Heat Pumps and Renewables in District Heating – Evaluation of Central and Decentral Approaches

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Abstract. The decarbonization of the building stock and thus of district heating (DH) systems is one of the main future challenges in the building sector. It is controversial which role district heating will play in the future, i.e. to what extent an expansion of DH is beneficial and necessary, but it is undisputed that DH will take or hold a relevant share. With the increasing decarbonisation of the electricity mix, the use of heat pumps (HP) in buildings will be significantly more competitive than (existing fossil-based) DH systems, at least in terms of CO_2 emissions. On the other hand, especially in urban areas and in existing buildings, the use of heat pumps is limited and also technically and economically challenging (source exploitation, space restrictions, architecture, sound emissions, etc.). Decarbonisation of DH might include waste heat, geothermal or solar thermal and heat pumps (in combination with electricity from renewables). Both, decarbonization of DH and electricity mix is challenging and full decarbonization requires electrical and thermal energy storage. Based on the energetic and ecological evaluation of exemplarily DH systems, different variants considering heat pumps integration, i.e. large central HPs central DH or block-wise or decentral i.e. building-wise, or apartment-wise are compared and evaluated. The assessment includes the own-consumption of the Photovoltaic (PV) yield and is then expanded to include various scenarios for the development of the electricity mix and the decarbonisation of DH.

Keywords. Decarbonisation, District Heating, Heat Pumps, Renewables, PV-own consumption, CO_2-Emissions, energetic and environmental evaluation.
DOI: https://doi.org/10.34641/clima.2022.306

1. Introduction

The decarbonization of district heating (DH) is one of the core tasks of the future in the building sector. It is controversial to what extent an expansion of district heating is beneficial and necessary in a future climate compatible energy system, but it is undisputed that DH will take or hold a relevant share. On the one hand, with the increasing decarbonisation of the electricity mix, the use of heat pumps (HP) in buildings will be significantly more competitive than existing DH, at least in terms of CO_2 emissions [1]. On the other hand, especially in urban areas and in existing buildings, the use of heat pumps is limited or at least challenging (source exploitation, space, architecture, sound, etc.).

HPs are effective to reduce energy consumption in buildings and facilitate the integration of renewable sources. While the use of solar thermal and small PV systems combined with HPs is common in single and increasingly also in multi-apartment buildings, HPs in DH is still a slowly growing kind of experimental application. However, DH offers the opportunity to effectively exploit also geothermal energy, industrial waste heat, biomass-based Combined Heat and Power (CHP) and other heat sources, see [2], [3] and [4]. Thus, the integration of HPs in DH systems allows to reduce the share of fossil sources and enables recovering low-temperature heat sources [5]. Possible heat sources are ambient air, ground, sewage and seawater. Among the commercially available heating, ventilation, and air-conditioning (HVAC) systems, ground source HPs outperform the others in terms of energy performance, as shown by [6]. However, depending on the location, exploitation of sources other than air can be challenging and in the case of air as a source, temperature fluctuations have an important influence on the HP performance [7]. A parallel decrease of the heating capacity and the coefficient of performance (COP) as to be accounted for [8].

Partly renewable block heating systems exist as prototypes or demonstrators since many years, but most renewable district heatings rely on biomass, which is a limited resource. A mentionable example of a solar neighborhood is the "Solarsiedlung

Freiburg" that consists of 20 terraced houses [9]. Other concepts are so-called cold DH [10], low-ex [11] or solar assisted DH [12], which can be summarized as so-called 4th generation district heating systems [13].

One main driver to integrate HP into buildings and DH is the possibility to increase the PV own consumption in particular in combination with thermal storage [14], which is mainly motivated because of commonly low PV buyback prices in most European countries [15]. Another motivation increasingly seen is the possibility to use the HPs also for space cooling [16].

1.1 Role of DH in Future Energy System

The shares of renewables, waste incineration, industrial waste heat, CHP and fossile for the DH of Innsbruck (IBK), Vienna, Graz and Lienz are reported in [17]. The largest DH system in Austria is Vienna with a high share of waste incineration. The DH in Graz is dominated by CHP, while in Innsbruck (IBK) there is a high share of biomass and industrial waste heat. There exist several scenarios for the development of DH in Europe. Exemplarily, two different studies, one for Austria and one for Germany are presented to show the wide range of expected contributions of DH in a future energy system. According to [18] in Austria, the assumption is that the buildings will be deeply renovated and in contrast to a further extension of the DH system the share and size in terms of energy remain rather constant. While for Germany, the prediction according to [19] is that the role of DH will significantly increase with a share of 40 %. The share of large-scale HP in the DH in 2050 is assumed to be almost 50 %. It is noteworthy that according to [20] the current German district heating is predominantly fossil-based and the 2030 scenario seems very ambitious in that respect.

