Design and performance analysis of a zero-energy settlement in Greece

Fabrizio Ascione[1], Nicola Bianco[1], Rosa Francesca De Masi[2*], Maria Dousi[3], S. Hionidis[4], S. Kaliakos[4], Elena Mastrapostoli[5], Michael Nomikos[3], Mattheos Santamouris[5], Afroditi Synnefa[5], Giuseppe Peter Vanoli[2] and Kostantina Vassilakopoulou[5]

[1]DII—Department of Industrial Engineering, University of Naples Federico II, Piazzale Tecchio 80, 80125 Napoli, Italy

[2]DING—Department of Engineering, University of Sannio, Piazza Roma 21, 82100 Benevento, Italy

[3]School of Architecture, Aristotle University of Thessaloniki, University Campus, 541 24 Thessaloniki, Greece

[4]Olympias Company, Katerini, Greece; [5]Group Buildings and Environmental Studies, National and Kapodistrian University of Athens, Building of Physics—5, University Campus, 157 84 Athens, Greece

Abstract

Zero-energy and zero-carbon buildings would be a huge opportunity for contrasting the climatic changes and, more in general, the deterioration of the microclimate inside and around cities. About it, a question appears compulsory: are zero-energy and zero-carbon concepts applicable at urban scale? This paper tries to answer to this question, by discussing the possible effects of the application of appropriate city planning techniques when a new settlement is designed. An integrated approach to urban planning is applied to a case study, for promoting the design of buildings with very low (or zero) energy needs, characterized by high indoor comfort conditions, by taking into consideration whole city areas, with different kinds of services. Passive heating, cooling and daylighting techniques have been combined, as well as the integration of renewable sources, in order to minimize the energy demand and environmental impact, for having a sustainable 'urban balance' and, in general, a sustainable urban growth. As real case study, the design of the holiday village 'Olympiad' is presented; it should be built in an unstructured seaside area in Greece. Several indexes are introduced to evaluate the global sustainability of the settlement, through the application of the definition of 'on-grid ZEB', with reference to each building as well as for the entire village. This kind of research could help city planners for a growth inspired to general goals of urban sustainability.

Keywords: net zero-energy buildings; sustainable building activity; energy efficiency measures; numerical simulations; indoor thermal comfort

*Corresponding author.
rfdemasi@unisannio.it

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1 INTRODUCTION: NET AND NEARLY ZERO-ENERGY BUILDINGS

A strong reduction in $CO_{2\text{-eq}}$ emissions in the building sector, which currently account for 43% of the European Union's total, is essential to meet the goal of a progressively carbon-free European economy [1]. The reduction in energy consumption in this sector is, therefore, a priority of the '20–20–20' actions for energy efficiency [2–4].

EU policymakers have largely recognized the importance of energy-efficient buildings in mitigating the climatic change, starting from the Energy Performance of Buildings Directive (EPBD) during the 2002 (revised by means of the EPBD Recast in the 2010 [5]) and, recently, through the Energy Efficiency Directive (EED)

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2012/27/EU [4]. A key element of the EPBD Recast, in order to achieve long-term objectives of energy efficiency and sustainability, is the introduction of the standard of nearly zero-energy building (NZEB). According to the EPBD, an NZEB is 'a building that has a very high energy performance, for which the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby'.

Presently, Member States are discussing about how much energy the building can consume, which renewable energy sources are allowed and how close to the building the energy has to be generated. The European Commission Overview document [6], as well as the same Directive 2010/31/EU [5], established that the definition of NZEB is a task that should be defined at national level. Today, where a numerical indicator is set, the requirements—in terms of primary energy—range rather widely from 0 to 270 kWh/(m^2y). For residential buildings, the energy demands range between 33 kWh/(m^2 year) in Croatia and 95 kWh/(m^2 year) in Latvia, with a majority of countries aiming at 45–50 kWh/(m^2y). Few Member States mentioned objectives that go beyond NZEB requirements, and thus the targets of net zero-energy buildings (ZEBs) in the Netherlands, positive-energy buildings in Denmark and France, carbon neutral new buildings in Germany and zero-carbon standard in the UK.

In the present scientific literature, the net ZEB and NZEB concepts are described with a wide range of approaches, such as evidenced in the deep review proposed by Marszal *et al.* [7]. The most important issues are: the metric of the balance, the balancing period, the types of energy use included in the balance, the kind of energy balance, the accepted renewable energy supply options, the connection to the energy infrastructure, the requirements of energy efficiency and the indoor microclimate. As stated by Torcellini *et al.* [8], four general principles concerning the ZEB definitions have to be considered:

- Net zero site energy: the building produces at least as much energy as it uses in a year, when accounted for at the site.
- Net zero source energy: the building produces at least as much energy as it uses in a year, when accounted for at the source.
- Net zero-energy costs: the money paid to the building owner for the energy supply to the grid is at least equal to the amount of money that the owner pays for the service and the energy used over the year.
- Net zero-energy emissions: the building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

Hernandez and Kenny [9] have introduced the definition of life cycle ZEB. Some methods for energy/emission calculation for ZEBs have been proposed in the framework of the International Energy Agency [10], as discussed recently by Bourrelle *et al.* [11]. The authors proposed an alternative balance following an attributional approach aimed at preventing an increase in the demand for non-renewable energy.

For what concerns the design process of a ZEB, Wang and colleagues [12] underline that at least three focuses are required: (a) the analysis of local climate data, (b) the application of both active and passive design solutions and (c) the integration of renewable energy systems. However, few studies emphasize the importance of employment of energy efficiency measures before utilization of renewable energy sources. In this frame, Pless and Torcellini [13] introduce a new definition in which a ZEB is 'a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies'. Furthermore, Iqbal [14] says 'zero-energy home is the term used for a home that optimally combines commercially available renewable energy technology with the state of the art energy efficiency construction techniques'. Moreover, with reference to the design approach, there are not many scientific studies and the most part of these does not consider all involved decision variables. As underlined by Ferrara *et al.* [15], the technical optimum of an NZEB is not the product of a simple sum of performances related to the optimal value of each parameter, but it is determined by the optimal interaction among the design parameters. Kapsalaki *et al.* [16] have proposed a methodology and a calculation platform for identifying the economic-effective design solutions for residential NZEB, by taking into consideration the influence of local climate and economic conditions. The authors affirmed that the most expensive NZEB design solution, in terms of initial cost, is at least three times more expensive than the cheapest design solution in terms of life cycle cost. They have also found that the 'optimal' design solutions, for mild-winter climates, can be significantly cheaper compared with the ones for cold-winter climates. Moreover, by using a cost-optimized approach, Sun [17] has investigated the impacts of the main NZEB design parameters with reference to the sizes of HVAC systems, renewable energy technologies and energy storage systems. He has found that all building system sizes and the overall initial investment costs are highly sensitive to the indoor temperature set points. Efficiency and coefficient of performances (COPs) of active systems and internal gain intensity are significant, while wall thicknesses and window-to-wall ratios have medium impacts. Infiltration rate and wind turbine losses have very slight impacts, while the PV efficiency has different effects, depending on the system sizes and the overall costs.

Lu *et al.* [18] have presented a comparative study concerning two design optimization methods, for renewable energy systems, in NZEB and net ZEBs, by means of a single objective optimization, based on a genetic algorithm (GA) and a multi-objectives' optimization by using non-dominated GAs. They have underlined that, when the emphasis is put on $CO_{2\text{-eq}}$ emission, grid interaction index—or to combined objectives concerning the total cost, $CO_{2\text{-eq}}$ emissions and grid interaction index—the performances of both ZEBs and low-energy buildings are better compared with the benchmark building. Furthermore, some other studies concern the application of the cost-optimal methodology, established by the EPBD Recast [5], for designing especially NZEB. Becchio *et al.* [19], for a single-family house in northern

Italy, have compared different solutions of HVAC systems according to the macro-economic approach of the EPBD guidelines. They have concluded that NZEBs are technically feasible but, today, are not the cost-optimal solution. Ascione *et al.* [20] proposed a large study about the cost-optimal refurbishment of a multi-story building in Italian Climates, by finding the optimal solutions, in terms of energy efficiency measures and packages of refurbishment technologies, when various budgets are available for different stakeholders. Analogously, Hamdy *et al.* [21] have proposed a multi-stage optimization method to find the cost-optimal configuration and the levels of energy performance for NZEB, for a single-family house in Finland. They conclude that it is economically feasible to achieve NZEB with an energy demand of 70 kWh/(m^2a), even if incentives are required for promoting houses with lower environmental impacts.

Kurnitski *et al.* [22], for an Estonian reference detached house, have tested a seven-step procedure for determining the cost-optimality and levels of energy performance for NZEB. They underline that the cost-optimal primary energy can be calculated also without the use of an iterative approach or optimization algorithm. Sesana and Salvalai [23] have provided an overview of the main life cycle methodologies (LCMs) for identifying their principles, limitations and implications. The authors concluded that all of these approaches need further researches to embrace the concept of ZEB.

Based on the existing scientific works, it is evident that the scientific community has been interested, until now, to the optimization of single building design, with deepening of both technologies and methodological approach. Indeed, for different climates, the most effectiveness solutions have been investigated or the design and refurbishment approach has been discussed through the presentation of complex optimization procedures. Few studies emphasize the necessity to extend the 'zero approach' to the urban scale. About it, Marique and Reiter [24] propose a simplified framework applied to two representative case studies (an urban neighborhood and a rural neighborhood), in order to investigate the feasibility of zero-energy standards.

According to the opinion of the authors, since environmental sustainability of our global society is becoming more and more questionable, it should be investigated the feasibility of zero-energy and zero-carbon concepts at the urban and district level. European environmental goals could be reached only with the strong involvement of local authorities on the production, maintenance and management of zero energy buildings on the city level. Indeed, due to the fast urbanization and increasing of living standards, it is necessary to develop a real global approach of sustainability at the 'urban scale', connected with the evaluation of energy performances and pollution emissions. About it, the proposed paper discusses the possible effects of the application of suitable city planning techniques when a new settlement is designed. Some indexes and their limits are introduced for evaluating the effectiveness of the proposed energy conservation measures.

The proposed paper is aimed to contribute to future research in matter of urban planning for improving the living condition and the economic potentialities of large amount of citizens. Indeed, there are not studies that evaluate how it is possible to improve the energy and environmental conditions in cities or districts and open urban areas by considering the NZEB approach. Thus, the investigations provide comparative results for different types of buildings in several scenarios, so as to achieve a zero or nearly zero energy consumption rating. The analysis of these results could be useful for introducing a methodological approach for designers and stakeholders in order to define a strategy for nearly zero-energy settlements. Briefly, the results of the proposed case study could be the starting point for the development of new more efficient legislative frames, by setting mandatory targets of sustainable and green design for a whole urban district.

Moreover, the results could allow also the investigations of the most suitable design solutions, if any, that lead to ZEBs in a Mediterranean climate. Indeed, in the design of a ZEB or, with greater difficulties, during the refurbishment of an existing building with the aim of making this low- or zero-energy, there are many selectable technical solutions. The most current technologies are: thermal insulation materials and windows highly efficient, mechanical ventilation systems with heat recovery and integration of renewable energy sources. The combinations of these energy efficiency measures are varied and the resulting effect is different from the linear sum of the results achieved by the individual measures. In other words, a linear superposition principle cannot be applied. It is also clear that the optimal solutions, under the point of view of the energy performance, are also linked to the climate of the location and to the kind of use of the building. Moreover, each solution, however, is associated with an investment cost that often becomes the main obstacle to the application, or the main criterion by which the technical solutions are chosen. Therefore, the case study results allow to evaluate if the current nearly or net ZEB principles are feasible and obtainable with already existing technologies in the Mediterranean area.

In the next sections, the proposed approach will be extensively discussed as well as all results of the proposed case study.

2 ZERO-ENERGY AND ZERO-CARBON SETTLEMENT: DESCRIPTION OF THE PROPOSED DESIGN APPROACH

The aim of this study is to discuss the feasibility of the 'zero balance approach' from the energy and environmental point of views, by considering entire settlements with different kinds of use of buildings. Therefore, in this section, it is described a comprehensive methodological approach concerning the evaluation of the sustainability of a town or an urban district. Some indexes, suitable for selecting energy efficiency measures to design low- and/or ZEBs, are introduced too, also by taking into account the minimization of environmental impacts. The proposed 'settlement zero approach' considers three issues:

- net site energy flux;
- integration of renewable production;
- avoided polluting emissions.

