Chapter 17

‘Zukunftsquartier’—On the Path to Plus Energy Neighbourhoods in Vienna

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Abstract This paper presents an approach to define and implement a ‘Zukunftsquartier’ (future neighbourhood) in the context of the densely populated city environment of Vienna, which is in line with the national energy targets 2050. The ‘Zukunftsquartier’ project explores the feasibility of plus energy neighbourhood concepts at four prospective project sites in Vienna. The case studies evaluate the potential of demand side management, innovative renewable energy systems including photovoltaic and near-surface geothermal energy by hourly energy balancing and are compared for the Austrian building code and ‘passive house’ construction standards. Due to the high floor space index of urban projects, all investigated concepts failed to achieve a positive energy balance, except theoretical variants with unfeasibly high PV utilization of virtually the entire roof and façade surfaces. To offset the unintended effect of plus energy being harder to achieve in a dense urban context, we propose a correction factor for the target energy balance of ‘plus energy’ buildings and neighbourhoods based on the floor space index. Together with a second energy balance adjustment, reflecting the prospective renewable energy system (RES) of Austria 2050, most ambitious variants (utilizing ground heat and moderate PV surfaces) achieved ‘plus energy’ standard for dense urban areas and life cycle costs compared to conventional realizations within 30 years.

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17.1 Introduction

With the Smart City Vienna Framework Strategy, published in 2014, Vienna committed to a path of decarbonisation. Developing sustainable, secure and affordable strategies to supply (new) urban districts with energy is one of the many challenges in this context. The City Administration of Vienna aims at realizing an innovative showcase of modern city quarters as part of its governmental agreement (2015). The intended exploratory project ought to make a valuable contribution and, with the help of a competent consortium in the field of research–planning–implementation, to substantially advance the preparation of such a showcase city quarter with new knowledge and experience.

AQ2

With the support of the City of Vienna and numerous developers, at least five urban mixed quarters, which will be developed over the next 2–5 years and whose energy supply has not yet been decided, are being investigated in this exploratory project. One task of the project tries to answer the question of adequate system boundaries and indicators for positive energy neighbourhoods. Furthermore, the consortium develops and evaluates early-stage concepts and options for the neighbourhoods to determine the most promising ones for realization and detailed planning in the next step.

So far, for four quarters, preliminary draughts of energy concepts based on the local energy situation and the requirements of stakeholders/users have been developed.

17.2 Aim

This paper presents an approach to define and implement a ‘Zukunftsquartier’ (future neighbourhood) in the context of the densely populated city environment of Vienna, which is in line with the national energy targets 2050. Therefore, a proposal is presented on how a compensation between low-density and highly dense urban areas, in terms of ‘effort sharing’ can be achieved. This approach is essential as a push towards the development of high-density urban plus energy districts and can be observed on both, international and national levels [6]. Development of plus energy neighbourhoods, or even districts, is not easy to achieve in terms of technical feasibility and marginal costs (Iturriaga et al. 2018). Through the analysis, modelling and simulation of the considered neighbourhoods, including their technical and economic conditions, and the subsequential derivation of recommendations for action (e.g. for the planning process, for technology combinations and for stakeholder integration), the project aims to provide insights into the broader applicability of the plus energy neighbourhood concept.

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17.3 Status Quo Plus Energy Quarters

There is no uniform definition for system boundaries and calculation method for plus energy quarters. Common sense is that a plus energy quarter produces more energy than it consumes throughout the year. How to reach the 'plus' (efficiency in energy demand, increase in renewable energy production or use of smart controls is open as well as the considered main indicators, like operating, final or primary energy or CO_2-emissions. In general, definitions are based on those applied for plus energy buildings, supplemented by general electricity demand of the quarter, like outdoor lighting in the neighbourhood. Considered energy services commonly include heating, cooling, ventilation and hot water demands plus the electricity like user electricity, lighting and auxiliary requirements. The extended view at neighbourhood or district level can increase the ratio of internal consumption and thus are improving the profitability. Reasons are mixed usage effects and the circumstance that energy can be exchanged between the buildings; however, there is no positive effect on the annual energy balance. Generally, the way to a plus energy neighbourhood is similar to the challenges of plus energy buildings. The neighbourhoods that own energy supply capabilities are limited by the available plot size (for solar and ambient energy), or more accurately by the ratio of the conditioned space to the available plot size (also known as 'floor space index' or FSI). This is the predominant factor for the on-site renewable energy supply (RES) potential of any building or quarter.

