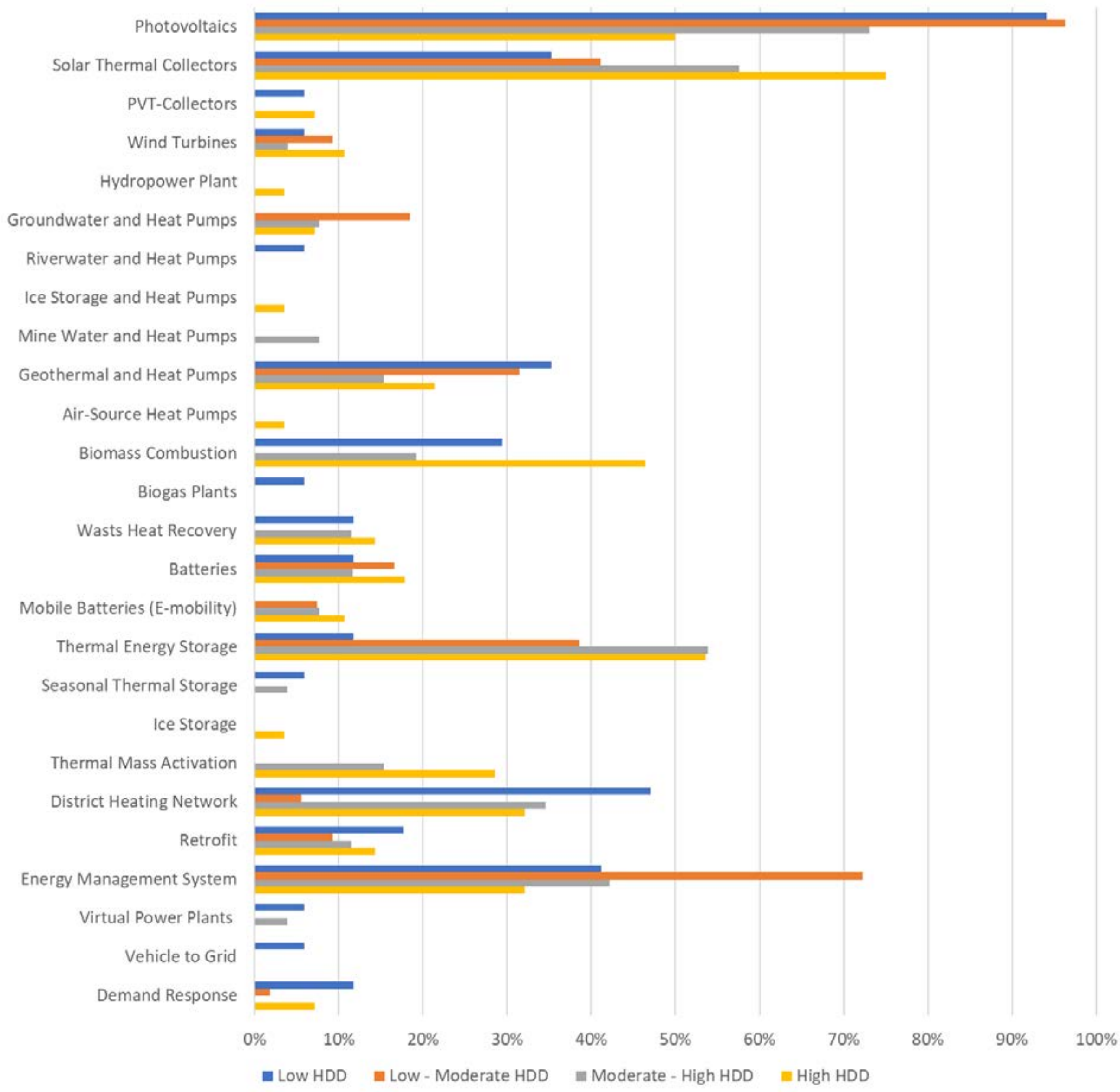

Figure 4: Graph showing SEB technology integration across the four HDD climate zones

Energy systems using ground or groundwater heat are most frequently used in Low HDD and Low HDD – Moderate HDD zones. In regions with higher HDD, biomass boilers are installed as heating systems (46%).

Wind energy is implemented to a small degree in all climate zones, but no hydropower plants are used in the documented SEBs, apart from one installation in a High HDD zone.

