ISEC 2024 – 3rd International Sustainable Energy Conference

Positive Energy Buildings and Districts

https://doi.org/10.52825/isec.v1i.1206



Published: 25 Apr. 2024

# Towards Positive Energy Districts

## Innsbruck, "Campagne Areal"

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**Abstract.** Positive energy districts (PEDs) are a vision to enable and foster the energy transition in the building sector. The integration of heat pumps (HP) in buildings and districts to achieve a net positive energy balance is crucial. The efficiency of the electric and thermal energy system of districts can be improved with the use of HPs. This refers to both, the upgrade of waste heat and benefiting from simultaneous use and generation of energy in buildings at different temperature levels (space heating, DHW, space cooling/dehumidification) and includes self-consumption of on-site renewable electricity generation. Using the example of the new district Innsbruck Campagne, HP integration options as well as photovoltaic (PV) integration potentials are evaluated with respect to reaching a positive energy balance. Both simulation results as well as monitoring results are presented. The importance of very high building efficiency standards as well as well-designed and dimensioned systems to achieve a positive energy balance and to reduce the so-called winter gap is highlighted.

**Keywords:** Positive Energy District, Heat Pump, District Heating, Photovoltaic

## 1. Introduction

The building sector plays in many countries a key role for $CO_2$-emission reduction. IEA's Net Zero by 2050 Roadmap includes the goal of almost 70% of electricity generated by solar photovoltaic (PV) and wind and 1.8 billion heat pumps for the operation and supply of buildings [1]. Clustering individual buildings to districts offers the potential for further performance increase by different building uses and load patterns which can offer synergies both on the electrical side and on the thermal side. Moreover, a combination of different buildings could create load patterns that might be favourable e.g. simultaneous cooling and DHW or waste heat use [2], [3]. Heat pumps show high performance in nZEB applications, but for larger buildings or districts, it is still challenging to implement efficient heat pump systems and a plus energy balance is not possible because of the limited space for PV (in relation to the treated area). New concepts are required in order to further reduce $CO_2$ consumption in the next decades. Heat pump concepts for groups of buildings and districts in combination with renewable energies can notably contribute to $CO_2$ emission reduction [4]. For high-performance and plus energy districts, the buildings become net energy producers and thereby an active part of the energy systems. Heat pumps are a key technology on the district level for sector coupling to link the heating and cooling demands with electricity production and integrate renewable energies.

in this study, different HP integration options [4] as well as the potentials of PV integration are evaluated and compared in terms of $CO_2$ emissions based on a net positive energy balance and considering the so-called winter gap. Both simulation results as well as monitoring results are presented using the example of the new district Innsbruck Campagne [5].

## 2. Case Study: Innsbruck Campagne

With the urban development project "Innsbruck Campagne", a new city quarter is being planned in the east of Innsbruck on an area of approx. 78000 m² [5]. Four blocks are planned, accommodating approximately 1100 new apartments, numerous local supply and service facilities as well as sports fields and a club building are planned. As part of the Smart Cities Demo program, the project “Smart City Campagne Areal Innsbruck” was developed. The project involves one of the four blocks, which includes 4 multi-apartment buildings for a total of 307 apartments and 2500 $m^2$ of commercial space. The buildings were built according to (or very close to) the Passive House standard, i.e. heating demand of approximately 15 kWh/(m²a). Innovative energy supply and distribution concepts were developed in cooperation with the housing companies and ESCOs involved.