1.2 Research Gap and Paper Organisation

The literature review reveals that HPs will play a major role in the heating of buildings as well as in a decarbonized DH system, but a comprehensive investigation is missing on how to optimally integrate HPs. In particular, the evaluation of the efficiency and the environmental impact of the energy supply of multi-apartment residential buildings connected to DH with so-called booster HPs and PV has not yet been investigated.

Based on the energetic and ecological evaluation of two exemplary district heating systems (Innsbruck and Vienna), various variants of integrating heat pumps in district heating are evaluated. By means of a simulation study, the efficiency and the environmental impact of the energy supply of multi-storey residential buildings with DH and HPs are evaluated. Of particular interest in this study is the integration of decentralized so-called booster HPs in combination with photovoltaics (PV) to increase the PV own consumption.

2. Methods

2.1 Reference Building and DH System

Fig. 1 shows a sketch of the reference building used to model the energy demand of a generic DH system and **Tab. 1** summarizes the characteristics of the building.

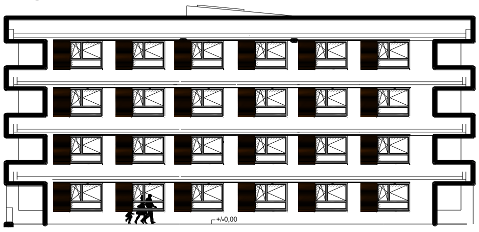

Fig. 1 - Sketch of the reference building, Multi-apartment building with 4 storeys and 16 flats (Neue Heimat Tirol).

Tab. 1 - Overview of characteristic data of the building, variant with Passive House quality [21]

Number of apartments	16
Number of stories	4
Treated area A_T	1295.6 m²
Design Space Heating (SH) demand	11.0 kWh/(m²·a)
Number of occupants	48 (design value)
MVHR	2 centralized units
PV (max.)	270m² (south 40 °) $A_{PV,max} = 0.6 \cdot A_{Footprint}$
U-value – wall / roof / floor	0.10 / 0.09 / 0.11 W/(m²·K)
Triple glazed windows with U- and g-value	0.58 W/(m²·K) and 0.56 [-]
Internal heat gains (design value)	2.7 W/m²

Standard profiles are used for hot water consumption. [22] resulting in Domestic Hot Water (DHW) demand of 20 kWh/(m² a) including storage losses and 25 kWh/(m² a) and distribution losses (within the building). Furthermore, standard profiles are used for household electricity [23] resulting in 25 kWh/(m² a) of electricity (appliances, lighting, etc.).

2.2 PV and PV own consumption

The building's footprint is 449.4 m² with a treated area of 1295.6 m². With the realistic assumption of a max. coverage of 60 % of the flat roof with PV (south oriented with 40° slope and an overall system efficiency of $\eta = 12$ %) the annual yield of a PV system is 90.3 kWh/($m^2_{footprint}$ a), corresponding to 31.3 kWh/($m^2_{treated\ area}$ a). Because of low PV buyback prices, the share of PV that is directly used in the building shall be optimized (from the economic point of view of the building user/owner).
Typically, the PV own consumption is evaluated in terms of load and supply cover factor as defined by Eq. (1) and (2).

$$LCF = PV_{own}/W_{el,tot} \quad (1)$$

$$SCF = PVown/PVtot \quad (2)$$

In the evaluation of LCF and SCF, the total electricity demand (el) including aux. and appliances should be considered

2.3 District Heating System

A generic DH system is assumed (see **Fig. 2**) that consists of 100 buildings with a normal distribution of SH demands (i.e. 5% with 15 and 80 kWh/(m² a), 24% with 25 and 60 kWh/(m² a) and 40% with 45 kWh/(m² a)).

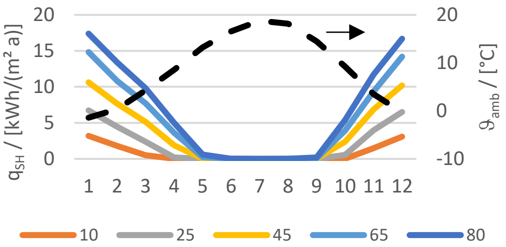

Fig. 2 - Monthly space heating demand of the building with different qualities of the envelope in kWh/(m² a), considering the climate of Innsbruck (site climate acc. to OIB-6_2019)

2.4 District Heating in Vienna and Innsbruck

Because of the high space heating demand in winter, there are strong seasonal variations of the DH load. The DH system in Innsbruck is comparatively small and complex with several small distributed heat sources (Details can be found in [17]). The largest DH system in Austria is Vienna with a high share of waste incineration [24]. The monthly energy balance of the DHs of Innsbruck and Vienna were evaluated.

