Heat Pumps in Positive Energy Districts

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Abstract

The new Annex 61 in the Technology Collaboration Programme (TCP) on Heat Pumping Technologies (HPT) of the International Energy Agency IEA entitled "Heat pumps in positive energy districts" deals with in-depth investigations on heat pump (HP) application in clusters of buildings and positive energy neighbourhoods/ districts. As extension of the unique features of HP in individual buildings, the application of HP in clusters of buildings and neighbourhoods can unlock further potentials of load balancing and waste heat recovery. Based on the state of the art the Annex systematically investigates HP concepts in more detail regarding design, control and integration potentials by both system simulation and monitoring. Besides new built clusters, also renovation concepts for existing neighbourhoods are a focus to shift the balance in the direction of zero energy/emission targets. The paper gives an outline of the Annex work and more detailed insight into four exemplary case studies to be investigated within the Annex framework.

Keywords: heat pump, positive energy district, clusters of buildings, simulation, monitoring

1. Introduction

Climate protection developed as one of the largest challenges to secure the survival of mankind. The global carbon budget for keeping the 1.5 °C target established in the Paris Agreement of 2015 (UN, 2016) is reached within a time frame of less than 10 years at current CO_2-equivalent emissions (IPCC, 2021). Thus, efforts in all fields to reduce greenhouse gas emissions are urgently required and many cities have already declared climate emergency in the recent years.

The built environment is a key sector for fast emission reductions in many countries. For instance, in the EU, 36% of the emissions are due to buildings, so reaching ambitious climate targets will be strongly facilitated by transforming the building sector. For new building standards have developed to high performance requirements. Furthermore, buildings shall contribute to cover their own demand, leading to the nearly zero energy concepts (nZEB), which has been established in the EU with the recast of the Energy Performance of Buildings Directive (EPBD, EC 2010) and is the current requirement from January 1, 2021 in the EU member states. Also the USA and Canada as well as Japan and China have targets to reach Net Zero Energy Buildings (NZEB) in the time frame of 2020 to 2030. Ambitious targets, though, are harder to achieve in existing buildings. However, the latest version of the EPBD of 2018 also requires the member states to develop retrofit strategies to notably enhance the energy performance of the building stock. For new dwellings, also examples to even transcent the nZEB balance and reach a positive energy balance exist with the ability to export parts of on-site energy production to connected grids. This concept can be extended to clusters of buildings and districts deriving a positive energy district. However, former work, among others in the HPT Annex 49 on "Design and integration of HP in nZEB" confirmed, that in particular for larger residential and office buildings, reaching a positive energy balance on the individual building level can still be challenging (Wemhoener, 2020). In this sense, extension to clusters of buildings with different load structures also have potentials to enhance the heat pump (HP) performance and enable to reach ambitious energy targets.

On the other hand, in the Net Zero Roadmap of the International Energy Agency (IEA) (IEA, 2021), HP are seen as dominating heating systems with a share of 70% globally by 2050.

doi:10.18086/eurosun.2022.11.13 Available at http://proceedings.ises.org

While HP are already establishing as standard heating system in the new built market in many countries, application of (larger) HP for the use in cluster of buildings and neighborhoods are not yet as common. Comprehensive recommendations for the best integration of the HP from a purely decentralized use on individual building level to an entirely centralized integration are missing, and performance potentials of HP application in districts depending on load boundary conditions are not obvious. Moreover, further benefits of HP in cluster of buildings regarding storage options and unlocking of energy flexibility as well as economic implications are further investigated to entirely assess potentials and facilitate ambitious energy performance/emission reduction.

2. Outline of the HPT Annex 61

On this background, the new Annex 61 in the Technology Collaboration Programme (TCP) on Heat Pumping Technologies (HPT) of the IEA entitled "Heat Pumps in Positive Energy Districts" studies the application of HP for clusters of buildings and positive energy neighborhoods (PEN)/ -districts (PED). The focus is on smaller clusters of buildings and neighborhoods, mainly with residential and office use. While the majority of project contributions concentrate on new built clusters, quite some projects also focus on strategies to increase the energy performance of existing neighborhoods to approach a zero energy/emission balance, which is also in the scope of the Annex. Thereby renovation strategies include both the improvement of the building envelope and the integration of HP, and optimized concepts are to be evaluated.

Besides the unique performance features of HP and the ability to provide the different building services of space (SH)/domestic hot water (DHW) heating and space cooling (SC)/dehumidification (DH) even at the same time, HP are also a key technology to link the on-site electricity production and heating/cooling demands in districts, respectively. Thus, supposed benefits of the HP integration in districts are manifold.

