buildings

MDPI

Article

Redesign of a Rural Building in a Heritage Site in Italy: Towards the Net Zero Energy Target

Maurizio Cellura, Giuseppina Ciulla, Francesco Guarino * and Sonia Longo

Department of Energy, Information Engineering and Mathematical Models (DEIM), University of Palermo, Palermo 90128, Italy; maurizio.cellura@unipa.it (M.C.); giuseppina.ciulla@unipa.it (G.C.); sonia.longo@unipa.it (S.L.)

* Correspondence: francesco.guarino@unipa.it; Tel.: +39-091 23861977

Received: 5 April 2017; Accepted: 18 July 2017; Published: 28 July 2017

Abstract: In order to achieve the ambitious objective of decarbonising the economy, it is mandatory, especially in Europe and in Italy, to include the retrofitting of existing buildings. In a country where a large share of existing buildings have heritage value, it is important to design effective retrofit solutions also in historical buildings. In this context, the paper describes the experience of re-design of an existing rural building located in Sicily, inside the ancient Greeks' "Valley of the Temples". An energy audit was performed on the building, and its energy uses were thoroughly investigated. A building model was developed in the TRNSYS environment and its performances validated. The validated model was used for redesign studies aimed towards the achievement of the Net Zero Energy Building target. The best performing solutions to be applied to a case study like the Sanfilippo House were those regarding the management of the building, as in the case of the natural ventilation and the energy systems setpoints, that would allow a large impact (up to 10% reductions in energy uses) on the energy performances of the building with no invasiveness, and those with very limited invasiveness and high impact on the energy efficiency of the building, as in the lighting scenario (up to 30% energy uses reduction). The most invasive actions can only be justified in the case of high energy savings, as in the case of the insulation of the roof, otherwise they should be disregarded.

Keywords: historical buildings; building simulation; Net Zero Energy Buildings

1. Introduction

Historic and traditional buildings represent one of the most important territorial resources in many European cities, and constitute an integral part of the European's cultural heritage [1].

However, they are among the largest contributors to the poor energy performance of the building sector [2]. They often have non-optimized HVAC systems and poor envelopes that contribute substantially to CO_2 emissions and rising energy bills, and to the increase of indoor environment quality issues [3].

About 25% of existing European buildings are older than 50 years, with many buildings that are hundreds of years old. Furthermore, more than 40% of residential buildings have been constructed before the 1960s, when energy-building regulations were very limited [4]. Only a small part of these buildings have undergone major energy retrofits, meaning that these have low insulation levels and their systems are old and inefficient.

In Italy, 60.44% of buildings were built before 1976 (13.15% of these before 1919 and 22.90% between 1919 and 1945). More than 3,900,000 buildings have been built before 1920, and several of these constructions are characterized by historical and artistic value. Furthermore, there are 1,376,304 rural buildings used in continuous or seasonal activities, 68% of which are premises to store farm machinery and equipment; 1,084,038 are animal shelters, 45% of which were built or restored before 1970; the stock of housing within farms amounts to a total of 1,460,980, 358,422 of which are unoccupied [5]. The age of the Italian building stock, in most cases, is accompanied by limited thermal-physical performances of the envelope and by the HVAC systems installed.

The above figures highlight that if the Italian building stock is to achieve higher performances, it is mandatory to operate energy retrofits in the field of historic and traditional buildings [6].

At the European level, the main policy drivers related to the energy performance of existing buildings are directives on the energy performance of buildings [7] and on energy efficiency [8].

The first one introduces the concept of Nearly Zero Energy (NZE) for existing buildings. In detail, it states that "when buildings undergo major renovation, the energy performance of the building or the renovated part thereof is upgraded in order to meet minimum energy performance requirements [7]. Member States shall develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings" [7].

The second one indicates that "Member States shall establish a long-term strategy for mobilizing investment in the renovation of the national stock of residential and commercial buildings, both public and private [8]. Each Member State shall ensure that, as from 1 January 2014, 3% of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least the minimum energy performance requirements that it has set in application of Article 4 of Directive 2010/31/EU" [8].