2.5 Generic District Heating

For the purpose of further investigation, a simplified generic DH system is developed which consists of different shares (in %) of biomass and gas heating: 30-70, 40-60, 50-50, 60-40, 70-30. The overall efficiency of the biomass and gas heater is included in the CO_2 conversion factors, see section 2.9. Fossil gas post-heating is then partly replaced by integrating HPs with different capacities.

2.6 Integration Heat Pumps in District Heating

Generally, the following types of HP integration options are possible (see also **Fig. 3**) :

- DH + central HP (air, ground, water, waste-heat);
- DH + building/block-wise HP for SH;
- DH + building/block-wise HP for DHW;
- DH + decentral/flat-wise air - HP for DHW (PV-own consumption)
- DH + decentral/flat-wise booster or return flow (RF) - HP for DHW (PV-own consumption)
- DH + decentral/flat-wise booster HP for SH and DHW (low-ex)
- Building/Block-wise HP for SH and DHW (no DH)
- Decentral/flat-wise air - HP for SH and DHW (no DH)

Any combination is possible, here the different options are evaluated and compared against each other on a building level and on DH system level.

Typical DH systems are operated with a flow temperature of up to 130 °C in winter and 90 °C in summer with a return temperature of 60 °C. HPs can be integrated as large-scale absorption or compression heat pumps centrally in the DH system. The source is low-grade environmental energy (air or ground) or low-temperature waste heat. The supply temperature of at least 90 °C has to be delivered if (fossil-based) post-heater are not available.

Decentral HPs can be integrated block-wise with a low-temperature distribution system (e.g. 80/30) or building-wise. In low-energy buildings typically 60 °C flow temperature is required for DHW, while space heating can be provided even at lower temperatures (e.g. 35 °C with underfloor heating). Decentral flat-wise heat pumps can deliver DHW at 50 °C to 55 °C.

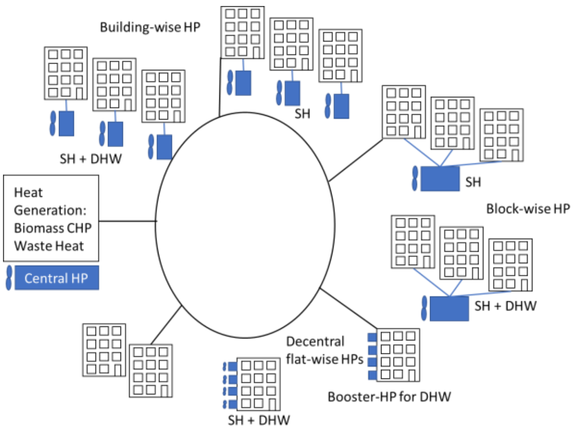

Fig. 3 – Sketch of possible solutions for HP integration (in blue) in a DH system.

2.7 Decentral Booster Heat Pump

There exist different variants of these so-called decentral booster HPs. A common concept is shown schematically in **Fig. 4**. The apartments are heated centrally, i.e. here by means of DH. The heat emission system in the apartments is a low-temperature heating system (i.e. underfloor heating). The central heat supply from a buffer store is controlled via the return temperature. There is a decentral booster HP in each of the apartments for preparing domestic hot water. It consists of a small (1.5 $kW_{thermal}$) water-to-water HP and a small domestic hot water tank of typically 120 l or 150 l. The HP source (evaporator) is connected in parallel to the branches of the underfloor heating. Typically, there is an additional (1.2 kW) heating rod in case backup heating is required. In summer the underfloor heating loops are used to extract heat from the conditioned space (i.e. to provide space cooling) and the central source is only activated if the underfloor heating temperature falls below a threshold or if comfort conditions in the conditioned space cannot be met anymore. Thus, in summer only a negligible amount of heat is extracted from the district heating, instead.

Another concept is represented by the so-called return flow (RF) HP, where the evaporator of the HP is in series to the floor heating loops see [16], which is not further considered, here.

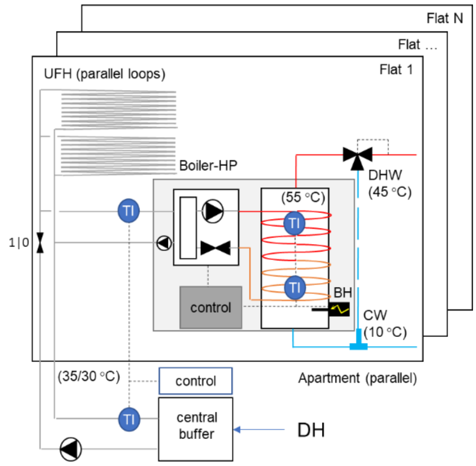

Fig. 4 – Simplified hydraulic scheme of a booster heat pump.

