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RENEWABLE ENERGY IN PLANNING OF SUSTAINABLE URBAN UNITS, IS ENERGY AUTARKY POSSIBLE IN NZEB BUILDINGS?

Abstract
Energy autarky is a concept commonly used in the context the of power off-grid or remote island systems. However, it has rarely reflected the idea of self-sufficiency of urban units, especially in cities with access to external technical infrastructures such as power and district heating networks. Energy autarky can also be considered auxiliary to nZEB calculation procedures, as an energy demand-supply balancing approach for calculating renewable energy shares. In fact, in Central and Eastern Europe for existing urban tissues buildings' self-sufficiency would be difficult to achieve due to a dominating role of space heating in energy demand shares. Proportions can, however, change in nZEB (nearly zero energy) buildings, with increasing importance and shares of electricity in the final energy consumption and a decreasing role of space heat. In this article a new approach to planning of energy (electricity) autarky at the level of an urban unit is presented, taking into account new nZEB standards at the same time. This is supposed to serve as a voice in the discourse on the formulation of future methodologies.

Key words
energy autarky, nZEB, renewable energy, urban unit energy analysis

Energy autarky – general concept

Energy autarky (autonomous energy entity) has been defined in the surveyed literature as a partial or total independence from energy supply networks (electricity, heating and gas) [1]. On the supply side the question is how energy demands can be sustained by clean, renewable energy sources (such as solar energy, biomass, wind, or heat pumps). Energy autarky while focusing mainly on energy efficiency and green energy supply measures (renewables) can also integrate other technological concepts such as smart grids or energy storage, serving to optimize the energy demand-supply balance of an urban unit [2], [3]. The energy autarky concept based on intermittent, weather dependent renewables (such as wind and solar energy, with hourly balancing procedures); additionally has to incorporate energy storage systems. Such solutions have been applied on islands, remote farms in the US, Australia or in countries, where power grid has been underdeveloped (Asia, Africa) [2], [4]. Another niche for autarky systems lies in rural areas with emerging energy cooperatives.

Due to economic reasons European power systems work prevailingly as on-grid systems (connected to the national power grid), due to increasing popularity of individual energy storage (supported also by economic incentives), *e.g.* in Germany [2].

It needs to be stressed that currently achieving even a partial energy autarky for an urban unit would be difficult, although there were numerous attempts undertaken to introduce energy autonomous systems [5]. An example of such is Frederikshavn, a Danish city of 50 thousand inhabitants, where the energy system is based on geothermal, offshore wind, as well as energy from biomass and biowaste. Ambitious targets were subject to computer modeling for regions or even for whole countries such as Ireland, Portugal and Denmark [6]. In total 40 islands all over the world were identified as off-grid semi-autarky systems, *e.g*.: Utsira (Norway), Salina (Italy), Azores (Portugal) or Bornholm (Denmark). However, due to various techno-economic constrains a 100% level of energy autarky (covering energy demands with renewables) has never been reached in real life (usually the outcome was 20-80%) [4].

Energy autarky, renewable energy as a part of nearly zero energy (nZEB) concept

According to the EU legislation a nearly zero energy is a building that "*has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewables produced on-site or nearby*" [7]. The Article 9 of the EPBD recast [7] states that Member States shall ensure that new buildings occupied by public authorities are Nearly Zero Energy

Buildings (nZEB) by December 31st 2018 and that new buildings become nZEBs by December 31st 2020. This legislation does not indicate, however, how member states should define the desired high energy performance [1]. For new and retrofitted buildings, energy performance of a building means that the calculated or measured amount of required energy meet the demand associated with a typical use of the building, which includes, *"inter alia, energy used for heating, cooling, ventilation, hot water and lighting"*. The term *inter alia* (among others) indicates that the catalogue of other energy demands is opened. Electricity used for household appliances (e.g. kitchen appliances, laundry equipment, TVs, etc.) is not mandatory under EPBD recast but not excluded as an option from EPBD recast's methodology. It can and should be considered in the future nZEB methodologies as the electricity demand by other household appliances and devices has been steadily growing [8]. This article assumes that nZEB methodologies would change in the future and the presented approach can serve as a voice in the relevant scientific discourse.

