ORIGINAL ARTICLE

AiCARR Journal / Vol 61, n. 2, 54 - 59, 2020

Sonia Longo[1], Francesco Guarino[1], Giovanni Tumminia[2], Daniele Friscia[1], Maria Anna Cusenza[1], Marco Ferraro[2], Maurizio Cellura[1]*

Reaching net zero energy at the neighbourhood scale: feasibility studies in the south of Italy

Raggiungere l'energia netta zero a livello di quartiere: studi di fattibilità nel sud Italia

[1] Department of Engineering, University of Palermo, Viale delle Scienze, Building 9, 90128, Palermo, Italy
[2] Institute for Advanced Energy Techonologies "Nicola Giordano" - National Research Council of Italy, Via Salita S. Lucia sopra Contesse 5, 98126 Messina, Italy

***Corresponding author:**
Prof. Maurizio Cellura
Department of Engineering
University of Palermo
Viale delle Scienze, Building 9
90128, Palermo, Italy
maurizio.cellura@unipa.it

DOI: 10.36164/AiCARRJ.61.02.04

Abstract

The concept of "net zero energy building" has been recently implemented in regulations throughout Europe: however, some aspects regarding e.g. the interaction of generation and load between buildings and the energy interactions of each building between each other are often overlooked by an approach that focuses mostly on the single building scale. The objective of the study is to evaluate the potential for reaching net zero energy target on a district level in a mixed-use community in southern Italy. The paper identifies a district case study, made of around twenty buildings having mixed uses. The buildings were modeled in Energy Plus environment and a set of retrofit solutions are identified, including HVAC and envelope components, as well as energy generation options from photovoltaic systems. The retrofitted neighbourhood shows an overall electricity yearly energy use of around 628 MWh_e, with a reduction of around 28% if compared to the existing one. All retrofit solutions show payback times below 13 years.

Keywords:

- Net zero energy building
- nZEB
- Energy retrofit
- Net zero energy clusters

Sommario

Il concetto di "edificio a energia netta zero" è stato recentemente implementato in tutti i regolamenti dei paesi europei. Tuttavia, l'approccio dettato dall'Europa si concentra principalmente sulla scala dell'edificio singolo, tralasciando alcuni aspetti riguardanti ad esempio l'interazione di generazione e carico tra edifici e le interazioni energetiche tra edifici. L'obiettivo di questo studio consiste nell'applicazione della definizione di net zero energy building ad un gruppo di edifici ubicati nell'Italia meridionale e caratterizzati da una destinazione d'uso variegata.

Lo status quo di una ventina di edifici è stato simulato in ambiente energy plus e sono state successivamente selezionate una serie di soluzioni di retrofit applicate sia sull'involucro sia sugli impianti. Per raggiungere il target di edificio a energia netta zero si è ipotizzato di generare energia da sistemi fotovoltaici a scala di distretto. Grazie alle soluzioni di retrofit il quartiere avrà un consumo complessivo annuo di circa 628 MWh_e, con una riduzione di circa il 28% rispetto alla situazione precedente. Tutte le soluzioni di retrofit proposte hanno tempi di ritorno dell'investimento inferiori ai 13 anni.

Parole chiave:

- Edificio a energia netta zero
- nZEB
- Retrofit energetico
- Quartieri a energia netta zero

Introduction

Net zero energy buildings (nZEB), defined as a grid-connected building that generates as much energy as it uses over a year (Salom et al., 2014) are currently included in research agendas as well as policy plans throughout the world. The concept of net zero energy on a single building level, in any of its declinations and shapes, is of particular relevance to several domains of application. Although a wide variability of definitions exist for how "net zero" should actually be achieved throughout the world (i.e. uncertainty on conversion factors and energy uses to include in the energy balance) (Mohamed et al., 2014; Noris et al., 2014) some of the aims and targets are usually shared in any regulatory framework.

Firstly, the idea of nZEB aims at a decarbonization of the economy and of the energy sector through an intensive deployment of renewable energy technologies, but also is oriented towards the new paradigm in distributed energy generation (D'Agostino e Mazzarella, 2019; Candanedo e Athienitis, 2011) as well as to relieve the load on the energy distribution system (Guarino et al., 2015; Bobba et al., 2018). However, applying the definition of net zero energy to the single building has some limits: basically focusing on a single building with specific use profiles, occupants behaviour, features and specifics of the energy load to cover, may have only limited impacts on the actual achievement of the on-site consumption as the heterogeneity in energy generation/use profiles might still cause lack of alignment between generation and energy use (Marique et al., 2013). Moreover, another issue may lie within specific buildings features, i.e. the historical value in heritage buildings, whereas it may be impossible to perform energy oriented retrofits or installing renewable based systems, or the geometry i.e. tall buildings may not have sufficient areas where to physically place renewable energy generation systems to cover the whole of their needs. Thus the step towards the neighbourhood level when defining net zero energy targets may be particularly effective, as the load diversity may smooth load profiles inside the district, generation excesses from one building may be re-directed towards those with higher needs at the specific time – thus reducing the need for energy storage. Moreover, reasoning on a district scale can allow a more efficient energy planning of the renewable energy systems being needed in the neighbourhood with no constraints on the fulfilment of an energy balance limited on the boundaries of the single unit (Franzitta et al., 2010; 2014).