Based on the efficiency (COP) of the HP for DHW preparation of 4.1 at 28 °C and 2.7 at 20 °C source temperature at 55 °C sink temperature, a Carnot performance factor η_C between 0.28 and 0.34 can be determined.

2.8 Modelling Approach

All heat pumps are modelled for sake of simplicity with a Carnot based approach:

$$COP_C = T_{max}/(T_{max} - T_{min}) \qquad (3)$$

$$COP = \eta_C \cdot COP_C \qquad (4)$$

Different Carnot performance factors η_C and flow temperatures (ϑ_{flow}) are used depending on the type of HP:

Central HP: For the COP of large-capacity high-temperature HPs a cascade system is assumed. The overall COP is approximated with a relative optimistic Carnot performance factor of 0.55 leading with a flow temperature of ϑ_{flow} = 90 °C to a COP in winter conditions of about 2.2 and in summer of 2.8 and a SPF of 2.5.

The Building-/Blockwise HP for DHW and SH is modelled as air sourced HP with a rather conservative Carnot performance factor of 0.35 leading to a SPF of 3.

The Building-/Blockwise HP for SH is modelled as air sourced HP with a conservative Carnot performance factor of 0.35 leading with (ϑ_{flow} = 35 °C for SH and ϑ_{flow} = 55 °C for DHW to a SPF of 3.4.

The Decentral DHW HP is modelled as air-sourced HP that delivers hot water at 55 °C with a Carnot performance factor of 0.35. The SPF results to 2.49.

Decentral Booster HP: As described in section 2.7 above, winter and summer operation has to be distinguished in the case of the Booster HP. In winter, the HP uses the flow temperature of 35 °C (max., with a heating curve) as a source to provide DHW at 55 °C. The relatively high COP of about 5 in winter reduces the energy provided by the DH system to 4/5th.

In summer, the source of the HP is the room temperature (20 °C in the transition seasons and 25 °C in summer) and the COP of the HP is correspondingly lower (i.e. 2.8). In the transition months (May and September) a mixed operation (i.e. average of winter and summer conditions) is assumed.

The seasonal performance factor (SPF) is evaluated on monthly basis.

2.9 CO_2 emissions from DH and HP

The CO_2 emissions resulting from DH strongly depend on the energy mix (see section above). In case HPs are involved, the (European) electricity mix has to be considered, which is also subject to decarbonization. According to [25], and depending on the assumed scenario the share of fossils (coal, oil, gas) will decrease from approximately 50 % to 20 % in 2030 and further to 30 % in 2050 with main contributions from wind, biomass and PV but also nuclear power and imported hydrogen and biofuels.

Both, the DH load curve and the electric load curve depend significantly on the time of the year and to account for that, monthly energy conversion factors are recommended [26]. In this work**,** the CO_2 conversion factors suggested by OIB-6:2019 [27] are used. Because of the high share of hydropower, the electricity conversion factors are comparatively low in Austria compared to Germany.

In the case of combined heat and power (CHP) the distribution of CO_2 emissions to the electric and the heating part should be calculated using the Carnot Method. CHP has an important contribution in many DH systems, but is disregarded here for sake of simplicity.The CO_2 emissions are evaluated on monthly level using the Eq. (5) where the q_{DH} is calculated according to Eq. (6) and w_{el} according to Eq. (7) and (8). Relative losses of f_{loss} = 10 % related to the space heating (SH) and domestic hot water (DHW) demand and 1 % for auxiliary energy (i.e. pumps), respectively is taken based on measurements of the DH in Innsbruck presented in [17].

$$CO_2 = q_{DH} \cdot f_{CO2,DH} + w_{el} \cdot f_{CO2,el} \qquad (5)$$

$$q_{DH} = f_{loss} \cdot (q_{SH} + q_{DHW}) \qquad (6)$$

$$w_{el} = w_{el,AUX} + w_{el,HP} \qquad (7)$$

$$w_{el,AUX} = f_{AUX} \cdot q_{DH} \qquad (8)$$

In the reference DH system the resulting CO_2 conversion factor can be calculated according Eq. (9):

$$q_{DH} \cdot f_{CO2,DH} = Q_{Gas} \cdot f_{CO2,Gas} + Q_{Bio} \cdot f_{CO2,Bio} \qquad (9)$$

For the following evaluations conversion factors based on OIB-6:2019 were used:

- Electricity 227 t_{CO2}/MWh;
- Gas 244 t_{CO2}/MWh (incl. 82 % thermal efficiency);
- Biomass/Waste Heat 50 t_{CO2}/MWh.