Despite the fact that the above directives include existing buildings, they only partially cover the field of buildings renovation. In fact, they state that "Member States may decide not to set or apply the minimum energy performance requirements to buildings officially protected as part of a designated environment, or because of their special architectural or historical merit [9]", because improving their energy efficiency and respecting certain minimum energy performance requirements could means alterations to their character or appearance, which may impact upon their integrity and historical value.

Improving the energy efficiency and comfort in historic and traditional buildings, while simultaneously preserving and promoting their value and the historical character, is only viable by balancing the requirements of cultural protection, obligatory architectural heritage conservation requirements, indoor comfort, energy efficiency, and the NZE building target [10,11]. Thus, buildings renovation implies a careful and effective choice among the retrofitting possibilities aimed at preserving cultural and patrimonial value.

Obtaining the above balance is a complex task. In fact, when designing an intervention aimed at improving the energy performance of a historical or traditional building, the project development process must consider a number of factors: the historical features to be protected, the final use of the building as a whole, and the energy and comfort requirement for people and artworks [12].

Studies on the energy retrofit of historical or traditional buildings available in literature showed that deep energy renovation can be achieved through a combination of energy efficiency measures and installation of renewable energy technologies (RETs) that allow the building to improve its performances, whilst retaining its historic character and minimizing the visual impact of the changes [13–25].

The analysis of the literature studies showed that the proposed energy retrofit actions can be grouped into five main categories: (1) thermal insulation of the building envelope (roof, exterior walls, floor, doors); (2) windows replacement; (3) use of more efficient energy production systems (heating, cooling and domestic hot water systems); (4) use of RETs, both solar thermal and photovoltaic systems; (5) others actions as installation of LED lighting or low-energy light bulbs, natural or mechanical ventilation, shading devices.

The combination of the above actions can allow the reduction of energy needs from about 22% to about 90%. Generally, the most remarkable contribution to the reduction of energy needs after the retrofit (higher than 50%) is obtained by increasing the efficiency of energy generation systems.

Among the above solutions, choices have to take into account the respect of the typological, technical and historical characteristics of the building. The best retrofit strategy is to evaluate, case by case, the most effective solution responsive to the needs of each case, both in terms of aesthetics and in technology [26].

However, it is often difficult to operate energy retrofits in the context of historical buildings, since the main focus is the achievement of higher energy performances without compromising the architectural and historical value of the building [27].

Moreover, the regulations in Italy make a clear difference between historical buildings and non-historical ones. For the first ones, these buildings are excluded from the minimum energy requirements fulfilments, even after retrofits. Furthermore, the retrofit itself is to be subject to a feasibility verification, in order to identify whether the action configures as an 'unacceptable alteration of the historical character' of the building.

In this context, this paper presents an energy retrofit experience of a traditional rural building located in an Italian heritage area. The building is located in a United Nations Educational, Scientific and Cultural Organization (UNESCO) world heritage site called the "Valley of the Temples", since it houses some of the most ancient and well-preserved Greek temples in the Mediterranean. The research can serve as basis for future studies in similar buildings, and for practitioners to have an example of a potential retrofit methodology to follow in protected sites.

The goal of the research was to identify possible energy retrofit actions aimed at achieving the Net Zero Energy Building (NZEB) standard in such a site, taking into account the limits and the bounds of the protected area, and without affecting the historical and architectural value of the building.

The research represents a knowledge basis for other similar experiences in the building renovation process in the Mediterranean area, and can contribute to increasing the small number of studies on the retrofit of rural traditional buildings towards the NZEB. In fact, even if different studies have analyzed the improvement of energy performance of historic buildings, much less information exists about the energy renovation of traditional rural houses [13].

The paper is composed of the following sections:

- The "Methods" section includes all the relevant information concerning the case study identification, including climate data, building features, bills analysis, building energy model definition, and calibration,
- The "Results" section describes quantitatively the identification of the re-design actions aimed towards the improvement of the building energy performances, and a description of the energy balances tailored on the building to calculate whether it could be considered a NZEB,
- The "Discussion" section puts the study into context while explaining the limits and potential of the approach in similar contexts,
- The "Conclusion" section draws some general conclusions to the work.