In previous studies, the net zero energy objective is most often considered at the building scale. Several papers propose thus definitions of net zero energy buildings (Marszal et al., 2011), calculation methodologies (Cellura et al., 2011; 2018), renewable technologies (Beccali et al., 2016; Finocchiaro et al., 2016; Guarino et al., 2017) or support tool for early stages of design (Cellura et al., 2017; Ciulla, 2012). However, despite the different advantages to extend the net zero energy targets from the single unit to neighbourhood level, research and papers dealing with net zero energy at larger scales are not numerous: a few papers study the design of a net zero energy neighbourhood (Hachem-Vermette et al., 2018), while only a limited range of research addressing the problem of retrofit at neighbourhood scale (Sartori e Calmon, 2019). Moreover, comprehensive retrofit guidelines for achieving high-energy performance mixed-use neighbourhoods are sorely lacking.

In this context, this paper aims at contributing the existing papers relating to net zero energy by investigating the feasibility of this objective at the neighbourhood scale. Moreover, the study forms part of a large scope research programme aimed at assessing the effects of multiple retrofit parameters on energy performance of such neighbourhoods, and the development of guidelines for their redesign.

This study therefore aims to analyse the energy consumption and the application of different retrofit measures in an existing neighbourhood located in the southern coast of Sicily (Italy). The buildings were modeled in Energy Plus environment and a set of retrofit scenario is identified, including HVAC and envelope components, as well as energy generation options from PV systems. In addition, a preliminary analysis of the economic feasibility of the different scenario options have been conducted.

Methods

Case study

The selected neighbourhood is located in the city of Sciacca, in the southern coast of Sicily (Italy). This location is characterized by a comfortable climate, with mild winters and moderately hot summers. Although not representative of all the locations of the Mediterranean, this climate is very close to a wide range of coastal Mediterranean sites. Figure 1 shows an aerial image of the selected neighbourhood and identifies the location and quantity of the buildings analysed.

Figure 1 - Aerial image of the selected neighbourhood

Figura 1 - Foto aerea del quartiere esaminato

The case studies were selected to obtain a sample of buildings having mixed uses, such as residential, offices, commercial activities and schools. In total, 19 multi-storey buildings were identified, including 147 residential apartment (R), 1 school (S), 16 commercial activities (C) and 8 offices (O). In detail, all the selected buildings are detached building with balconies. Of these, 12 are six floors buildings, 5 have five floors, while the remaining 2 buildings are 2 and 3 floors buildings, respectively.

All buildings were built in the period between 1970 and 1980. Since it was not possible to analyse the envelope features of each building, they were chosen according to the typical construction used in the Sicilian context during the decade 1970-1980. In particular, the thermophysical properties of existing buildings envelope components in terms of U-values are estimated at 0.86 W/(m^2 K) (walls), 5.8 W/(m^2 K) (windows), 0.33 W/(m^2 K) (roofs), 2.19 W/(m^2 K) (basement concrete slab floor) and 1.73 W/(m^2 K) (ceiling floor). All external walls have a mass layer (brick, 25 cm for external walls) without insulation material. The buildings were fitted with clear single-glazed aluminium window, whit a solar heat gain coefficient equal to about 0.82. For each building, heating is based on a conventional natural gas boiler and an autonomous air-to-air heat pump, which also covers cooling needs. The only exception is Building 1 (the school), which is not provided of a cooling system.

Table 1 shows the intended use and useful area of all the buildings selected. One building has a useful surface less than 1,000 m^2 (Building 4), five buildings have a useful surface between 1,000 m^2 and 1,500 m^2, while nine of these have a useful surface between 1,500 m^2 and 2,500 m^2, finally four buildings have a useful surface higher than 2,500 m^2.

