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Nearly Zero Energy Community - a transition concept towards sustainability

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ABSTRACT. Environmental challenges imposed by greenhouse gases are currently well recognized and a worldwide commitment tends to be reached, to replace fossil fuels (mainly responsible for global warming and climatic changes) with renewables. Concepts were formulated, as the *Net Zero Energy Building (NZEB)*, although the current building stock mainly consists of old buildings (97%). Thus, technical and cost-related barriers are faced and transition concepts are formulated, as the *Nearly Zero Energy Building (nZEB)*, legally binding for the EU states (starting with 2019/2021), that may ease the transition and can be realistically met, considering the current situation. Following this pattern the paper proposes the Nearly Zero Energy Communities (nZEC) concept, as a transition path to be implemented in various geographical locations, with specific prerequisites. Different scenarios are discussed based on coherent technical solutions, involving large(r) community/districts; the public support is required for a clear definition of the short and long-term community gains.

Keywords: Sustainable built environment, Sustainable communities, Renewables in the built environment, Nearly Zero Energy Communities, Net Zero Energy Communities

1. Energy and the built environment

The role of human settlements in mitigating global heating is currently well-recognized and there are many concepts and scenarios designed to support this aim. However, large scale implementation is still scarce and is mainly focused on individual solutions for buildings further on integrated as NZEB/nZEB in aggregates, [1], or in pilot level applications as the 40 household district in Ithaca N.Y. or the Kupuni village reported by NREL in 2015.

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For a community, the transition towards the Net Zero Energy Community (NZEC) status is a complex task due to the broad variety of the existing buildings, with various energy needs and different energy consumption patterns. In most cases, the implementation of clean energy sources (renewables) has to be simultaneously done with decreasing the energy demand (energy saving) along with increasing the efficient use of the energy (energy efficiency), as proposed by the *Trias Energetica* concept [2].

Considering the renewable energy systems that can be implemented to cover the thermal and electrical energy demand in the built environment, it is obvious that sustainability is mostly insured by solar energy convertors, alone or part of energy mixes that can be accepted in a village, district or city, as those also involving heat pumps, micro-wind turbines, small-hydros, etc. This scenario has limitations coming from the variability of the solar energy input (daily, seasonally, etc.) which does not usually match in the built environment the energy demand pattern, thus raising the problem of energy storage as one of the most challenging issue in the NZEC development. This is particularly valid for thermal energy, as for electricity the grid-connected communities can use in the first transition stages the grid as a backup system or as electrical energy source. Thus, changing an existing community currently relying on fossil fuels to NZEC is a challenging task, with questionable acceptance coming from the inhabitants, if not well prepared. Therefore, gradual changes are recommended, starting with common and accepted steps, further on extended with increasing the solar energy share, by reinvesting the expected profit. This asks for coherent technical planning and management, as already outlined, [3].

The EU strategy set concrete targets for the sustainable development: until 2020 it is expected that 20% of the European energy consumption to be met by using renewable energy systems resulting in a 20% reduction in the greenhouse gases (GHG) emissions; these values have to increase by 2030 to 27% for the renewables share in the total energy consumption and to a 40% reduction of the GHG emissions (compared to 1990); finally, the targets set for 2050 are 41…55% of the RES share in the total energy consumption and an overall reduction of 85…90% in the GHG emissions.

This legal frame supports an intensive work focusing on new and innovative solutions adapted to the built environment; different approaches were set for the new buildings design and for refurbishing the old ones (particularly those built before 1970), [4]. These measures started to be implemented in the individual buildings but it soon became obvious that a more cost-effective solution is to approach groups of buildings (as districts or communities), to estimate the energy demand and to plan how this can be met by renewable energy systems implemented at community level.

Thus the Nearly Zero Energy Community (nZEC) concept was proposed and detailed, [5] as a community with high energy performance buildings and at least 50% of their energy demand covered by renewables implemented in or near the community.