The CO_2 conversion factors of four generic DH systems with a different share of biomass/waste heat and natural gas are shown in **Fig. *5*** and compared with the factors determined for the DH in Vienna and Innsbruck (IBK).

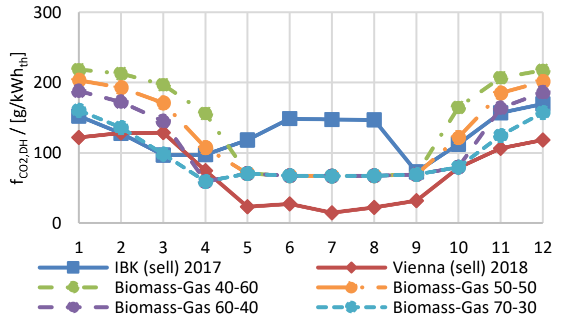

Fig. 5 - CO_2 conversion factors for DH Vienna and Innsbruck (IBK) as well as 4 generic DH systems with different shares of biomass/waste heat and natural gas (own calculations based on [17] and [24]).

CO_2 conversion factors for electricity in Germany (D 2019) and Austria (At, 2019) are taken as a reference [28] and are compared to two scenarios of a generic electricity mix with 10 % hydro, 10 % wind and 10 % PV and 10 % hydro, 30 % wind and 30 % PV, respectively (residual fossil) according to [26] (see **Fig. 6**). For further investigation, the scenario 10-10-10 is used as it might well represent a near-future energy mix for Germany.

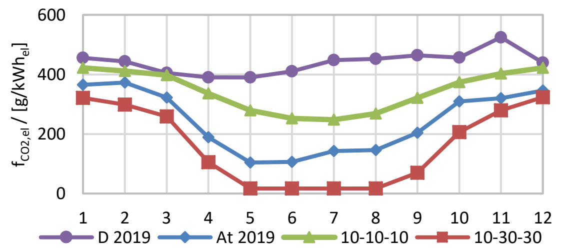

Fig. 6 – CO_2 conversion factors for electricity in Germany (D 2019) Austria (At, 2019) acc. to [28], and acc. to two scenarios of a generic electricity mix with 10 % hydro, 10 % wind and 10 % PV and 10 % hydro, 30 % wind and 30 % PV, respectively (residual fossil) according to [26].

3. Results

The following results apply under the assumption of a limited availability of biomass of (here exemplarily) 32 kWh/(m² a), i.e. in the reference system gas contributes to approx. 60 %. Here, only the case of the reference DH, the central HP and the decentral booster HP are presented examplarily.

3.1 Reference District Heating

Fig. 7 shows the monthly balance of the reference DH system with 40 % biomass and 60 % gas.

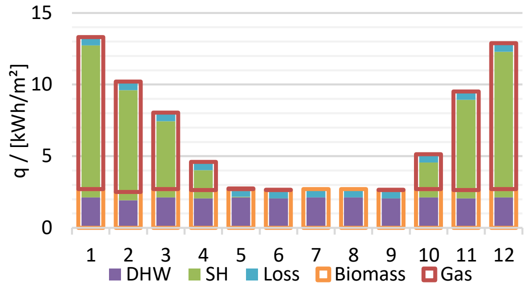

Fig. 7 - Reference DH system with 40 % biomass and 60 % gas.

3.2 District Heating with Central HP

A central HP can be used to reduce the share of fossil gas. Two examples are presented with different heat pump capacities contributing to 16 % and 31 % of delivered heat, respectively (see **Fig. 8**).

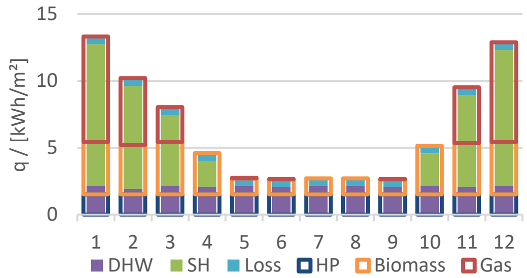

Fig. 8 - DH with central HP 23 %, biomass and gas.

3.3 District Heating with Decentral Booster HP

The monthly balance of a DH heating system with decentral booster HPs is shown in **Fig. 9**.