Table 1 - Intended use and useful surface of the analysed buildings. R: residential apartment; S: school; C: commercial activities; O: offices

Tabella 1 - Destinazione d'uso e superficie utile degli edifici analizzati. R: appartamenti residenziali; S: scuole, C: attività commerciali; O: uffici

Building	Intended use	Useful Surface [m²]	Building	Intended use	Useful Surface [m²]
1	S	5,170	8a	R - C - O	1,440
2a	R	1,800	8b	R - C	1,440
2b	R - C	1,800	8c	R - C	1,440
2c	R	1,800	9	R - C	3,240
2d	R	1,800	10	R - C	2,640
3	R - C	1,200	11a	R	2,000
4	R	486	11b	R	2,000
5	R - C - O.	2,160	11c	R	2,000
6	O	3,102	11d	R	2,000
7	R - C	1,440	Neighbourhood	-	31,947

Modeling

Buildings have been modeled in Energy Plus environment (Crawley et al., 2000). Simulations were run with meteorological data from the Meteonorm database [22] for the city of Sciacca. Infiltration, always active during the day, is modeled using the equation (ASHRAE, 2017):

$$\text{Infiltration} = I_d \cdot (A + B \cdot (T_z - T_o)) + C \cdot W_s + D \cdot W_s^2) \qquad (1)$$

where I_d is the expected average infiltration hourly value, T_z is the air temperature of the zone, T_o is the outside air temperature and W_s is the wind speed. All constants (A, B, C, D) are those used for the BLAST software and reported in the Energy Plus documentation [2].

Natural ventilation is modeled through the separate contributions of wind and stack to the airflow through the Wind and stack empiric formulation (ASHRAE, 2017). In detail, wind induced ventilation is obtainable through equation (2), while equation (3) is used for calculating the ventilation rate due to stack effect.

$$Q_w = C_o \cdot A \cdot F \cdot W_s \qquad (2)$$

$$Q_s = C_D \cdot A \cdot F_s \cdot \sqrt{2 \cdot g \cdot \Delta H_{NPL} \cdot (|T_z - T_o| / T_z)} \qquad (3)$$

where C_o is the opening effectiveness, A is the opening area [m²], F is the opening area fraction, C_D is the discharge coefficient for opening, ΔH_{NPL} is the height from midpoint of lower opening to the neutral pressure level [m]. In detail, windows are open when external air temperature is in the range of 17 °C < T_e < 25 °C, internal temperature is higher than 21 °C and wind speed is lower than 3 m/s.

Levels of occupancy were based on the real occupancy levels of the investigated buildings. In detail, for the residential use, through surveys analysis to the owners of each building, ten different types of representative use profiles were identified. The offices and the commercial activities, were occupied during working days from 9:00 a.m. until 8:00 p.m., with a break for lunch from 1:00 p.m. to 4:00 p.m., while the school (Building 1) was occupied from 8:00 a.m. until 2:00 p.m.

Lighting and electrical loads are determined in terms of average load per unit area, through site investigations. In detail, Figure 2 shows the electric daily profile for lighting and electrical loads assumed for each building analysed. The lighting systems use light bulbs while the electric equipment included different appliances depending on the type of building, such as refrigerators, computer, etc.

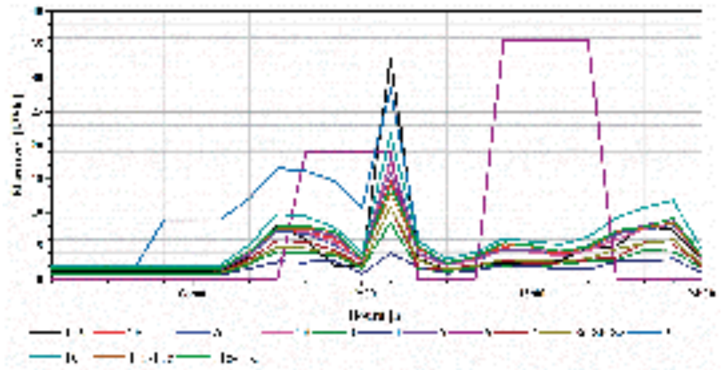

Figure 2 - *Electric daily profile for electrical loads*

Figura 2 - Profilo giornaliero dei carichi elettrici

Heating is based on a conventional natural gas boiler (total efficiency equals to 0.77) and an air-to-air heat pump (coefficient of performance (COP) of about 3 and energy efficiency ratio (EER) of about 4.). To cover the heating and cooling demand an ideal loads air system, using 20 °C and 26 °C as heating and cooling set-points, was used. Electricity and gas data for heating and cooling are calculated as generated with a heat pump and a gas boiler with constant performance coefficients over time.