On the energy supply side EU member states are free to elaborate their own methodology for calculating renewable energy shares in covering energy demands in nZEB buildings. Poland has been so far very cautiously implementing new requirements. Energy demand targets were set for new and retrofitted buildings, both private and public (Table 1). However, the legislation did not stipulate any means for calculating renewable energy shares. In Poland, unlike in other countries, exact siting options for renewables were not specified (distinction between onsite, nearby and external sites) [1]. The current legislation (latest amendments of 2015) does not refer to the nZEB standard specifically (only energy efficient building are mentioned) [1].

Table 1. Current requirements for new and retrofitted buildings in Poland (EP indicator for space heating, hot water, ventilation)

Type of building		2014	2017	2021*
		EP kWh/(m² a)		
Residential buildings	a) single-family housing	120	95	70
	b) multifamily housing	105	85	65
Non-residential buildings		95	85	75
Public buildings	a) health care	390	290	190
	b) others	65	60	45
Warehouse and production buildings		110	90	70

* 2019 for buildings owned by public entities.

Source: [9]

Renewable energy sources integration in the building stock

The majority of buildings in Poland are residential houses, they make up some 5.5 million buildings [10], with 1% of new stock per year. Although residential housing (Table 2) makes the majority of the building stock in Poland, buildings with other functions (Table 3) also need to be considered. 100 thousand buildings in Poland (source: various statistical books of the Central Statistical Office) have a good educational and demonstrational potential for renewable energy integration in the building stock. Additionally, the non-residential sector is characterized with dynamic growth rates (*e.g.* for offices and depots 20% increase annually). The potential in rural areas (Table 2) also cannot be omitted as 40% of the Polish population still live there.

Table 2. Building stock and most typical capacities of renewable micro installations applied in new/retrofitted buildings, in Poland

Building's function	**Number of buildings in 2011**	**Typical installation capacity (kW)**				
Renewable micro installation		**W**	**PV**	**STC**	**HP**	**BB**
Multifamily houses in cities *only in cities <20 thousand inhabitants	0.3 million		30	30	100	120*
Single-family houses in cities and *peri-urban areas only	< 2 million		3	7	10	10*
Residential buildings in rural areas	>3 million	1.5	3	7	10	10
W-wind, **PV**- photovoltaic, **STC**- solar thermal collectors, **HP**-heat pumps, **BB**- biomass boilers						

Source: [10]

Table 2 presents possible power capacities of different renewable micro installations, which can be installed in buildings, with most typical (based on the so-far experience in Poland) power capacities. The application of dispersed renewable energy heating technologies is restricted only to smaller cities and peri-urban areas. In densely populated areas it would not be an economically viable option due to access to district heating networks.

Table 3. Non-residential building stock and most typical capacities of renewable micro installations typically applied in new/retrofitted buildings, in Poland

Building's function	Typical installation capacity (kW)			
Renewable micro installation	**W**	**PV**	**STC**	**HP**
Education: kindergartens, primary schools, secondary schools, universities *etc*.	2	30	35	100
Human health and social work entities, hospitals*, health resorts , medical clinics		15 200*	35 175*	700*
Hotel facilities ** hotels, motels**, guesthouses**, holiday villages, centers for training and recreation, teams, camping sites, camping sites, hostels, health establishments, lodging agritourist, hostels***		30	35	100**
Churches, parish buildings, monasteries		50		30
Commercial buildings, large > 2000m^2, petrol stations	10	30		150
Arts, entertainment and recreation, cultural centers, museums		15	20	100
Offices, 57% located in Warsaw		15		100
Storage spaces, logistics and warehousing centers	10	100		200
W-wind, PV- photovoltaic, STC- solar thermal collectors, HP-heat pumps, *applied only in chosen buildings				

Source: Author's

Once the correlation between the building function and a micro installation's size is identified, technical parameters for calculating energy production (energy supply) can be assumed. Capacity ranges, capacity utilization rates, final energy use, energy storage options were assumed for the purpose of further analyses, as presented in Table 4.