The net site energy flux (Φ) allows to evaluate if a building converts enough renewable energy, on site, for balancing or to exceed its annual energy use. Thus, it is the difference between 'surplus energy going to utility' and 'electricity coming from utility'. If it is 'zero-energy', the building generates at least as much energy as it uses in a year, when accounted for at the site (net ZEB).

The renewable integration will be evaluated in terms of 'on-site use' to 'total renewable production' ratio: ($E_{\mathrm{rw,use}}/E_{\mathrm{rw}}$). This index indicates the penetration of renewable production on the energy balance of the complex 'building/HVAC' system. A high value for this index means that a great part of renewable production is used on-site, and it is has a significant value, above all if the criticalities of management of the national networks—when there is an excessive imbalance between energy supply and withdrawn—are considered.

Moreover, the 'use of renewable energy' to 'the total building electric demand' ratio has been calculated too ($E_{\mathrm{rw,use}}/E_{\mathrm{el}}$). Obviously, this give a measure of the amount of renewable energy used for the building services: a high value means that a small amount of energy is required from the grid. Furthermore, other two indexes will be used for the settlement evaluation:

- the 'net electricity coming from utility' to 'the total building electric demand' ratio: $E_{\mathrm{utility,IN}}/E_{\mathrm{el}}$,
- the 'surplus electricity going to utility' to 'the total building electric demand' ratio: $E_{\mathrm{utility,OUT}}/E_{\mathrm{el}}$.

The avoided emissions of equivalent carbon dioxide ($\Delta CO_{2\text{-eq}}$) of each building and of the whole urban area will be evaluated, because this causes the Global Warming phenomenon. This index allows to establish the effectiveness in terms of avoided carbon pollution and possibility to support a clean-energy economy, for the proposed design solution compared with a reference scenario. The emission of equivalent carbon dioxide will be evaluated by considering the LCA (Life Cycle Assessment) emission factors. In detail, for the request of natural gas and electricity, respectively, the values of 0.237 $tCO_{2\text{-eq}}/MWh$ and 1.167 $tCO_{2\text{-eq}}/MWh_{el}$ have been considered, by taking into account the overall life cycle of the energy source or vector, as suggested by the studies of the Covenant of Majors [25].

Immediately, it has to be clarified that the baseline concept of ZEB, for this study, is that each building is bi-directionally connected to the electric grid and the 'balance approach' is based on the evaluation of both primary and electric energy requests, by taking into consideration a time period equal to 1 year. Indeed, as underlined in [26], by taking into account both energy and $CO_{2\text{-eq}}$ emissions, the energy performance of a net ZEB or NZEB should be indicated in terms of primary energy, because it accurately reflects the depletion of fossil fuels and it is sufficiently proportional to the $CO_{2\text{-eq}}$ productions.

The proposed approach is applied at the design of a holiday village in Greece. The main typologies of analyzed buildings are: retail stores, leisure and central markets, touristic residences and hotels. Several energy simulations have been performed by means of EnergyPlus v 8.1 [27], a well-accredited simulation tool operating under transient conditions, based on the resolution methodologies of BLAST and DOE-2, developed, respectively, by the Department of Defense (DOD) and the Department of Energy (DOE), with the ASHRAE (Technical Committee 4.7 Energy calculation) contribution. This whole energy simulation program has been successfully used in many studies, because of its authoritativeness and capability, at the building scale [28, 29] or with reference to set of buildings [30] or urban level [31], even if, of course, proper definitions of models and calibration are needed.

The paper is organized in three main sections: (i) presentation of reference buildings for the case study; (ii) energy and environmental analyses of passive and active energy conservation measures for the design of ZEB; (iii) discussion about environmental impact and green energy effectiveness for the sustainability of the settlement.

3 A ZERO-ENERGY SETTLEMENT DESIGN IN MEDITERRANEAN AREA

The designed holiday village, called 'Olympiad', will be examined. In the incoming years, it should be built in an unstructured seaside area of 2 350 000 m^2 in Katerini (Figure 1), with the aim to achieve very low energy needs and high indoor comfort conditions, as described in the next lines. The design is a collaboration between engineers, technicians and architects and considers also social/functional issues, integration with the environment, morphological and geometrical characteristics.

One of the main design targets is to achieve huge energy savings compared with a reference normative scenario, so that, by means of integration of renewable energy systems, it allows to build a net or nearly zero-energy district. For this reason, in this study, before the discussion concerning the sustainability of the settlement, the effect of single energy efficiency measures will be evaluated by considering the energy saving (ΔEP) achievable compared with a reference scenario. This last is the result of the application of the legislative requirements and prescriptions, concerning both the building thermal envelope and the active energy systems.

3.1 Presentation of the case study: geo-morphological details and urban setting description

Katerini is the Capital city of the Regional Unit Pieria (Central Macedonia, Greece). It lies on the Pierian plain, between Mt. Olympus and Thermaikos Gulf, at the sea level. Katerini is included in the Greek climatic zone G and has a typical Mediterranean climate, characterized by warm-to-hot and dry summers and cool and wet winters, according to the Köppen climate classification. The average low air temperatures (∼1°C) occur in January, while the hottest months are July and August, when the average high temperatures rise up to 33°C. During spring and autumn, the high temperatures range between 15°C (March and November) and

Figure 1. *Overview of Olympiad village.*

25°C (May and October) with average low temperature around 5°C (March and November) and 12°C (May and October).

A bioclimatic approach has been established since the settlement conception, so that the overall picture of the area would present an interesting variety within a single style, in relation with the natural environment and the characteristics of the local—often historical—architectures. The central commercial and administrative functions are located in the center of the settlement, while recreational functions are placed along the beach. The residential areas and small hotels, moreover, will be located in a quiet tree-lined area, protected from noise, in a pleasant natural environment.

The total area is divided into three zones with different functional, morphological, geometric and urban characteristics. The first sector (A), with orthogonal shape, is ~789 500 m^2. It includes residential uses, hotels (up to 20–30 beds), retail shops, restaurants and leisure facilities as well as central functions (central market, administrative center). The area of roads, walkways and parking zones is ~283 000 m^2 (i.e. 35% of total), while the common green is ~139 200 m^2 (i.e. 18% of total).

The second sector (B), adjacent to a protected natural area, has mainly residential uses, hotels (up to 20 beds), retail shops and playgrounds. It is ~1 210 300 m^2. Roads, walkways and parking areas occupy ~31% of global extension, while the green area is 342 700 m^2 (28% of global extension).

Finally, the area C (~41 500 m^2) has a big hotel complex, of ~32 286 m^2 (78% of total area).

3.2 Definition of the reference buildings for a holiday village

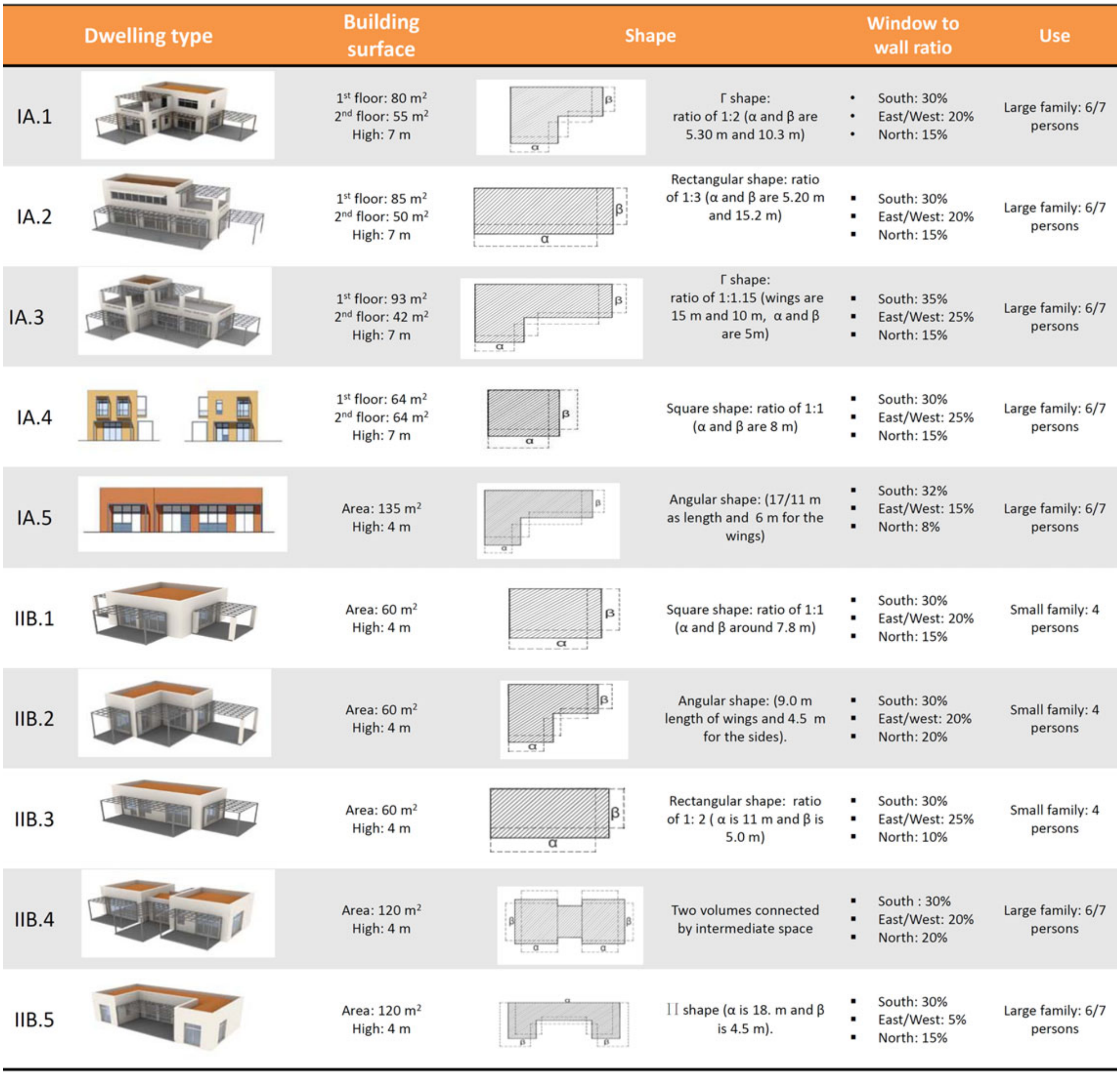
The EU Delegated Regulation n. 244/2012 of 16 January 2012—supplementing the Directive 2010/31/EU of the European Parliament and of the Council—introduces the concept of 'Reference Building' (RB). This is a hypothetical or real building, having typical building geometry and systems, typical energy performances, functionality and costs, with reference to both thermal envelope and energy systems. Moreover, RB is representative of climatic conditions and geographic location. Starting from this definition, the reference design scenario is based on the requirements of the 'Regulation on Energy Performance in the Building Sector—KENAK' issued by the Greek Ministry of Environment, Energy and Climatic Change (YPEKA), with the Ministerial Decision MD6/B/5825 (FEK 407/B/9.4.2010). The KENAK introduces the general calculation method in compliance with the European standards, among which the EN ISO 13790/2008 [32] and the overall approach for issuing an energy performance certificate (EPC). This takes into consideration also the four technical guidelines (TOTEE 20701-4/2010), developed by the Technical Chamber of Greece (TEE) and approved by YPEKA (MD 17178 FEK 1387/B/2.9.2010). In our case study, the RBs for the buildings under investigation will be characterized by the minimum requirements established by the national regulation, with reference to both the building construction and the heat generation, storage and distribution system types for the space heating and the domestic hot water (DHW).

3.2.1 *Architectural description*

For the Olympiad village, 10 different residential building typologies have been designed (from A.1 to A.5 and from B.1 to B.5), by taking into consideration typical sizes of the Greek residential building stock. Figure 2 summarizes the main geometrical characteristics of the houses.

Buildings with two floors host large families, since, at the ground floor, living room and kitchen, two bedrooms and one bath are located, while, at the first floor, there are other two bedrooms and one bath. One-story dwellings, more generally, can have a large living room with separated kitchen, two large bedrooms and two baths.

For commercial activities, six reference buildings (Figure 3) are proposed. More in detail, A.k1 and A.k2 are designed for being used as retail markets, catering or bar-cafeteria. At the ground floor, there are kitchen, toilets, dinner room and services for disabilities, while, in the basement, public toilet and staff facilities can be located. The main room is organized with large windows and can use the shaded outdoor areas. Moreover, the commercial building types of sector B can be used for retail market, with the exhibition and sale of the products at the ground floor and, in the basement (if provided), the services for the staff. The building identified as A.k3 is a small commercial center. The geometric organization is based on a square grid, with a porch that creates a gallery for the customers. The functional grid of the building allows small (4 × 4 m) and medium (4 × 8 m) spaces, sometimes larger, depending on typology of commercial activity. Thus, the building can host small offices, small shops or superstores, restaurants etc. Furthermore, the inner courtyard can host several social and cultural events.



