# Modelling and Simulation of Booster Heat Pump for DHW Preparation in a Multi-Family Building Connected to the District Heating

**Mara Magni[1], Fabian Ochs[1], Georgios Dermentzis[1] and Elisa Venturi[1]**

[1] University of Innsbruck, Innsbruck (Austria)

**Abstract**

Booster Heat Pumps (HPs) are integrated into the District Heating (DH) networks aiming at increasing the PV-self consumption. In this work, a dynamic model of a booster HP for the preparation of the Domestic Hot Water (DHW) in a typical Austrian multi-family house is developed. A series of dynamic simulations considering different controls, DHW profiles, storage quality, demand for the appliances and common areas, PV and battery sizes are performed to analyse the influence of this technology on the PV self-consumption, electricity demand and thermal energy demand from the DH network. The results show that when appliances are included in the balance, the PV yield available for the booster HP is limited. A non-optimal control logic of the booster HP could lead to an increase in electricity demand from the grid. The application of battery to increase the PV self consumption for the common areas is not beneficial as the available PV peak power per flat is limited and it would be anyway self used for appliances and HP. Batteries contribute to a slight reduction in electricity demand from the grid when the PV yield cannot be used to cover the appliances. Moreover, the operation of the booster HP influences the energy demand from the DH and makes the $CO_2$ emission of the building dependent on the energy mix of both DH and electricity grid.

*Keywords: Booster heat pump, District heating, PV self-consumption, Domestic hot water preparation, Appliances, Battery.*

## 1. Introduction

The buildings sector is responsible for around 37% of global $CO_2$ emissions (United Nations Environment Programme, 2021) and in order to achieve the 2050 neutrality targets, it will be necessary to drastically reduce current emissions and offset the rising trend in $CO_2$ emissions due to population growth. According to global reports (United Nations Environment Programme, 2021), it is expected that by 2050 over 85% of the buildings will be zero-carbon-ready leading to a reduction of 75% of the heating intensity of which around 50% will be covered by Heat Pumps (HP) and 10% by DH. From this framework, it is clear that in the future the HP technology will be strongly integrated with the urban DH networks (Biermayr *et al.*, 2019). In addition, HP can support the transition toward low-temperature DH since they influence the energy demand and temperature required by the buildings (Østergaard *et al.*, 2022). HP technology can be integrated in many different ways into the DH network: providing heat to the DH network, centrally for a building or a building block for heating and/or DHW preparation, or decentrally flat wise for heating and or DHW preparation. Hence, it is clear that the possibilities for integrating the HP into the DH are manifold and that this integration has consequences for the operation of the DH (see (Ochs, Magni and Dermentzis, 2022) for a comprehensive overview). Integrating HP into the DH, makes the DH dependent on the electricity network, might reduce the DH operation time (e.g. if all the buildings use a HP for the DHW preparation, the DH is not needed in summer), influences the capability of self-consume the PV yield (Ochs, Magni and Dermentzis, 2022).

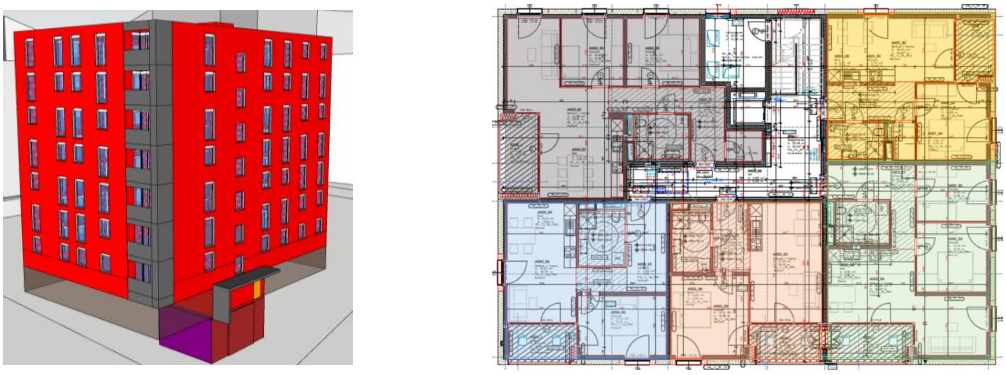
Booster HPs are able to decouple the supply temperature required by the building from the DH temperature (Østergaard and Andersen, 2016) allowing to operate the DH network with a lower temperature reducing distribution losses. In addition, HPs could contribute to increase the PV self-consumption potentially offering an economic advantage from the user's point of view. This work focuses on the analysis of the flat-wise integration of a booster HP for DHW preparation, considering a newly built multifamily house building located in Innsbruck. The source of the HP is a central storage supplied by the DH network. The goal of this analysis is to assess the contribution of the booster HP to the increase of PV self-consumption by means of dynamic simulation performed with Matlab/Simulink using the CARNOT Toolbox (*CARNOT Toolbox - File Exchange - MATLAB Central*, 2020). To make this analysis more robust the simulation is performed considering different scenarios for PV and battery size, control of the booster HP, DHW tapping profile, appliances profiles, different thermal qualities of the decentral storage.


doi:10.18086/eurosun.2022.11.09 Available at http://proceedings.ises.org

## 2. Method

### 2.1. Building

A newly built multifamily house located in Innsbruck is used as a basis for this work. This building (see Fig. 1) is built with a Passive House standard and it is composed by 7 floors and 35 flats. The footprint area of the building is 412 $m^2$ and the total heated area is 2209 $m^2$.



(a) (b)

**Fig. 1: (a) view and (b) floor plan of the reference building (Neue Heimat Tirol - NHT)**

The building is equipped with a 1000 l central storage heated by the DH network, which supplies in each flat in parallel the floor heating loop and the booster HP for the DHW preparation. The booster HP is used to charge the decentral storage of 150 l for the DHW preparation (see also Fig. 3). The PV yield is used first for the building electricity demand and the excess is delivered to the electricity grid. A battery system is used with the aim of maximizing the self-consumption of the PV for the electricity demand of the common areas.

A scheme of the developed model implemented in Matlab/Simulink is reported in Fig. 2 and each part is explained in the following sections.