- the high energy performance of HP enables to reach ambitious energy/emission targets
- the simultaneous operation of HP for different building services enables a waste heat recovery for other building services, e.g. by simultaneous space cooling and DHW heating within the district
- the link of electric and thermal energy allows for load balancing within the district of electric and/or thermal loads as well as on-site electricity production for enhanced self-consumption
- the load balancing can also provide energy flexibility for connected grids, so that the district can provide services for other parts of the city

In order to assess the HP potentials the Annex work follows a 4-step methodology divided into Tasks. Based on the state-of-the-art analysis of HP use in already existing clusters of buildings or PED, a concept analysis for HP in PED is carried out. For promising concepts a detailed techno-economic analysis is accomplished and backed-up by monitoring of HP operation in PED, which are evaluated in parallel to the concept analysis. Details on the individual Tasks is given in the following

- Task 1: State of the art analysis (January 2022 – December 2022)

  Starting from already existing HP systems in cluster of buildings the state of the art is characterized and boundary conditions for the follow-on tasks are gathered. As Key Performance Indicators (KPI) CO_2-eq-emissions and further ecological and economic KPI are considered. As result of Task 1 an assessment of technically realistic options for PED as well as an economic estimation of reachable ambition levels and the economic handicap could be evaluated. Therefore, standardised load profiles are generated and used for archetype district, e.g. entire residential use, mixed residential and office use etc. These archetype districts are to be characterised by the building quality reflected in the loads, the available renewable sources and the on-site energy production options.

- Task 2: Generic concepts development (July 2022 – July 2023)

  Task 1 is followed by Task 2 for the analysis of generic system concepts. Starting from decentralized concepts on individual building level as reference different categories to a central integration are defined, comprising a purely electric connections, a collective heat source, a semi-centralized integration in terms of mixed centralized and decentralized HP, e.g. a central SH HP combined with a "booster" decentralized DHW HP up to a fully centralized HP integration. Figure 1 shows the generic concepts dependent on the degree of integration of the HP in the district. For each subsystem, a short technical characterization is elaborated. As result, an overview of generic integration options of the HP in districts with pros and cons and favorable applications as well as recommendations are foreseen.

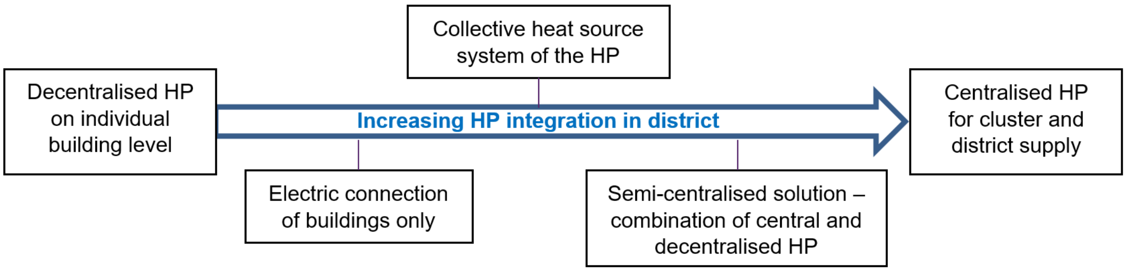

Fig. 1: Generic system concepts depending on the degree of integration of the heat pump in the district

- Task 3: Techno-economic analysis of promising concepts (January 2023 – December 2024)

Based on the favorable system concepts derived in Task 2 a more detailed techno-economic analysis is carried out, in particular regarding the design and control as well as integration with storage and other generators to optimize the HP operation regarding performance, renewable energy integration, system cost and energy flexibility. The detailed investigations are carried out by simulations where also modelling aspects of larger heat pumps are a research topic. Task 3 also serves to evaluate optimization potentials of real system in monitoring in Task 4, which in turn yield operation and performance data to validate the models.

- Task 4: Monitoring and system optimization of the real performance of HP in districts

As mentioned above Task 4 is dedicated to the evaluation of the real performance of HP in district applications and to the identification of typical optimization potentials in the real operation for the different heat pump integration options in monitoring. Moreover, a comparison and verification to simulated values is enabled by the real operational data.

- Task 5: Dissemination of interim results

All task are accompanied by dissemination activities like workshops, articles, website information and presentations, which are summarized in an overarching Task 5

Table 1 gives an overview of possible contributions of the interested and participating countries in the Annex.