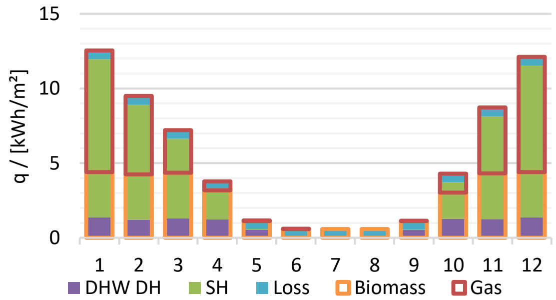

Fig. 9 - Decentral Booster-HP; 40 % Biomass, 60 % natural gas.

3.4 Evaluation of reference DH and DH with HP

Based on the monthly balance, the total annual CO_2 emissions are compared in **Fig. 10.** In all combinations integration of a HP (or replacing DH with HP) leads to a reduction of the CO_2 emissions. The best performance is obtained with either building-wise HP for SH and DHW or DH for DHW and building-wise heat pump for SH. The higher the share of HP and in particular of HP in SH, the larger is the difference between constant CO_2-emission conversion factors and monthly ones according to the scenario “10-10-10”. It has to be noted that the assumption of low-temperature heating in (renovated) buildings with an HD of 45 kWh/(m² a) is optimistic. In this sense, the solution with Booster-

HP is not applicable or at least not recommended in buildings with HD higher than 45 kWh/(m^2 a). The overall performance depends on the number of buildings equipped with a heat pump.

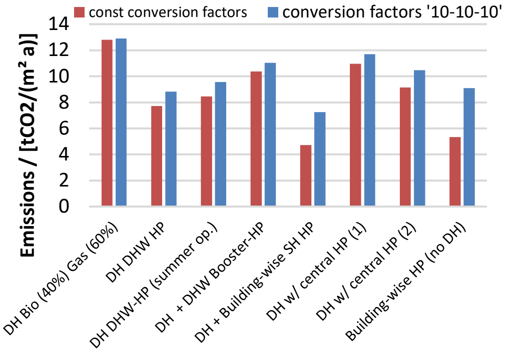

Fig. 10 - CO_2 emissions of the different systems without and with central, building-/block-wise or decentral HP.

3.5 DH level considerations

Given a (rather arbitrary) threshold of 75 % with respect to the energy delivered by the DH without integration of HPs, it can be determined how many buildings in the DH system can be equipped with HP until the operation of the DH system loses economic feasibility. In case of HPs on building (or block level) for SH and DHW, max. 25 % of the buildings can be equipped leading to a building averaged emission of 12 $tCO_2/(m^2$ a). In case of building or block-wise SH HPs, 45 % of the buildings can be equipped with HP before the threshold of 25 % is reached. This would result in an average of 10.5 $tCO_2/(m^2$ a). However, as the load curve, in this case, is flat and operation of the DH system is constant throughout the year (i.e. relative low power, no peaks) an economic operation of the DH would also be possible with only 65 % of the original energy delivery. In this case (indicated by the dotted line) 60 % of the buildings could be equipped with such as SH HP and emissions would reduce to 9.5 $tCO_2/(m^2$ a). Decentral DHW HPs can reduce significantly the CO_2 emissions. However, as such a DH system (with decentral DHW HPs) would have no summer load (except for the losses if the system was operated throughout the year) and would thus feature relatively low operation time and relatively high peaks. Hence, in spite of the remaining high share of energy for SH, for an economic operation of a DH system only a few decentral DHW HPs might be acceptable (indicated by the dotted line) leading to CO_2 emissions of 11.2 $tCO_2/(m^2$ a).
Booster HPs do not significantly reduce the DH load except for a few months in summer, when ambient energy is used as a source. Because of the remaining high share of DH demand, all buildings could be equipped with such an HP without threatening economic operation. However, this would also lead to a rather low reduction of the CO_2 emissions from 12.9 $tCO_2/(m^2$ a) to 11.0 $tCO_2/(m^2$ a). The CO_2 emissions given in the previous figures apply for a constant relative share of biomass in the DH system. Considering that the HP replaces partly biomass, an additional replacement of gas with biomass would be possible.

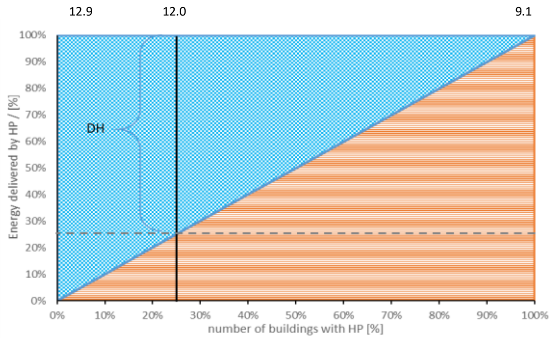

Fig. 11 - DH (for SH and DHW) and HP (for SH and DHW), and specific CO2 emissions in $tCO_2/(m^2$ a).