2. The *Nearly Zero Energy Community* concept

The main steps that should be followed in designing a sustainable community are presented in Fig. 1, corresponding to the *Trias Energetica* concept. Firstly the energy demand is decreased by reducing the losses and increasing the energy efficiency in buildings and then the new green energy systems are implemented along with adequate control systems, required in the new buildings.
The first step „Defining the community” is important as it sets the concrete limits of all planning; there can be defined very small communities (as of one apartment or house) or small communities (of few apartments, houses), average or large (micro-) communities (as e.g. a district) or very large communities, as a city.

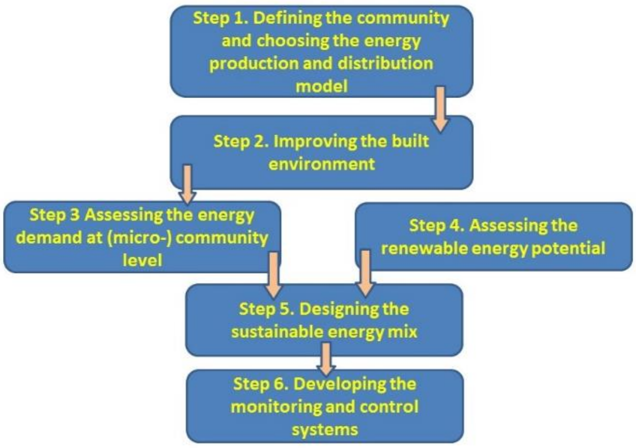

Fig. 1. Steps in the design of a sustainable community

Recommendable is to consider the size that can be unitarily prepared and upgraded to the sustainability level, with affordable costs and with the inhabitants support. In terms of energy use, the thermal energy production required for well-functioning with minimal changes of the existent infrastructure represents the key issue in stating the limits of the community. Basically, two different scenarios can be considered, as presented in Fig. 2:
Scenario A: renewable energy systems scattered implemented, with limited interconnections (especially for thermal energy storage). This scenario mostly resembles a group of nearly zero energy buildings that still has room for improvements.
Scenario B: a coherent approach over the entire community, with specific solutions for each neighbourhood or district (D1, D2 ...). It is to mention that, by careful community planning, it is possible to go from Scenario A to Scenario B, with obvious benefits.

The second step is related to improving the built environment. About 90% of the buildings in Romania are traditional buildings with an average specific energy demand of 200...600 kWh/(m^2 year). These buildings have first to be refurbished, to reach the Low Energy Buildings (LEB) status, [6], with an energy demand of 50...125 kWh/(m^2 year); further on, in an nZEC this demand has to be satisfied at least 50% with energy produced using renewables. Additionally, water management should be considered, targeting water re-use along with the use and management of wastes, e.g. for energy production [7, 8].
The third step is the accurate assessment of the energy demand at community level (yearly and monthly values), outlining the extremes (highest and lowest values). These data can be obtained using the buildings codes and regulations but the best estimations are using the infield data of the actual consumption, using energy consumption records, if available. As by now, thermal energy (heating, cooling, domestic hot water, DHW) is mostly produced in decentralized systems, it is rather difficult to get all accurate and reliable consumption data. So, at least one full year of monitoring with the support of the inhabitants would be necessary, and the values has to be compared with the values given by the building codes.