Electric storage systems are integrated into SEBs relatively evenly across climate zones, but thermal storages appear more prevalent in the colder climates (>50% in High and Moderate – High HDD; 40% in Low – Moderate HDD). Thermal building mass activation is mentioned in climate zones with higher HDD.

District heating systems are often just one element of a flexible energy system. The district heating supply leads to comparatively low CO_2 emissions per inhabitant. The mentioned district heating systems are often low-temperature systems with renewable energy sources production and waste heat usage.

Energy efficiency, advanced control, and optimization with energy management systems are mentioned most often in the documentation related to SEBs in Low – Moderate HDD climates but are also very relevant in all the other three climate zones.

Data on further integrating PEB technologies (virtual power plants, vehicle to grid, and demand response) is relatively limited across all the HDD zones.

3.2 Technologies in the Task 66 Case Studies

3.2.1 Overview of Task 66 Case Studies

As the next step after the stocktaking exercise, the Task 66 members provided several detailed case studies to give insights regarding developing SEBs that go beyond the overarching stocktaking exercise. The case studies contribute to more in-depth information on individual SEB projects. In particular, the case studies provide further details on the technologies used, the building performance, and additional relevant SEB KPIs. The detailed case study descriptions are presented in the Task 66 deliverable, “Summary of demonstration cases (case studies),” while this part of the report delves into some key findings. The analysis focuses on the technologies for the selected SEBs (see Figure 5 and Figure 6).

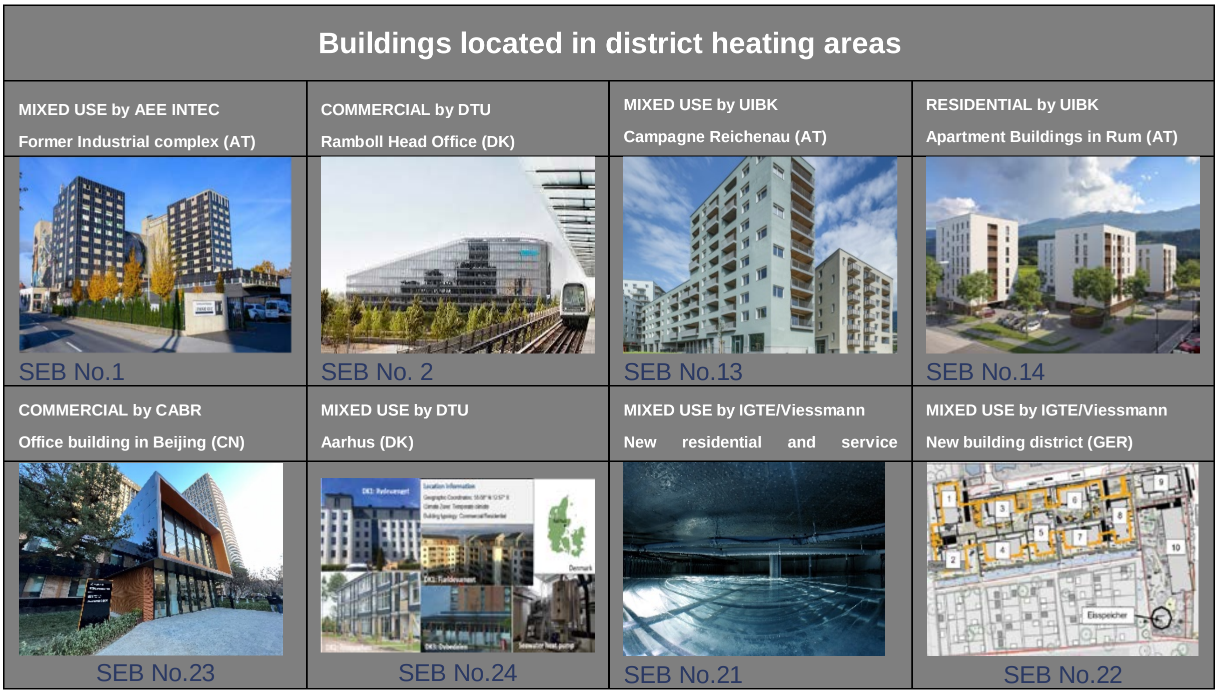

Figure 5: Overview of SEBs in district heating systems selected for more in-depth case studies.