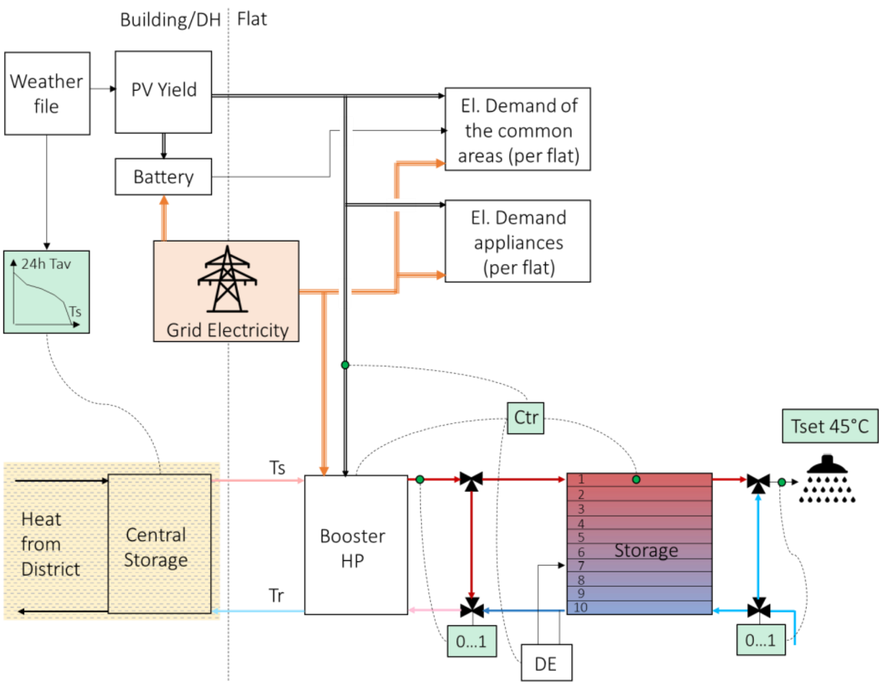



**Fig. 2: Simplified scheme of the developed model of the flatwise booster HP for DHW preparation with PV and battery. The central storage (i.e. dashed area) is not modelled**

### 2.2. Weather description

The weather file used for performing the dynamic simulations is based on the OIB 2019 (Österreichisches Institut für Bautechnik, 2019) climate for Innsbruck.

Fig. 3 shows the monthly ambient temperature (black line) and the monthly solar irradiation on a horizontal surface (red bars).

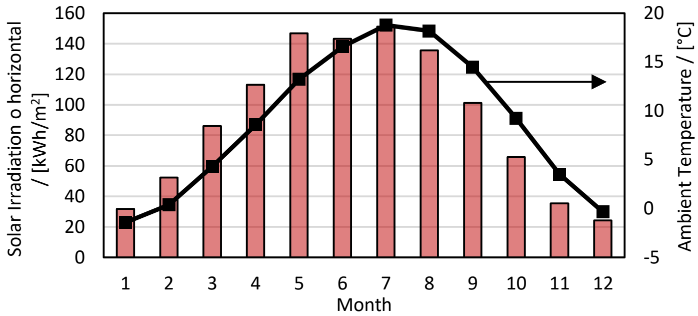



**Fig. 3: Solar irradiation on a horizontal surface (left side) and monthly average ambient temperature (right side) for the climate of Innsbruck according to OIB 2019** (Österreichisches Institut für Bautechnik, 2019)

### 2.3. Photovoltaic Panels and Batteries

PV panels are simulated with a south orientation and 10° of inclination and they have an efficiency of 20 %. The climate of Innsbruck (OIB climate 2019 (Österreichisches Institut für Bautechnik, 2019)) is used in the calculations and simulations. An inverter efficiency of 97% is considered. Different sizes of PV are considered ranging from a peak power per flat of 0.5 kWp to 5 kWp (see Tab. 1).

A roof coverage of 60% is normally reachable while reaching a share between 60 % and 80 % is challenging and requires accurate planning. Therefore, the scenarios from PV1 to PV3 are plausible while scenarios PV4 and PV5 are only reachable for low-rise buildings, or they require to partly cover the façade of the building with PV.

**Tab. 1: Analysed PV scenarios**

| Case | PV peak per flat [kWp/flat] | PV peak total [kWp] | Roof coverage [%] |
|---|---|---|---|
| PV1 | 0.5 | 17.5 | 22% |
| PV2 | 0.86 | 29.9 | 37% |
| PV3 | 2 | 70.0 | 85% |
| PV4 | 3.5 | 122.5 | - |
| PV5 | 5 | 175.0 | - |

PV self-consumption is evaluated using the Load and Supply Cover Factors (i.e. LCF and SCF respectively) according to equations 1 and 2:

$$LCF = PVSelf / Wel,tot \quad \text{(eq. 1)}$$

$$SCF = PVSelf / PVtot \quad \text{(eq. 2)}$$

Where PVSelf is the self-consumption of the PV yield, PVtot is the total PV yield and Wel,tot is the electricity demand of the building. LCF and SCF are also calculated for the individual applications of PV energy (i.e. common area, battery, appliances, HP). In this case, PVSelf is the PV energy consumed directly for the application under study.

In addition to different PV sizes also different battery sizes, storing energy for the common areas, are analysed (see Fig. 2). The simulated scenarios regarding the batteries are reported in Tab. 2. A charging and discharging efficiency of 0.9 and a standby consumption of 10 W are considered in the simulation model.

**Tab. 2: Analysed scenarios for the battery size.**

| Case | Battery size |
|---|---|
| BATT1 | No battery |
| BATT2 | 15 kWh |
| BATT3 | 30 kWh |

### 2.4. Booster Heat Pump

The maps of performance of the booster HP (see Fig. 4), used in the dynamic simulation model analysed (see Fig. 2), are calculated by means of a simulation of the refrigerant cycle (Monteleone *et al.*, 2022). Considering a source temperature of 35 °C and a sink temperature of 55 °C, the booster HP works with a COP of 3.06 and a compressor power of 654 Wel.