2. Methods

2.1. The Case Study

The historic building chosen for the study was the "Sanfilippo House" (See Figure 1), located in the city of Agrigento. It houses the offices of the Park and the Archaeological Landscape of the Valley of the Temples in Agrigento, (37°17′ N and 13°36′ W, at 270 m hsl), one of the most important examples of old Greece architecture. The area was included in the UNESCO Heritage Site list in 1997.

Figure 1. Images of the Sanfilippo House.

Agrigento is an Italian town of 59,000 inhabitants in Sicily. The climate is mild in winter, and the weather is hot and warm in the summer. An analysis of the weather data for the site leads to the following average, maximum and minimum data reported for the site (See Figure 2).

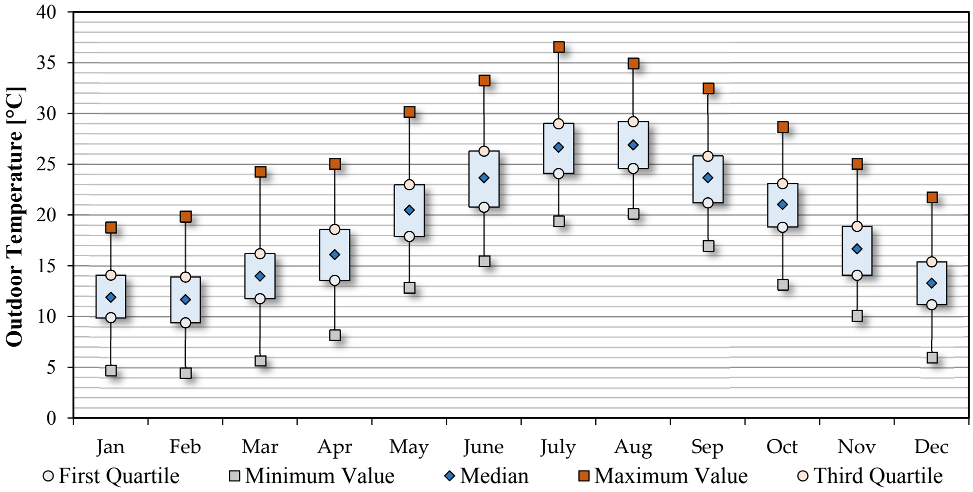

Figure 2. Site air temperature analysis.

The building develops on two levels: a ground floor (Figure 3) and a basement (Figure 4). The ground floor is a single body with an L shape. All around it in the two sections of the L shape, the building houses offices. Restrooms are located outside the core of the building and are located in the smaller construction on the far North of the plan.

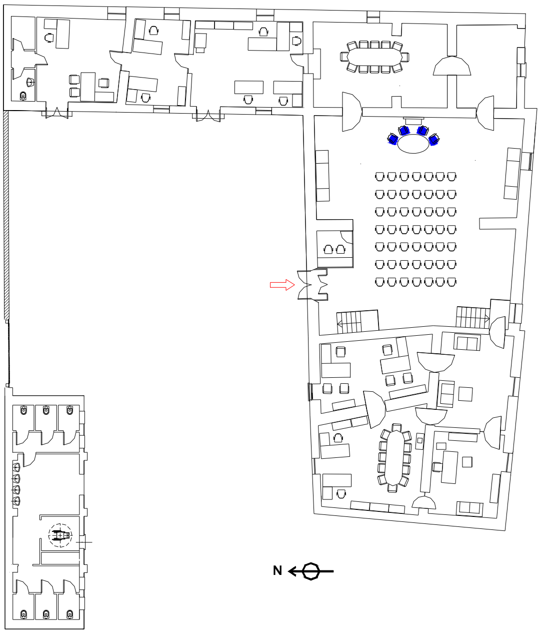

Figure 3. Ground and upper ground floor planimetry.

The basement of the building includes more offices and technical spaces.