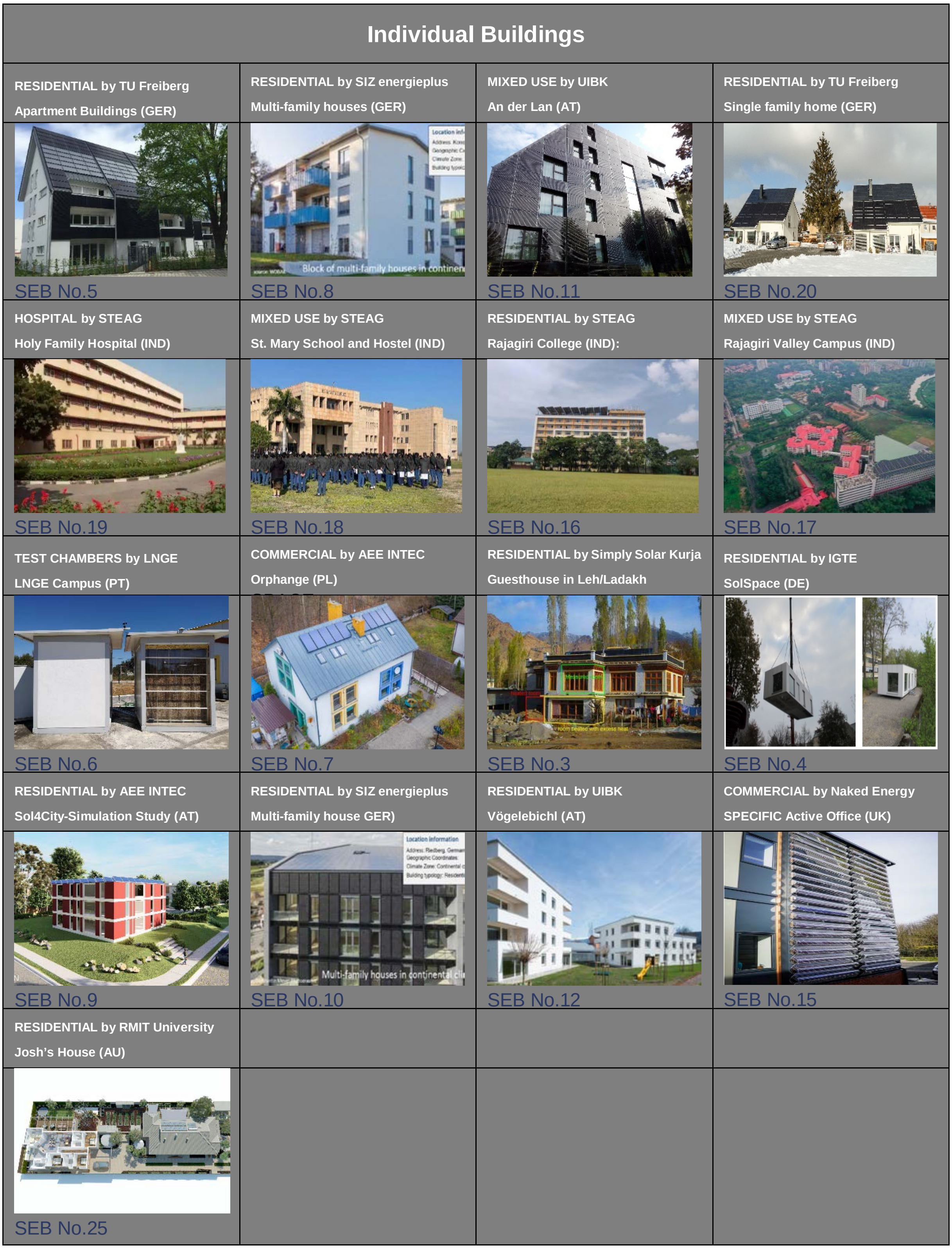

Figure 6: Overview of SEBs selected for more in-depth case studies.

3.2.2 Short descriptions of technology portfolio in Task 66 Case Studies

SEB No.1 | Former Industrial Complex (AT): A PEB in passive house standard will be achieved via highly insulated pre-fabricated multifunctional facade elements, including active heating and cooling elements for activating the existing thermal mass of the building structure, 80 kWp façade integrated PVs and groundwater heat pumps. Further innovative elements in the plus energy district are additional BIPV (365 kWp), hydropower plant

(140kW), electricity storage (225 kWh), E-mobility, centralized and decentralized thermal storage (water storage, TBA), user integration and predictive control system to achieve maximum energy flexibility.