17.3.1 Plus Energy Districts in Urban Context

In Austria, there are so far no realized projects for plus energy quarters in dense urban areas that have achieved the desired goals. In Europe, while the number of projects in the implementation or planning stage is quite high (compare [4]), a few projects are in operation (for example, Hunziker Areal, Zurich, Switzerland, Fleuraye, Carquefou/Nantes, France). To guarantee the actual implementation of the concepts from the planning to the operation stage, the economic feasibility is crucial. In Austria, for example, the concept of the quarter Reininghaus Süd was initially planned as a plus energy network [9]. In the realization phase, the PV system was saved and therefore no plus energy was reached.

17.4 Methodology and Assumptions

For the preliminary calculation of the envisaged quarters, the energy demand as well as the on-site potential for renewable energies are determined in dynamic simulations, described under Sect. 17.4.1. The following variations based on Fig. 17.1 were calculated. The main considerations of the project are variations of the building stan-

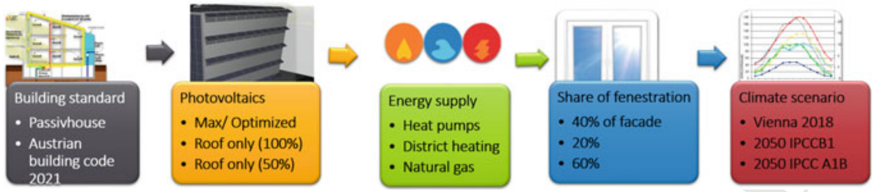

Fig. 17.1 Main variants which are considered for calculations

dard, different photovoltaics allocations and energy supply systems. Three different shares of fenestration and various climate scenarios for 2050 are additional subjects.

17.4.1 Energy Demand Calculation and Potential for Renewables Energies

Simulation Method, Zoning and Usage Profiles

For the calculation of the heating and cooling demand, a simplified dynamic calculation of the neighbourhood was implemented in a single-zone model, in which all relevant heat flows (into the system positive, from the system negative) in hourly resolution are incorporated. By rearranging Eq. 17.1, the respective capacity can be determined.

$$\mathrm{C}^{*}\,\mathrm{dT/dt} = \dot{Q}_{\mathrm{T}} + \dot{Q}_{\mathrm{v}} + \dot{Q}_{\mathrm{s}} + \dot{Q}_{\mathrm{I}} + \dot{Q}_{\mathrm{H}} + \dot{Q}_{\mathrm{C}} \tag{17.1}$$

C	Effective storage capacity in $\mathrm{Wh/m^2_{NFA}K}$
dT	Temperature difference between two timesteps in K
dt	Time difference in h
$\dot{Q}_{\mathrm{T}}$	Transmission heat flux in $\mathrm{W/m^2}$
$\dot{Q}_{\mathrm{V}}$	Ventilation heat flow in $\mathrm{W/m^2}$
$\dot{Q}_{\mathrm{S}}$	Solar gains due to transparent components in $\mathrm{W/m^2}$
$\dot{Q}_{\mathrm{I}}$	Internal gains by persons, equipment, lighting, etc. in $\mathrm{W/m^2}$
$\dot{Q}_{\mathrm{H}}$	Heating capacity in $\mathrm{W/m^2}$
$\dot{Q}_{\mathrm{C}}$	Cooling capacity in $\mathrm{W/m^2}$.