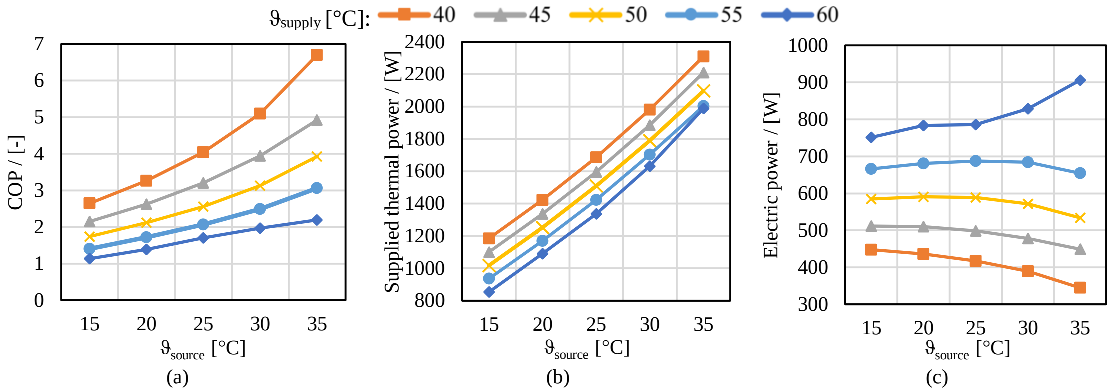



**Fig. 4. Performance Maps of the booster HP: (a) COP, (b) Thermal power and (c) Electric power**

The booster HP located in each flat uses as a source the energy from the DH delivered to the flats through a central storage (see Fig. 2) controlled with a set point temperature, which is a function of the ambient temperature (see Fig. 5). During the summer period (i.e. July and August) it is assumed that the HP extract heat from the floor heating loop contemporarily providing cooling energy to the building and not requiring any energy from the DH network.

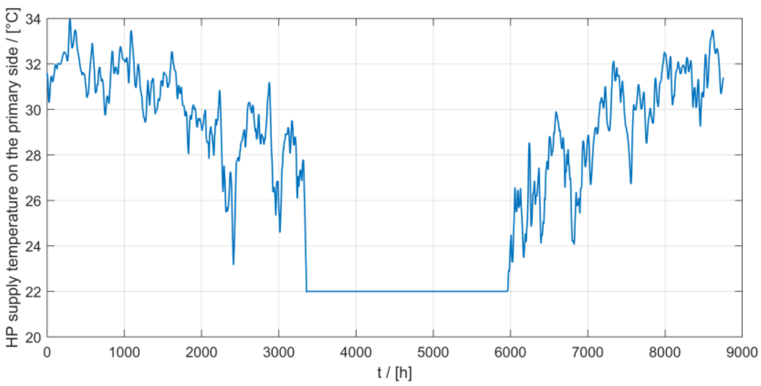


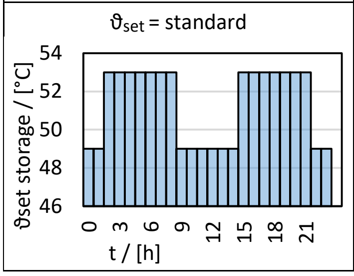
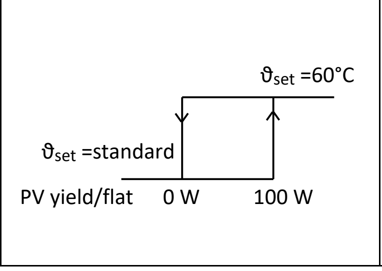
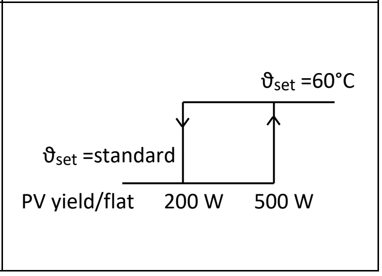

**Fig. 5. Supply temperature to the booster HP throughout the year**

The decentral storage, heated up by the booster HP, is a 150 l storage and it is analysed considering two different energy classes (i.e. A and B). A three-way valve between the booster and the decentral storage prevents ruining the temperature stratification of the storage (see Fig. 1). While the three-way valve after the decentral storage controls the supply temperature to the user (see Fig. 1). In addition, a minimum run time of 15 min and a minimum off time of 5 min are considered in the simulation model of the HP.

### 2.5. Heat Pump Control Strategies

Based on the available PV yield for the booster HP, different control logics are implemented to analyse their impact on the PV-self consumption (see Tab. 3). The standard control logic (CTR1) foresees to warm up the decentral storage to 53°C from 2 to 8 a.m. and from 3 to 9 p.m. to guarantee the comfort during the morning and evening shower, while the strategies CTR2 and CTR3 increase the set point to 60°C when power from the PV modules is available. A direct electric heater (DE) is activated in parallel to the booster only when the storage temperature drops below 47.5 °C.

**Tab. 3 Control logics of the set point of the decentral storage depending on the PV yield**

| CTR1 | CTR2 | CTR3 |
|---|---|---|
|   |   |   |

2.6. Domestic Hot Water Tapping profiles

Three different tapping profiles with the same total daily energy of 5.9 kWh/day are analysed (i.e. DHW1 considering one shower in the morning and one in the evening, DHW2 with two showers in the morning and DHW3 with two showers in the evening), see Fig. 6. The tapping mass flow is controlled with an energy-based control.

The monthly energy balances for the different cases are calculated by averaging (with equal weight) the simulation results obtained with the three different profiles as the real DHW tapping profile is not known and it affects the energy balance of the system.