SEB No.2 | Ramboll Head Office (DK): The building is supplied with renewable energy from a district heating grid, passive solar energy, a PV system, and a heat pump/groundwater system for cooling and heating.

SEB No.3 | Campagne-Reichenau (AT): A Smart City quarter (of approximately 84,000 m²) is being created east of Innsbruck. Approximately 1,100 new apartments, numerous local supply and service facilities, sports fields, and a club are planned. The focus is on energetic and economic optimization in combination with mobility solutions in the new smart city quarter. Important aspects are reducing greenhouse gas emissions, social sustainability, highest energy efficiency, ecological quality, and renewable energy, which are essential parts of the energy supply.

SEB No.4 | Residential complex in Rum (AT): Five buildings are designed according to the Passive House Plus standard. The entire residential complex is heated through the waste heat network of the Tirol Kliniken. The heat is provided to the apartments through a floor heating system. Moreover, a mechanical ventilation heat recovery system is installed in the buildings. One of the key points of the project is the so-called booster heat pump to provide domestic hot water and designed to maximize the PV self-consumption. Photovoltaic panels are installed on the building roofs for a total of 710 m². The energy generated is available for the decentralized water heating and building services. Saltwater batteries are installed to store the excess energy produced by the renewable source to increase the energy self-consumption.

SEB No.5 | Office building in Beijing (CN): The ZEB (Zero-Energy Building) is in the office parks of CABR (China Academy of Building Research). The original building is a brick-concrete building that was built in the 1970s. The building area is 3,000 m2 and has two layers. The building is cooled by a split air conditioner and heated by connecting to the municipal thermal grid. The heating period is from mid-November to mid-March. The ZEB was converted from the original office building by installing PV modules and replacing high-performance doors and windows. The sc-Si cells and thin-film CdTe cells were used on the roof and higher elevated parts of the building. The total installed capacity is 235 kWp, and the PV system can provide 21,700 kWh of electricity per year, according to the measurement. This can ensure that the PV power generation meets the ZEB energy consumption needs and supplies the surrounding buildings in the same park.

SEB No.6 | Aarhus (DK): Energy refurbishment of three existing multi-family buildings with a total area of 47,442 m^2 and one office building with an area of 1,448 m^2 has reduced the building's energy demand by about 70%. The refurbishment includes an improved building envelope, new 3-layer energy windows, and an upgraded heating and ventilation system (balanced ventilation with heat recovery). Additional, 479 kW_p PV panels, 743 m^2 PVT panels + heat pumps (3 x 12 kW) + water storage tanks (3 x 800L) for DHW production, 18 food waste disposers + wastewater heat recovery pumps (10 kW) for supporting the existing DH, new batteries (79 kW) and second life batteries (35 kWh), a 1MW seawater heat pump for DH and 54 electrical vehicles (EV) chargers are installed to reduce the use of fossil fuels. In Aarhus, the renewable share in the district heating network is 80%, while the renewable share in electricity production is 66%. The monitoring results show possible self-sufficiency levels of >80% (heating), 66% (cooling), and >75% (electricity).

SEB No.7 | New residential and service complex (DE): The residential and service complex with a floor space of 1,240 m² distributed over three floors includes ten residential units, a physiotherapy practice, and a diaconia station. The first floor also includes an underground garage with electrified parking spaces and wall boxes for a car-sharing station. The planning team assumed an annual heating demand of 87.3 MWh/a and a cooling energy demand of 9.7 MWh/a. The heating and cooling supply is based on an energy network for a central heat pump (42.8 kW_{th} at B0/W35) in combination with a central latent heat store with the storage medium water (196 m³) as well as photovoltaic-thermal sun-air collectors (238 m²). The maximum electrical power of the four PVT collector fields is 44.8 kWp. Low-temperature heating ceilings heat the attic, and concrete core-activated ceilings heat the ground and upper floors. The domestic hot water is produced using electric instantaneous water heaters. A key technology of the heating and cooling supply system is the control strategy, which mainly depends on the state-of-charge of the ice store.

SEB No.8 | New building district (DE): The new building district consists of nine multi-family houses and a kindergarten with three residential units above. In total, the district with 107 residential units offers a heated floor space of 8,567 m². For the design of the system components and an energy network, an annual heating demand of 508 MWh and a cooling energy demand of 167 MWh is assumed. The solar heating and cooling supply is based on an energy network for building-wise decentral heat pumps (in total 428 kW_{th} at B0/W35) in combination with a central latent heat store with the storage medium water (660 m³) as well as with thermal sun-air collectors (137 m²).