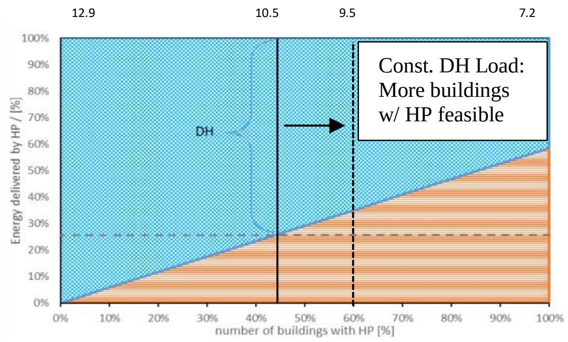

Fig. 12 - DH (DHW) and building-wise HP (for SH), and specific CO2 emissions in $tCO_2/(m^2$ a).

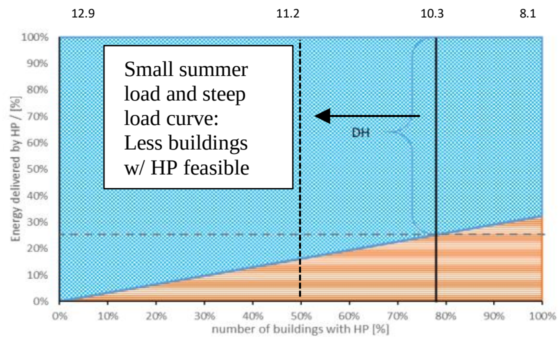

Fig. 13 - Decentral A-W DHW-HP, and specific CO_2 emissions in $tCO2/(m^2$ a).

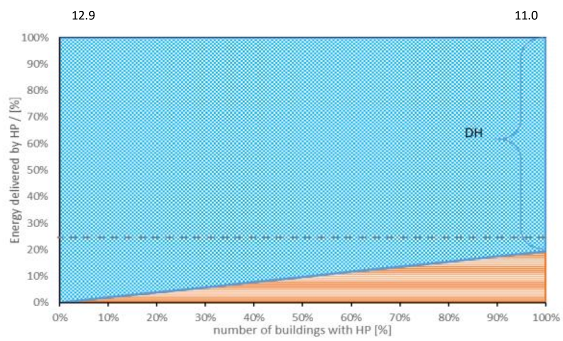

Fig. 14 - Decentral DHW Booster HP, and specific CO_2 emissions in $tCO_2/(m^2$ a).

3.5 PV own-consumption

To increase the PV own consumption is one of the main motivations for integrating booster HPs in DH systems. The specific PV yield of the 270 m^2 PV system (2.35 kW_p/flat) is shown in **Fig. 15** together with the own consumption with respect to the Booster HP. With a HP electricity demand of 443.2

kWh/a per flat, the SCF is 10 % and the LCF is 50 % with respect to the electricity demand of the booster HP with a standard control scheme. The CO_2 emissions can be reduced from 11.5 $tCO_2/(m^2\ a)$ to 10.1 $tCO_2/(m^2\ a)$. If the entire DHW production was provided by PV, the emissions could be further reduced to 9.2 $tCO_2/(m^2\ a)$. Various control strategies to increase the PV own-consumption should be taken into account.

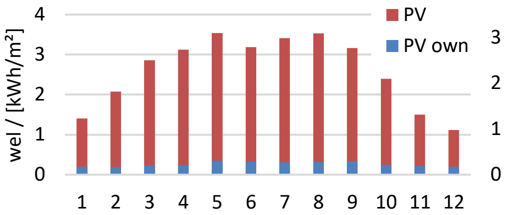

Fig. 15 - specific PV yield in $kWh/m^2_{treated\ area}$ and own consumption with respect to Booster HP.

It is noteworthy that PV own consumption would be higher in the case of DHW-HP and even higher in case of an electric boiler, but this would not lead to a reduction of CO_2 emissions. Furthermore, all PV yield could be used instead to cover the appliances.

4. Discussion

The possible CO_2 emission savings that can be obtained from integrating HPs in DH systems depend on the energy mix of the DH system, the electricity mix and the type of integration. If instead of biomass waste heat is used in the DH, the use of decentral HPs can even lead to an increase of the CO_2 emissions. Generally, the integration of decentral HPs for DHW preparation reduces the summer load thus leading to a more pronounced (relative) winter peak. Typically, DH system operators prefer the reduction of winter load and rather flat load curves.