Tab. 1: Possible contributions of the interested and participating countries

Country	Institution	Contributions
AT	UIBK, AIT, AEE-intec	• Concept for 7 equal multi-family houses (MFH) by simulation/monitoring • Evaluation of HP in clusters of buildings (decentral, semi-central, central)
BE	ULB, KU Leuven, Swecobelgium, Vito	• Design, simulation and monitoring of clusters of offices and neighbourhoods with sewage water heat source • Clean cluster concepts for dedicated load situations • HP in a retrofitted neighbourhood to plus energy level
CA	Concordia	• Case studies of positive energy neighbourhoods by simulation
CH	IET OST	• Simulation and monitoring of positive energy neighbourhood • Design of larger heat pumps for MFH and clusters of buildings
DE	THN, SIZ energieplus	• Model predictive control of 8 single family houses for energy flexibility • (Retrofit) concepts for MFH/neighbourhood by simulation and monitoring
IT	Univ. Firenze	• Monitoring and simulation of neighbourhood with seasonal thermal storage, HP and solar collectors/troughs
JP	Univ. Nagoya	• Evaluation of contribution of HP in positive energy district to reach climate protection targets • Case studies of simulation and monitoring of HP in districts
NL	EnergyGo	• Investigation of decentralised and centralised system concepts for HP in new built and retrofit application
SE	RISE	• HP modelling and development for the use in thermal grids • Control of HP flexibility in thermal grids and large-scale control of HP
US	NIST, ORNL, EPRI	• Simulation, testing and monitoring of high performance ground source integrated HP with different ground-source systems (horizontal/borehole)

3. Case studies in clusters and districts

In the following four examples of the contributions of Austria, Germany and Switzerland are given. The projects have a different state, since the Annex 61 is in the starting phase. The monitoring projects of Germany refer to clusters of buildings, where the monitoring is already ongoing; the projects of Switzerland and Austria refer to larger clusters of above hundred flats and are in the planning and commissioning phase. The project apply different degrees of HP integration. The ongoing monitoring in Germany refers to a cluster of eight single family plus energy houses in a semi-central configuration with central space heating and free-cooling and decentralized DHW supply. Moreover, two cluster of two and four multi-buildings, respectively, are in monitoring in Konstanz and Wolfsburg. In the Austrian project central district heating is combined with decentralized heat pumps and in the Swiss project, a centralized HP integration is investigated.

2.1 Cluster of eight terraced plus energy houses, Herzo Base, Germany

The cluster of eight terraced houses is located in Herzogenaurach, Germany in the new district Herzo Base and built in 2017. The buildings were designed as an "all electric buildings", which means that the core source of energy is electricity. A PV-system (88 kWp) on the roofs delivers an annual surplus of energy. The idea of small neighbourhoods creating an energy community and share energy systems enables higher potential to increase the PV self-consumption. Furthermore, synergies between different electrical loads lead to a more even electrical profile and reduces electrical load peaks. The terraced houses share a central heat pump system of two modulating heat pump (MHPs) of each 17 kW_{th}, with geothermal heat source as well as a battery system with a capacity of 40 kWh_{el}. The supply of domestic hot water is decentralized in each terraced house by a domestic hot water-HP (Booster), which use the heating buffer storage units as heat source. All 8 terraced houses are equipped with floor heating and decentralized ventilation devices. The objectives of the field monitoring is the evaluation of the plus energy balance and PV self-consumption. Another aspect is the field test and evaluation of advanced control strategies in order to increase PV self-consumption and reduce energy costs. Fig.2 show the building cluster and and its position in the district.

Fig. 2: Building cluster Herzo Base, Herzogenaurach, DE

In the planning phase, a plus energy balance has been envisaged and just reached. The monitoring data demonstrate a clear positive energy balance on an annual observation period. In the simulation, a standard weather data set of the German Weather Service (DWD) was used, which has lower solar radiation and outdoor temperatures compared to the monitoring. Also, in contrast to the planning phase, less electricity is consumed due to low household electricity consumption and lower number of electrical vehicles. On the other hand, the heat energy consumption is higher than expected due to higher room set point temperatures and window ventilation. Nevertheless, the supply cover factor (incl. PV and battery) is 37 % and load cover factor is 64 %.