Dwelling type	Building surface	Shape	Window to wall ratio	Use
IA.1	1st floor: 80 m^2 2nd floor: 55 m^2 High: 7 m	Γ shape: ratio of 1:2 (α and β are 5.30 m and 10.3 m)	South: 30% East/West: 20% North: 15%	Large family: 6/7 persons
IA.2	1st floor: 85 m^2 2nd floor: 50 m^2 High: 7 m	Rectangular shape: ratio of 1:3 (α and β are 5.20 m and 15.2 m)	South: 30% East/West: 20% North: 15%	Large family: 6/7 persons
IA.3	1st floor: 93 m^2 2nd floor: 42 m^2 High: 7 m	Γ shape: ratio of 1:1.15 (wings are 15 m and 10 m, α and β are 5m)	South: 35% East/West: 25% North: 15%	Large family: 6/7 persons
IA.4	1st floor: 64 m^2 2nd floor: 64 m^2 High: 7 m	Square shape: ratio of 1:1 (α and β are 8 m)	South: 30% East/West: 25% North: 15%	Large family: 6/7 persons
IA.5	Area: 135 m^2 High: 4 m	Angular shape: (17/11 m as length and 6 m for the wings)	South: 32% East/West: 15% North: 8%	Large family: 6/7 persons
IIB.1	Area: 60 m^2 High: 4 m	Square shape: ratio of 1:1 (α and β around 7.8 m)	South: 30% East/West: 20% North: 15%	Small family: 4 persons
IIB.2	Area: 60 m^2 High: 4 m	Angular shape: (9.0 m length of wings and 4.5 m for the sides).	South: 30% East/west: 20% North: 20%	Small family: 4 persons
IIB.3	Area: 60 m^2 High: 4 m	Rectangular shape: ratio of 1: 2 (α is 11 m and β is 5.0 m)	South: 30% East/West: 25% North: 10%	Small family: 4 persons
IIB.4	Area: 120 m^2 High: 4 m	Two volumes connected by intermediate space	South : 30% East/West: 20% North: 20%	Large family: 6/7 persons
IIB.5	Area: 120 m^2 High: 4 m	∐ shape (α is 18. m and β is 4.5 m).	South: 30% East/West: 5% North: 15%	Large family: 6/7 persons

Figure 2. *Reference buildings for dwellings.*

Six reference four-stars hotel have been proposed (Figure 4):

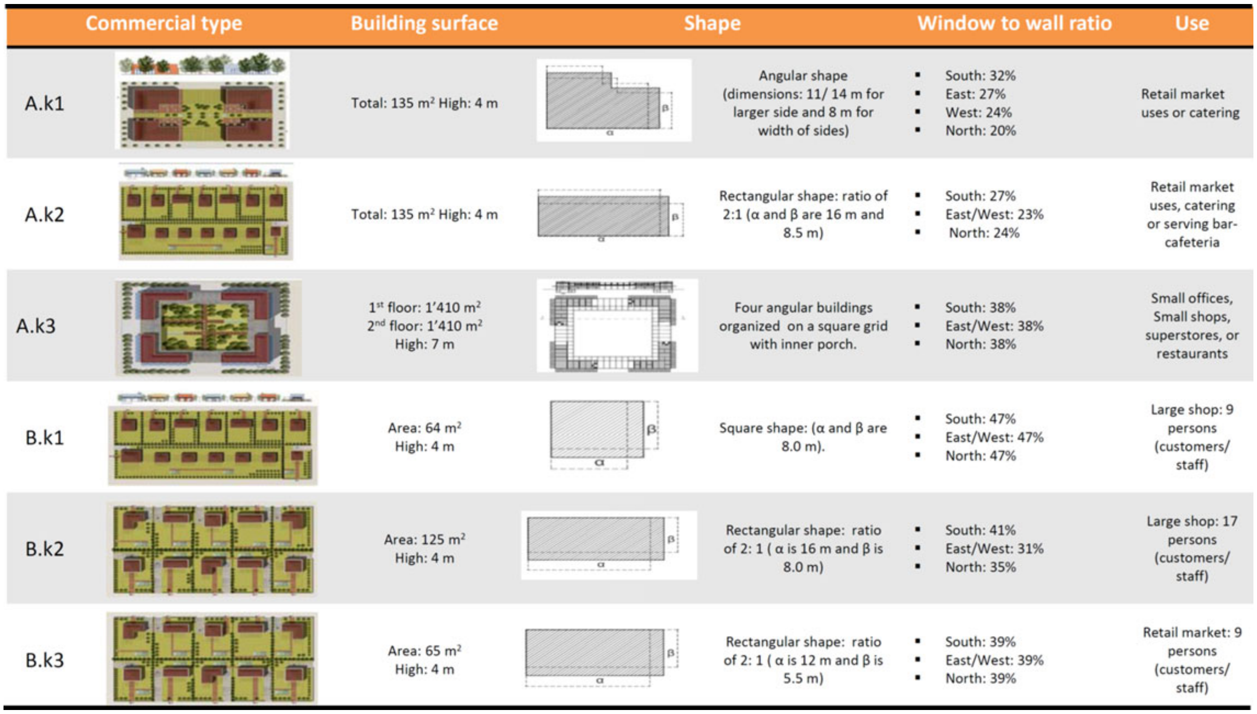
- from 20 to 30 beds (sector A),
- to 20 beds with volume equal or lower than 1000 m^3 (sector B).

In the first type of hotel, common services (i.e. reception rooms), cloakrooms, breakfast area and bar are placed on the ground floor. In sector B, hotel provides separated double rooms in which the costumers have private services such as a small kitchen. In the main square building, there are all public areas, like entrance and reception, breakfast area, bar etc.

Finally, one five-stars hotel has been proposed (C, Figure 4). The basic principle of the design is to organize a building complex, for 500 beds, with rooms oriented toward the sea or to the Mount Olympus and having, in the middle zone, the reception and other services with extensive outdoor spaces for various sports, cultural and other events.

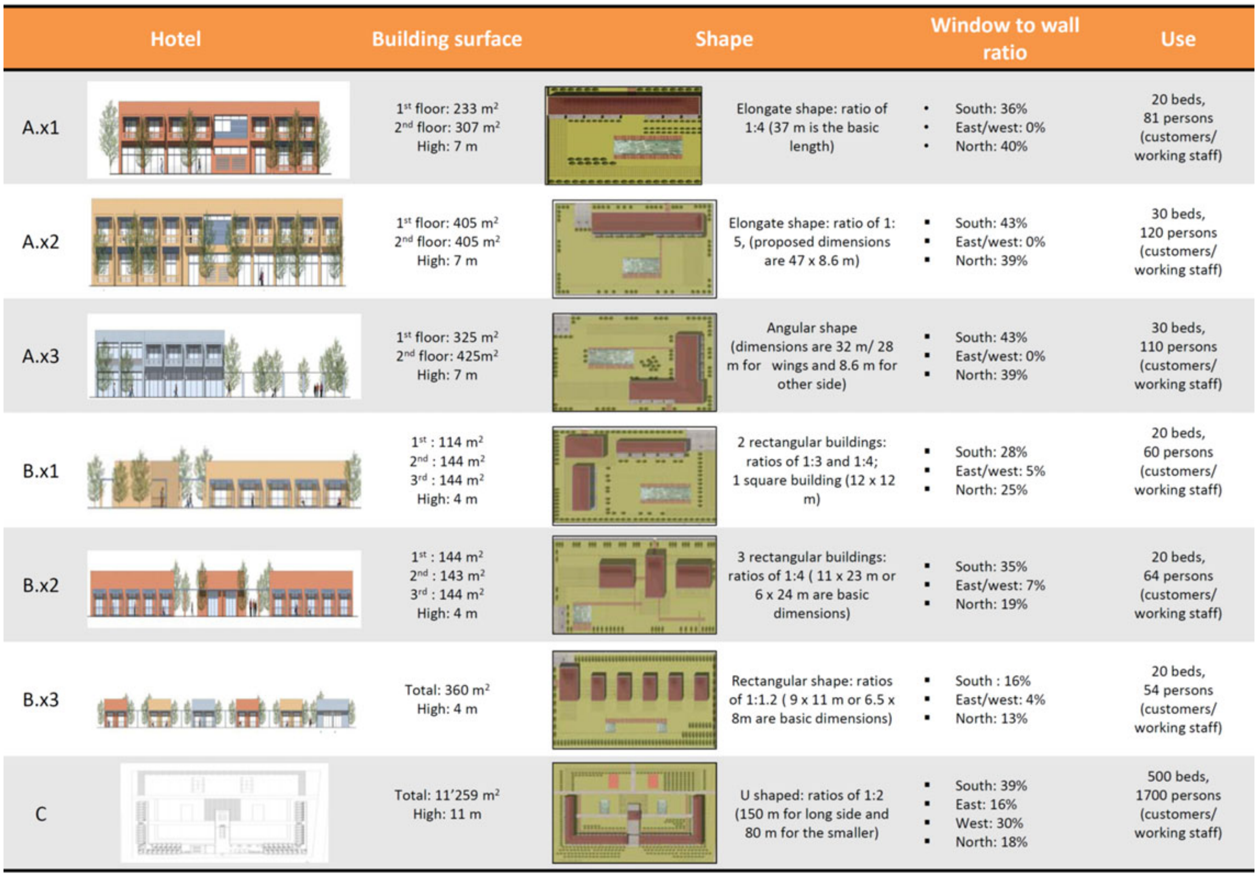
3.2.2 *Bioclimatic design of the village*

All reference buildings are designed with passive bioclimatic technologies aimed at an optimum integration in a natural context. According to Attia and Duchhart [33], the first step, before any urban planning, should be the analytic investigation of the local environment and climatic factors. Moreover, as recommended by Mingozzi and Bottiglioni [34], it is important to think to the project area as a unique entity, without splitting this into many separated parcels, disconnected and undifferentiated. In order to address those considerations, the Olympiad village has been



Commercial type	Building surface	Shape	Window to wall ratio	Use
A.k1	Total: 135 m² High: 4 m	Angular shape (dimensions: 11/ 14 m for larger side and 8 m for width of sides)	South: 32% East: 27% West: 24% North: 20%	Retail market uses or catering
A.k2	Total: 135 m² High: 4 m	Rectangular shape: ratio of 2:1 (α and β are 16 m and 8.5 m)	South: 27% East/West: 23% North: 24%	Retail market uses, catering or serving bar-cafeteria
A.k3	1st floor: 1'410 m² 2nd floor: 1'410 m² High: 7 m	Four angular buildings organized on a square grid with inner porch.	South: 38% East/West: 38% North: 38%	Small offices, Small shops, superstores, or restaurants
B.k1	Area: 64 m² High: 4 m	Square shape: (α and β are 8.0 m).	South: 47% East/West: 47% North: 47%	Large shop: 9 persons (customers/ staff)
B.k2	Area: 125 m² High: 4 m	Rectangular shape: ratio of 2: 1 (α is 16 m and β is 8.0 m)	South: 41% East/West: 31% North: 35%	Large shop: 17 persons (customers/ staff)
B.k3	Area: 65 m² High: 4 m	Rectangular shape: ratio of 2: 1 (α is 12 m and β is 5.5 m)	South: 39% East/West: 39% North: 39%	Retail market: 9 persons (customers/ staff)