The following assumptions were made:

- Transmission heat flux according to PHPP results in Table 17.1 outlined characteristic values, depending on building energy standard.
- Increased summer air exchange via windows for natural cooling was not taken into account.
- A heavy construction method was assumed with $\mathrm{C = 204\,Wh/m^2_{NFA}K}$.

Table 17.1 Used characteristic values for building envelope

Characteristic values	Passive house	OIB 2021	
Exterior wall	0.12	0.18	W/m^2 K
Roof	0.1	0.12	W/m^2 K
Ceiling	0.12	0.19	W/m^2K
Basement ceiling	0.15	0.19	W/m^2 K
Windows	0.83	0.93	W/m^2 K
Thermal bridges	0.03	0.06	W/m^2_{NFA} K

- Distinction between heating and cooling periods is determined monthly, depending on the quality of the building envelope, resulting in three possible building states, either heating, cooling or 'freerunning'.
- Assumptions for the internal heat are differentiated into winter and summer case according to ÖNORM B 8110-5: The internal loads in cooling mode are assumed to be twice as high as in the heating mode, with linear interpolation in the transitional period.
- The solar gains are assumed for the simplified calculation with a fixed shading factor of 0.75, resulting in a total solar transmission rate of 0.39 including g-value, frame section, etc.

There are two setpoint room temperatures considered, one each for heating and cooling:

- Minimum target room temperature: This must not be under-(heating case) or exceeded (cooling case) even in the case of DSM. Without DSM, this represents the target room temperature.
- Maximum and minimum target room temperature: Use of the building storage mass for the DSM, this represents the maximum (heating mode) or minimum (cooling mode) room temperature.

Photovoltaics

The assessment for the potential of the usable solar energy for PV was performed for four exploitation strategies of different size and cost with PV sites. The variants are the maximum technical potential, maximum roof utilization, half roof utilization and an optimized case. For the roof allocation, a 15° inclination, east/west orientation was carried out for each case. In addition, maintenance corridors and distances of 0.6 m to the roof edge are provided between the module rows. The bifunctional PV canopies (sun protection) are mounted at an angle of 30°. In the case of façades, the considered window area proportions (20, 40, 60%) are deducted from the yields. For the optimized variant, special areas, if any, are also taken into account and removed (keyword: conflict of use). In addition, no PV modules were planned for façades with annual irradiation of <500 kWh/m^2. The 3D model in PV sites takes into account shading of surrounding buildings. The PV yields can be displayed in hourly resolution, which is an important prerequisite in combination with the dynamic energy demand calculation for determining the own consumption rate. The simulations are carried out with a highly efficient state–of-the-art solar panel from LG with 320 W power (LG 320N1C G4), which is characterized by a typical size of 1.6 m by 1 m.

Energy Supply
One conventional and one plus energy neighbourhood energy concept was developed for each use case by taking the local renewable potentials into account. Plus energy variants for the considered neighbourhoods are implemented by using on-site PV, waste heat and geothermal potentials via heat pumps. The potential for the use of near-surface geothermal energy by geothermal probes was determined for the rough concepts with a withdrawal capacity of 35 W/m. The maximum probe length is assumed to be 150 m if no restrictions exist on-site. The annual coefficient of performance of the heat pump was assumed to be 5 for heating, 7.5 for cooling and 3 for domestic hot-water demand. Distances between the probes are 8 m without regeneration or 5 m with regeneration.

17.4.2 System Boundaries

Current system boundaries serve many functions but fail to connect directly to local and national climate goals. Hence, three extensions to the common system boundary of the primary energy balance for building operation are proposed [10].

System Boundary Extension 1: Regional Renewable Peak Shaving
The Austrian renewable energy strategy [8] aiming at 100% renewable energy supply by the year 2050, requires a fivefold capacity increase of wind power. However, how to integrate this volatile energy supply in the future energy system? An increased energy flexibility in buildings and districts [5] in combination with other storage technologies could be the solution. Alham et al. [1] and [11] show that it is both technically and economically feasible to dispatch wind power generation in accordance with building demand side response. Therefore, the system boundary of the plus energy neighbourhood is extended to include possible peak shaving of regional wind power due to demand response potentials of the buildings.