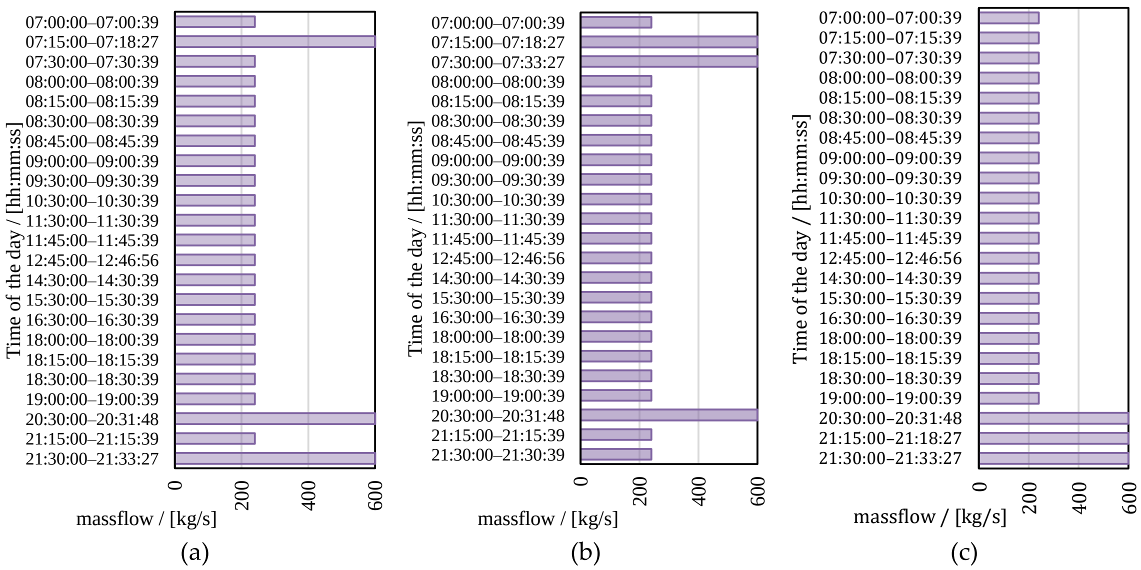



**Fig. 6: Domestic hot water tapping profiles characterized by an energy of 5.9 kWh/day, but with different distribution of the showers throughout the day (a: one shower in the morning and one in the evening, b: two showers in the morning and c: two showers in the evening)**

2.7. Appliances

Five different scenarios are considered regarding the electricity demand of appliances and common areas (see Tab. 4). The APP4 and APP5 scenarios consider the same electricity demand as the APP3 and APP2 scenarios, but the PV yield cannot be used directly for the household appliances.

**Tab. 4: Annual electricity consumption per flat considered for the appliances and common areas for the three different variants (i.e.APP1, APP2, APP3, APP4 and APP5)**

| | Appliances | Possibility to use the PV yield for appliances | Common areas | Total |
|---|---|---|---|---|
| | [kWh/(a flat)] | Yes/No | [kWh/(a flat)] | [kWh/(a flat)] |
| APP1 | 0 | Yes | 0 | 0 |
| APP2 | 1600 | Yes | 252 | 1852 |
| APP3 | 2500 | Yes | 252 | 1752 |

| | | | | |
|---|---|---|---|---|
| APP4 | 2500 | No | 252 | 1752 |
| APP5 | 1600 | No | 252 | 1852 |

A dynamic profile is used for the appliances (1600 or 2500 kWh/(a flat)), see Fig. 7, while a constant profile for the electricity demand of the common areas (252 kWh/(a flat)) is used.

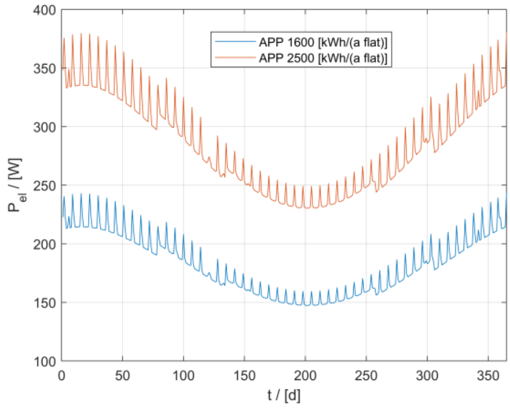



**Fig. 7: Daily average appliances profiles**

## 3. Results and Discussion

The storage quality does not significantly affect the energy balance of the flat. A class A storage compared to a class B reduces the electricity demand from the grid of maximum 3%. For this reason and for sake of simplicity only the results obtained with a class A storage are reported.

The different DHW tapping profiles (see Fig. 6) influence the temperature of the storage throughout the day and therefore the control of the HP. In Fig. 8a and Fig. 9a the temperature of the top part of the storage, as well as the set point temperature, is reported while in Fig. 8b and Fig. 9b the electric power of the HP and the PV yield are shown for different DHW tapping profiles (i.e. DHW1, DHW2 and DHW3), considering the appliances profile APP2 (see Fig. 7), the PV size PV2 (see Tab. 1) and the storage quality A. In Fig. 8 the results for the control strategy CTR1 (see Tab. 3) are reported while in Fig. 9 the results for the control strategy CTR2 are reported.

From Fig. 8 and Fig. 9 it can be noticed that the tapping profiles DHW1 (i.e. one shower in the morning and one in the evening) and DHW3 (two showers in the evening) have a similar profile of the storage temperature, the only difference is that the storage temperature is slightly lower in the evening with DHW3 and during the day with DHW1. The storage temperature during the daytime is consistently lower for the DHW2 (two showers in the morning). This allows to harvest a higher share of renewable energy during the day. With DHW1 and DHW3 the storage is quite empty in the evening leading to a night-time charge (to guarantee the comfort for the morning shower) that cannot take advantage of the PV yield. From Fig. 8b and Fig. 9b it can be seen that the charging periods are shifted during the daytime with DHW2 compared to DHW1 and DHW3. The effect of the control strategy CTR2 can be seen in Fig. 9b, in fact at around midday, when the PV yield is at its maximum, the set point of the storage is increased to 60 °C in order to enhance the PV self-consumption attempting to shift the load from the night-time to the day-time. Nevertheless, when the appliances are considered (i.e. APP2 and APP3), only a small share of PV yield is left for the HP (i.e., considering the case PV2 only 12 % with APP3 and 26 % with APP2 is available for the HP).

As explained in Section 0, the HP has a minimum run and off time. The effect of the minimum run time is visible in Fig. 8a and Fig. 9a. In fact, at around 5 a.m. when there is no DHW demand and the storage temperature falls slightly below the set point, the HP switch on and even though the set point is quickly reached, it stays on until the minimum rum time has elapsed (i.e. 15 min). The minimum run time together with the non-modulating behaviour of the HP considered in this case study, makes it difficult to match the electricity demand with the PV yield optimizing the self-consumption.