Additional photovoltaic (PV) modules with a total area of 1085 m² (12 ° inclination angle, east/west orientation), with a maximum electrical power of 220 kWp, are installed. Also, additional heat exchangers are used to implement natural cooling operations on a building-wise decentral basis. The district is heated and cooled via underfloor heating. The domestic hot water is produced by electric instantaneous water heaters. As in SEB No.21, a key technology of the heating and cooling supply system is the control strategy, primarily depending on the state-of-charge of the ice store.

SEB No.9 | Apartment Buildings (DE): Two highly solar-supplied buildings with solar thermal (100 m²) on the roof and photovoltaics (172 m², 29.6 kWp) on the roof and façade, built in 2018. It also has a heat storage with 24.6 m³a and a battery storage with 46.8 kWh. There is also the option of cooling the flats via a geothermal collector system. A special feature is a flat-rate rent for the residents, which includes heating, cooling, and electricity. Surplus PV yields from the houses are mostly consumed by an office building in a separate district electricity net. Further, a small local heating network transfers surpluses from the solar thermal system to surrounding residential buildings.

SEB No.10 | Multi-family houses (DE): Two ground-coupled heat pumps (30 kW_{th} + 27 kW_{th}) are designed to supply the floor heating, provide domestic hot water, and support the low temperature circuit for both buildings, built in 2016. The geothermal system consists of nine borehole heat exchangers, each 100 m long. Since solar energy plays a central role in the energy supply, 59,2 kW_p of photovoltaics were already installed on the roof. To improve the flexibility potential in a targeted manner, a battery storage facility with a capacity of 30 kWh (Lithium-ion) is integrated.

SEB No.11 | An der Lan (AT): The An der Lan building is a small residential complex with 14 studio flats and several common rooms in Innsbruck. The building fulfills the Passive House standard, ensuring good thermal comfort and energy efficiency. The An der Lan building has an electric system to provide heat for space heating (electric radiators) and domestic hot water (e.g., electric boilers in every apartment). A mechanical ventilation heat recovery system is installed. A distinctive aspect of the building is the relatively large photovoltaic system (32.0 kWp) on the south façade. Three electric batteries (total capacity of 20.1 kWh) are installed in the basement to increase the self-consumption of energy from the renewable source.

SEB No.12 | Energy-autonomous single-family homes (DE): In Freiberg in Saxony (Germany), there are two energy self-sufficient single-family houses. Currently, one is used as a residential building, the other as an office building. 46 m² of solar thermal collectors and 8.4 kWp photovoltaics are installed on the roofs of the buildings. The heat yields can be temporarily stored in a 9.1 m³ hot water tank, and a battery with 58 kWh storage capacity is available for the electrical yields. In addition, a charging station for an electric vehicle is connected to the residential building. The monitoring results show possible self-sufficiency levels of 94 % (electricity) and 70 % (heat).

SEB No.13 | Holy Family Hospital (IN): Holy Family Hospital is a 345-bed multi-specialty hospital run by the New Delhi Holy Family Hospital Society and managed by the Delhi Catholic Archdiocese. The Hospital is spread over a green campus of 23 acres. The objective of the hospital is to use maximum green energy possible and reduce carbon emission footprint by reducing the use of grid and diesel generators, providing an uninterrupted 24/7 power supply. Grid interactive Solar PV is installed to meet the CCHP load. No major storage system has been installed except for the individual UPS systems.

SEB No.14 | St. Mary School and Hostel (IN): The St. Mary Sr. Sec. School, Rohtak consists of two major buildings. The school can proudly boast of being the first environment-friendly school in the vicinity to use solar energy for the entire school, ensuring an inexhaustible supply of lighting and heating throughout the year. St. Mary School has approximately 900 students. The project's main objective is to reduce carbon emission footprint by reducing the use of diesel generators and to utilize the maximum amount of green energy possible by self-sustained generation. Solar PV with Battery storage is installed to meet the CHP load.

SEB No.15 | Rajagiri College of Social Science (IN): Rajagiri College of Social Sciences (Autonomous) was established as part of a large educational Network hosted by the religious institute Carmelites of Mary Immaculate. The campus of Rajagiri College of Social Sciences is spread over an area of around 29 acres. One of the project's key objectives is to have net zero energy; that is, all the energy consumed by the load yearly is from solar PV in the Carmel block. Solar PV is installed to meet the Combined Cooling, Heating, and Power (CCHP) load. There is no storage installed, but it does have a net metering system.