Figure 3. *Reference buildings for commercial activities.*



Hotel	Building surface	Shape	Window to wall ratio	Use
A.x1	1st floor: 233 m² 2nd floor: 307 m² High: 7 m	Elongate shape: ratio of 1:4 (37 m is the basic length)	South: 36% East/west: 0% North: 40%	20 beds, 81 persons (customers/ working staff)
A.x2	1st floor: 405 m² 2nd floor: 405 m² High: 7 m	Elongate shape: ratio of 1: 5, (proposed dimensions are 47 x 8.6 m)	South: 43% East/west: 0% North: 39%	30 beds, 120 persons (customers/ working staff)
A.x3	1st floor: 325 m² 2nd floor: 425m² High: 7 m	Angular shape (dimensions are 32 m/ 28 m for wings and 8.6 m for other side)	South: 43% East/west: 0% North: 39%	30 beds, 110 persons (customers/ working staff)
B.x1	1st : 114 m² 2nd : 144 m² 3rd : 144 m² High: 4 m	2 rectangular buildings: ratios of 1:3 and 1:4; 1 square building (12 x 12 m)	South: 28% East/west: 5% North: 25%	20 beds, 60 persons (customers/ working staff)
B.x2	1st : 144 m² 2nd : 143 m² 3rd : 144 m² High: 4 m	3 rectangular buildings: ratios of 1:4 (11 x 23 m or 6 x 24 m are basic dimensions)	South: 35% East/west: 7% North: 19%	20 beds, 64 persons (customers/ working staff)
B.x3	Total: 360 m² High: 4 m	Rectangular shape: ratios of 1:1.2 (9 x 11 m or 6.5 x 8m are basic dimensions)	South : 16% East/west: 4% North: 13%	20 beds, 54 persons (customers/ working staff)
C	Total: 11'259 m² High: 11 m	U shaped: ratios of 1:2 (150 m for long side and 80 m for the smaller)	South: 39% East: 16% West: 30% North: 18%	500 beds, 1700 persons (customers/ working staff)

Figure 4. *Reference buildings for hotels.*

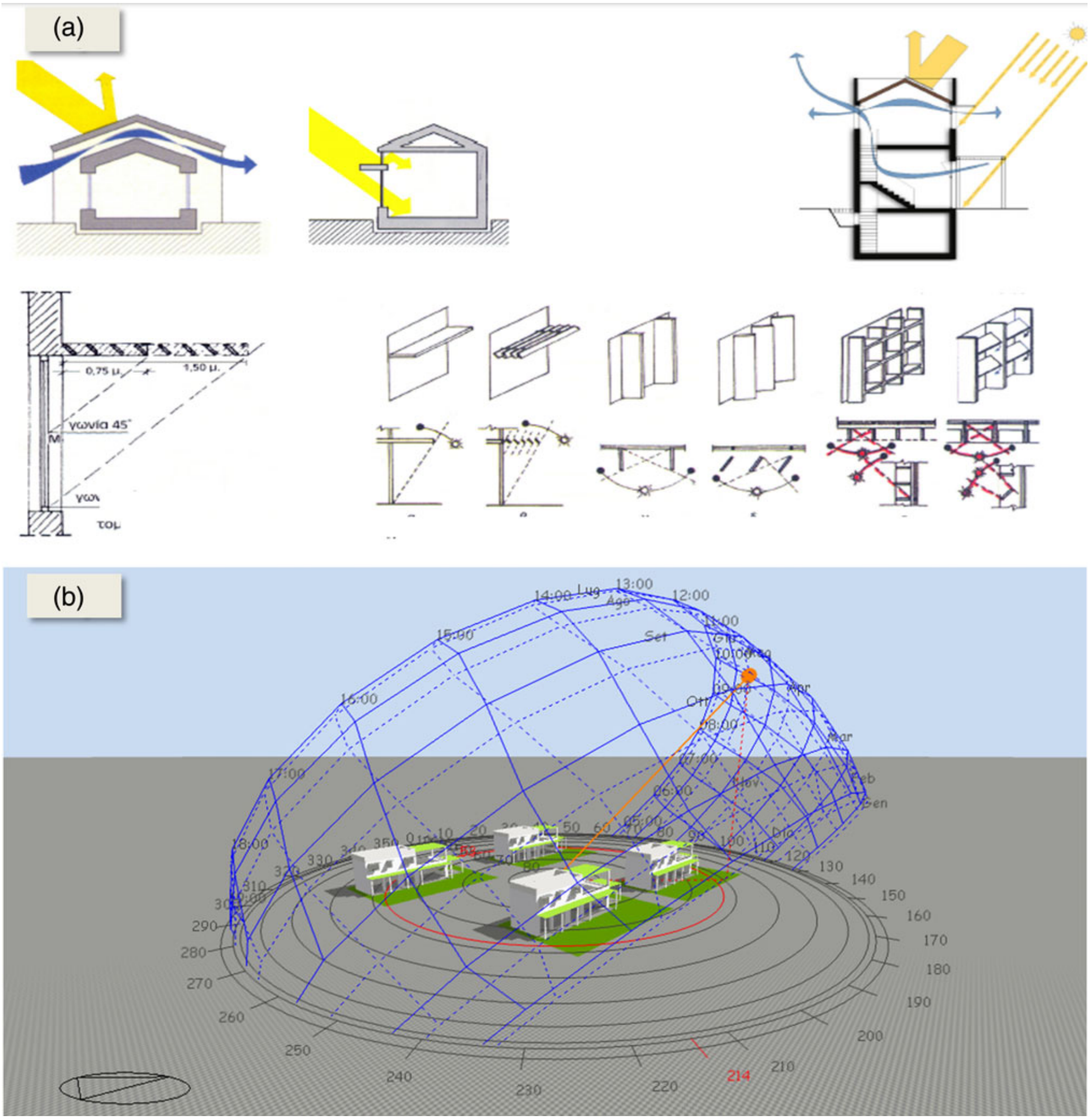


Figure 5. *Design: (**a**) windows and ventilation study and (**b**) rendering of building model (e.g. IA.2).*

designed by taking into careful consideration orientation, wind direction and topography. Landscape planners have used all available design elements and landscape measures including vegetation, water and hardscape. A continuous checking of design objectives has been done during the design process, by means of different simulation tools. This allowed several and progressive modifications in order to evaluate the satisfaction of sustainable targets. Different options have been evaluated to check their effects on the solar control and on the other bioclimatic issues. This approach of continuous feedback and audit—which keeps alive the dialogue among all the involved professionals during the entire design period—is essential for achieving high-quality results. Figure 5 shows some sketches of the design phase and the rendering of the building model (e.g. IA.2). For each building, the orientation and the effect of surrounding buildings and vegetation has been considered.

More in detail, as underlined by Vissilia [35], the evaluation of the settlement design should be done in terms of:

(a) building layout (orientation in relation to sun and wind, aspect ratio);
(b) spacing (site planning);
(c) air movement;
(d) openings (size, position, protection);
(e) building envelope (construction materials and thicknesses, construction details).

Building layout Planners have identified the most appropriate layout and distribution in order to combine optimal southern exposure with the best visual sightings (Mount Olympus and sea), by considering also the dominant local winds. The common green was planned to serve as a general connective element, joining the new settlement both with the surrounding cities and with the countryside.

All buildings have compact geometry and extensive courtyards, with private gardens providing shady and cool places that become the main living units of the summer months. Also by taking into account the effects of the variations of the apparent sun orbit, the southern exposure was preferred. The ratio of the longer dimensions of a rectangular plan to the shorter in N/W and S/E walls varies from 1.0 to 2.0. Rooms are arranged consequently: the main spaces (e.g. living room, kitchen and bedrooms for the dwellings) face south, in the middle, there are horizontal and vertical connections, while accessory spaces, as garages and storerooms, are north-oriented.

Outer spacing Each building has a shaded outdoor space, created with the aim to extend the activities of the internal space and for recreation uses. The connection between outer and inner spaces and gradations of natural light are values stemming from climatic conditions of the place and these contribute to the overall sustainability of the building. Since during the summer, in Greece, the meridian sun is high, any kind of canopy protects part of the underlying space from the radiation. The ideal roof is the foliage of trees or climbing plants, because these allow the air movement in all directions.

The degree of effectiveness of plants in shading an environment depends on their size, shape, density and location. The proper location of vegetation has been determined by using the sun path diagrams. Climbing and clinging vines work as solar control devices, and this approach is widespread throughout the Greek building tradition. The right trees in the right location can give shading to the building during the hottest period of the year, allowing, at the same time, the winter sun, because of the adoption of deciduous species. In the settlement, the effect of different trees, bougainvillea, shrubs, groundcovers, vines and turf has been carefully investigated. Typical applications are the covering of roofs and terraces, with arbor or wattle. The foliage and branches of plants selectively reflect, absorb and transmit solar radiation and provide the cooling effect for evapotranspiration. Vegetation with a loose open foliage and branch structure will filter radiation, by allowing that a portion passes through the canopy, which also acts as a buffering agent to abrupt temperature changes. Dense foliage and multiple layers of canopy can almost totally stop the incoming radiation.

Air movement The rooms are provided with sufficient natural ventilation, through a suitable design and localization of openings, in order to achieve advantages from the breezes. Windows have been dimensioned in relation to the size of the rooms. Furthermore, the building indoor distribution is thought to allow an easy cross-ventilation, which is much more effective than single-sided ventilation.

Openings Windows and openings have been designed according to the most favorable exposures, topography, panorama and wind patterns. Their types, proportions and sizes are determined by the orientation of their wall. In dwellings, there are several south openings with relatively big sizes, whereas on the other sides, these are fewer and of small dimensions. For the hotels, the N/S windows are the greater, while in the commercial buildings, the distribution of the openings is quite the same for all sides: here, the target was a suitable natural ventilation from prevailing breezes in summer. Together with windows and balconies, also overhanging shading and roof projections have been properly dimensioned, in order to achieve good shadows from the summer sunrays and, at the same time, for maximizing the free heat gains during the heating season. The protection of the openings from solar radiation during summer is achieved with the use of movable shading devices and pergolas. Three different systems have been designed according to their position.

Table 1: *Roof slab/terrace stratigraphy.*

	s (m)	λ (W/m K)	ρ (kg/m^3)
Asphalt	0.02	0.23	1100
Light concrete	0.15	0.22	600
Insulation	0.06	0.033	35
Reinforced concrete	0.25	2.50	2400
Plaster	0.03	0.87	1800

All structures are independent, without being in contact with the building. The height of these structures is 30 cm above the lintel of the openings, between 3.20 and 3.30 cm from the planking level. Coatings of these structures will be flat and they can be done in several ways to ensure ventilation of the underlying space (such as trellises, reeds, sails, fixed or movable louvers) combined, when possible, with climbing vegetation. Other protecting shading devices, used together with the external ones, are indoor blinds, lattices and curtains.

All these provisions contribute to energy savings and comfort conditions, by ensuring the obtainment of a pleasant living during the summer months, but also throughout the year, both inside and outside of the buildings.

3.2.3 *Construction details*

All buildings have structures in reinforced concrete, properly thermally insulated. Tables 1–3 summarize the typology for each building component, by explicating, for each 'in-series' layer, thickness (s), thermal conductivity (λ) and density (ρ). The overall thermal transmittance values are lower than the minimum requirements established by the Hellenic laws. In details:

- for the roof slab, the U_r is equal to 0.35 W/(m^2 K),
- for the opaque vertical wall, U_w is equal to 0.36 W/(m^2 K),
- for the basement slab, U_b is $\sim$0.64 W/(m^2 K).

Moreover, all windows have double clear glasses, argon-filled cavity (4/12/4) and wooden frame and these are certified for the highest class of airtightness. A reliable value of the overall heat

Table 2: *Composition of the walls.*

	s (m)	λ (W/m K)	ρ (kg/m^3)
Plaster	0.03	0.87	1800
Insulation	0.08	0.06	35
Concrete	0.30	0.22	600
Plaster	0.03	0.87	1800

Table 3: *Basement/ground floor stratigraphy.*

	s (m)	λ (W/m K)	ρ (kg/m^3)
Waterproofing and finishing	0.01	1.20	1900
Insulation	0.035	0.06	35
Concrete slab	0.20	0.25	2500
External finishing	0.03	0.87	1800

transfer coefficient of the fenestration is 2.8 W/(m^2 K). All windows have to ensure a continuous natural ventilation of the indoor spaces. Generally, buildings have pitched roofs with the possibility of integration of solar panels.

For the opaque envelope, the use of natural materials (stone, brick, wood) and tenuous colors is proposed. Moreover, ventilated roofs and foundations, drainage ditches around the perimeter of the exterior masonry and vapor barriers on the foundation level have been also chosen. Ventilated roofs avoid—at the same time—winter heat losses and summer overheating. The waterproofing of the terraces has to be externally finished with material capable to reflect highly the solar radiation. The rainwater harvesting from the surfaces of crowning and terraces is recommended. Indeed, it can help to save water for auxiliary uses of households and for watering the vegetation.