(a)

(b)

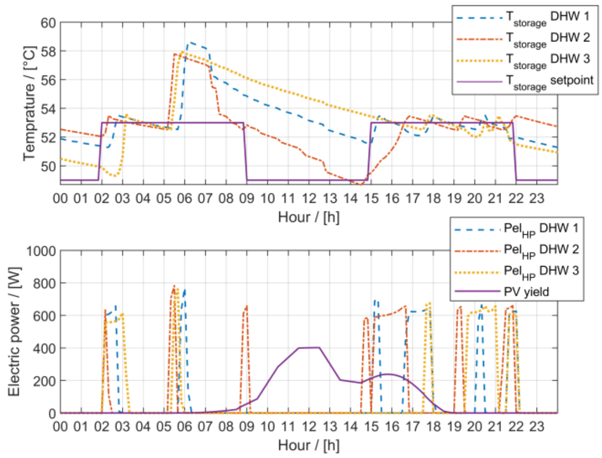



**Fig. 8: (a) Storage temperature and set point and (b) electricity demand of the HP and PV yield (April 16th) for the different DHW tapping profiles considering APP2, PV2, BATT1, CTR1 and storage quality A**

(a)

(b)

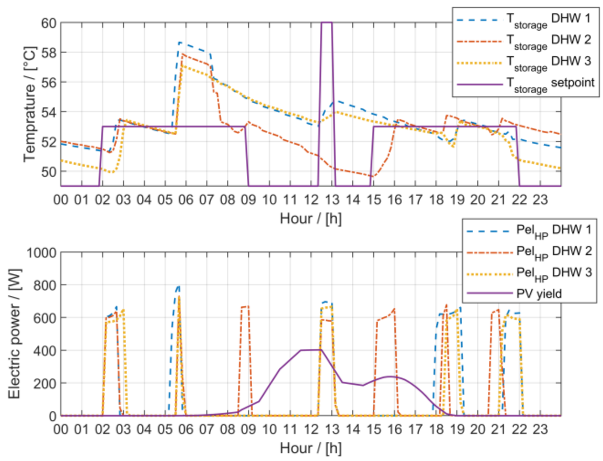



**Fig. 9: (a) Storage temperature and set point and (b) electricity demand of the HP and PV yield (April 16th) for the different DHW tapping profiles considering APP2, PV2, BATT1, CTR2 and storage quality A**

Fig. 10 shows the sorted plot of the (a) temperature of the top part of the storage and (b) the COP of the HP for the different control strategies and DHW tapping profiles considering APP2, PV2, BATT1 and storage quality A. From here it is visible that the control strategy CTR2 leads to a higher storage temperature, as the increase of set point to 60°C is activated more often compared to CTR3. The increased storage temperature leads to a lower COP of the HP and higher losses. In addition, when the HP is on, its power is not fully covered by the PV yield as it is not modulating, and a high share of PV is already used to cover the electricity demand in the common areas and appliances. Therefore, the control strategy that aims only at the maximization of the PV self-consumption is not always the optimal one. Disregarding the electricity demand of appliances and common areas and controlling the HP according to the total available PV yield could lead to an increase in electricity demand from the grid of up to 14% (considering the control strategy CTR2).

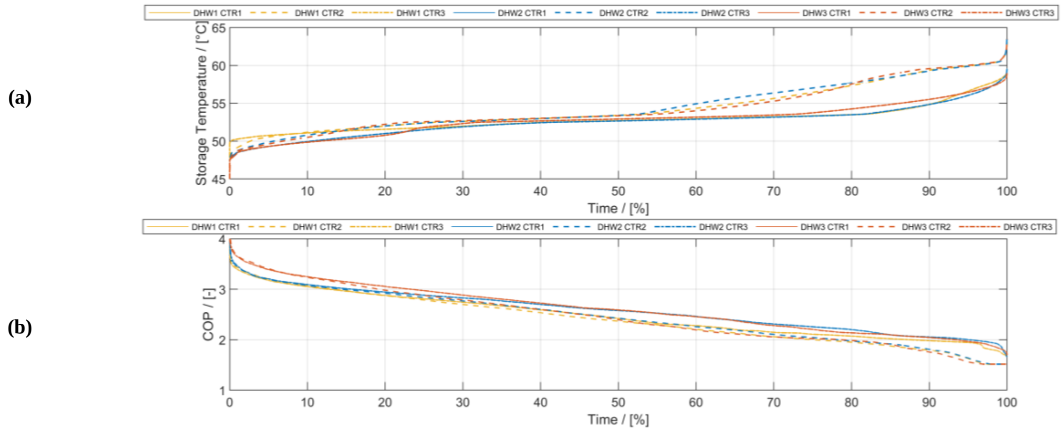



**Fig. 10: (a) Sorted storage temperature, (b) sorted COP of the HP for different DHW tapping profiles (i.e. DHW1, DHW2, DHW3) and different control strategies (i.e. CTR1, CTR2, CTR3) considering APP2, PV2, BATT1 and storage quality A**

Fig. 11 shows the monthly electricity balance of one flat for the case considering CTR2, DHW2, APP2, PV2, BATT1 and storage quality A. The internal green staked columns represent the electricity demand of the common area (per flat), appliances and HP, while the external staked columns represent the self-consumption of the PV yield for common areas, appliances and HP and on top (in dark brown) the electricity demand covered by the grid. The dark dashed line represents the PV yield, and the patterned part of the columns represents the PV yield fed into the grid. From Fig. 11, it is clear that the PV size of the case PV2 (see Tab. 1) barely cover the electricity demand of appliances and common areas. A small overproduction of PV is fed to the grid only during the summer months.