Retrofit solution scenario

Five retrofit solutions, commonly used in the Mediterranean building retrofitting projects, were selected for the retrofit analysis, as shown in Table 2. The energy-saving measures were applied to both the building envelope and the heating system. Within the five solutions, two are HVAC measures covering efficiency of cooling and heating equipment; one is for lighting upgrade to LED; another one is replacement with high-performance windows. Finally, insulation measures were taken for the roof, façade and floor.

Table 2 - The proposed retrofit solution

Tabella 2 - Soluzioni proposte per il retrofit

Name	Description
HVAC - heating	Replace existing heating systems with high-efficiency natural gas condensing boiler with an annual fuel utilization efficiency of 0.84
HVAC - cooling	Replace existing cooling systems with an air-to-air heat pump with an EER of 6.2
Transparent envelope	Replace existing window glasses and frames with high performance windows (U-value: 3 W/(m² K) - SHGC: 0.78)
Opaque envelope	Installation of a layer of insulating material (thickness: 5 cm; thermal conductivity: 0.038 W/(m K) on the external side of all external walls
Lighting	Replace existing lighting systems with LEDs

In addition to the measures applied to the buildings envelope and the HVAC systems, the potential of renewable energy generation on site was analysed. Therefore the economic and energy impacts of adding a photovoltaic system were calculated for each examined building. In detail, a PV system is assumed to cover all the available roof surfaces of each building. The tilt angle of 30° is selected for being within the optimal range for the studied location (Sciacca, latitude 37.3 °N) corresponding to latitude ±10°. The Equivalent One-Diode model employed in EnergyPlus is selected to perform electricity generation simulations of the PV systems. This model employs a four-parameter empirical model to predict the electrical performance of PV modules [24]. Table 3 shows the nominal power of the photovoltaic systems installed on each building. In detail, the nominal power of photovoltaic systems varies between 8.1 kW_p (Building 1) and 62.4 kW_p (Building 9), with a total nominal power equals to about 413 kW_p.

Table 3 - Nominal power of the photovoltaic systems installed on each building

Tabella 3 - Potenza nominale dei sistemi fotovoltaici installati su ciascun edificio

Building	PV system [kW_p]	Building	PV system [kW_p]
1	8.1	8a	18
2a	21.6	8b	19.8
2b	25.2	8c	21.6
2c	23.4	9	62.4
2d	23.1	10	31.5
3	12.6	11a	13
4	9.6	11b	12.5
5	27	11c	13.5
6	40.8	11d	13.5
7	16.2	-	-

Assessment Criteria

The comparison between the existing neighbourhood (the base case) and the retrofitted one was performed based on primary energy consumption. Moreover, to verify if the nZE district target, defined in this work as primary energy balance greater than or equal to zero, on a single and on district level is achieved, the following primary energy balance was considered:

$$\text{Primary Energy Balance} = G \cdot W_{gen} \, (L_{el} \cdot W_{el} + L_{gas} \cdot W_{gas}) \qquad (4)$$

where G is the generated energy, L_{el} is the electrical load, w_{el} is the weighting factor for the electricity energy carrier (2.42 kWh_p/kWh_f), w_{gen} is a generation weighting factor (2.42 kWh_p/kWh_f), which in this study is considered equal to the grid electricity generation conversion factor in order to give value to the fact that the PV generated energy substitutes the energy generation from the conventional power grid. L_{gas} is the natural gas consumptions and w_{gas} the weighting factor for the natural gas energy carrier (1.05 kWh_p/kWh_f).

Moreover, also an import/export balance was calculated, considering only the electric energy:

$$\text{Import / Export Balance} = E_{export} - E_{import} \qquad (5)$$

where E_{export} and E_{import} are the exported and imported energy, respectively.In order to investigate the temporal match between load and generation for the retrofitted neighbourhood, the load cover factor (γload) index was calculated. Defined in equation (6), it represents the percentage of the electrical demand covered by on-site electricity generation:

$$\Upsilon_{load} = \int_{\tau_1}^{\tau_2} \min[g(t),l(t)] \, dt \Big/ \int_{\tau_1}^{\tau_2} l(t) \, dt \qquad (6)$$

where g(t) is the on-site generation (kW), while l(t) is the building load (kW), t is the time, τ1 and τ2 are the start and the end of the evaluation period, respectively.

Finally, since to reach the target of nZEBs, the technical feasibility in general is not sufficient to help the diffusion of nZEBs into building current practice, a preliminary analysis of the economic feasibility of the different retrofit option was conducted. However, since the research goal was not the costs minimization of the proposed retrofit solutions, a method for the cost minimisation was not taken into account, but to investigate the economic feasibility of the proposed retrofit solution, a simple investment payback time was calculated as the retrofit investment cost divided by the annual savings (the general assumptions are summed up in Table 4).