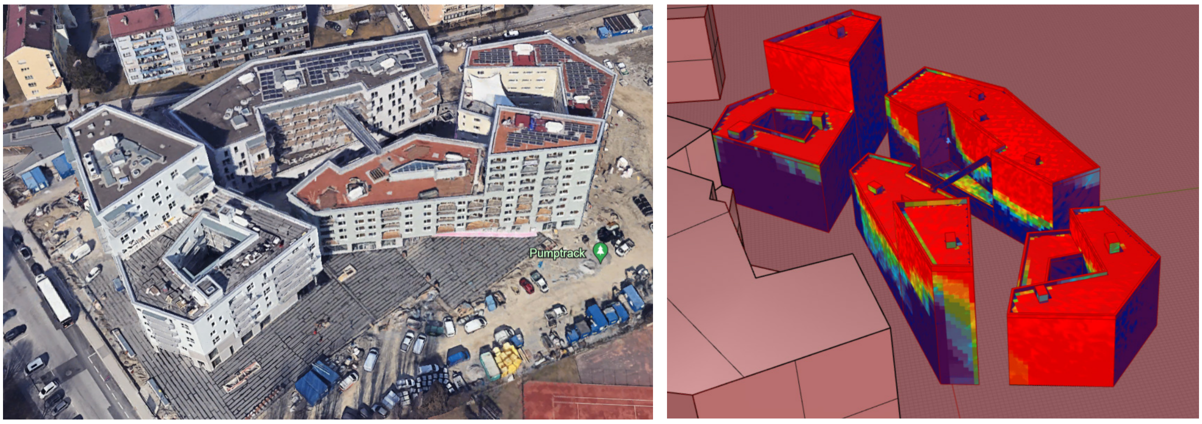


***Figure 1:*** *(left) Relative small PV on the roof of the four multi-apartment buildings (block 1), buildings from NHT and IIG, photo from Google Earth; (right) visualization of the shading of adjacent buildings.*

In the planning process, a simulation study for block 1 of the Campagne area was carried out for using a new simulation tool that allows to compare various types and combinations of heat generation systems (heat pump systems and/or district heating) [5]. The degree of centralization of the heat generation system and the type of heat distribution system with different concepts were investigated and compared. The aim of the study was to find the best combinations in terms of energy and environmental impact. Especially in low-energy or passive houses, domestic hot water (DHW) preparation often accounts for a higher contribution than the space heating of the building [5]. The choice of a DHW supply concept can have a very large impact on the overall system efficiency and the total energy consumption of a building. Centralized or decentralized systems with the associated temperature levels and heat generators have to be carefully designed to achieve the desired high efficiency.

The chosen central system combines a groundwater heat pump for space heating (allowing the possibility of free-cooling in summer) and district heating (DH) for DHW preparation. The distribution system is a 2+2 pipe system with decentral fresh water stations (FWS) for DHW. As each two of the buildings were realised by different housing companies, a system separation for DHW and space heating was implemented. The district heating and the heat pump are charging primary side storage tanks, which then serve the respective hydraulic systems separated by heat exchangers. It is noteworthy that this system separation results in additional temperature losses that could have been avoided.

A comprehensive monitoring campaign pays special attention to the central hot water generation and distribution. The goal is to gain in-depth knowledge about the various influencing variables (such as DHW demand and tapping profiles including simultaneity) and their effect on the efficiency of the hot water supply, distribution and generation (i.e. thermal losses and return temperature). The monitoring data is used to validate the simulation tool with the real data. Furthermore, tapping patterns will be derived (including simultaneity factors) as an important input for future heat pump system design and dimensioning. More details about the project can be found in [5] and [6].

# 3. Method

## 3.1 Heating demand and heating system

Space heating demand (SHD) and domestic hot water demand (DHW) were determined using the design plans and PHPP calculations. The design SHD is compared with the real SHD measured in 2023. For all four buildings heat meters measure the energy demand in the main distribution line. In addition, one of the buildings is measured in more detail, i.e. the energy on the primary side of the FWS is measured in each flat. Furthermore, indoor temperatures and relative humidity are monitored. With the average internal temperature of all flats and the weather data for Innsbruck from 2023 from Meteostat [7], the heating degree days ($HDD_{measured}$) and furthermore a heating degree day correction factor ($f_{HDD}$) is determined. Using this correction factor for all the buildings the monitored SHD can be compared with the HDD corrected design SHD.

$$f_{HDD} = \frac{HDD_{measured}}{HDD_{design}} \tag{1}$$

$$SHD_{corrected} = f_{HDD} \cdot SHD_{design} \tag{2}$$

The following heating system configurations are analysed and compared in terms of energy demand and $CO_2$ emissions:

(a) Heat pump for each building (SH and DHW)
(b) Heat pump for each building (SH) and direct electric (DE) DHW preparation with E-boilers
(c) District heating for SH and DHW
(d) Central heat pump for SH, district heating for DHW (as built)