Table 4. Typical technical parameters of renewable energy micro installations

Renewable micro installation	Capacity range [kW]	Capacity utilization rate [h]	Final energy demand use	Energy storage
Wind	1.5-10	950	EL	
Photovoltaic	3-200	800	EL	yes for off-grid
Biogas and other cogeneration	5-40	7,000	H, HW, EE	
Solar thermal collectors	7-175	630	HW	hot water cylinder
Heat pumps	10-200	4,500	H, HW	
Biomass boilers	20-150	2,200	H, HW	
EL - electricity, H- space heating, HW- hot water				

Source: Author's

Different urban resolutions can be chosen for energy autarky analyses: a household, building, housing estate, block of flats, district, city, region or even a whole country. As a consequence such delimitation results in a higher or lower level of input/output details. At the building level an energy audit procedure would be the best recommended option to calculate the energy standard, currently the most frequent option chosen by the member states to elaborate the methodology required by the EU legislation [7]. Some member states, in fact, have already considered a building site consisting of a group of buildings as the unit to be analyzed under the nZEB procedure [1]. On a zone level an energy audit, however, would be too much detailed; for many buildings it would turn out to be time consuming and superfluous.

Case study analysis

Assumptions

The analysis was performed for a newly designed urban unit of Czerniaków South district, delineated in the capital city of Poland. The urban and architectural design of the area was prepared by SOL-AR company. The analyzed urban unit is located in the south-western part of Warsaw, in the district called Mokotów with the area of 54 ha and planned density of population 163 persons per hectare. The green areas take up 11.7% of the total, the whole urban unit is located in the vicinity of a valuable green belt of the Vistula river, the Czerniakowskie lake nature reserve and a nearby park.

Fig. 3 Conceptual urban design for the analyzed area
Source: K. Solarek, J. Solarek, SOL-AR

The unit consist prevailingly of commercial buildings with 62% of the built-up area and 4.9 hectares followed by multi-family and services with 2.4 hectares and single-family housing with 0.6 hectares (Table 5).

Table 5. Calculation of electricity demands split-up into different building functions

Function	Built-up area (ha)	Number of inhabitants	Electricity energy demands [MWh/a]		
			Residential	Other buildings	Trade and commerce
MW	1.4	2,147	1,717	0	0
MW/U	1.0	1,007	1,941	0	0
MN	0.6	1,545	3,337	0	0
U-HA	4.9	0	0	2	3
KP/ZP/US	<0.1	0	0	0	0
MW- multifamily housing, **MW/U** - multifamily housing with commercial areas, **MN**- single family housing, **U-HA** - commercial areas (trade and administration), **KP/ZP/US/UO** - other buildings (*e.g.* educational)					

Source: Author's

Energy demand of the case study area

The aim of the analysis was not to show how the current nZEB requirements can be fulfilled, but also to present options for possible future modifications of existing methodologies. According to the EPBD recast minimum requirements for electricity calculations are to include energy used for space heating, cooling, ventilation, hot water and lighting [7]. However, it is upon national decisions to take into account also electricity used by other appliances in households (occupants') electricity [11]. The delimitated area would be supplied with heating energy from the external municipal district heating (DH) system, in Warsaw so far 76% of inhabitants have been connected to the DH network [12]. Due to the above, on the demand side only electricity was considered for energy calculations (so far household appliances were excluded from EP calculations by the Polish legislation).

The electricity demands were calculated with current specific electricity demand assumptions, provided by the City of Warsaw [12], [13]:

- residential buildings: 800 kWh/inhabitant per annum,
- offices, educational entities 200 kWh/m^2 per annum,
- trade and commerce 570 kWh/m^2 per annum.

The above values for households energy consumption (including lighting and appliances) can be compared with those in other European places- in Scandinavian countries: 3,700 - 4,200 kWh/dwelling per year, as well as in Central and Eastern Europe: 1,000- 1,300 kWh/dwelling per annum [8]. Assuming that the size of an average household in Poland consists of 3 inhabitants, the above values can be regarded as a reliable.