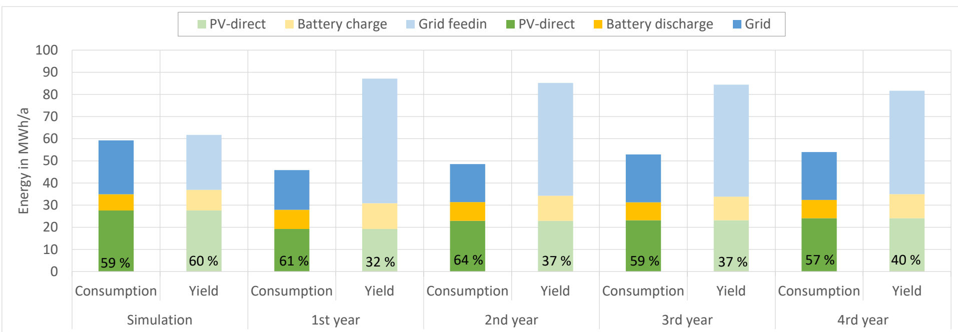

Fig. 3: Annual balance for PV yield and consumption

Fig. 3 shows the annual balance of PV yield and total electricity consumption. The total electricity consumption includes all consumers of the terraced houses: electricity for appliances, heat pumps, auxiliary energy and other consumers. By the change of control strategy of the heat pumps to a PV optimized operation in the 2nd year, the PV self-consumption could be increased by 12.5%. Regarding the efficiency of the heat pumps, the MHPs achieve a good overall system performance factor (SPF) of about 4.8. The SPF of the boosters are quite constant by 4.2, which is very good for providing high storage temperatures. The balance is based on the produced energy and the electrical power consumption of the compressor and the source circulation pump. The SPF of the system, which includes the thermal used energy (heating + DHW) and thermal losses as well as electrical energy for all heat pumps and auxiliary energy, is constant at approx. 3.3 over the years. In the winter months, the SPF of the system reaches good values of 4, but it drops to just under 2 in the summer. Due to high auxiliary energy, e.g. circulating pumps and circulation, especially in summer, the SPF of the system is only 3.3. The share of auxiliary energy is about 13% in summer and about 5% in winter. With regard to the individual heat pumps, very good SPFs are achieved. When considering the overall system, only moderate SPFs are achieved due to high auxiliary energy. Tab. 2 shows results from the monitoring over four monitoring periods.

Tab. 2: Monitoring results (average over four years (2019 – 2022)

	Building cluster Herzo Base
Heating consumption	Space heating 32.8 kWh/(m²a) (59%) Domestic hot water 22.6 kWh/(m²a) (41%)
Electricity consumption	Heat pumps 11.1 kWh/(m²a) (25%) Boosters 5.4 kWh/(m²a) (12%) Household and other technical 27.3 kWh/(m²a) (62%)
Load Cover Factor and Supply Cover Factor	LCF ~ 64% SCF ~37%
SPF HP	MHPs 4.8 Boosters 4.2 all HP together 3.3

In addition to monitoring, the operation of a model predictive control (MPC) is investigated (Betzold et al., 2022). On the one hand, a simulation study was carried out, on the other hand, the operation was implemented in real in the terraced houses. The simulation of the control strategies shows that due to the large PV production, a very high PV self-consumption is already achieved in heat-controlled operation. Advanced control strategies, like MPC, increase the load cover factor by only 2% to 3% percentage points. Energy cost savings can be achieved especially by MPC by up to 34%. In addition to operation at PV production, efficient operation with high COP at partial load is crucial for energy cost savings. The real operation of the MPC in the terraced houses shows that deviations in the prediction and modeling as well as the interpretation of the setpoint from the online simulation lead to different results in real operation. The operating costs of online simulation and measurement show deviations of -64%.

The terraced houses present the integration of renewable energies in a cluster of buildings and achieve very good values in terms of load cover factor, efficiency and operating costs. Under real weather conditions, the PV system could be scaled down to still achieve very good results.

2.2 Multi-family building clusters with EnergyPlus concept in Konstanz and Wolfsburg, Germany

The planning and implementation of a completely renewable energy supply for a block of residential buildings in an urban structure presents a challenge. This was achieved in the two projects by providing heat using a ground-coupled HP. The multi-family houses in Konstanz and Wolfsburg were completed in 2016 and supply a net floor area of 1140 and 9500 m².

Fig. 4 shows the building cluster in Konstanz (two buildings) and Wolfsburg (four buildings). The energy concepts of the residential buildings are based on heat supply via HP. The generated heat is temporarily stored in buffer tanks and delivered to the low-temperature heating systems. The DHW is heated via fresh water stations or storage tank charging systems. Decentralized exhaust air systems or central ventilation systems ensure a constant air exchange. Natural ventilation via the windows is possible in all properties.

Fig. 4: Cluster of multi-family buildings in Konstanz (left) [source: WOBAK] and Wolfsburg (right), DE

Photovoltaic systems are installed to cover the electrical energy needs of the system technology and the connected households. The system technology is optimized for so-called "PV self-consumption", which means direct use of the photovoltaic yields. Electrical energy from the PV systems that cannot be directly consumed or stored is fed into the public electricity grid. The comparison of the multi-family buildings refers to their efficiency, ecology and economy, with the overall balance and thus the total consumption of electrical energy serving as the basis for evaluation. The consumption of the buildings is made-up of the electricity consumption of HP and circulation pumps, general electricity (lift, staircase, garage, etc.) and the user electricity of the individual flats (appliances).