To determine the electrical energy demand of the heat pump, a simplified monthly calculation was performed based on the Carnot approach with a Carnot performance factor of 40%. The monthly average groundwater temperature (annual average of 11.9 °C) and the set temperature (55 °C for DHW and 40 °C for SH) were used to determine the performance factor (PF) and the electrical energy demand.

$$PF = \eta_C \cdot \frac{T_{set}}{T_{set} - T_{GW}} \tag{3}$$

The thermal losses (storage and distribution) were considered in a simplified way depending on the system configuration based on [5] and on the available monitoring data. The losses are assumed relative to SH and DHW demand. In case of heat pump for space heating (i.e. (a), (b), and (d)), losses can be disregarded due to the low temperature distribution system and the position of the pipes in the thermal envelope. In contrast, in the configuration with centralised district heating (c), a significant portion of the pipes are located outside the thermal envelope and relative losses of 20% are assumed. For the central DHW preparation, relative losses are assumed to be 75% (configuration (c) and (d)), which could be reduced to ca. 50 % with a reduced set temperature (due to the 2+2 pipe system with FWS). In the configuration (a) with the building-wise heat pump, DHW storage and distribution losses are 50%. Decentral E-boilers for DHW (configuration (b)) are assumed with relative low losses of 20%. Relative losses for SH and DHW in the different system configurations as summarized in Table 1.

***Table 1:*** *Relative losses (storage and distribution) for space heating (SH) and domestic hot water (DHW) for the four heating system configurations, based on [4]*

| | | SH | DHW |
|---|---|---|---|
| **(a)** | **HP** | 0 % | 50 % |
| **(b)** | **HP + DE** | 0 % | 20 % |
| **(c)** | **DH** | 20 % | 75 % |
| **(d)** | **HP + DH** | 0 % | 75 % |

## 3.2 Photovoltaic systems

As part of the simulation study, the PV potential of all available areas was compared with each other at various levels of detail [8]. In the first step, all opaque surfaces were equipped with PV ("all areas" variant), which includes not only the roof surfaces but also the façade. As a more realistic/economical alternative, an annual PV yield criteria ("AYC" variant) was also introduced to exclude the surfaces where the annual PV yield falls below a threshold (due to shadings). As the most detailed variant, the shading of neighbouring buildings, self-shading and the real module geometry were also considered (detailed variant). The photovoltaic potential has been analysed at different levels of detail, with the highest yield being achieved when all potential surfaces are considered, neglecting intrinsic shading from balconies and module geometry. This means that in the ideal case roof and façade areas are also covered with PV, with a very low annual global radiation yield, which would not be justified from economic point of view.

## 3.3 Net-Zero - $CO_2$ balance

Electricity and district heating demand are evaluated and balanced with the PV generation including appliances and auxiliary energies. In order to compare the different heating systems and PV field sizes, conversion factors are necessary to compare different energy carriers (i.e. DH and electricity) and the point of time of energy demand and supply. Annual conversion factors, such as e.g. from OIB-6 (2023) [9] for Austria (electricity: 156 $gCO_2/kWh$ and district heating: 67$gCO_2/kWh$) do not consider that the share of renewables in the energy system varies with time, i.e. higher renewable share in summer and relative low share in winter. Furthermore, they represent the energy system of the previous years and not the prediction of the future period in which the building is operated [4],[10]. Table 2 shows the monthly conversion factors for electricity ($f_{el}$) and district heating ($f_{DH}$). The net balance is calculated using these monthly factors. Additionally, annual factors (average, OIB) are used and results are compared with those derived with the monthly factors.

***Table 2:*** *Monthly $CO_2$ conversion factors in [$gCO_2/kWh$] based on [3]*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $f_{el}$ | 430 | 410 | 400 | 335 | 280 | 260 | 260 | 270 | 320 | 380 | 400 | 420 | 347 |
| $f_{DH}$ | 240 | 230 | 190 | 160 | 155 | 166 | 155 | 158 | 160 | 158 | 215 | 220 | 184 |

# 4. Results, Discussion and Conclusion

## 4.1 Space heating and DHW demand

The measured space heating demand of the first year of operation proves the high quality of the building thermal envelope. The measured demand is comparable with the design values (PHPP calculations) as shown in Table 3. More details can be found in [6]. The measured

DHW demand is with 12.3 kWh/(m² a) lower than the design values (20.2 kWh/(m² a)). The actual number of tenants is not known. Further analysis will be done in future work.