The calculated total annual electricity demand for the whole urban unit was roughly estimated at 7.0 thousand MWh. However, it has to be remembered that for the residential housing electricity demand per capita in Poland has been much lower that the EU average, therefore, in the analyzed lifetime of 20 years a gradual increase to 10.4 thousand MWh was the calculation outcome (Table 5).

Energy supply with PV generated electricity

Under this research a simplified method was applied to show how to achieve a PV-nZEB standard (as an nZEB sub-standard) for areas, which are connected to district heating networks (therefore, only electricity demand-supply analyses were performed). A PV-nZEB unit can be defined [1] as a building with a relatively low electricity demand covered by a photovoltaic system (PV).

Three PV technological groups can be considered for application, their technical parameters are presented in Table 7:

- I[st] generation: mono-crystalline solar cells (sc-Si), polycrystalline solar cells (mc-Si), multi-junction Si-thin-film (mj-cells),
- II[nd] generation: thin film amorphous silicon (a-Si), cadmium telluride thin-film solar panels (Cd-Te), CIGS thin-film technology (Copper Indium Gallium Selenide),
- III[rd] generation: DSSC – Dye Sensitized Solar Cells, organic solar cells (OSCs).

Table 6. Chosen technological parameters of I-III PV technology generation [14]

	I[st] generation			**II[nd] generation**				**III[rd] generation**	
Name	mj-cells	sc-Si	mc-Si	a-Si	μc-Si	CdTe	CIGS	DSSC	oSC
Efficiency	30-43%	14-22%	13-18%	6-9%	6-11%	9-11%	10-12%	12%	4-6.5%
*Wp/m²	n.a.	130-190	120-155	50-75	50-110	90-125	70-145	n.a.	n.a.

**peak power to area installed ratio*

Source: Author's

For the analyzed urban unit only two market well established PV technologies were chosen for further calculations: traditional polycrystalline solar cells (mc-Si) and a thin film amorphous silicon (a-Si) technologies (Figure 2). Additional assumptions refer to the decline of PV efficiency in time assuming the rate of 0.5% annually. Later climatic and technical data were used to calculate energy generation in a 20 year perspective (Figure 3).

polycrystalline solar cells (mc-Si)

Source: Internet
http://www.blpower.com.pk/coming-soon/solar-panel/

thin film amorphous silicon (a-Si)

Source: Internet
http://img.archiexpo.com/images_ae/photo-g/62630-7425769.jpg

Fig. 2 PV technologies chosen for calculations
Source: Author's

The roof area dedicated to PV installations was assumed in 3 variants: 30% of the total roof area (33 thousand m^2), 55% (61 thousand m^2) and 70% (77 thousand m^2) respectively.

Table 7. Energy calculations for polycrystalline solar cells (mc-Si), roof inclination angle 30 degrees, facing south

Roof area: 33 thousand m²		**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Solar radiation intensity	Wh/m² per month	37,241	42,707	78,310	103,888	146,709	156,343	157,000	139,619	90,143	55,348	25,960	21,192
I_S_30	kWh/m² per annum	1.0 thousand											
Incident radiation	W/m²	144	134	116	187	213	293	311	347	368	274	210	107
Peak power capacity	kWp	4.5 thousand											
Produced electricity	kWh per month	137,638	137,638	157,840	289,425	383,958	542,220	577,826	580,254	516,016	333,158	204,560	95,945
	MWh per annum	3.8 thousand											

Source: Author's

Results

Under this short research only annual electricity demand/supply balances were analyzed to exemplify the possibility to use buildings' roof for PV installations. It has to be remembered, however that electricity is only a part of the final energy consumption (apart from space heat, ventilation and hot water preparation). Thus, the proposed methodology can serve as an example of calculations in case of areas, which are supplied with heating by district heating networks.