Tab. 3: Key data on the building and supply concept

	Konstanz	Wolfsburg
building	2 buildings (2016) with 12 apartments in total; 3 floors each; Net Floor Area (NFA) 1140 m² (total)	4 buildings (2016) with 68 apartments in total; 4 floors each; Net floor Area (NFA) 9500 m² (total)
PV-system	59.2 kWp on the roof; roof slope 10° to west and east	27.4 kWp on the roof of house A; Roof slope 45° to south (possible PV size ~160 kWp)
heat pump	2x brine-to-water-HP (30 + 27 kW)	2x brine-to-water-HP (90 + 50 kW) and 4x air-to-water-HP (each 14 kW)

In Fig. 5, the electricity consumption (divided into self-consumption and electricity from the grid) compared to the PV production (divided into self-consumption and grid feed-in) for the years 2018 to 2021 as well as the planning values are listed. It can be seen that the electricity requirements estimated in the planning for the buildings do not correspond to the determined electricity consumption; more electricity is consumed. This is due to higher user electricity for appliances and hot water consumption. Nevertheless, it can be shown that a solar load cover factor of up to 35% of the total energy consumption and a supply cover factor up to 40% can be realized.

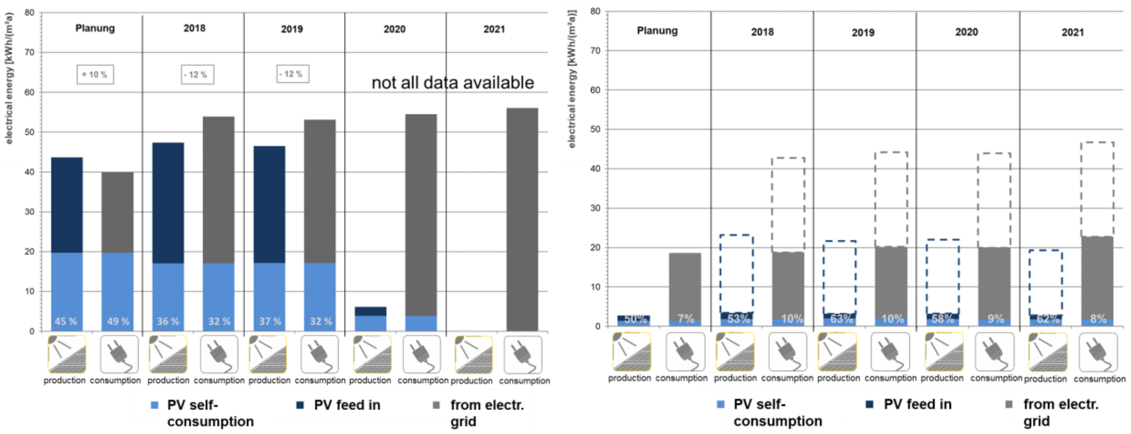

Fig. 5: Annual energy balance, multi-family buildings Konstanz (left) and multi-family buildings Wolfsburg (right) (dotted bars: possible PV yield for total PV on the roof and additional electricity for appliances), DE

The EnergyPlus balance could not achieved due to the higher electricity consumption and in the case of Wolfsburg, the possible PV area on the roofs is also too small to cover the total electricity demand (annual balance). Table 3 shows the annual averages of the four monitoring years for the multi-family houses in terms of heat and electricity consumption and coverage shares. Differences in the coverage shares between the monitoring years can be attributed to volatile PV yields and fluctuating electricity consumption.

Tab. 3: Monitoring results (average over four years (2018 – 2021)

	Konstanz	**Wolfsburg**
Heating consumption	SH 56.3 kWh/(m²a) (71%) DHW 23.0 kWh/(m²a) (29 %)	SH 41.7 kWh/(m²a) (66%) DHW 21.6 kWh/(m²a) (34 %)
Electricity consumption	HP 23.0 kWh/(m²a) (43%) appliance and other technical 31.0 kWh/(m²a) (57 %)	HP (incl. auxiliaries/general consumption) 20.0 kWh/(m²a) (46%) Appliances 24.0 kWh/(m²a) (54 %) (assumption)
Load Cover Factor/ Supply Cover Factor	LCF ~ 32% SCF ~37%	LCF ~9% * SCF ~60% *
SPF HP	3.94 (all HP together)	3.96 (all HP together)

*Includes only the technical room; without appliances

In the case of the multi-family building in Wolfsburg, it must be taken into account that only the technical room (HP and heating supply systems, auxiliaries and general electricity) is supplied with PV electricity in the evaluation and balance. The electricity for appliances is not included, as it is not measured and cannot be covered by PV electricity in the implementation. For legal reasons regarding the grid connection and supply of the four buildings, the PV system cannot be fully installed in Wolfsburg. For this reason, PV was only installed on one roof and only supplies the building technology in the technical room with electricity. Figure 4 shows the possible PV yields as dotted bars, if the cluster had been equipped with all possible PV modules and the additional electricity consumption for appliances.