SEB No.16 | Rajagiri Valley Campus (IN): The Rajagiri institutions in Rajagiri Valley (RV) are comprised of four major entities on a 90-acre (360,000 m2) campus on the banks of the Chitrapuzha River. The project's main objective is to reduce carbon emission footprint and utilize the maximum green energy possible by self-sustained generation. Solar PV is installed to meet the CCHP load. There is no storage installed, but it does have a net metering system and redundant power supplies.

SEB No.17 | TEST CHAMBERS (PT): This test facility has two modules for testing new building façades: the reference module has a south façade and masonry wall, and the other has a south façade and new building wall. The first new building element developed was a dynamic thermo-regulative wall with nanofluids (water with copper nanoparticles) implemented in the south façade. The two cells are made of two galvanized steel sheets lacquered with 0.50 mm thickness and 40 mm of insulation in rigid polyurethane foam injected with a density of 40 kg / m3. The south-facing masonry comprises a double wall with 11 cm brick, 4 cm of XPS thermal insulation, plaster, and white painting. The nanofluid façade has thermo-regulative behavior with the help of two submersible pumps installed in the inner and the outer cavities. The wall is made of transparent acrylic sheets with 50 mm of thermal insulation and agglomerated cork. The thickness of the fluid wall is 120 mm.

SEB No.18 | Orphanage: The "CREATE" system features a modular prismatic storage module based on thermochemical materials (TCMs). The storage material used is granulated potassium carbonate (K2CO3). In the project scope, a complete system with three modules and a total of 1,250 liters of K2CO3 with a storage capacity of around 182 kWh was demonstrated.

SEB No.19 | Ladakh (IN): This robust, low-cost system is a proven solution for heating homes reliably and cheaply in challenging high-mountain regions like the Argentinian Altiplano or Ladakh in the Himalayas. Solar heated air circulates in a closed loop through a rock bed below the floor. The floor provides in-floor heating, creating an ideal temperature distribution in the room. Due to the big thermal capacity of the rock bed, rooms are heated 24 hours per day and during 1-2 days without sun. Air is used as the heat transfer medium to avoid anti-freezing agents, pressure at stagnation temperature in summer, and corrosion. Small leakages do not affect performance. The modular design allows collector sizes of 2 m² to 120 m² and facilitates transport and assembly. Rocks are available at low cost, which permits big storage heat capacity. Minimal user operation required: just an on/off switch for the automatic fan operation in the heating season. Based on experience from several pilot projects, the system saves up to 90% of the conventional fuel used for space heating, translating to USD 370 per home in Ladakh and Kargil. The initial investment is paid off in 4-5 years. Locally sourced and produced materials allow for easy maintenance and job creation in the region.

SEB No.20 | SolSpace (DE): The SolSpaces building is a research building based on the prefabricated residential building type Flying Spaces by SchwörerHaus KG. The living space is approximately 45 m². In this building, a solar air heating system with seasonal heat storage is used for the first time. The core element of the solar air heating system is thermochemical storage on adsorption basis in combination with a vacuum tube air collector. Approximately 80% of the heating demand (ca. 2,300 kWh/a) is covered by the solar thermal system.

SEB No.21 | Simulation Study – Sol4City: The central objective of the Sol4City project is to develop highly integrated energy supply systems that can ensure sustainable reliability of supply to meet the heating and electricity requirements (including e-mobility) of multi-story residential buildings. Potential system combinations will be elaborated in detail and optimized with respect to technical, economic and control issues. The focus is on the local use of renewable energy generators in combination with highly efficient storage solutions. Central components are covered PVT collectors, PV modules, ground source heat pumps, thermal water storages, and the thermal activation of building mass. To increase the self-sufficiency battery storage and a bidirectional use of e-mobility will be investigated.

SEB No.22 | Multi-family house (DE): In August of 2015 the five-story multi-family residential building (17 apartments) was completed. This electric-only building is equipped with a 50 kW_{th} electric brine-to-water heat pump that uses a total of 85 m² of solar air absorbers in addition to an ice storage (100 m³). To provide a balance-sheet excess of electricity, PV modules on the roof (84 kW_p) and on the façade (15 kW_p) are installed. To improve the flexibility potential in a targeted manner, the use of a battery storage facility with a capacity of 59,4 kWh (Lithium-ion) is integrated.