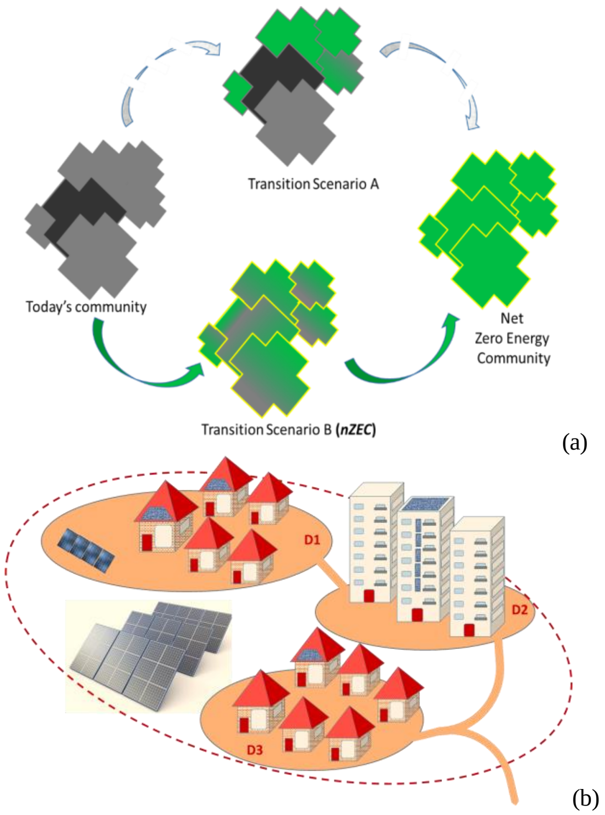

Fig. 2 a) Transition scenarios towards nZEC; b) specific solutions, part of Scenario B

Once estimated the energy demand, the fourth step involves the assessment of the renewable energy potential. The main sources are outlined in Fig. 3:

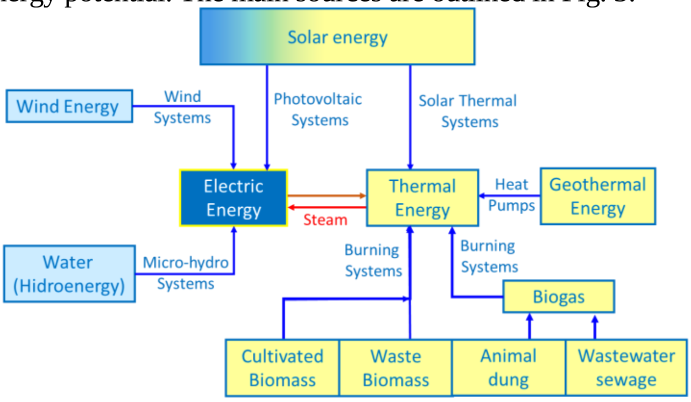

Fig. 3. The renewable energies potential at community level

The energy potential should be estimated based on the prediction and simulation models but at least one year of on-site monitoring is recommended to validate the models. It is important to outline the variability of the renewable resources, with large variations during one year in the solar, wind and hydro energy potentials and much smaller variations of the available geothermal energy. For biomass, one can consider a planned variability, thus biomass can be used also as a backup source when designing systems that involve the other renewable sources.

Further on, in the fifth step, the sustainable energy mix can be designed, considering the systems that can be installed on buildings, [9], and the systems that should be installed at community level, Fig. 4:

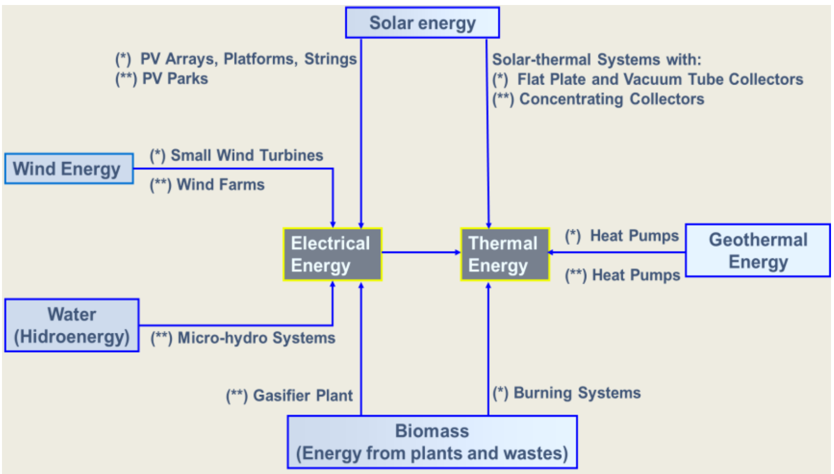

Fig. 4. Renewable energy systems in the community energy mix; (*) systems installed on buildings, (**) systems installed at community level

It is important to consider the variability of the renewable energy potential over the year when designing the components of an energy mix, as for example in a solar-thermal (STS) – heat pump (HP) system, to produce heat. For a given climatic profile (temperate, with cold winters and rather hot summers), modelling data were previously presented, [6] for two mixes having 20% STS and 80% HP, respectively 50% STS and 50% HP; the results showed that the 50:50 energy mix was actually over-dimensioned while the first thermal energy mix was more appropriate for the application. Further on, Fig. 5 shows further optimisation results of the investigated case study.