A comparison for estimating the CO_2 reduction is based on the supply concepts with gas condensing boiler with solar thermal and electricity grid connection as well as district heating and electricity grid connection depicted in Fig. 6. The two example concepts are common supply concepts for multi-family houses in Germany in order to fulfil the minimum standard. No credits for feed-in of PV electricity into the grid were taken into account. It can be clearly seen that the conventional concepts emit 10 to 80 t/a or 40 – 108 % more CO_2 (depending on the concept and building) than the implemented HP concept. Both the results determined from the monitoring and the general energy conceptualization prove that, in addition to the use of HP, photovoltaic systems also represent essential building blocks for achieving the goal defined by the federal government of a nearly climate-neutral building stock by the year 2045. Both in the balancing and in future concept considerations and designs, care should be taken to ensure that the concepts are designed for an overall energy balance, i.e. heat and electricity requirements including user electricity for the entire building are taken into account.

Fig. 6: Annual CO_2 emissions compared to supply concepts with gas boiler and solar thermal or district heating (heat + electricity)

2.3 Campagne district in Innsbruck, Austria

A new low-energy residential district is being built in Innsbruck, Austria. The building owners (social housing companies) had to make decisions with respect to the energy quality of the buildings and the heating system with respect to the energy and environmental impact. The district will be composed of 16 buildings grouped in four blocks (Fig. 7). The main part of the buildings is residential and will consist of approximately 1100 new apartments for a total surface of 78027 m^2. Moreover, sport facilities, cafes, schools and kindergartens will be constructed. In the planning phase, a cooperative process was carried out, involving neighbouring residents and local associations.

Fig. 7: Building cluster of Campagne, Innsbruck, AT (source: ibkinfo.at; stadtteilzentrum-reichenau.at, Bogenfeld Architekten)

The buildings are built according to Passive House standard (space heating demand lower than 15 kWh/(m^{2}a)). The space heating demand is supplied by a groundwater HP and the emission system is floor heating. The domestic hot water is provided by the district heating network, which accounts for a high proportion of heat by renewable sources, industrial waste and bioenergy. The shares of renewable sources and industrial waste heat of the district heating of Innsbruck are higher than other cities in Austria and it is foreseen that these shares are going to increase in the future. Photovoltaic panels are installed on the roof on the buildings to cover the electrical demand of auxiliaries. Moreover, sustainable mobility solutions are planned to enhance the electric mobility.

A comprehensive simulation study has been carried out (Dermentzis et al., 2021) investigating different types of heat generation system (e.g. alternatives and/or combinations with HP), varying the level of centralisation of the heat generation system and the type of heat distribution system. The aim of the study was to find the best combinations with respect to energy and environmental impact. The results supported the decision-making procedure of the Campagne project. The options concerning the heating system are district heating (DH), heat pump (HP), or the combination of both (HP and DH). In the latter case, the two systems are hydraulically separated, i.e. HP covers the space heating and DH covers the DHW demand. A natural gas boiler was used as a reference heating system. The selected KPIs to compare the system concepts were the total primary energy demand (i.e. renewable and non-renewable primary energy demand) and the CO2 emissions. Besides, the KPIs were evaluated with annual or monthly conversion factors. One building was modelled and simulated in detail, and then the results were extrapolated to the whole district. The assumed characteristics of the buildings are shown in Tab. 4.

Tab. 4: Assumption of the modelled building

Space heating demand	14.5 kWh/(m^2·a).
DHW profile tapping cycle	Type M, as described in EN 16147 (2017)
Average number of persons per flat	2.1
Internal gains	3.1 kWh/day for each flat

Five concepts of pipe distribution systems including decentralized DHW systems (one per flat) were investigated:

1. a 4-pipe system with hot water circulation for DHW
2. a 4-pipe system with a fresh-water station in each flat (including a heat exchanger for the DHW)
3. a 2-pipe system with a fresh-water station in each flat (including a heat exchanger for the DHW)
4. a 2-pipe system with the so-called return-flow heat pump
5. a 2-pipe system for space heating and a simple electric boiler in each flat for the DHW preparation

The integration of HPs on building level instead of district level is significantly preferable resulting in total primary energy (PE) savings of 23%.