Table 4 - Systems costs assumed for the retrofit solution

Tabella 4 - Costi dei sistemi assunti nelle soluzioni per il retrofit

	[€/kW_p]		[€/m²]		[€/W]
HVAC - heating	60	Transparent envelope	140	Lighting	1
HVAC - cooling	185	Opaque envelope	7.8		

Results and discussions

Results of the simulations of each type of building for the base case, in terms of electricity consumption, natural gas (NG) consumption and of primary energy consumption are summarized in Table 5. At the neighbourhood scale, the yearly electricity and the natural gas demand are about 805 MWh_e and 84 10^3 m^3, respectively. The primary energy consumption is about 2,830 MWh_p, it is for the most part due to appliances and lighting (59%). Limited impact on the consumptions are due to heating (31%), cooling (10%).At building level, the primary energy consumption is variable between 77.71 MWh_p (Building 4) and 360.68 MWh_p (Building 9).

Table 5 - Simulation results for the base case neighbourhood

Tabella 5 - Risultati della simulazione per il caso base del quartiere

	Final energy		Primary Energy		
Building	NG	Electricity	NG	Electricity	Total
	[10^3 m^3]	[MWh_e]	[MWh_p]	[MWh_p]	[MWh_p]
1	13.03	21.5	137.50	52.03	189.53
2a	2.96	43.32	31.24	104.83	136.07
2b	5.16	46.52	54.45	112.58	167.03
2c	4.19	40.7	44.21	98.49	142.71
2d	4.13	41.75	43.58	101.04	144.62
3	2.27	24.03	23.95	58.15	82.11
4	1.33	26.31	14.03	63.67	77.71
5	5.59	79.75	58.99	193.00	251.98
6	0	82.11	0.00	198.71	198.71
7	3.64	30.62	38.41	74.10	112.51
8a	4.04	33.56	42.63	81.22	123.85
8b	4.22	35.18	44.53	85.14	129.67
8c	5.53	37.01	58.36	89.56	147.92
9	9.24	108.75	97.51	263.18	360.68
10	7.56	59.12	79.78	143.07	222.85
11a	2.29	23.41	24.17	56.65	80.82
11b	2.55	24.06	26.91	58.23	85.13
11c	2.77	24.19	29.23	58.54	87.77
11d	3.24	23.22	34.19	56.19	90.38
Neighbourhood	83.74	805.11	883.67	1,948.37	2,832.03

Table 6 presents the simulation results for the proposed retrofit solutions summarized in Table 2. At neighbourhood scale, the results show an overall electricity energy use and an overall natural gas consumption of around 628 MWh_e and 49 10^3 m^3, respectively, marking a reduction of around 22% and of about 42%, respectively, if compared to the existing one. Considering the primary energy uses, the results show an overall reduction of about 28%, while at building level, if compared to the base case, it decrease between the -15% (Building 11c and Building 11d) and the -51% (Building 5).

Due to the measures applied to the buildings envelope and the HVAC systems, if compared to the base case, the heating primary energy demand and the cooling primary energy demand show an overall reduction of about 41% and 63%, respectively. Considering the heating energy demand, if compared to the base case, Building 1 is characterized by the lowest reduction (-8%), while Building 6 is characterized by the highest decrease (-82%). On the other hand, for the cooling energy demand, Building 6 is characterized by the lowest decrease (-51%) while Building 10 is characterized by the highest reduction (-73%). Finally, Table 6 also shows also the preliminary cost analysis results in terms of simple payback time (PBT). The results show that the proposed retrofit solutions are economically feasible because for all buildings the return times of economic investments are lower than the mean useful life of the proposed solutions. In detail, in all cases the PBTs are lower than 13 years; for 50% of the buildings the PBTs are below 9 years.