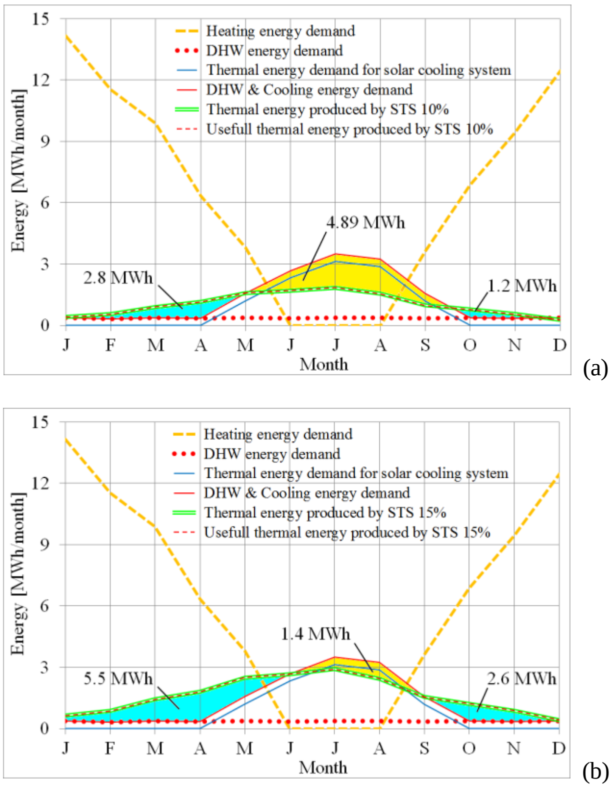

Fig. 5 Energy produced by the STS in (a) a 10% STS+90% HP energy mix and (b) a 15% STS and 85% HP energy mix

As Fig. 5b shows, an energy mix producing 15% of the required thermal energy using solar-thermal systems (STS) and 85% using a heat pump will cover the DHW demand and will fully use the heat produced by the STS for heating (during January – May and September - December), leaving a thermal energy deficit of 1.4 MWh/year particularly for cooling to be covered by conventional sources or other renewables as biomass.

Finally, it is important to have a well-planned control system that gives priority to the best option for energy production in a given situation; this can be the best available renewable energy source, or the most cost-effective renewable source, or the most environmentally friendly one, etc. This can be done at buildings level through the BEMS (Building Energy Management Systems), and it is expected to be further used in the future CEMS (Community Energy Management Systems).

As in developing sustainable communities the technical aspects are important but are not the only ones to be considered, a Community Company for Sustainability can be launched having as main task the successful operation of the sustainable community as a business, [3]. This company should involve local stakeholders and community representatives and should focus on insuring the needs at community level and on investment in future infrastructure, using funds gained after the payback time of the initial investment.

3. Case studies

The steps for the nZEC development were applied in designing the education and research infrastructure in the Faculty of Product Design and Environment dedicated to the study programme Engineering of Renewable Energy Systems, Fig. 6. The infrastructure is located in the Solar House, part of the Transilvania University campus, on the Colina Hill in the city of Brasov, Romania; as presented in Fig. 6 this involves:

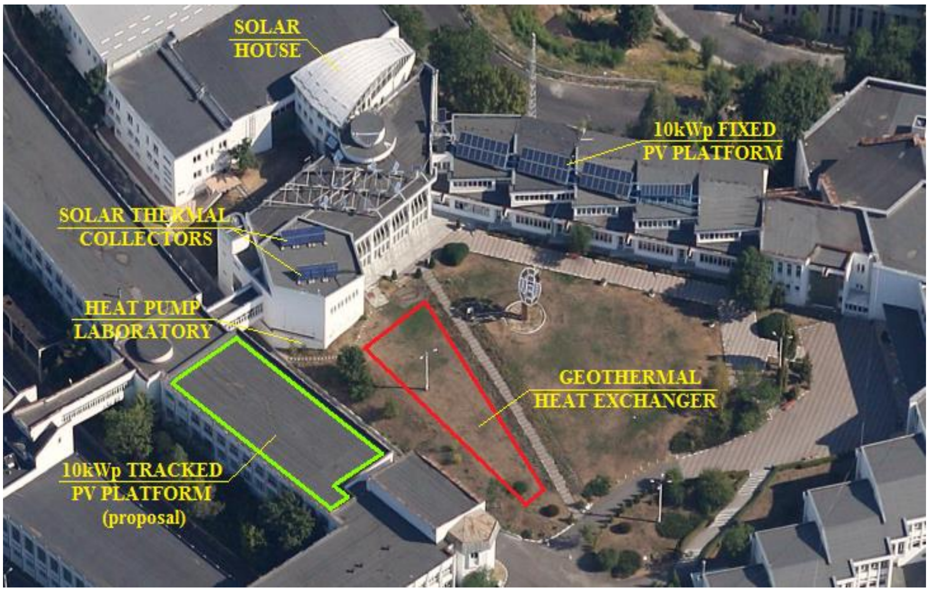

Fig. 6. Education and research infrastructure for sustainable communities (Transilvania University of Brasov, Faculty of Product Design and Environment), [9]

- *For electrical energy production*: photovoltaic modules; there are currently installed: a 10 kWp fixed array and a tracked platform (2 kWp). Further on a tracked 10 kWp array is expected to extend the green electricity production in the near future.

- *For thermal energy production*, an energy mix based on flat plate solar-thermal collectors and a ground coupled geothermal heat pump (10 kW) is implemented.

Considering these systems and the monitored data for the components already installed, it was estimated that about 84% from the total energy demand can be met using renewable energy systems, Table 1. This qualifies the location as a (small) nearly zero energy community.

Table 1. Thermal and electrical energy demand satisfied by renewable energy systems

Thermal energy (heating and DHW) [MWh/year]		Electric energy [MWh/year]		Total energy [MWh/year]	
Demand	Supplied by RES	Demand	Supplied by RES	Demand	Supplied by RES
46.76	44.79	12.75	5.1	59.51	49.89
95.78% RES		40% RES		83.83% RES	

The second case study is the R&D Institute of the Transilvania University of Brasov, launched in 2012 as the major result of the structural funds project „*R&D Institute High-tech Products for Sustainable Development”*, ID123, SMIS 2637, contract no. 11/2009.

The Institute consists of 12 three floors buildings (basement, ground floor and first floor), and an overall surface of 16200 m^2. The buildings are interconnected by a spine and a central meeting space, Fig. 7. The thermal energy demand was estimated based on the actual consumption data, Table 2, and the values confirm that this community reaches the low energy buildings status, with an average yearly consumption of 79 kWh/(m^2 year).

The monitoring data gathered in Table 2 allowed to estimate the thermal energy demand of the community represented by the Institute at: 57.8 kWh/(m^2 year) for heating, 5.75 kWh/(m^2 year) for cooling and 3.14 kWh/(m^2 year) for domestic hot water. Additionally, the electricity consumption for lighting and other appliances (except the laboratory equipment) was 12.3 kWh/(m^2 year). This gives an overall energy demand of 79 kWh/(m^2 year) for the Institute and qualifies the construction in the Nearly Zero Energy Building standard. The average electrical energy mix, for lighting, common appliances and for powering the thermal systems will consist of photovoltaic systems and small wind turbines and will use the grid as backup source. The PV systems can be mounted on the top terrace of each building (117535 kWh/year) and nearby the buildings as a 1 MWp tracked PV park, Fig. 7, while the small wind turbines can be installed on the rooftops (34672 kWh/year). Currently the installed components of the energy mixes are monitored.