3.2.4 *Systems and equipment for the space heating and cooling*

The mechanical and electrical systems and equipment are installed at the basement of buildings, in order to provide and satisfy heating, cooling, ventilation and electrical loads. For all buildings, as reference, a hydronic air-conditioning system has been assumed. Fan-coil units are used for the control of sensible loads, with hot water produced by gas boilers with nominal efficiency evaluated around 0.85. The space cooling is provided by electric air-conditioning units, with an energy efficiency ratio, at rated conditions, equal to 2.0 W_{th}/W_{el}. Buildings are heated at 20°C, from 15 October to 30 April, and these are cooled at 26°C from 1 June to 30 September.

For all commercial buildings, in both seasons, the HVAC system can operate every day, except on Sunday, and these spaces are heated and cooled between 6:00 and 24:00. Conversely, hotels have the possibility to turn on the heating and cooling systems always (24 h), if needed.

3.2.5 *Electric equipment and internal gains*

In the reference scenario, fluorescent lamps are installed with simple 'on/off' control system, exclusively managed manually by means of wall-mounted switches, placed at the entrance of each room. According to the normative suggestions, the lighting load is 6.4 W/m^2 for dwellings, 9.1 W/m^2 for retail stores, leisure and central market and 5.5 W/m^2 for hotels.

Table 4: *Internal gains, ventilation and infiltration rates.*

	Dwellings	Commercial buildings	Hotels
Required fresh air	2.5 ACH	2.5 ACH	2.5 ACH
Infiltration	1.0 ACH	1.0 ACH	1.0 ACH
Domestic hot water	2.5 l/m^2/day	0.14 l/m^2/day	9.0 l/m^2/day
Plugged powers and equipment	4 W/m^2	10 W/m^2	3.0 W/m^2

Table 4 summarizes the internal gains for plugged equipment and the main data concerning the natural ventilation (assured by means of the opening of windows), infiltration rates (from windows and doors), by taking into account each kind of building.

4. ANALYSIS OF PASSIVE AND ACTIVE DESIGN STRATEGIES AND TECHNOLOGIES FOR NZEB DESIGN

According to future European objectives, several energy conservation and energy efficiency measures are here proposed, for achieving the requisites of net ZEB or NZEBs for all types of constructions included in the village. The adopted methodological approach is developed by means of two main steps:

- Analysis of the reference design scenario, named 'RBs';
- Analysis of passive and active design strategies and technologies for the NZEBs.

Many simulations have been performed in order to evaluate the transient thermal performance of the buildings. In this regard, common boundary conditions for this kind of investigations—and thus CTF (Conduction Transfer Functions) solution algorithms, simulation time-steps equal to 6 energy balances per hour, surface convection algorithm based on the ASRHAE TARP (that considers variable heat transfer coefficients for convection depending on the temperature differences) have been assigned directly in EnergyPlus. The hourly whether data and reference year of Thessaloniki have been used for the dynamic simulation.

4.1 Assessment of the energy performance of the reference buildings

The first consideration, when an NZEB is designed, concerns an initial reduction in energy need for space heating, cooling and lighting. Indeed, a proper definition of the building thermophysics (e.g. wall and roof insulation, high-efficient windows and so on), natural and passive strategies such as ventilation, natural daylight, skylights or solar tubes, suitable selection of high-efficient systems for the indoor microclimatic control (e.g. new

Table 5: *Primary energy need for air-conditioning and polluting emissions.*

	Heating [kWh/(m^2 year)]	Cooling [kWh/(m^2 year)]	CO$_{2\text{-eq}}$ (t/year)
Dwelling			
A.1	63	26	3.61
A.2	77	37	4.68
A.3	79	38	4.80
A.4	69	34	4.02
A.5	75	35	4.52
B.1	102	49	2.76
B.2	88	43	2.40
B.3	73	42	2.15
B.4	76	82	6.53
B.5	71	59	5.15
Commercial			
A.k1	41	44	3.96
A.k2	72	30	4.13
A.k3	33	13	38.2
B.k1	69	56	2.62
B.k2	56	35	3.61
B.k3	69	42	2.28
Hotel			
A.x1	118	73	32.6
A.x2	235	110	84.8
A.x3	186	146	81.4
B.x1	112	68	22.7
B.x2	119	66	24.8
B.x3	206	153	42.1
C	241	81	1707

generation heat-pumps) and for the artificial lighting (e.g. LED lamps) can allow low-energy demands. Then, the last step is the design of the most effective method to deliver energy to the building/site, by including the so-called demand-side renewables.

For this reason, the RB scenario is characterized by the minimum requirements imposed by the national regulation, for building construction and heat generation, storage and distribution systems for space heating, cooling and DHW. According to these criteria, the building numerical models, for the reference scenario, have been defined by implementing the construction details and internal gains described in previous sections.

Table 5 shows the annual energy requests of the Reference Buildings, with reference to both the heating and cooling seasons, as well as the yearly operational emissions, in terms of equivalent carbon dioxide ($t\mathrm{CO}_{2\text{-eq}}$). According to the simulation results, in the reference scenario, the buildings do not show satisfactory energy performances. Indeed, the total primary energy demand, by considering standard input parameters for dwellings, is in the range 70–140 kWh/(m^2 year). On the other hand, all modeled commercial buildings have similar energy requests, annually around 100 kWh/(m^2 year). Finally, the hotels have the greatest consumptions, mainly because of the energy demand for the space heating, related to the greater air changes. Conversely, for all buildings, the shading ventilated areas help to keep low the cooling demand. High values for the annual energy requests testify high losses and this affects the indoor thermal comfort conditions, mainly during the hours in which the HVAC systems are turned off.

4.2 Characterization of energy efficiency measures, standing-alone or combined

The second step concerns the application of some active and passive energy conservation measures, with the goal to reduce, significantly, the building energy need for the space heating and cooling. In detail, a first target is the halving of the energy requests of the reference scenario. Opportunities for improving the energy performance are many, by including improved operational and maintenance practices, equipment retrofit, occupant behavioral changes and building envelope modifications. For the building under investigation, four design solutions aimed to nearly or net ZEB design are proposed. In the following lines, the main technological characteristics of each suggested measure are explained.

4.2.1 Case 1: infiltration/ventilation scenario

A lower undesired air infiltration, if a proper ventilation, natural or mechanical, is guaranteed, can greatly reduce the energy demand without compromising the quality of indoor air. This is possible by designing building envelope with high quality and air-tightness, and by adopting suitable systems for controlling the ventilation rate. Moreover, this allows, at the same time, a better air circulation and distribution, by avoiding both draft risks and stagnancy, due to excessive or insufficient air currents, respectively.

In residential buildings, issues concerning the lowering of heating energy use, cold drafts in winter and overheating in summer can be addressed through appropriate design of a controlled ventilation, using both natural circulation and fans. Moreover, a proper strategy allows also processes of charging and discharging of thermal mass, if opportunely coupled with the nocturnal free-cooling.

In residential buildings, occupants can handle the windows but, in the case of opening, automatically the cooled systems are switched off. This is a minimum level of automation that characterizes almost all new buildings. On the other hand, the behavior of the occupants, during the hours in which the building is not occupied, is not a matter, because this is impossible to predict. In any case, in these hours, the heating and cooling systems are turned off, being convective and thus not proper for heating or cooling the building masses, so that the use of the thermal envelope as thermal buffer is not contemplated. Finally, during the unoccupied hours, the cooling systems do not work and the windows can be leave open or close and this does not affects significantly the energy demand for air-conditioning.

With reference to commercial buildings and hotels, advanced sensors and control systems can be installed to provide ventilation only where and when it is needed. In this study, we have considered on/off systems, with fixed air-exchange rates. Conversely, also ventilation systems based on demand control ventilation, for instance, by adopting CO$_2$ sensors, could be installed, even if these are not common for these kind of applications. Indeed, the demand control ventilation—that detects concentrations of contaminants and provides appropriate adjustments of ventilation rates—can be easily applied in combination with all-air HVAC systems, with a variable mix of outdoor and recirculation air.

All told, in the first scenario (M_INF in the following lines of the paper), the infiltration rate has been reduced to 0.2 air changes for hours, volume/h (ACH), while the required fresh air has been set to 0.8 ACH. This value assures satisfaction of the minimum ventilation rate prescribed by the ASHRAE 62.1 Standard—Ventilation for Acceptable Indoor Air Quality, for each kind of use.

4.2.2. Case 2: Scenario of high-efficient HVAC systems

The energy performance of the heating, ventilating and air-conditioning (M_HVAC in the following lines) systems is one of the key factors for long-term energy savings. Efficient generation system with proper controls (e.g. electronic thermostats that adjust the temperature based on the scheduled occupancy periods or computerized energy management that takes into consideration occupancy, weather and time of the day) can greatly reduce the energy requests. For the investigated buildings, among the possible and commercially available solutions, the most appropriate technology for the heat generation could be an air source heat pump, air-cooled, with a COP at design conditions equal to 3.5 W_{th}/W_{el} (heating service) and 3.2 W_{th}/W_{el} for the cooling period (this parameter is often called EER—energy efficiency ratio). Once defined the kind of systems, the operational conditions, weather data, COP and EER at the rated conditions, the seasonal coefficient of performance (SCOP) and energy efficiency ratio (SEER) are automatically calculated, on the basis of the part load ratios.

4.2.3 Case 3: package of measures for the NZEB scenario

An integrated methodology for energy efficiency looks for the simultaneous design/retrofit of multiple building systems, with packages of measures capable of energy benefits that could be applied at the same time. Thus, the third scenario (named M_P1) concerns the combination of energy conservation measures, in terms of both thermal envelope and HVAC system. In detail, the following technologies and strategies have been combined:

- reduction in infiltrations and controlled ventilation rate;
- adoption of natural ventilation strategy during the night;
- installation of more efficient lighting system;
- installation of more efficient generation systems for the space heating and cooling.

First, the infiltration is reduced to 0.2 ACH and the ventilation rate is set to 0.8 ACH, with the aim to improve thermal comfort and to decrease energy consumption. This can be achieved by bettering the building construction quality and the airtightness of doors and windows.

On the other hand, the cooling energy requirements can be reduced by means of night ventilation. The indoor ventilation, during the night, operates by using natural or mechanical strategies, aimed at the discharging of the structures and surfaces of the building envelope and it is more effective if the building is massive. In this way, the high thermal capacity allows the storing, during the day, of a great amount of thermal energy, without a significant increase in the indoor temperatures. Then, during the night, the building mass can be discharged by means of the radiative cooling with the sky and the indoor space ventilation. In this way, night ventilation can positively affect the internal conditions during the diurnal time in four ways:

- by reducing the indoor air-temperatures at the peak;
- by reducing air temperatures throughout the day, and in particular during the morning hours (when the building envelope is cool because of the night-discharging);
- by reducing the slab temperatures and thus the mean radiant temperatures;
- by shifting, by means of the buffer function given to the thermal envelope, the maximum internal effect (i.e. the cooling load) from the occurrence of maximum external heat gain (due to the ambient air temperatures and solar radiation).

In the proposed configuration, for the cooling period, an airflow rate of 4.0 ACH has been set for the night ventilation, between 22:00 o'clock in the evening and 06:00 o'clock in the morning.

Moreover, there is significant opportunity to reduce energy and environmental impacts, mainly for the hotels, through adoption of efficient lighting systems and control strategies. In this regard, it should be noted that commonly the guests like comfortable spaces that are environmentally responsible. For this reason, the installation of LEDs with smart control (daylight sensors, occupancy sensors etc.) has been simulated, also by taking into account occupation patterns. At rated conditions, the internal heat gains from lights have been fixed to 3 W/m^2, while the lighting efficiency is the one of LED lamps. Furthermore, the installation of more efficient HVAC systems (at rated conditions: COP = 3.5 W_{th}/W_{el}, EER = 3.2 W_{th}/W_{el}) for the space heating and cooling has been considered too.

For commercial buildings and hotel, also a further scenario (i.e. M_P2 in the following lines) has been considered and it takes into consideration, together with the aforementioned energy conservation measures of the case 'M_P1', a further strategy and thus a different indoor set point temperature for the cooling period. Indeed, some studies show that—if a good natural ventilation strategy is applied (and this is the case of the bioclimatic project of the Olympiad village)—the slight increase of indoor air speed, also aided by fans, makes comfortable also higher values of the operative temperature, with significant energy savings for the space cooling. Thus, for these buildings, a set point temperature of 27°C has been considered.

4.2.4 Case 4: solar PV installation

All energy efficiency measures of the third scenario have been coupled with the installation of PV panels, facing southeast and placed on the building roof. The installed nominal power can vary between 1.0 and 35 kW$_p$. The European PV calculation sheet (PV-GIS—photovoltaic geographical information system—interactive maps [36]) has been used to simulate the electric conversion capability. The evaluation takes into account the rated power, the angle of inclination according to a complete integration with the pitched roof, the losses of the PV generator. More in detail, the energy losses (resistive and due to the difference in temperature of modules, reflection and mismatching between strings), the efficiency of the inverter, as well as the reflection coefficient of the ground in front of the modules (albedo) have been considered. The main input data are listed in Table 6, and these concern a commercial polycrystalline panel.