System Boundary Extension 2: National RES User Credit
On the basis of the ‘renewable Austria 2050’ scenario, the renewable energy from large-scale wind parks, water power stations and biomass will first be allocated to energy uses, which are difficult to supply locally: Industry, public transport and large-scale power2hydrogen or power2gas. The remaining RES from large-scale power plants can be nationally allocated to all inhabitants as an ‘individual renewable credit’, which can be taken into account for primary energy balancing of a building: The cumulative RES credit of all building inhabitants’ counts towards its PEB.

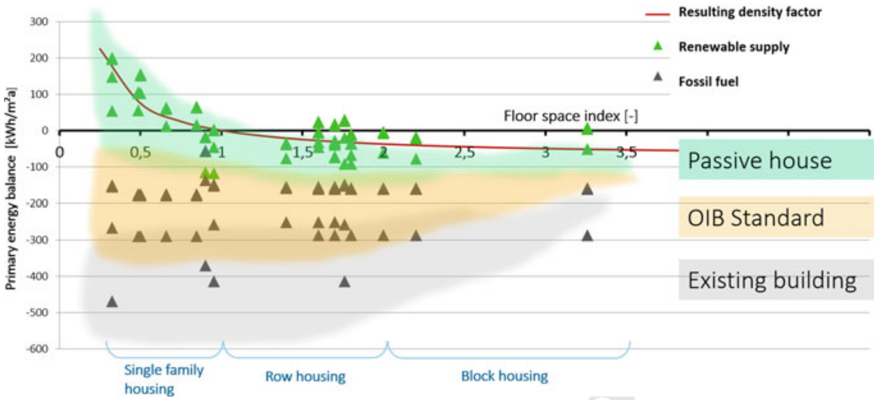

Fig. 17.2 Graphical dependence of the '*primary energy credit*' determined by energy supply system, building density and building standard

System Boundary Extension 3: Density Factor
Contrarily to the energy demand, the local RES potential is approximately proportional to the plot size. Thus, the lower the floor space index of a building is, the easier it will achieve plus energy standard. In Fig. 17.2, the maximum primary energy balance achievable for projects of different floor space index, as compiled by the research project *SC_Microquartiere* [3] is shown. The red coloured curve shows the proposed density factor, depending on the floor space index.

Conversely, it is virtually impossible to achieve conventional plus energy standard at a certain higher floor space index—there is not enough on-site renewable energy potential for the useable floor area. This leads to the effect that the more efficient a building is in terms of land use, the more difficult, if not impossible, it will be to achieve a plus. Paradoxically, the classical NZEB as well as plus energy standard, which aim to improve energy efficiency and use of renewables on-site, indirectly promote less efficient use of the finite resource that is buildable land. Therefore, depending on the floor space index, a density factor is introduced as extension 3.

17.4.3 Investment Costs Difference

For the project, no full life cycle assessment is carried out, but a simplified differential cost analysis. Following are the assumptions to determine the resulting costs for the variants:

- The imputed real interest rate of the investment was assumed with 2%.
- Total costs within the first 30 years (excluding the development of income).
- Subsidies not taken into account.
- Residual values were not considered.

Table 17.2 Structural data from the considered quarters

Zukunftsquartier		Pilzgasse	Ottakringerjeben An der Kuhtrift		Marx Hub
Gross floor area (GFA)	m^2	23,435	40,069	33,010	25,740
Net floor area	m^2	18,748	32,055	26,408	20,592
Useable area	m^2	15,936	27,247	22,447	17,503
Floor space index (FSI)	–	3.2	2.8	3.6	1.7
Building density	–	0.6	0.7	0.7	0.3
Characteristic length (lc value)	m	3.9	2.9	4.0	5.0
Households (fictitious)	number	268	458	377	294
Persons (fictitious living)	number	536	916	755	588

The cost calculation of the building services represents a conservative estimate because

- Maximum service life of 30 years is not identical with the actual service life of individual components (higher realistic service life of components such as geothermal probes are not taken into account).
- The average increase in energy prices and maintenance costs is assumed to be in line with the inflation rate.