Table 6 - Simulation results for the retrofitted neighbourhood

Tabella 6 - Risultati della simulazione del quartiere post retrofit

Building	Final energy NG	Final energy Electricity	Primary Energy NG	Primary Energy Electricity	Primary Energy Total	PBT
	[10^3 m^3]	[MWh$_e$]	[MWh$_p$]	[MWh$_p$]	[MWh$_p$]	[years]
1	11.94	12.51	126.00	30.27	156.27	12.70
2a	1.07	27.83	11.29	67.35	78.64	5.60
2b	3.01	39.02	31.76	94.43	126.19	8.00
2c	2.12	34.91	22.37	84.48	106.85	9.00
2d	2	35.37	21.11	85.60	106.70	8.60
3	1.02	19.56	10.76	47.34	58.10	11.30
4	0.64	14.93	6.75	36.13	42.88	3.70
5	2.1	41.59	22.16	100.65	122.81	3.30
6	0	63	0.00	152.46	152.46	10.20
7	1.85	24.91	19.52	60.28	79.80	8.00
8a	1.86	27.85	19.63	67.40	87.02	9.70
8b	2.02	29.32	21.32	70.95	92.27	9.00
8c	3.15	32.86	33.24	79.52	112.76	10.60
9	4.62	96.09	48.75	232.54	281.29	7.60
10	3.98	48.66	42.00	117.76	159.76	8.00
11a	1.13	20.23	11.92	48.96	60.88	11.40
11b	1.35	19.5	14.25	47.19	61.44	9.70
11c	2.49	19.95	26.28	48.28	74.55	9.90
11d	2.67	20.22	28.18	48.93	77.11	12.40
Neighbourhood	49.02	628.31	517.28	1,520.51	2,037.79	7.90

Figure 3 shows the potential yearly electricity PV generation for each building (Figure 3a) and the monthly electricity generation at neighbourhood scale (Figure 3b). Moreover it shows two yearly different energy balances at building level: a primary energy balance calculated using equation (4) (Figure 3c) and an import/export energy balance considering only the electricity energy (Figure 3d). Finaly, Figure 3e and Figure 3f show monthly the primary energy balance and the import export energy balance at at neighbourhood scale, respectively. The yearly electricity energy produced at neighbourhood level is about 660 MWh$_e$ (1,600 MWh$_p$ of primary energy), while at building level it varies between 13.10 MWh$_e$ (Building 1, 8.1 kW$_p$ PV system) and 97.85 MWh$_e$ (Building 9, 62.4 kW$_p$ PV system). As shown by Figure 3c for the base case, even if photovoltaic systems are installed on each building with a total installed power equal to 413 kW$_p$, the NZE target at neighbourhood scale is not achievable, with a deficits of about 1223 MWh$_p$ of primary energy. Moreover, although the primary energy deficit (-441 MWh$_p$) has decreased significantly compared to the base case, also the retrofitted district does not achieve the nZEB target. Only Building 2a (+3.98 MWh$_p$), Buidling 4 (+31.75 MWh$_p$) and Building 6 (+1.28 MWh$_p$) are able to achieve a positive primary energy balance, while for all the 16 buildings analysed, the NZE target is not attainable: the primary energy balance varies between -124.54 MWh$_p$ (Building 1) and -10.47 MWh$_p$ (Building 3).

As shown in Figure 3d, while the base case neighbourhood shows a negative import/export balance (-145.33 MWh$_e$), the retrofitted neighbourhood shows a positive balance (+31.47 MWh$_e$), which means that yearly at district level the building export electricity. Moreover, at building level, for the retrofitted district, only the building 10 shows a negative import/export balance (-2.65 MWh$_e$), while for all the others investigated building the import/export balance varies between +0.12 MWh$_e$ (Building 3) and +15.91 MWh$_e$ (Building 4).