Table 2. Monthly thermal energy demand for
the R&D Institute of the Transilvania University of Brasov

Month	Average outdoor air Temp. [°C]	Available solar radiation [kWh/m^2/month]	Degree days [DD/month]		Energy demand in the R&D Institute [MWh/month]		
			Heating	Cooling	DHW	Heating	Cooling
January	-4.90	37	772		4.32	169.56	
February	-2.50	50	630		3.96	138.36	
March	2.60	84	539		4.32	118.56	
April	8.50	105	345		4.2	75.84	
May	13.30	146	208	47	4.32	45.6	10.44
June	16.10	156		92	4.2		20.16
July	17.50	170		123	4.32		27.12
August	17.00	143		114	4,32		24.96
September	13.40	90	198	47	4.2	43.44	10.44
October	7.90	71	375		4.32	82.44	
November	2.80	51	516		4.2	113.4	
December	-1.90	25	679		4.32	149.16	
TOTAL		**1128**	**4262**	**424**	**50.88**	**936.36**	**93.12**

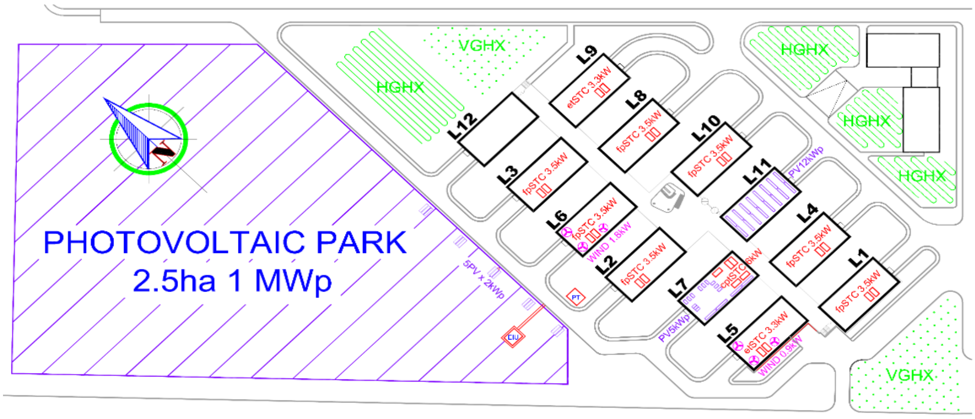

Fig. 7. The renewable energy mix in the R&D Institute of the Transilvania University of Brasov

The implementation of renewable energy systems in the built environment has to comply also with architectural constraints. This is why new geometries and colours are identified for the solar energy convertors, as for the novel solar-thermal collectors with trapeze, [10] or triangle shapes.

4. Conclusions

The wide spread implementation of the measures aiming at increasing the sustainability of our future is linked in a great extent to the way the energy is produced and consumed in various applications.
The built environment is a major energy consumer and there are specifics that has to be considered, related to the types of energy (mostly thermal and electrical energy) and the daily, seasonally and yearly variability of the consumption. This is why the optimal and feasible meeting of the energy demand in the built environment represents a hot research topic.
The implementation of the research findings in the current built environment asks for acceptance and for commitment from the users, and this can be gained if the solutions are technically meeting all the standards and if they are market acceptable. Therefore, EU policies and development strategies are focusing on concepts that support the increased quality of the buildings and the use of renewables as for example in the concept (part of the EU legislation) of *Nearly Zero Energy Buildings*.
Developing these sustainable buildings is well supporting the final aim and the associated costs can be mitigated if more buildings are simultaneously considered as part of a sustainability plan, with the design developed at community level (instead of building level), using joint facilities, e.g. for energy storage. Thus, the paper discusses the advantages of sustainable community planning but also the associated challenges.
The compulsory steps to be followed in planning and implementing a sustainable community are presented and discussed. These are relying on increasing the energy efficiency at buildings level and in supporting large energy savings, to reduce the energy consumption over one year. Further on, the implementation of renewable energy systems is discussed and it is outlined that the community level is more affordable when compared to the sum at building levels, considering the available space and the consumption (the storage systems that can give a significant advantage to community planning).
Last but not least, the involvement of users/inhabitants is important in the transition of traditional communities towards sustainability or in the development of the new sustainable communities, as they are key actors that will benefit and will therefore actively support the novel technical solutions from the beginning. Additionally they will be those that will continuously be part of the quest for finding and implementing more and more efficient and feasible solutions, part of the future energy scenario.

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