The most efficient distribution systems combined with an HP are a 4-pipe system with a freshwater station or a 2-pipe system with return-flow HP. A 2-pipe system with a freshwater station in combination with the highest insulation level is the optimal distribution system.

The study results show that HPs are more beneficial than DH or gas boiler for space heating and DHW preparation. Both KPIs (PE and CO_2) lead to this conclusion. This applies also to air-source HPs, which are less efficient than ground-source HPs in supplying space heating. The highest savings compared to natural gas are observed in CO_2 emissions. The use of heat pumps or district heating instead of gas boilers decreases the carbon emissions by a maximum of 75% and 52%, respectively. In this study, the design supply temperature of 35 °C for space heating is relatively low due to the combination of the low heating load of a Passive House and the use of a floor heating system. This improves considerably the performance of the HP.

Both KPIs increase for the case of HP when monthly factors are used, because of the seasonal variations of the electricity conversion factors. Moreover, the higher the share of renewables on the energy mix (e.g. for electricity or DH) is, the higher the importance of monthly conversion factors.

The results indicate that in the case of an HP, the systems with low supply temperature are preferable i.e. four pipe system with freshwater station and 2-pipes system with the so-called return-flow heat pump. Besides, the choice of one HP per building instead of one per district reduces the thermal losses by 79%. However, the maintenance effort might be lower with one central HP instead of 16 HPs. One HP per block would increase the thermal losses by 23% (compared to one HP per building). As mentioned above, the installed system consists of DH for DHW and groundwater HP for space heating. The decision of using both DH and HP instead of only HP is made mainly due to the limitation for ground water use. The installed system (4-pipe system with a fresh-water station in each flat) saves up to 44% of primary energy and 60% in CO_2 emission compared to the gas system.

A detailed monitoring system (on building and flat level) is installed in one block (consisting of 4 buildings) of the Campagne district. Several heat meters and electricity meters were installed along the production system and the distribution system to monitor both space heating and domestic hot water preparation, collecting data on building- and apartment-level. Electricity consumption for appliances and auxiliaries is also available, as well as the produced energy from the photovoltaic panels. The aim is to analyse the power consumption and the output of the heat pump, as well as the heat losses of thermal storages, heat exchangers and distribution pipes. Moreover, in one building, temperature and humidity are monitored on flat level. In the same building a CO_2 sensor is installed in each of the five central ventilation units. Design values and results of the simulation study can be confirmed by the monitoring data and potential problem can be detected. A detailed study of the distribution losses along the pipe can be carried out. Monitored data can also be used as input of further simulations to investigate alternative system using validated dynamic models.

2.3 Papieri district in Cham, Switzerland

The Papieri district in Cham, CH, is an old estate of the Paper industry, which is rebuild to a comprehensive new neighbourhood in six phases over the next years for 1000 inhabitants and 1000 additional workplaces in the final development. Fig. 8 left shows a picture of the district, the first development phase is depicted in Fig. 8 middle and the energy concept of the borehole field connected to the central HP heating and cooling is shown on the right.

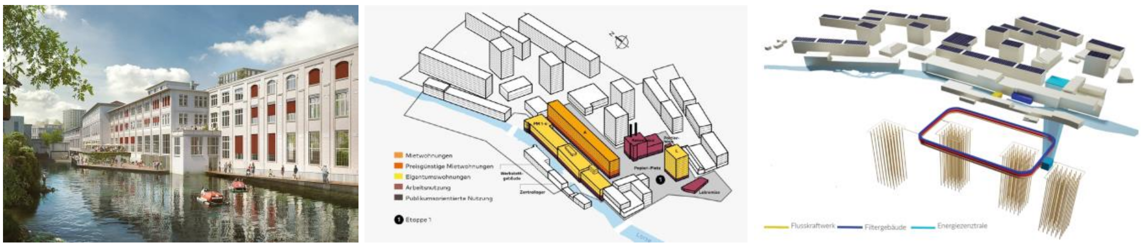

Fig. 8: Papieri neighbourhood, Cham, CH, with neighbourhood view from the river (left), buildings of the first phase (middle), and the energy concept (right) source: www.papieri-cham.ch, AWIAG, Cham group)

The neighbourhood consists of industrial heritage buildings of the paper industry which are preserved and retrofitted for a new use and are amended by new buildings, which create a mix of about 30% of existing and 70% of new buildings. In the first phase depicted in Figure 7 middle, 105 condominiums and 160 rental apartments together with 4400 m^2 floor area of commercial and office use will be commissioned by the end of 2022.