***Table 3:*** *Measured and calculated space heating demand (SHD) in [kWh/(m²a)] for the buildings A,B,C and D.*

| | A | B | C | D |
|---|---|---|---|---|
| $\mathbf{SHD_{measured}}$ | 20.9 | 19.8 | 27.4 | 21.9 |
| $\mathbf{SHD_{design}}$ | 15.0 | 15.0 | 21.3 | 18.3 |
| $\mathbf{SHD_{corrected}}$ | 15.5 | 15.5 | 22.0 | 18.9 |

For the following analysis, a total space heating demand of 16.2 kWh/(m² a) and DHW demand of 20.2 kWh/(m² a) is assumed.

## 4.2 Thermal and electric energy balance

The monthly thermal (left) and electric (right) energy balance is shown in Figure 3 for the four different heating system configurations. The “DH only” configuration (c) has the lowest electrical energy demand (APP and AUX), but a significant seasonal thermal load curve, covered by the DH. The seasonal variation in case of HP only (a) is not strongly pronounced because of the very low SH demand and the efficient groundwater HP.

## 4.3 Theoretical and realistic PV Yield

Exemplarily, the results of the simulation study on the PV potential of the roofs and the facades including the effect of (self-)shading are shown (Figure 2). Due to the limited roof space in relation to the treated area and the relevant self-shading in the dense block, the PV potential is limited.

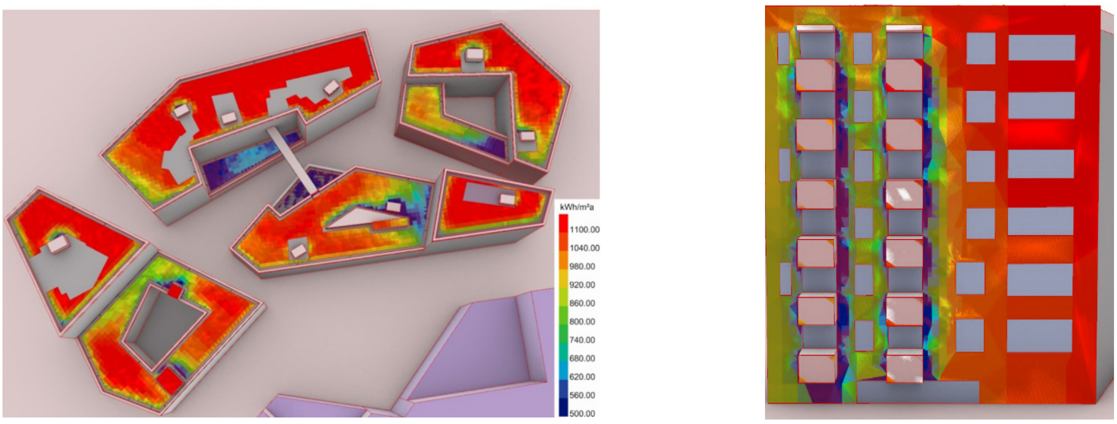


***Figure 2****: Example of the PV Potential on roofs (left) and façade (right) of the four buildings in Innsbruck Campagne [8]*

Introducing a limit of the total irradiance on the surface (of here exemplarily >700 kWh/(m² a)), available areas for PV are significantly reduced compared to the case with full PV coverage (in particular in case of the facades, see Table 4). With the realistic variant, in which, besides shadings also the PV module geometry is taken into account, the yield is further reduced as presented in Figure 4. A net positive balance cannot be achieved without employing additional areas for PV production, i.e. free field PV.