SEB No.23 | Vögelebichl (AT): Two multifamily houses located in the neighborhood of Vögelebichl in Innsbruck, Austria were designed to achieve an annual net-zero energy balance for heating and domestic hot water. They fulfil the Passive House Plus standard, meaning that the annual heating demand is limited to a maximum of 15 kWh/(m^2 a), the buildings have a bounded renewable primary energy demand and renewable energy has to be produced onsite (at least 60 kWh/(m^2 a)). PV panels are installed on the roof of both buildings and part of the north block is used for solar thermal panels. A double-staged groundwater-source heat pump with de-superheater delivers heated water to a buffer storage. A mechanical ventilation heat recovery system is installed to provide good quality air while ensuring energy savings.

SEB No.24 | SPECIFIC Active Office (UK): The SPECIFIC Active Office is an energy positive concept: it generates more energy through its renewable energy installations than is used to operate and heat the building. Included in this energy system are 40 Virtu PVT hybrid solar collectors, providing heat and power to the building, which are mounted on the south facing façade of the office and have been operating since January 2019. It also has an integrated thermal air source heat pump and electrical storage systems.

SEB No.25 | Josh's House (AU): Built in 2013 and renovated in 2018, the Josh's House located in Fremantle's Hilton suburb, WA, Australia, integrates advanced technologies to achieve energy efficiency and environmental sustainability. It includes a 6.4 kWp PV array with a 5 kWp inverter for electricity generation, supplemented by a 10 kWh LiPO Battery System that powers both the household and an electric vehicle. To reduce reliance on natural gas, a heat pump hot water system and an induction cooktop were installed. An integrated water system, paired with a UV disinfection system, collects up to 32,000 litres of rainwater for internal use, while a Grey Flow Diversion Device recycles greywater for irrigation. The house has smart metering systems and solar irradiance, wind speed, direction, temperature, and humidity sensors (including built-in sensors in the slabs, walls, ceiling, and roof) for continuous energy performance monitoring. These features earned the house a 10-star NatHERS energy efficiency rating and serve as an example of achievable, cost-effective sustainable construction.

3.2.3 Overview of building features and technologies in Task 66 Case Studies

Table 2 recaps the installed technologies in the Task 66 Case Studies.

Table 2: Overview of SEB-Technologies applied in Task 66 Case Studies

SEB Technologies																				
	Energy Generation											Energy storage				DH	Other Energy Features			
SEB N°	Photovoltaics	Solar Thermal Collectors	PVT-Collectors	Groundwater and Heat Pumps	Ice Storage and Heat Pumps	PVT and Heat Pumps	Geothermal and Heat Pumps	Air-Source Heat Pumps	Biomass Combustion	Batteries	Mobile Batteries (E-mobility)	Sensible Energy Storage	Thermochemical Storage	Ice Storage	Thermal Mass Activation	District Heating Network	Retrofit	Thermo-regulative wall	Energy Management System	Demand Response
No.1	X			X						X	X	X			X	X	X		X	X
No.2	X			X					X			X			X	X				
No.3	X			X				X								X				
No.4	X			X						X		X				X				
N0.5	X									X	X					X				
No.6	X		X			X				X		X				X	X		X	
No.7			X		X	X					X			X	X	X				
No.8	X	X			X	X								X		X				
No.9	X	X								X	X	X								
No.10	X						X			X										
No.11	X									X										
No.12	X	X								X	X	X								
No.13	X																			
No.14	X									X										
No.15	X																			
No.16	X																			
No.17																		X		

SEB N°	Photovoltaics	Solar Thermal Collectors	PVT-Collectors	Groundwater and Heat Pumps	Ice Storage and Heat Pumps	PVT and Heat Pumps	Geothermal and Heat Pumps	Air-Source Heat Pumps	Biomass Combustion	Batteries	Mobile Batteries (E-mobility)	Sensible Energy Storage	Thermochemical Storage	Ice Storage	Thermal Mass Activation	District Heating Network	Retrofit	Thermo-regulative wall	Energy Management System	Demand Response
No.18		X										X	X							
No.19		X													X					
No.20		X											X							
No.21	X		X				X			X	X	X			X				X	X
No.22	X				X					X				X						
No.23	X	X		X																
No.24			X					X		X										
No.25	X	X						X		X	X									