This simplified case study showed that the available roof areas would allow to cover electricity demands for the Czerniaków urban unit only to a limited extent. The first limiting factor was that not the whole roof area can be designated for PV installations, the maximum was assumed at the level of 70%, as the remaining would need to be reserved for other technical functions of the building. In the initial analyzed period of the project 20 year life span, and the most efficient technological option of polycrystalline modules covering 70% of the roof area; the urban unit could produce more energy that it consumed (above 100% autarky level). However, in the later period (after 10 years) two unfavorable factors reverse the positive trend: a decrease of PV efficiency in time and the increasing electricity use per capita (including household appliances) would lower the level of energy to 80% (Figure 3). The choice of a PV technology also matters, the choice of less efficient amorphous silicon membranes resulted in much lower renewable energy shares compared with the polycrystalline PV solution. This is due to much lower peak power to area installed ratio (Table 7).

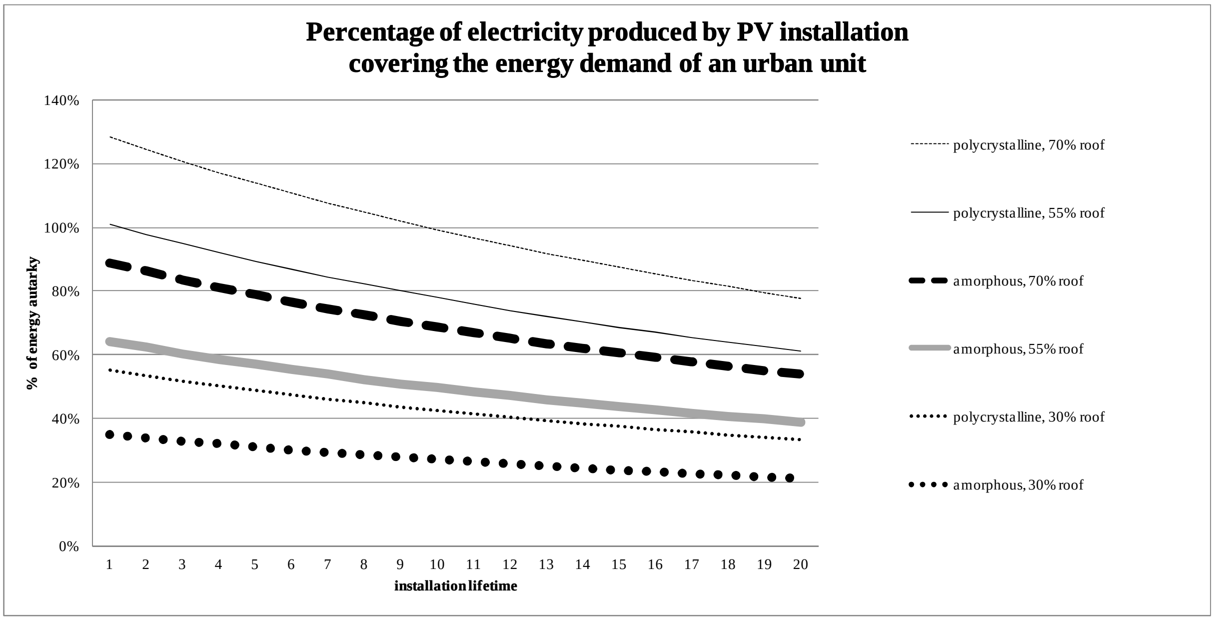

Fig. 4 Calculations of electricity autarky with the usage of 2 PV technologies taking up 30%, 55% and 70% of the available roof area of the urban unit.
Source: Author's

The indication for future modification of the nZEB methodologies would be that high shares of onsite renewables in the electricity balance of an urban zone would be difficult to achieve. An option could be to investigate the possibility of including in the calculation method wall mounted BIPV (building integrated) panels or nearby located generation sources - ground mounted, open space PV installations.

The simplification of the existing energy audit methodologies (departure from the energy audit detailed approach) served its usability and possibility of application at the urban zone level. This refers in particular to urban units, where only electricity balances are to be considered due to connection to an external, district heating system covering heating demands. The suggested new approach can contribute to its popularity among urban planners and other building/construction professionals.

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