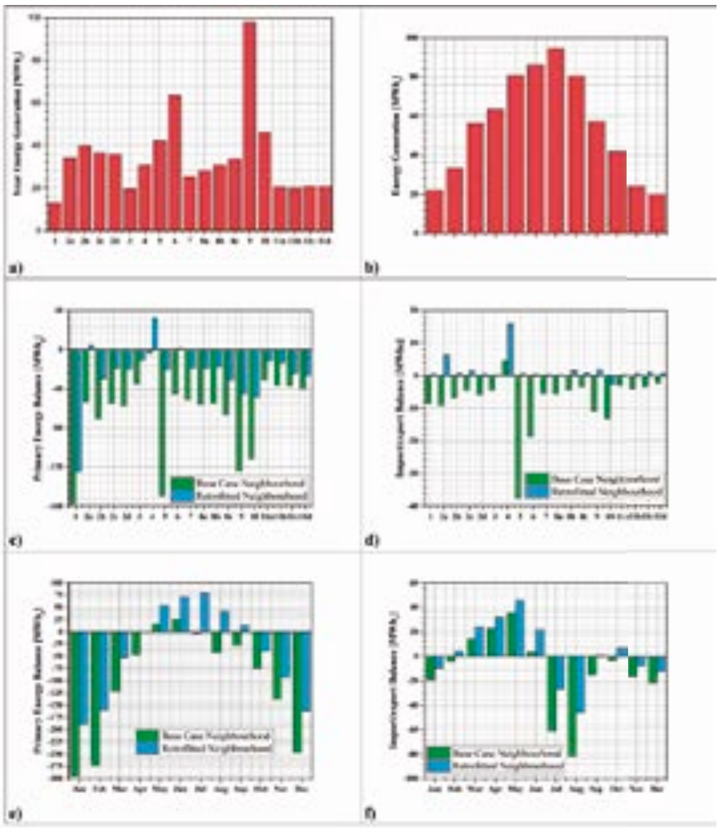

Figure 3 - *a) yearly PV electric energy generation at building level; b) monthly PV electric energy generation at neighbourhood scale. c) yearly primary energy balance at building level; d) yearly import/export energy balance at building level; e) monthly primary energy balance at neighbourhood scale; f) monthly delivered/exported energy balance at neighbourhood scale*

Figura 3 - a) generazione annua di energia elettrica da PV a livello di edificio; b) generazione mensile di energia elettrica da PV a livello di quartiere. c) bilancio annuo di energia primaria a livello di edificio; d) bilancio annuo di energia importata/esportata a livello di edificio; e) bilancio mensile di energia primaria a livello di quartiere; f) bilancio mensile a livello di quartiere; f) bilancio di energia importata-esportata a scala di quartiere

Finally, the yearly graphical representations of γload for the retrofitted neighbourhood (Fig.) shows the correlation between on-site energy demand and supply. In detail, X-axis in the graph represents the hours of the day (1-24), the y-axis are the days of the year (1-365), while the levels of colours in the graph represent the values γload. The γ_{load} strictly follows the on-site PV energy generation. In particular, sometimes it can reach 1 during the day as generation reaches its peak, decreases during low solar radiation hours while during the night it is equal to zero.

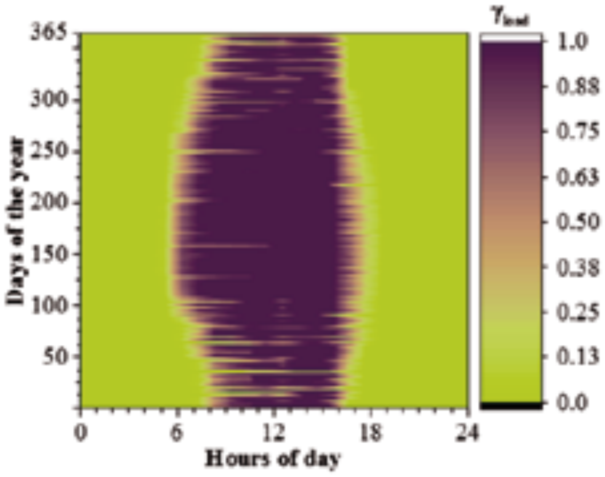

Figure 4 *- Hourly γ_{load} for the retrofitted neighbourhood*

Figura 4 - γ_{load} orario relativo al caso studio post-retrofit

CONCLUSIONS

This paper presents a set of retrofit solutions to reach the NZE target at district level of a mixed-use neighbourhood located in Sciacca, Italy. The neighbourhood comprises offices, a school, commercial activities and about 150 residential units for a useful buildings surface of about 32,000 m^2. The measures applied to the buildings envelope and the HVAC systems allow to reduce primary energy consumption at district level by 28% compared to the base case. Moeover, while the base case yearly at district level imports about 145 MWh$_e$, retrofitted neighbourhood annually exports 31.5 MWh$_e$.

The preliminary cost analysis shows that the proposed retrofit solutions are economically feasible: in all cases the PBTs are lower than 13 years. In this context, the paper shows as analysing energy performance of a mixed-use community as an integrated system represents a prospect to share energy resources (e.g. between energy positive buildings and others), and to explore opportunities for seasonal storage, controlling peak electricity production timing and reducing utility peak demand. Further benefits could be achieved by the use of energy flow optimization algorithms or by the use of Supervisory Control And Data Acquisition (SCADA) systems between the various buildings. Finally, this work is intended to serve as a model for the redesign and analysis of mixed-use neighbourhoods in the Mediterranean climate.

REFERENCES

ASHRAE. 2017. Fundamentals. ASHRAE Handbook. Atlanta: ASHRAE.

Beccali M., Cellura M., Longo S., Guarino F. 2016. Solar heating and cooling systems versus conventional systems assisted by photovoltaic: Application of a simplified LCA tool. Solar Energy Materials and Solar Cells. 156, 92-100.

Bobba S., Mathieux F., Ardente F., Blengini G.A., Cusenza M.A., Podias A., Pfrang A. 2018. Life Cycle Assessment of repurposed electric vehicle batteries: an adapted method based on modelling energy flows. Journal of Energy Storage, 19, 213-225.