17.5 Case Study

All the quarters under consideration comprise at least three building complexes with a total floor area of above 20,000 m^2 and are characterized by high mixtures of usage.

Table 17.2 summarizes the structural data of the considered neighbourhoods. Unless otherwise stated, the reference unit for all specific key figures is the net floor area (NFA), which is conditioned and ventilated. The net floor area is presumed with 80% of the gross floor area (GFA). The usable area was assumed to be 85% of the net floor area.

17.6 Results

The proposed system boundaries are applied to four plus energy quarters in Vienna, while Extension 1 (wind peak shaving) is used in general. The results for highly efficient passive house building standard are shown in Fig. 17.3. As can be seen, PV installation size has by far the biggest impact on the achievable primary energy balance of the variants. All four quarters could achieve the conventional plus energy standard, PEB balance >0 only under the assumption of utilizing most of the building

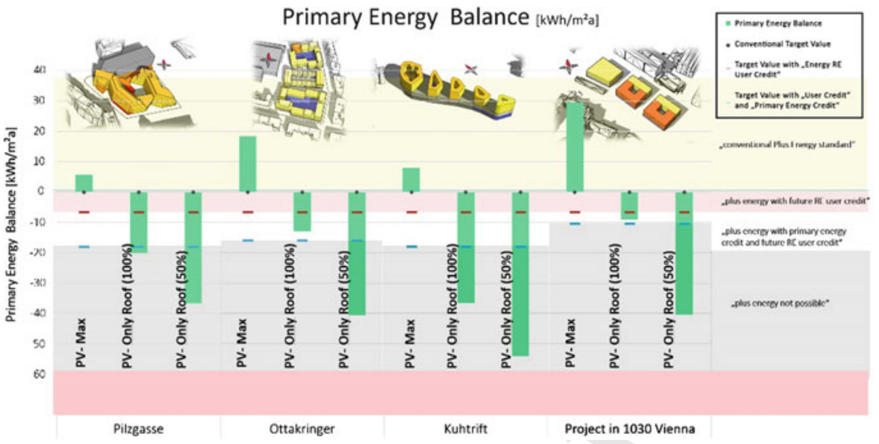

Fig. 17.3 Primary energy balance for four Plus Energy Quarters. Each Quarter is visualized in three variants: (1) PV max: All building surfaces with an insolation >500 kWh/m^{2}a are utilized for PV generation, (2) PV Roof only (100%) PV utilization on the entire roof area and (3) PV Roof only (50%): Only half of the roof

surfaces for PV power generation. Although technically possible, this is economically unfeasible. Apart from the extensive PV Max strategy, the more moderate variants all require adaptations to the classical primary energy balancing method to be plus energy feasible. The use of system boundary Extension 2 is marked with a red line and Extension 3 (density factor) in blue. Results show that a realistic roof PV allocation of 50% is not adequate. Therefore, for each site, an optimized variant (PEQ) was determined with optimized roof allocation and a share of PV façades depending on the resulting energy deficit.

The monthly results for the power supply are shown in Fig. 17.4. The PEQ variant clearly shows that the renewables (solar and wind surplus) in combination with DSM measures can cover well over 50% of the electrical energy requirement in the winter period. In very unfavourable climatic months (cold, almost no wind and solar energy), such as in December 2015, just about 25% can be generated from the considered renewable sources. The PV surpluses in the summer half-year can cover a significant proportion of the future e-mobility needs of living, working and educational persons in the neighbourhood.