5 RESULTS AND DISCUSSION

The energy performance of the settlement is analyzed by applying the definition of NZEB, first to each single building (Control Volume—VC1—Figure 6), then to the macro-zone (VC2, Figure 6) and, as last step, to the entire village. In this section, the indexes introduced for evaluating the 'zero approach' for the building will be calculated, by taking into account merely of the energy demand for the space heating and cooling. Indeed, the aim is to evaluate the kind of solution that is more suitable in the Mediterranean area, in order to optimize the incidence of renewables on the energy balance of the 'building/HVAC system' and for maximizing the avoided emissions of equivalent carbon dioxide. In the following section, when the entire settlement would be investigated, the indexes will be referred to all energy uses of buildings. With reference to the energy demand for the DHW, it has been considered the integration of solar collectors, capable of a full coverage of the energy request.

Table 6: *Characteristics of the PV module.*

Module dimensions	1655 × 989 × 39 mm
Rated power	250 W
Efficiency	15.3
N° module	Variable
Losses due to temperature and low irradiance	10.6%
Loss due to angular reflectance effects	2.9%
Other losses	14.0%

5.1 Dwellings

Figure 7, which concerns only buildings for residential use, compares the annual primary energy demand of the reference scenario and of the buildings after the re-design. A proper design of the building envelope, with airtight windows and controlled air change rates (M_INF scenario), allows a great reduction in the heating energy request from 42% (B.2) to 70% (A.5). The annual primary energy demand becomes lower, compared with the reference scenario, from 24% (for B.5) to 50% (for A.1, A.2, A.5). The installation of a high-efficient HVAC system determines both heating (36%) and cooling (43%) energy savings. Annually, the primary energy demand decreases of ∼38–40% compared with the reference scenario without affecting comfort and indoor air quality.

In the last configuration (M_P1), where different active and passive strategies have been combined, the annual energy primary demand is reduced from 64% (e.g. for B.3) to 78% (e.g. for A.5). Table 7 shows the final design configuration in which all previous measures (M_P1) have been coupled with the installation of PV-panels on the SE exposure of the building roofs (P_{pv} is the nominal power). This could be considered a package of measures suitable for net or nearly zero-energy design. Indeed, the electric consumption (Table 7), during the heating period, decreases for more than 70% for all buildings. Really, the energy demand is strongly lowered also during the cooling season, with savings in the range 45% (B.3)–73% (A.3).

By analyzing the index related to the utilization of PV electric conversion, it can be seen that more than 50% of the renewable

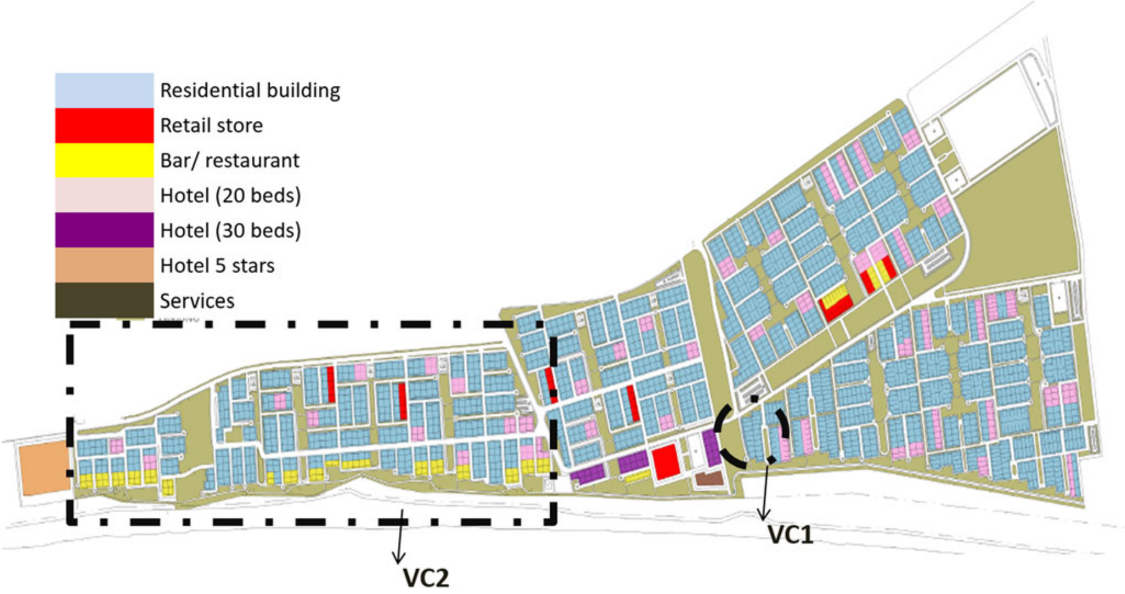


Figure 6. *Settlement topography and control volume for analysis.*

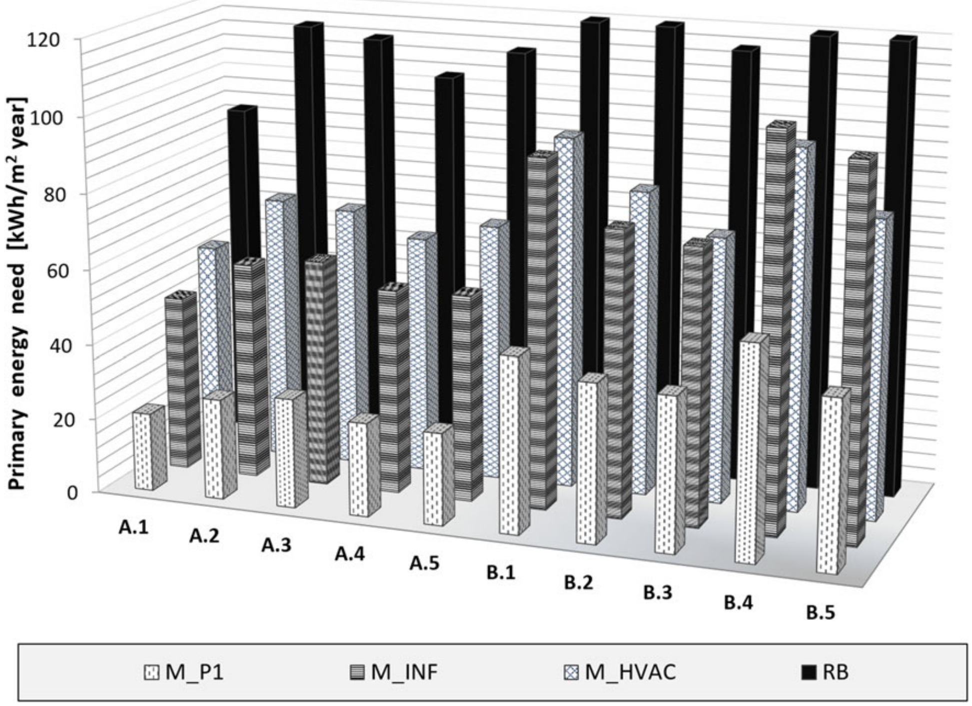


Figure 7. *Primary energy requests for dwellings.*

Table 7: *Energy performance and energy renewable effectiveness for dwellings (M_P1 scenario).*

	H_{el} (kWh/m^2 year)	C_{el} (kWh/ m^2 year)	ΔEP	P_{pv} (kW$_p$)	$E_{rw,use}$/ E_{rw}	Net electricity from utility (kWh$_{el}$)
A.1	5.1	2.8	77%	1.5	50%	—
A.2	5.5	4.7	76%	1	62%	—
A.3	7.1	3.9	74%	1	64%	—
A.4	4.9	4.5	76%	1.5	57%	—
A.5	4.8	4.5	78%	1.5	59%	—
B.1	10	7.4	69%	1.5	46%	74.3
B.2	7.9	8.0	68%	1.5	50%	—
B.3	6.9	8.6	64%	1.5	43%	—
B.4	7.0	14	65%	2	70%	737
B.5	9.2	7.8	66%	2	64%	555

energy conversion, for almost all buildings, can be used to cover the electric requests for the microclimatic control. The surplus energy can be used for the electricity demands of the other buildings (and thus by increasing the self-use of the *in situ* produced energy) or it can be supplied to the grid.

5.2 Commercial buildings

The category of commercial buildings is analyzed in Figure 8. The energy impact of infiltration, through doors and windows, is an issue concerning a variety of factors, among which: (i) the building size, (ii) the time of day when doors are open, (iii) whether the heating, ventilation and air-conditioning systems are operating when doors are open, (iv) whether the excursion of air humidity should be controlled. With the infiltration reduction and the ventilation control, the heating energy demand can be hugely reduced (until 82%). Of course, the total energy demand is also decreased, from 11% (e.g. A.k1 building) to 61% (for A.k3 type).

Analogously, large energy saving and operating cost reductions can be obtained by means of the improvement of the efficiency of the HVAC system and control. For the proposed commercial buildings, the energy consumptions can be reduced of ∼38–40% annually.

With the package of measures indicated as M_P1, the total energy demand becomes also 70% lower compared with the reference scenario. It happens, for example, for the building type A.k2 and A.k3.

As previously said, since the natural ventilation strategy is considered in this bioclimatic design, during the summer, the comfort zone can be extended with higher values admitted for

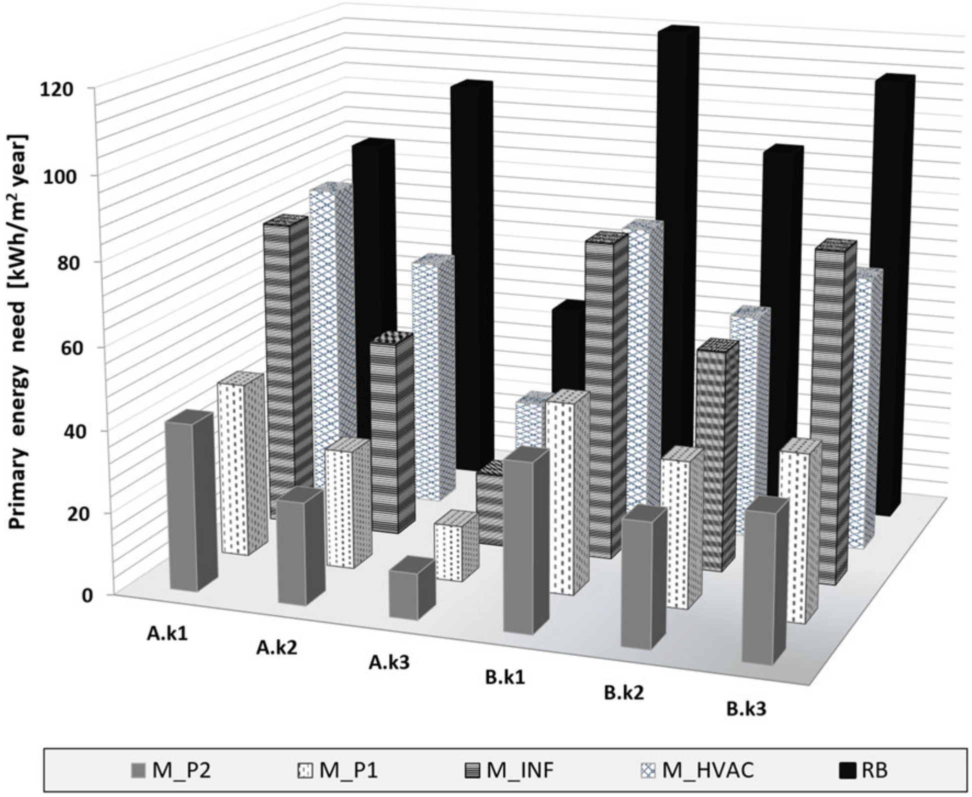


Figure 8. *Primary energy requests for commercial buildings.*

Table 8: *Energy performance and energy renewable effectiveness for commercial buildings (M_P2 scenario).*

	H_{el} (kWh/m^2 year)	C_{el} (kWh/m^2 year)	ΔEP	P_{pv} (kW$_p$)	$E_{rw,use}/E_{rw}$	Net electricity from utility (kWh$_{el}$)
A.k1	8.5	7.0	52%	2.0	62%	1148
A.k2	6.0	3.5	76%	2.0	45%	123
A.k3	2.1	2.1	76%	35	25%	—
B.k1	6.2	9.2	67%	1.5	45%	17.8

the operative temperature, so that also higher savings can be obtained. For this reason, starting from the previous outcomes, a new set point temperature for the cooling period (M_P2) equal to 27°C has been fixed. This allows a reduction in the cooling demand between 10 and 30% compared with the case with a set point of 26°C.