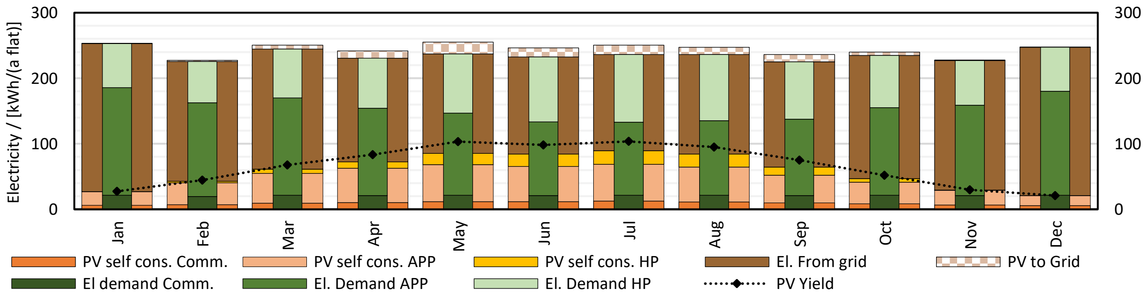



**Fig. 11. Monthly electricity balance for the case considering CTR2, DHW2, APP2, PV2, BATT1 and storage quality A**

In Fig. 12 the annual electricity balance of all the cases without batteries and averaging of the results for the three different DHW profiles are reported. When the appliances are included in the balance, the electricity demand of the HP is only around 25% of the total electricity demand considering APP3 and 35% considering APP2. Even in the most optimistic scenario, concerning the PV peak power (i.e. PV5), in none of the cases, a null electricity demand from the grid is achieved.

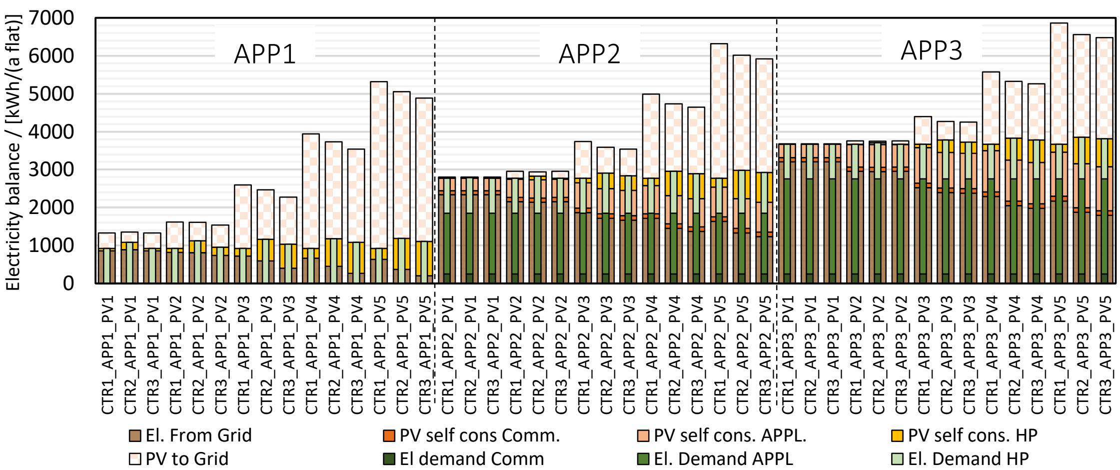



**Fig. 12: Electricity balance for all the cases considering no batteries and averaged results over the three DHW profiles**

Fig. 13 shows on the left y-axis the electricity demand of the HP flowing from the grid and from the PV and on the right side the share of the HP electricity demand covered by PV is reported. From here it can be noticed that the total electricity demand is always maximum applying CTR2 and that at the same time CTR2 allows to maximize the PV self-consumption for the cases PV1, PV2 and for the cases with appliances (APP2, and APP3) also for PV3. The increased set point (60°C) leads to higher storage losses and poorer COP of the HP. The Seasonal performance factor of the HP is around 2.5 when the control logic CTR1 is applied and can decrease down to 2.0 when CTR2 is used. The storage losses can increase up to 17% considering CTR2 with respect to CTR1. Thus, with the CTR2 the reduction in terms of efficiency outperforms the increased self-consumption leading to an increased electricity demand from the grid for the case APP1_PV1. In most cases, the control strategy CTR3 allows the highest reduction in terms of electricity from the grid as it activates the increased set point only when the PV yield available for the HP is higher than 500W covering most of the HP demand.

After subtracting the PV self-consumption for appliances, the PV yield available for the HP is limited especially for the cases PV1 and PV2 (a maximum of 3% of the HP electricity demand can be covered by the PV self-consumption considering APP2). When higher PV peak power per flat is available (i.e. from PV3 to PV5) it is possible to cover from 14% to 27% considering APP2 and from 8% to 19% considering APP3 of the HP electricity demand, nevertheless, these configurations are not realistic for multi-family houses.

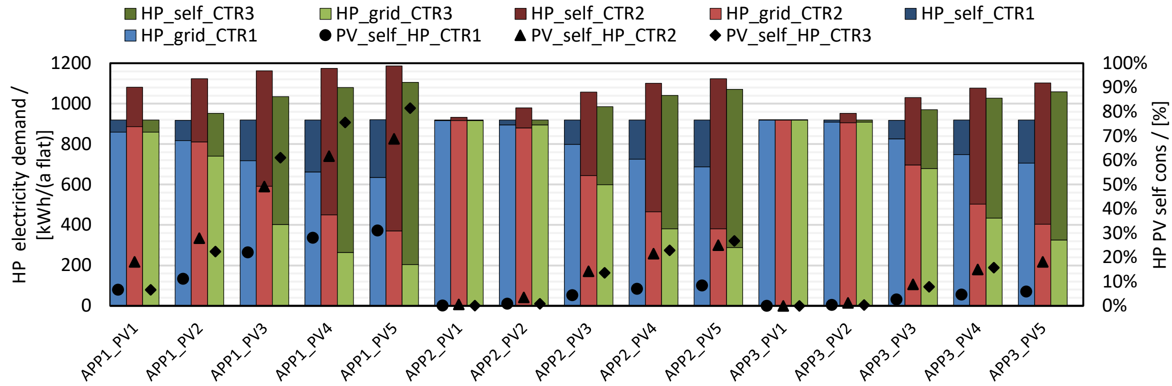



**Fig. 13: Impact of the control strategy on the HP electricity demand (i.e. PV self-consumption and electricity from the grid) for all the cases considering averaged results for the three different DHW profiles**

The influence of the batteries on the electricity balance is reported in Fig. 14 for the cases considering different PV and battery sizes, applying the control strategy CTR3, the appliances APP2 and APP5 and considering averaged results for the three different DHW profiles. The APP5 case considers the same electricity demand for household appliances as the APP2 case, but in APP5 the PV yield cannot be used to meet the demand of the household appliances. From Fig. 14 it can be noticed that, for the cases considering APP2, the contribution of the batteries to increase the PV self-consumption leads to a reduction of the PV self-consumption that, in the case without batteries (i.e. BATT1), would have been used for the appliances. This leads to an increase in electricity demand from the grid of 1%, 2% for the cases with small PV size (i.e. PV1 and PV2) and a maximum reduction of electricity from the grid of -6% for the case PV5. In addition, it can be seen that in the cases with APP5, the self-consumption of PV for the HP, the PV yield fed into the grid and the electricity demand from the grid are higher than in the cases with APP2, since the PV yield is not used for the appliances. Considering the APP5 cases, the batteries always lead to a reduction of energy from the grid of at least -3 % (case BATT2, PV1) to a maximum of -8 % (case BATT3, PV5).