***Figure 3**: Monthly thermal (left) and electric (right) energy balance for the four investigated cases (a) – (d); APP = Appliances, AUX = Auxiliary*

***Table 4:** Areas in [m²] available for PV on roof and facades and share in [%] with respect to total available area*

| | Roof | | Facades | |
|---|---|---|---|---|
| **Total** | 4798 | | 16430 | |
| **Available (ideal case)** | 2841 | 59 % | 11175 | 68 % |
| **Available (real case)** | 2658 | 55 % | 2164 | 13 % |

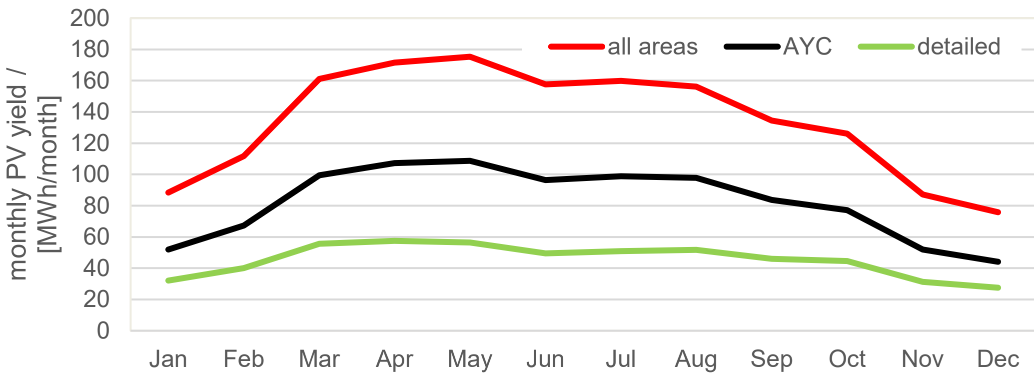


***Figure 4**: Monthly PV yield for the three considered cases. The annual yield for "all areas" is 1605 [MWh/a], "AYC" is 984 [MWh/a] and "detailed" is 543 [MWh/a]*

### 4.4 $CO_2$ emissions

The corresponding $CO_2$ emissions calculated with the monthly conversion factors, as well as with annual factors is summarized in Table 5. In all cases, the HP only configuration shows the lowest $CO_2$ emissions. In case of monthly factors, the lowest $CO_2$ emissions are obtained with configuration (a), followed by (d), (b) and (c). The ranking is the same with the mean conversion factors, but there are differences with respect to the relative difference. In contrast, with the conversion factors acc. to OIB, configuration (c) outperforms configuration (b).

***Table 5:** $CO_2$ emissions in [$ton_{CO2}$/year] for the variants and depending on the conversion factor*

| | (a) | (b) | (c) | (d) |
|---|---|---|---|---|
| $f_{monthly}$ | 104.7 | 209.3 | 258.8 | 198.0 |
| $f_{mean}$ | 93.6 | 198.5 | 237.5 | 187.2 |
| $f_{OIB}$ | 42.1 | 89.2 | 87.7 | 71.8 |

## 5. Discussion and Conclusion

A net positive energy balance (or zero $CO_2$ balance) can only be reached with very low energy demand and highest possible PV generation (onsite). In case of (multi-story) multi-apartment buildings with a high density (as here in the example of Innsbruck Campagne), the net balance cannot be reached. The gap would even increase if electric vehicles and or whole life carbon emissions (embodied energy) was considered in the energy balance. If the module geometry, self-shading and external shading are taken into account, there is a limited PV potential (as shown in Figure 2), i.e. demand reduction is of highest importance. If the annual $CO_2$ emissions should be compensated by PV, all considered configurations would need an additional horizontal (not shaded) PV area. In the best case (HP only) at least 1031m² additional area would be required (3068 m² in the worst case), as shown in Table 6. For sake of better understanding, the required area is expressed in relative football fields (100 m x 50 m). The horizontal global radiation has been used to calculate the additional required area. With a net annual balance, the required area would be underestimated. The required additional area increases by 20 % in case of configuration a) and 42 % in case of configuration c).