Table 8 summarizes the electric demand for heating and cooling and the annual energy saving for the configuration M_P2. Also for commercial buildings, it can be seen that a large part of the renewable energy is used directly for the heating and cooling energy needs. Moreover, since the building is connected to the city grid, it can both purchase energy from the grid and supply this to the net. In this way, the on-site electricity storage is avoided.

5.3 Hotels

In the reference scenario, the buildings can be considered as characterized by significant energy losses due to an unnecessary ventilation. It implies, therefore, an excessive energy demand. However, an adequate controllable ventilation has to be provided. As evidenced in Figure 9, the annual demand for air-conditioning can be lowered in different rates and percentage depending on the typology of the hotel. For example, the annual demand of the five-stars hotel (C) is reduced of 23%, while the building B.x2 can reduce its energy request of ∼70%.

The global energy performance of the HVAC system is one of the key factors for a long-term energy-saving strategy for hotels. Indeed, the systems for the active microclimatic control can operate continuously during the summer and winter seasons. Finally, higher is their efficiency, lower can be the energy consumption and the energy costs for managers and owners. For the buildings under investigation, the installation of an air source heat pump allows a reduction of ∼40% of the annual demand in each type of reference models.

The third proposed design scenario determines a reduction higher than 70%, also in this case with reference to all reference scenarios. Moreover, the reduction during the cooling season ranges between 42 and 76%, for type A.x2 and B.x3, respectively. If an 'extended comfort zone' (i.e. scenario M_P2, → summer

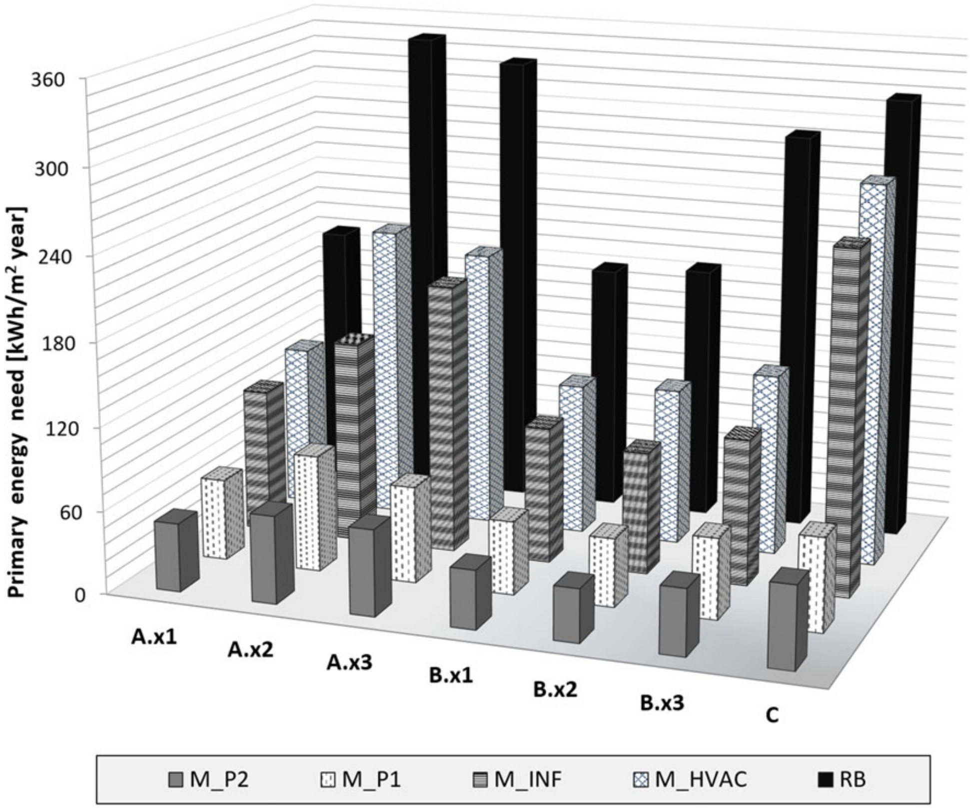


Figure 9. *Primary energy requests for Hotels.*

Table 9: *Energy performance and energy renewable effectiveness for hotels (M_P2 scenario).*

	H_{el} (kWh/m^2 year)	C_{el} (kWh/m^2 year)	ΔEP	P_{pv} (kW$_p$)	$E_{rw,use}/E_{rw}$	Net electricity from utility (kWh$_{el}$)
A.x1	8.6	10.2	74%	10	62%	1976
A.x2	7.6	16.4	82%	14	41%	108
A.x3	9.0	14.5	81%	6.0	64%	4375
B.x1	7.5	8.6	76%	6.0	68%	2651
B.x2	5.6	8.9	79%	7.0	64%	1644
B.x3	8.2	9.8	84%	7.0	63%	1052
C	12	10	82%	35	75%	54 221

set point equal to 27°C) is considered, the cooling demand becomes ∼30% lower than the scenario M_P1.

In Table 9, it can be seen that, for the M_P2 scenario, the overall annual energy saving, compared with the reference scenario, is ∼80% for almost all types of hotel. Moreover, if the energy balance of the building is analyzed in terms of electricity and on an annual basis, the energy conversion from renewable sources compensates greatly the demand for heating and cooling. Table 9 shows also the net electricity that comes from the city grid.

6 OPPORTUNITIES, IMPLICATIONS AND PROBLEMS FOR A ZEB SETTLEMENT DESIGN

Is it possible to realize a ZEB settlement? Starting from the results of the case study, some general considerations can be proposed. According to the EPBD Recast [5], only the energy use of equipment for selected 'building services' (namely: heating, cooling, ventilation and lighting) has to be considered in a nearly ZEB definition. This has been done in this study, by considering as control volume each building, sector and also the entire village.

With reference to the single building, Figure 10 shows the results in terms of $\Delta E_{rw,el}$ and $\Delta CO_{2\text{-}eq}$ when the package of measures (M_P1 for dwellings and M_P2 for commercial buildings and hotels) and the installation of PV systems are considered.

The environmental sustainability of the settlement is assured by the chosen measures, since the avoided emissions, compared with the reference scenario, are usually >50% and this saving rises up 80% for some buildings. The significant reduction in the amount of greenhouse emissions contributes to address the global warming problem.

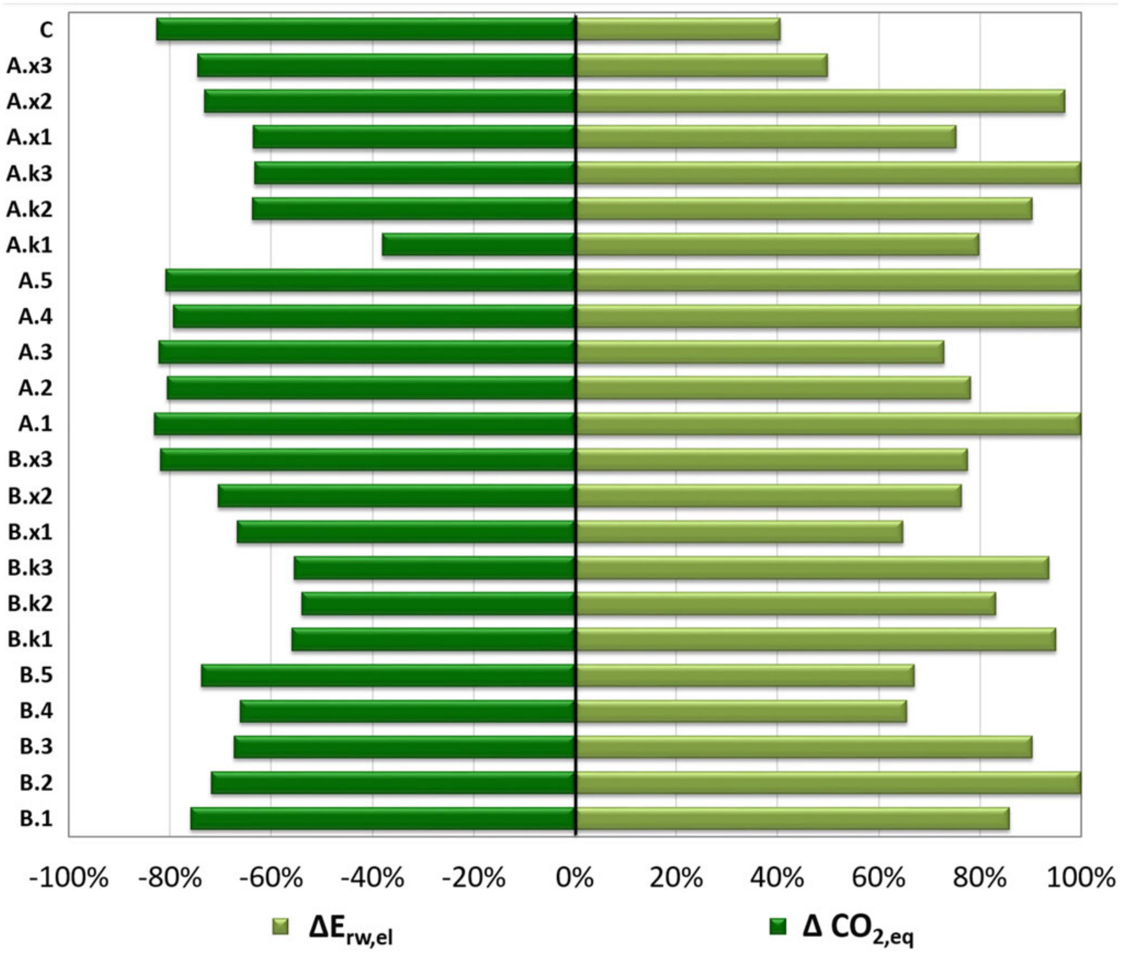


Figure 10. *Sustainability of settlement: environmental impact and green energy effectiveness.*

Table 10: *ZEB settlement indexes.*

Sector	$E_{rw,use}/E_{rw}$	$\Delta E_{rw,el}$	Φ_{el} (kWh$_{el}$)	$\Delta CO_{2,eq}$
A	48%	83%	42 779	71%
B	69%	76%	4040	73%
C	78%	41%	−46 448	83%
Settlement	60%	61%	371	81%

Moreover, by considering the ratio between the on-site PV use and the total electricity use, it is clear that, for all buildings, the renewable electric production compensates a great part of the energy request. More in detail, five typologies of these buildings (residential types and warehouses) can be considered ‘on-grid ZEB’, also known as ‘net zero-energy’, ‘grid connected’ or ‘grid integrated’. Indeed, with a global annual balance, by considering the electricity as energy vector, the renewable production covers completely the very low-energy requests.

As further analysis, the energy and emissions balances have been evaluated by considering the entire sectors as control volume. Globally, for sector A, the settlement design establishes ∼190 residential building (in detail, 35% A.1 type and 31% A.2 type), 70 commercial buildings (56% A.k1 type) and 9 hotel. In sector B, there are around 360 homes (the highest percentages are types B.1, B.2 and B.3), 30 shops (66% B.k1 type) and 10 hotels.

Starting from the results of the reference scenario, the ZEB indexes are shown in Table 10. In sectors A and B, the renewable electric conversion allows to balance more than 80% of the annual energy requests. The difference between surplus electricity supplied to the utility and the electricity coming from utility is positive. It means that these are ‘net zero site energy villages’ since these produce electric energy as much as they require, when measured at the site.

The five-star hotel (sector C) shows a quite complex phenomenon. Indeed, the renewable production covers ∼41% of annual energy demand. Moreover, the building requires to the grid more electricity than the renewable surplus. Although the measures introduced have reduced considerably the energy needs of the building compared with other hotels with the same standard of service, this cannot be considered a true net ZEB, but rather a building with a very low energy demand, which is partially covered by the photovoltaic conversion. In a further planning step, it would be possible to assess the integration of other types of renewable energy sources in order to reach the goal of net ZEB.