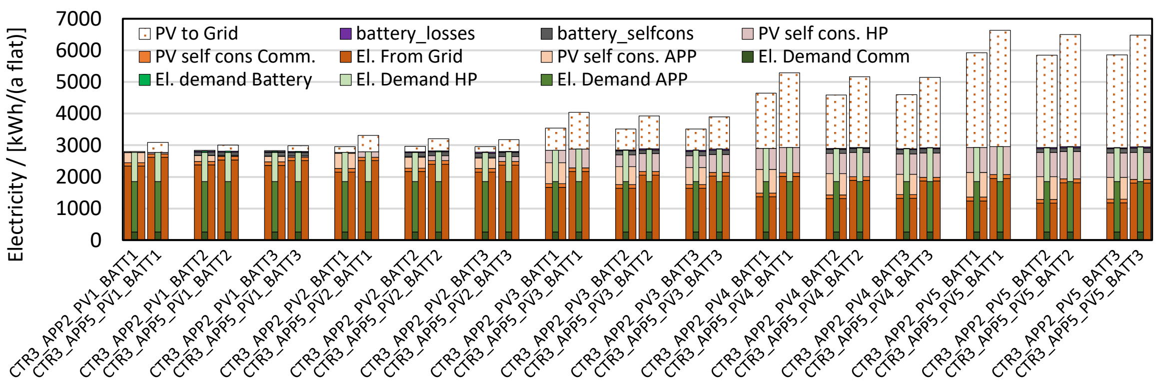



**Fig. 14: Influence of the battery system on the electricity balance**

Fig. 15 shows the SCF and LCF for cases with different battery and PV sizes, considering CTR3, APP2 and APP5 and averaged results for the different domestic hot water profiles. From Fig. 15 it can be seen that:

- SCF of up to 95% can be achieved for small PV systems (PV1 and PV2 cases), but for these cases only 20% to 30% of the electricity demand (i.e. LCF) can be covered by PV;
- Increasing the PVs from case PV4 to PV5 does not lead to important benefits in terms of LCF. This means that most of the additional energy generated by PVs is fed into the grid;
- Appliances make an important contribution to increasing SCF and LCF;
- If the PV output is not used for the Appliances (i.e. APP5), the batteries contribute to increase the LCF, while when the PV yield can be directly used in the flats to cover the electricity demand for appliances (i.e. APP2) the batteries lead to reduction of the LCF because they reduce the PV yield available for appliances introducing losses;
- The battery size BATT3 compared to BATT2 does not lead to a high increase in LCF for this case study.

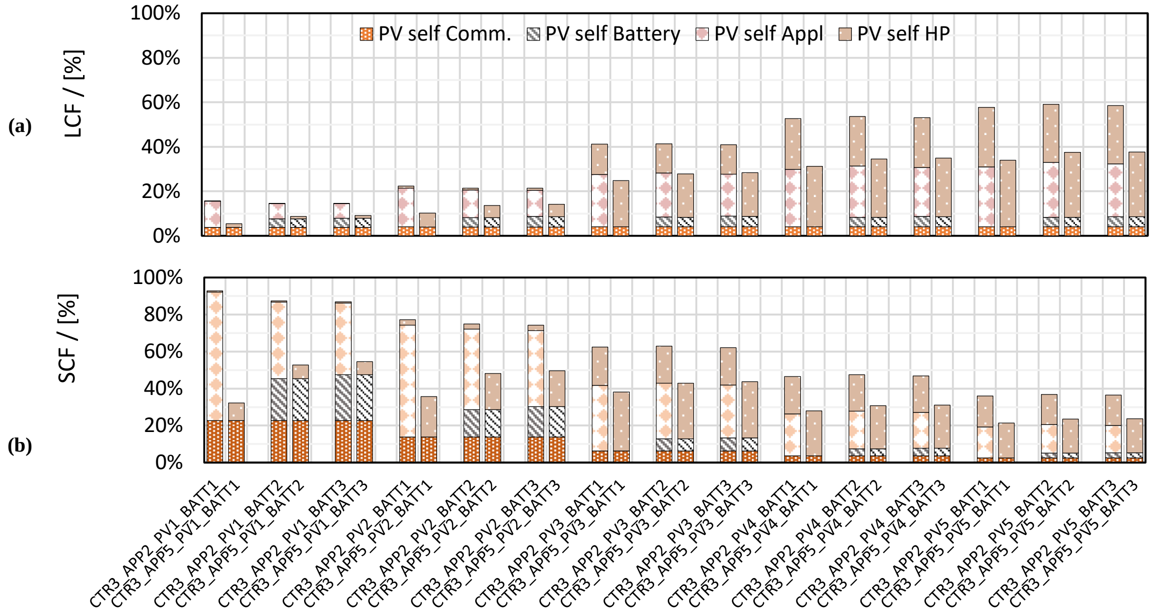
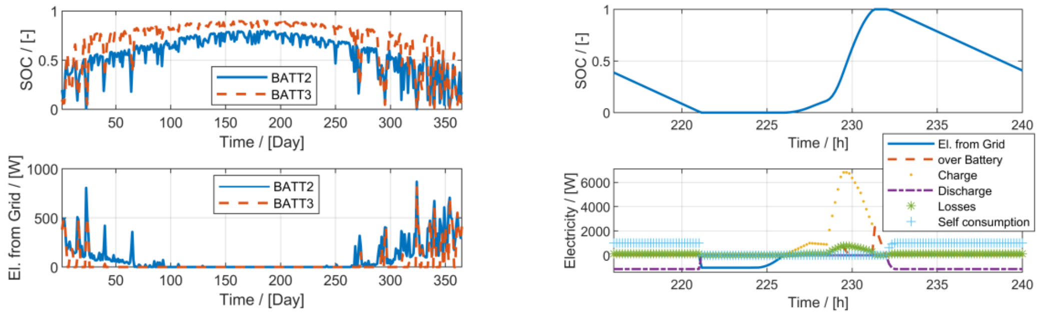