***Table 6:*** *Additionally required (not shaded) horizontal PV area to reach Net Zero $CO_2$ balance (in [m²] and percentage of football fields)*

| | **(a)** | | **(b)** | | **(c)** | | **(d)** | |
|---|---|---|---|---|---|---|---|---|
| $f_{monthly}$ | 1241 | 25% | 2482 | 50% | 3068 | 61% | 2347 | 47% |
| $f_{mean}$ | 1031 | 21% | 2184 | 44% | 2614 | 52% | 2060 | 41% |
| $f_{OIB}$ | 1031 | 21% | 2184 | 44% | 2146 | 43% | 1758 | 35% |

To reach a positive energy balance several aspects must be considered in the planning phase:

- Very high-quality building envelope
- low DHW demand (low distribution losses, implementation of shower drain water recovery)
- efficient appliances (including monitoring and tenant information)
- very efficient heating system with low auxiliary energy demand.

With respect to the onsite electricity generation, self-shading, external shading (including potential external shading in the future and an optimally designed photovoltaic systems with respect to module sizes have to be considered.

The reduction of the electric energy demand by means of a very high building envelope quality and a very efficient heat generation and distribution system is crucial. First monitoring results show potential for further improvements in particular concerning the control of the floor heating system (indoor temperatures) and the flow and return temperatures of the DHW preparation. The groundwater well is dimensioned for the final stage of the district (with 16 buildings) and is thus significantly over-dimensioned for the current status with only four buildings.

## Data availability statement

Data will be made available on request.

## Author contributions

Fabian Ochs: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration, Funding acquisition – Samuel Breuss: Writing - Review & Editing, Visualization – Elisa Venturi: Investigation, Validation, Review & Editing, Visualization – Mara Magni: Review & Editing, Visualization – Georgios Dermentzis: Review & Editing

## Competing interests

The authors declare that they have no competing interests.

## Funding

This research is possible through the financial support by the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology through the IEA Research Cooperation (IEA HPT Annex 61, IEA EBC A83 Positive energy Districts, IEA SHC T66 Solar Energy Buildings) as well as through the Climate and Energy Fund (Innsbruck_Campagne) and the Austrian Research Promotion Agency (FFG).

## Acknowledgement

This project is supported by Neue Heimat Tirol (NHT), Innsbruck, Austria and Innsbrucker Immobiliengesellschaft (IIG), Innsbruck, Austria. The authors are grateful for the support.

## References

[1] IAE, "Net Zero by 2050 – A Roadmap for the Global Energy Sector" (2021)
[2] Brozovsky, Johannes; Arild, Gustavsen; and Niki Gaitani. "Zero emission neighbourhoods and positive energy districts–A state-of-the-art review." Sustainable Cities and Society 72 (2021): 103013. https://doi.org/10.1016/j.scs.2021.103013
[3] Sareen, Siddharth; Albert-Seifried, Vicky; Aelenei, Laura; Reda, Francesco; "Ten questions concerning positive energy districts." Building and Environment 216 (2022): 109017. 10.1016/j.buildenv.2022.109017
[4] Ochs, Fabian; Mara, Magni and Georgios Dermentzis. "Integration of heat pumps in buildings and district heating systems—Evaluation on a building and energy system level." Energies 15.11 (2022): 3889. https://doi.org/10.3390/en15113889
[5] Dermentzis, Georgios; Ochs, Fabian; Thuer, Alexander; Streicher, Wolfgang; "Supporting decision-making for heating and distribution systems in a new residential district-An Austrian case study." Energy 224 (2021): 120141. https://doi.org/10.1016/j.energy.2021.120141
[6] Venturi, Elisa; Ochs, Fabian; Dermentzis, Georgios; Breuss, Samuel; Campagne project: Passive houses to enable Positive Energy District, 27th International Passive House Conference, Innsbruck, Austria, 2024.
[7] Meteostat.net „https://meteostat.net/de/station/11121?t=2023-01-01/2023-12-31" (18.01.2024)
[8] Heiß, Simon, „Bewertung von Plusenergiequartieren am Beispiel Innsbruck Campagne", Bachelor Thesis, University of Innsbruck, 2023
[9] OIB Richtlinie 6 (OIB-330.6-036/23), Österreichisches Institut für Bautechnik
[10] Dermentzis, Georgios; Ochs, Fabian; Thür, Alexander; "Primary-energy Based Optimization of a New Building District through Simulations on Flat, Building, Block and District Level" IBPSA (2019)