As shown in Fig. 17.5, the exemplary additional costs of a plus energy project area are mainly caused by the PV system, the ventilation system and the highly efficient heat/cooling distribution and storage system. Due to the partly less complex equipment standard of the reference variant (multi-split system attics, fixed shading, etc.), the differential costs are relatively moderate and are well below 10% of the planned construction costs. Maintenance and financing costs increase production costs by approx. 80%. The energy costs savings (on the right side) resulting in a total 'profit' over 30 years.

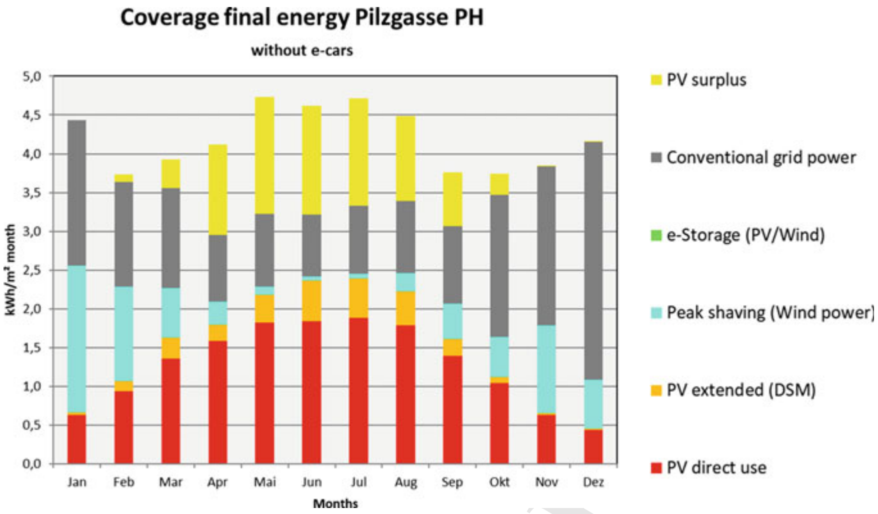

Fig. 17.4 Monthly coverage of final energy for the case area 'Pilzgasse'

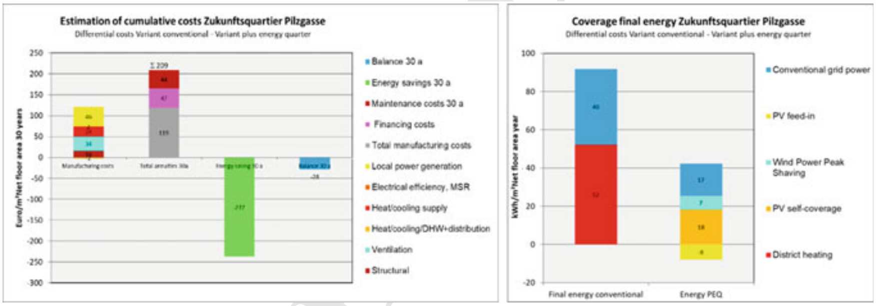

Fig. 17.5 Estimation of additional costs, considering annuities (left side) and energy savings. On the right side division of achievable energy savings

17.7 Conclusion

The results show that plus energy concepts with reduced PV areas in the façades are feasible for all considered quarters under consideration of consistent system boundaries. The proportion of façade-integrated PV is decisive for cost-effectiveness because investment costs are higher and the energy yield, compared to roof systems is lower. Due to the predominant mix of uses, high own consumption rates of the PV yield between 60 and 70% are achievable for all considered neighbourhoods, which are important for economic reasons. Depending on the future expansion rate of e-mobility, PV surpluses in summer can be largely absorbed. For the neighbourhood Kuhtrift (big car parking planned), in an estimation with relevant e-car share and low loading capacities, almost 100% own consumption was achieved. The estimation of differential costs shows large differences. In three quarters, there are not only moderate additional costs but also one with high additional burdens.

The main influencing factors are

- Reference standard of the conventional variant
- Predominant mixture of usage
- Availability of waste heat, otherwise, expenses for the active regeneration of the geothermal probes, like PVT collectors are challenging.

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Chapter 17

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