The estate development is designed in a way that all building services of heating, cooling and domestic hot water are entirely supplied by renewable energy. About 40% of the electricity use in the district is produced on-site. The electricity is produced by a 6500 m^2 PV-system of an installed peak capacity of 1.27 MWp and an estimated annual electricity production of 1.1 GWh, which is installed on the roof of the new buildings. As second electricity generator a hydro power plant with an installed capacity of 240 kW and a calculated annual production 1.25 GWh is installed in the river Lorze, which run through the district. The remaining electricity is imported as certified green electricity from the utility in order to reach a zero emission balance.

The space heating and cooling as well as the DHW production is supplied entirely renewable by four central ammonia HP of a total capacity of 4 MW, which use borehole fields of totally 192 ground probes of 320 m depth as heat source. As second heat source the river water of the Lorze is used either directly as heat source or as regeneration source for the borehole fields. The comfort cooling for the residential and office use is planned to be operated primarily by free-cooling from the boreholes. Active cooling by the HP in chiller operation is only provided for peak load cooling, whereby all the recooling (waste) heat from the active chiller operation is to be recovered for other uses like DHW production or for the regeneration of the borehole fields.

Since neither the modelling and simulation nor the monitoring has started, yet, only the above mentioned energy concept and design data are available of the neighbourhood. The HP system will be modelled, simulated and monitored in order to optimize the first operation years and retrieve on-site information for the further development of the neighbourhood in the later project phases. The evaluation includes the verification of the system performance of the centralized and the zero emission balance.

A special focus of the simulation and the monitoring is a more detailed analysis of the operation and the energy balance of the borehole fields for combined space heating, DHW and cooling operation. Moreover, the options for the interaction of the two heat sources of the borehole fields and the river water is investigated. Performance potentials are seen in the use of the source with most favorable temperature level, the regeneration of the borehole field for space heating and the simultaneous operation of the HP for heating and cooling in combination with high free-cooling shares. Thus, the objective for the system operation is the maximize the system performance of the HP by an optimized management of the borehole field as heat source and (free-)cooling heat sink and the integration of the ground and river water heat source.

4. Conclusions and outlook

Positive energy districts are an ambitious concept, which is currently promoted in order to enhance a high energy performance and on-site energy production as part of the transformation of the energy system. Extending the system boundary from the individual building to clusters of buildings and neighbourhoods offers the combination of different uses and load structures, which can unlock opportunities to increase on-site self-consumption of the produced electricity in the cluster by load balancing and to enhance the performance by waste heat recovery from one building use for another. Heat pumps can play an important role in positive energy district concepts, since they facilitate to reach ambitious energy targets by their high energy performance and can link both electric and thermal loads as well as different thermal uses like heating and cooling. As further aspect, sector coupling within the district and with connected grids can provide energy flexibility within and over the boundaries of the district.

The upcoming Annex 61 in the Heat Pumping Technologies TCP of the IEA investigate heat pump concepts for building cluster and positive energy districts. Starting with decentralized solutions on the individual building level, higher integration of the HP in the districts up to entirely centralized solutions and integration with other energy generators/supply like district heating is evaluated technically and economically. Based on generic concepts a detailed techno-economic analysis shall deliver favorable applications of HP in positive energy districts and recommendations for the integration, design and control of the HP systems.

As insight to the national contributions the paper presents four case studies with different degree of integration of the heat pump in the cluster or district. Already existing results of the case studies confirm that reaching a positive energy balance is a challenge, which requires high building performance to limit the loads, high performance generators for efficient energy supply and vast energy production with the cluster or district, in particular for larger buildings and non-residential use.

Higher integration of the heat pump can create opportunities of higher on-site energy consumption and waste heat recovery for different building services in the cluster, which may further increase the energy performance and flexibility, but may also increase the cost and losses due to necessary grid connections. Both technical and economic trade-offs with be analysed in the Annex 61.

Results of the case studies underline that HP reach high performance values in the application in clusters and can facilitate to reach ambitious objectives of zero or plus energy neighbourhoods or districts due to its unique features of even simultaneous provision of different building services with high performance. Furthermore, HP offer energy flexibility for higher PV self-consumption and reduced grid interactions. The upcoming Annex will derive favorable HP concepts for districts by simulation and monitoring in different case studies.

5. Acknowledgments

This paper presents an outline and interim results from Austria, Germany and Switzerland of the Annex 61. Acknowledgments are expressed to all present and future contributions to the Annex 61 of the Annex participants and to the Swiss Federal Office of Energy SFOE for the support and funding of the Annex 61.

This paper presents results from the projects "Herzo Base - Energy storage houses - An energy flexible building and energy concept of tomorrow" (FKZ 03ET1364A) and "Herzo Opt - Monitoring of the building envelope, thermal room comfort and energy system with operational optimization" (FKZ 03ET1641A). The project is funded by the German Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag.

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