From the energetic point of view, the application of decentral Booster-HPs in combination with DH is not recommended. In the heating season (typically 7 out of 12 months) the DHW is provided by approximately 1/5th of electricity and 4/5th of DH (COP of 5, the source of the HP is the DH). Only in 5 out of 12 months (or less) the source of the HP is ambient heat. Thus, in spite of reduced distribution (and storage) losses in the building, decentral integration for DHW preparation with Booster-HPs does not show significant savings. The advantage is instead (if the hydraulic configuration allows for it) the possibility to (partly) provide space cooling. Furthermore, the PV-own consumption can be slightly increased, which can be an advantage from the micro-economic point of view (view of the operator and or the tenants of the building), but cannot be recommended from the macro-economic view (see also [14]).

Decentral air-to-water HPs for DHW preparation outperform Booster-HPs. However, their integration into the building/flat is more challenging (air-source, visual/design aspects, sound emissions. However, the application of decentral DHW-HPs leads to a reduction of the base load of the DHW system. In a theoretic DH system with 100 % DHW-HPs, there would be no summer operation. Application of decentral DHW-HPs can be a good solution in the renovation of buildings if DHW distribution in the building is not available and cumbersome to install.

From the exergetic point of view, Booster-HPs in combination with DH seems kind of absurd. The high temperature of the flow of the DH (e.g. 90 °C provided by burning high exergy energy carriers such as biomass and gas) is transferred in a heat exchanger to the building and is then mixed with the return of the heating system (e.g. 30 °C) to provide a low-temperature flow for the underfloor heating (e.g. 35 °C). The flow is "boosted" with the Booster HP by means of exergy (electricity) to 55 °C to provide DHW. Integrating building or flat-wise HP for SH is beneficial in several aspects. For the DH system, the remaining DHW load represents a constant and flat load. HPs can be operated with low sink temperatures and thus with high performance. HPs can be used to provide space cooling when combined with underfloor heating or in combination with air-cooling coils. PV own consumption can also be increased if these decentral HPs are used for cooling. A drawback of building or block-wise SH HPs is the short operation time (only during the winter season) and thus their application might be economically challenging.

5. Conclusions

Heat pumps can significantly contribute to improve the efficiency in buildings for space heating and domestic hot water preparation. The advantage of building- or flat- wise integration of HPs is the lower temperature level (55 °C for DHW and 35 °C or lower for SH with underfloor heating). Contrariwise, central HPs in district DH have typically to provide up to 90 °C in Winter and 60 °C in Summer and even though large HPs typically perform better than small HPs the loss of efficiency due to high sink temperatures cannot be compensated. Assuming an existing DH system additional losses do not occur when a heat pump is integrated.

Thus in the sense of better performance, decentral application of HPs seems to be more favourable. However, the load of the DH system reduces by means of integrating decentral HPs and in particular in case of DHW HPs (both building-wise or flat-wise air-to-water) or decentral boiler HPs the load curve becomes unfavourable: the summer load reduces to close to zero or to zero leading to shorter runtimes of the DH system (only during the heating season from Sept. to May). Furthermore, the possibilities reduce to integrate waste heat or renewables in summer and at least to a lower energy delivery with only insignificantly reduced peak loads in winter and thus to a less economic operation. On a wider perspective, DH systems with a significant amount of buildings with decentral DHW HPs will not be operable in an economic way.

6. Abbreviations

A_T	Treated area
At	Austria
AUX	auxiliaries
Bio	biomass
C	Carnot
CHP	Combined Heat and power
COP	Coefficient of Performance
D	Germany
DH	District Heating
DHW	Domestic Hot Water
el	electricity
g-value	Solar Factor
HP	Heat Pump
HVAC	Heating Ventilation and Air Conditioning
IBK	Innsbruck
LCF	Load Cover Factor
MVHR	Mechanical Ventilation with Heat Recovery
PV	Photovoltaic
RF	Return flow
SCF	Supply Cover Factor
SH	Space Heating
SPF	Seasonal Performance Factor
UFH	Under Floor Heating
U-value	Heat transfer coefficient

7. Acknowledgement

The work presented in this paper is the result of a collaboration within IEA SHC Task 66. Financial support was provided by the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency (FFG) through the IEA Research Cooperation.The authors thank furthermore Neue Heimat Tirol (NHT) for the funding within the research cooperation in the Project ru27.

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The datasets generated during and/or analysed during the current study are not publicly available because the project is ongoing and the database will be further extended but will be available on request by sending an email to fabian.ochs@uibk.ac.at.