Candanedo J.A., Athienitis A.K. 2011. Strategies for reducting peak demand in net-zero energy solar homes. Proceedings of ISES Solar World Congress 2011, 1557-1567.

Cellura M., Campanella L., Ciulla G.., Guarino G., Lo Brano V., Cesarini D.N., Orioli A. 2011. The redesign of an Italian building to reach net zero energy performances: A case study of the SHC Task 40 - ECBCS Annex 52. Proceedings of ASHRAE Annual Conference, Part 2, Montreal,331-339.

Cellura M., Guarino F., Longo S., Mistretta M. 2017. Modeling the energy and environmental life cycle of buildings: A co-simulation approach. Renewable and Sustainable Energy Review, 80, 733-742.

Cellura M., Guarino F., Longo S., Tumminia G. 2018. Climate change and the building sector: Modelling and energy implications to an office building in southern Europe. Energy for Sustainable Development, 45, 46-65.

Ciulla G., Lo Brano V., Cellura M., Franzitta V., Milone D. 2012. A finite difference model of a PV-PCM system. Energy Procedia, 30, 198-206.

Crawley D.B., Lawrie L.K., Pedersen C.O., Winkelmann F.C. 2000. Energy plus: energy simulation program. ASHRAE Journal, 42, 49-56.

D'Agostino D., Mazzarella L. 2019. What is a Nearly zero energy building? Overview, implementation and comparison of definitions. Journal of Building Engineering, 21, 200-212.

Finocchiaro P., Beccali M., Cellura M., Guarino F., Longo S. 2016. Life Cycle Assessment of a compact Desiccant Evaporative Cooling system: The case study of the "Freescoo". Solar Energy Materials and Solar Cells. 156, 83-91.

Franzitta V., Milone A., Milone D., Pitruzzella S., Trapanese M., Viola A. 2014. Experimental evidence on the thermal performance of opaque surfaces in Mediterranean climate. Advanced Materials Research, 860, 1227-1231.

Franzitta V., Rizzo G. 2010. Renewable energy sources: A mediterranean perspective. ICBEE 2010. Proceedings of the 2nd International Conference on Chemical, Biological and Environmental Engineering, 48-51.

Guarino F., Athienitis A., Cellura M., Bastien D. 2017. PCM thermal storage design in buildings: Experimental studies and applications to solaria in cold climates. Applied Energy, 185, 95-106.

Guarino F., Cassarà P., Longo S., Cellura M., Ferro E. 2015. Load match optimisation of a residential building case study: A cross-entropy based electricity storage sizing algorithm Applied Energy, 154, 380-391.

Hachem-Vermette C., Guarino F., La Rocca V., Cellura M. 2018. Towards achieving net-zero energy communities: Investigation of design strategies and seasonal solar collection and storage net-zero. Solar Energy, 192, 169-185.

Marique A.F., Penders M., Reiter S. 2013. From Zero Energy Building to Zero Energy Neighbourhood. Urban form and mobility matter. Proceedings of 29th PLEA Conference on Sustainable Architecture for a Renewable Future,Munich, 1-6.

Marszal A.J., Heiselberg P., Bourrelle J.S., Musall E., Voss K., Sartori I., Napolitano A. 2011. Zero Energy Building - A review of definitions and calculation methodologies. Energy and Buildings, 43, 971-979.

Mohamed A., Hasan A., Sirén K. 2014. Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives. Applied Energy, 114, 385-399.

Noris F., Musall E., Salom J., Berggren B., Jensen S.Ø., Lindberg K., Sartori I. 2014. Implications of Weighting Factors on Technology Preference in Net Zero Energy Buildings. Energy and Buildings, 82, 250-262.

Salom J., Marszal A.J., Widén J., Candanedo J., Lindberg K.B. 2014. Analysis of load match and grid interaction indicators in net zero energy buildings with simulated and monitored data. Applied Energy, 136, 119-131.

Sartori T., Calmon J.L. 2019. Analysis of the impacts of retrofit actions on the life cycle energy consumption of typical neighbourhood dwellings. Journal of Building Engineering, 21, 158-172.

WEB REFERENCES

[1] https://inis.iaea.org/search/search.aspx?orig_q = RN:32006411
Global meteorological database for solar energy and applied climatology Meteotest.

[2] https://energyplus.net/sites/default/files/pdfs_v8.3.0/EngineeringReference.pdf
EnergyPlus engineering reference: the reference to EnergyPlus calculations 2005 US Dep. Energy.