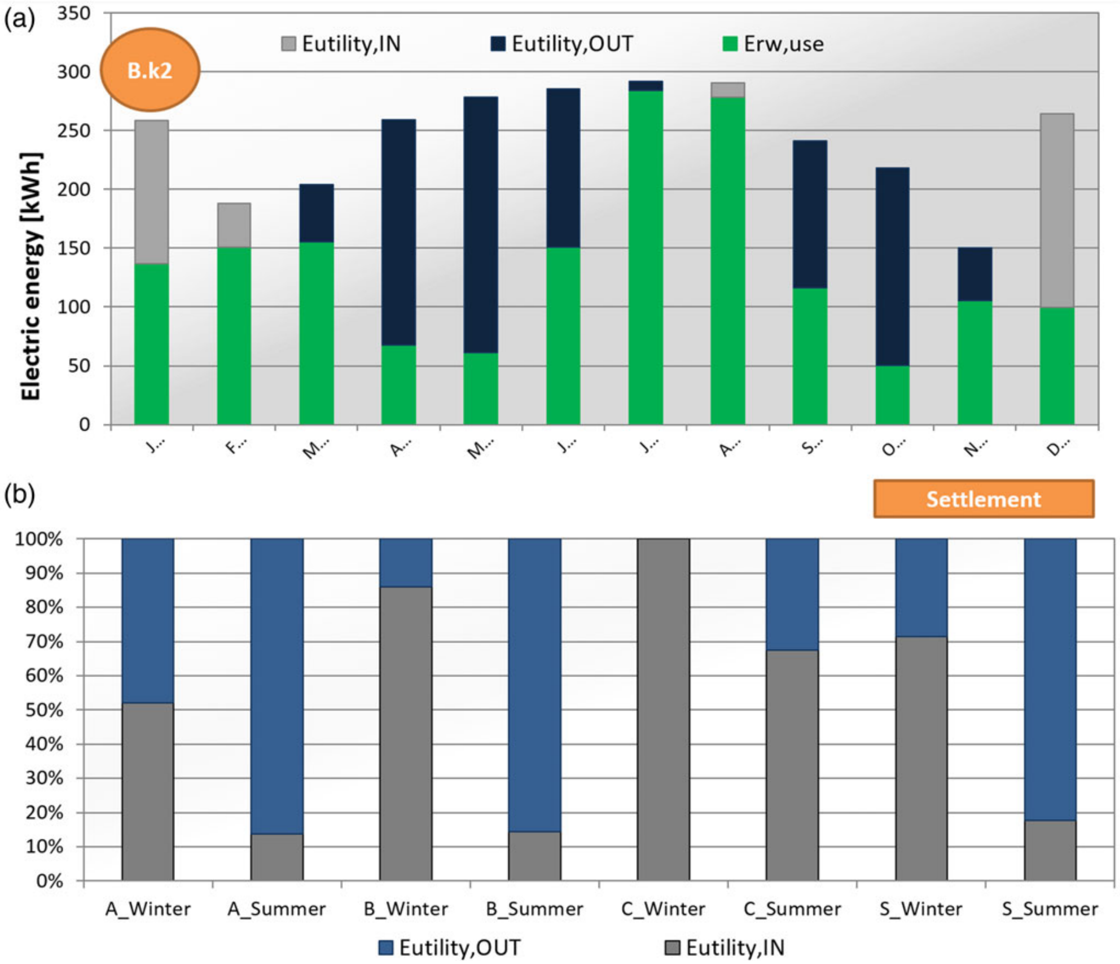


Figure 11. *Net electricity coming from utility and surplus electricity going to utility: (**a**) commercial building B.k2 and (**b**) settlement.*

Globally, by considering a control volume that includes all buildings of the village, the electric photovoltaic production is higher than the required energy. Thus, by taking into consideration the annual balance, in terms of electricity, the village can be considered as 'net site zero-energy'. Indeed, it gives to the grid around 30% of its production that is more than the electric energy taken from the grid. According to the 'grid connected ZEB' definition, it has the possibility of both purchasing energy from the grid and feeding the surplus energy to the grid and thus the on-site electricity storage is avoided.

Selected measures allow to strongly reduce the polluting emissions of ~76% compared with a scenario in which the buildings are designed merely for fulfilling the national regulation.

Another point should be underlined: the heating period has been considered in the global balance, although there may not be tourist activity in the region during the winter. Really, designers have organized the settlement primarily for summer holidays, since it is near the sea. However, due to the proximity to the urban centers, it could be used also for permanent residence or for weekends. For this reason, the results discussed until now can be considered representative of a new residential urban district near the coast.

Starting from these results, it is clear that if we assume the settlement as holiday village, the heating consumption can be neglected and the overall balance of the whole system is surely positive.

Figure 11a shows the monthly energy request of a commercial building of sector 2. During the summer months, the electric demand can be completely satisfied by the renewable energy, with the exception of July. For this building, the percentage of electricity coming from the utility compared with the total demand ($E_{\text{utility,IN}}/E_{\text{el}}$) is 33% during the winter and ~1% in summer.

Similar studies have been performed for all buildings of the settlement. The results are shown in Figure 11b. In each sector, the best results are obviously achieved during the summer, because of the nature of solar renewables. In sectors A and B, the amount of surplus electricity, $E_{\text{utility,OUT,}}$ is greater than the electricity coming from utility and the value of $E_{\text{rw,use}}$ is 89% (79%) for sector A and 92% (71%) for sector B during the summer (winter). On annual basis, $E_{\text{utility,IN}}/E_{\text{el}}$ is 21% for sector A and 10% for sector B. The five-star hotel has the most complex scenario, since during the winter, the 70% of energy demand is covered with non-renewable source from national grid; however, during the summer, $E_{\text{utility,IN}}/E_{\text{el}}$ becomes 28%, and thus the performance can be considered satisfactory. Finally, if only the summer period is considered, the settlement can be considered a zero-energy village. Indeed, according to the last column of Figure 11b, during the summer period, the surplus electricity is higher than the electricity coming from utility and the sustainable index are: $E_{\mathrm{rw,use}}$ $\sim$88%, $E_{\mathrm{utility,IN}}/E_{\mathrm{el}}$ $\sim$12%, $E_{\mathrm{utility,OUT}}/E_{\mathrm{el}}$ equal to 54%.

From these outcomes, it is clear that the minimization of the energy use, through an effective building design, should be a fundamental design criterion and the highest priority of all net or nearly ZEB projects. Indeed, the primary goal to obtain is the reduction in the demand-side loads. In this regard, high-efficient equipment, wall and roof insulation, high-efficient windows, natural ventilation and other techniques as natural daylighting and smart lighting systems (efficient LED lamps, dimmerable technologies, smart controls and suitable lighting levels) are highly recommended. Then, once building loads are lowered as much as possible, the most effective method to deliver energy to the building/site, by including the suitable design of renewables, has to be considered.

All told, combinations of passive heating, cooling and daylighting techniques, as well as the integration of renewable sources, are steps for minimizing the energy demand and environmental impact, so that the ‘urban balance’ could be positive.

As regards the building category, further investigations are under development for including the evaluation of the improvement of indoor and outdoor microclimate and the technical and economic feasibility of the proposed energy efficiency measures. Indeed, the proposed paper is aimed to contribute to future research in matter of urban planning, for improving the living conditions and the overall sustainability under the economic feasibility. Therefore, a further deepening is needed to codify a global approach for defining fully sustainable settlements and towns.

More in general, starting from the definition of urban sustainability, the design process should evaluate benefits and costs of each proposed energy conservation measure, as well as the combined effects of these, also by taking into account further issues, such as the energy needs for transport, mobility, public lighting and so on. It is a matter involving several stakeholders, with initiatives of politicians, technicians and citizens. The proposed paper, by considering merely the minimization of energy demand and emissions related to the use of the buildings, can be considered a starting point to reach the ambitious goal of a net zero-emission settlements, where buildings produce (or purchase) enough emissions-free renewable energy to offset emissions from all energy used, annually, by the buildings themselves.

7 CONCLUSIONS

Green buildings, characterized by remarkable energy performance, provide the best value for the citizens, because of both positive effects on human health and indoor comfort.

Starting from this assumption, this paper suggests an original approach to evaluate the sustainability of the design of entire urban districts or settlements. Some energy and environmental indexes have been introduced and discussed, in order to estimate the energy requirement, the integration of renewable sources and the improvement of outdoor microclimate, in terms of savings in energy demand and emissions. The definition of ZEB has been analyzed for single buildings as well as for entire small urban districts. Moreover, some guidelines have been proposed for orienting the choice of stakeholders (e.g. architects, engineers, owners) during the selection of the design alternatives depending on the characteristics of site and building type.

As case study, the design of a holiday village for the Pieria region in Greece has been proposed. The urban setting suggests a bioclimatic design, with three different sectors in terms of functional, morphological and geometric characteristics. According to the architectural dispositions, the main typologies of analyzed buildings are: touristic residences, retail stores, shops, leisure and central markets, hotels. Ten reference residential buildings, six commercial buildings and seven hotel types have been investigated; their size categories are representative of the diversity of building structures in the Greek building stock. A number of energy simulations have been performed by means of a transient numerical software, for each building typology, in order to compare the energy performance of a reference scenario (according to the Greek regulation presently into force), with several advanced design solutions aimed at achieving the goal of a very sustainable design. Already in the reference scenario, all dwellings, hotels and commercial buildings have been designed with passive bioclimatic technologies, namely: ventilated and highly insulated roof; insulated exterior walls; southern exposure of the main building areas; ventilated shadings over each exposures and a global protection of the building during the summer months; hanging vegetation on trellises in the courtyards.

The outcomes of the case study indicate that, if the buildings are designed with thermal envelopes more effective compared with the minimum level of insulation established by the law and by applying other energy efficiency measures concerning passive (e.g. night ventilation) and active energy systems (high-efficient systems and equipment for air-conditioning), the obtainable energy performance can be very high. About it—once optimized building envelope, HVAC systems and artificial lighting—the remaining energy demand can be easily assured by means of the *in situ* energy conversion from renewables.

In detail, for all buildings, the results reveal that the combination of various active and passive efficiency measures allows a reduction of $\sim$50–90% of the energy demand compared with the reference case. Briefly, the simulated package of energy efficiency measures provides the reduction in infiltration until 0.2 ACH and the adoption of a ventilation rate of 0.8 ACH. As further measures, the adoption of efficient artificial lighting equipment (mainly LEDs), with smart control (e.g. daylight and occupancy sensors etc.) and the installation of more efficient air-cooled heat pumps have been considered. Moreover, especially for improving the indoor comfort, natural night ventilation has been adopted to discharge the building structures during the nocturnal hours.

For hotels and commercial buildings—that are characterized by the highest cooling demand—also a further management strategy has been analyzed. Some studies, indeed, have shown that when a proper natural ventilation is adopted, buildings are comfortable also in the presence of slightly higher indoor operative temperatures. Therefore, since the bioclimatic design allows a constant natural ventilation and, moreover, customers and staff can apply numerous actions to keep themselves comfortable (e.g. by means of operation of windows and fans, by adjusting blinds/ shades, changing clothing, consuming food and drink), an ‘extended thermally comfortable zone’ can be considered. Thus, the set point temperature for cooling has been chosen at 27°C (and not 26°C). All these measures allow a reduction in the cooling demand of ~60–70% and, for some buildings, until 85%. Moreover, by installing photovoltaic systems on the pitched roofs, the target of ZEB is obtained for many buildings. The PV installation is characterized, depending on the specific building, by a nominal power that ranges from 1.0 to 2.0 kW_p (for residential buildings) to 35 kW_p (for hotels), and it allows, very often, to completely compensate the annual electric requests.

Obviously, it is clear that some buildings can achieve zero-energy more easily. Warehouses and dwellings have good opportunities, as these are typically one/two-story buildings, and thus they can easily generate more energy than they consume. In this case, in order to rise the self-use of the *in situ* electric generation, the surplus energy can be supplied to more energy-intensive sectors, such as hotels and commercial centers. Finally, by combining different building types, it is possible to reach net zero-energy villages.

With reference to the case study, the ratio of ‘on-site PV use’ and ‘total electricity use’ is ~60% and the net delivered electric energy is greater than the energy required from the urban grid. Thus, the settlement can be considered as ‘on-grid net site village’. Moreover, for each building, there is also the possibility of both purchasing energy from the grid and of supplying the surplus energy to the grid. Finally, the design has a great level of sustainability, since the reduction in polluting emission is ~81%. It can be concluded that a proper design—with application of active and passive efficiency measures—can transform ‘Olympiad’ in the first national example of NZEB village. This can be the starting point for a further deepening about the cost-effectiveness of nearly and net zero-energy concepts extended to urban areas and not merely concerning single buildings.

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