**Fig. 15: Influence of the battery system on (a) SCF and (b) LCF for the cases considering CTR3 and the average results for the three different domestic hot water profiles**

Fig. 16a shows the average daily state of charge (SOC) of the batteries and the electricity demand required from the grid to meet the electricity demand of the common areas when the batteries are empty, considering PV size PV2 the battery sizes BATT2 and BATT3. From Fig. 16a it can be seen that the daily mean SOC is higher on average for the case with BATT3 relative to BATT2, but in winter when solar availability is low, the grid electricity demand is similar in both cases.

Fig. 16b shows the dynamic behaviour of the batteries during the 9th day of the year for the case CTR3_DHW2_APPL2_PV2_BATT2. When the SOC is 0 (empty batteries), the power demand of the common areas and the self-discharge power of the batteries (10 W) must be covered with energy from the grid. During the day, the battery is charged with the PV electricity that is not directly used to meet the needs of the common areas. Some energy is lost during both charging and discharging (90% charging and discharging efficiency), which is shown in the graph with the green asterisks ("Losses"). When the batteries are full (SOC=1) or when the available power of the PV system is higher than the maximum charging power, the excess energy is bypassed by the battery (this is represented in the diagram by a red dashed line - "over Battery").




(a) (b)

**Fig. 16: (a) Average daily state of charge (SOC) of the batteries and electricity demand from the grid required to meet the electricity demand of the common areas when the batteries are empty for the two cases: CTR3_DHW2_APPL2_PV2_BATT2 and CTR3 _DHW2_APPL2_PV2_BATT3; (b) dynamic behaviour of the batteries during the 9th day of the year for the case CTR3 _DHW2_APPL2_PV2_BATT2**

In all the considered cases a DHW useful annual energy demand of 2133 kWh per flat is considered. Without the installation of the booster HPs in each flat, this amount of energy should be supplied by the DH network. With the booster HP a Seasonal Performance Factor of around 2.4 is achieved. This means that around 57% of the energy is still supplied by the DH network. Considering that during July and August the booster HP could be used for cooling purposes extracting energy from the floor heating loop, the energy extracted from the DH network would be around 44% of the DHW energy demand while the electricity demand is 43% of the total thermal energy demand. In all the simulated cases the energy extracted from the DH network depends on the seasonal performance factor of the HP and varies between 904 kWh/flat to 1073 kWh/flat.

The district heating network becomes, therefore, dependent on the electricity grid with regards to the price per kWh and $CO_2$ emission (i.e. fossil/renewables share in the district and electricity). A broad overview of the integration of HP in the district heating network is provided in (Ochs, Magni and Dermentzis, 2022).

## 4. Conclusions

The main motivations for the integration of booster HPs into the DH network are to increase the PV self-consumption and to decouple the supply temperature of the DH from the required temperature of the connected buildings. Within this work, the performances of a booster HP installed in a flat of a multi-family house served by the DH and equipped with PV are analysed by means of dynamic simulations. The results show that when a booster HP is solely controlled to increase the PV self-consumption, the electricity demand from the grid could actually be increased. In fact, when the solar energy is available the set point of the DHW storage is increased and the HP is switched on. In this situation the performance of the HP is reduced as the supply temperature increases, the storage losses increase, and the power of the HP is not entirely covered by the PV yield (in part because the PV yield is already used to cover the demand of the appliances and in part because the HP is not modulating). Particularly in the case of multi-family houses, the PV yield per flat is limited (as the available roof area per flat is reduced for high-rise buildings) and it could be so low that it would be almost completely used to cover the load from appliances. For this case study, the PV self-consumption is enhanced by the HP, only for a PV size bigger than 2 kWp/flat. Nevertheless, it is hardly possible to achieve this PV peak power per flat in multi-family buildings as it would require covering the building facades in addition to the roof of the building.

The domestic hot water tapping profile influences the capability of harvesting energy from the PV. A DHW tapping profile that leaves the storage empty in the morning enables to shift the load from night-time to the daytime allowing to use a higher PV share. If the tappings are concentrated during the evening, the storage will be charged overnight. For this reason, to make the analysis more robust, three different DHW tapping profiles are considered in this work.

The possibility of applying batteries to increase the self-consumption of the PV for the electricity demand of the common rooms has been also analysed. Nevertheless, for this case study, the application of batteries for a PV size below 2 kWp/flat would lead to a slight increase (i.e. around 2%) of electricity demand from the grid as the PV yield would be anyway self-consumed by the electricity demand of the appliances and the batteries only introduce additional losses. For a PV size higher than 2 kWp/flat, the batteries could lead to a maximum benefit of -6% of electricity from the grid. If the PV yield in the flats cannot be used to cover the household appliance demand, the batteries can help to reduce the electricity demand from the grid by 3% to 8% depending on the PV size. Nevertheless, the high additional cost has to be considered.

In future work, this analysis should be repeated for a modulating booster HP that would be able to cope with the PV yield increasing the self-consumption without requiring additional electricity from the grid. In addition, different profiles for the electricity demand of the common areas should be analysed.

## 5. Acknowledgments

The work presented in this paper was possible through the collaboration project "Rum 27" with Neue Heimat Tirol. The authors are grateful for the financial support. This work is also part of a collaboration within IEA SHC Task 66 "Solar Energy Buildings" and IEA HPT Annex 61 "Heat Pumps in Positive Energy Districts". 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.

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## Appendix

| **Abbreviations** | |
|---|---|
| APP | Appliances |
| BATT | Battery |
| COP | Coefficient of Performance |
| CTR | Control |
| DH | District Heating |
| DHW | Domestic Hot Water |
| HP | Heat Pump |
| LCF | Load Cover Factor |
| PV | Photovoltaic Panels |
| SCF | Supply Cover Factor |