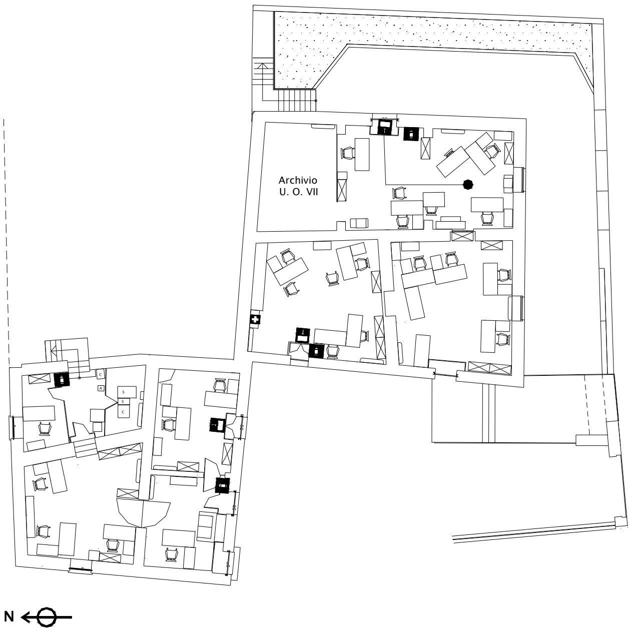

Figure 4. Basement planimetry.

The building is characterized by a total floor surface of about 730 m^2, a height of about 5 m, and a shape factor S/V = 0.51.

The envelope is characterized by tuff outer walls [U = 0.74 W/(m^2·K)] with a total thickness of about 0.8 m; externally there is a coating with stone and mortar; internally the walls are plastered and painted with lime and gypsum. The pitched roof [U = 2.55 W/(m^2·K)] is made of brick tiles on wooden decking; the wooden beams are exposed; all rooms are made of terracotta bricks. Floors are 160 cm thick and have a U value of 0.43 W/(m^2·K). Windows use single glazing (no film average

U = 6.5 W/(m^2·K) while door-windows are double glazed [no film U = 1.86 W/(m^2·K)]; window to wall ratios are never higher than 5% in all facades and orientations.

The state of the envelope is not optimal. An infrared analysis of the external envelope reported a wide variety of limits and defective insulation. A selection of the images from the thermographic studies are reported below in Figures 5–8. The overall results have identified a very large number of thermal bridges around all surfaces of the building (Figure 5). Temperature on the external surfaces are variable even up to 5–6 °C on the same façade (Figure 6).

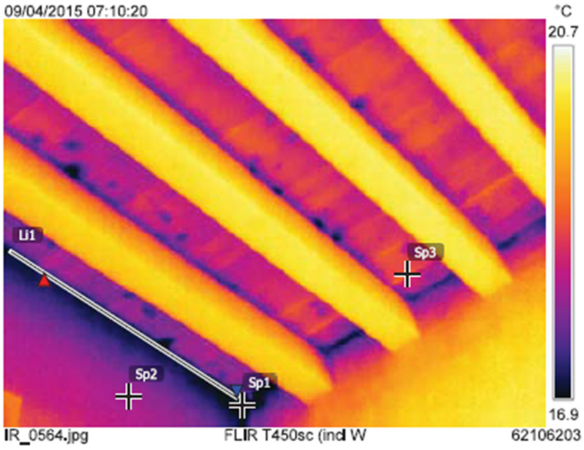

Figure 5. Thermal bridges on the roof, East façade.

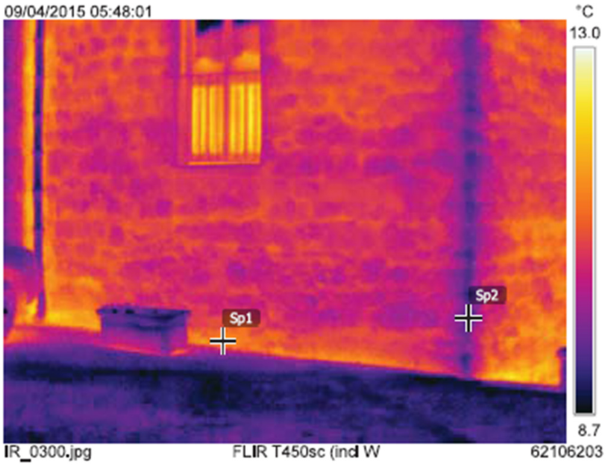

Figure 6. Exterior wall, South façade.

The internal envelope showed several points where the internal plaster was damaged, as shown in the example reported in Figures 7 and 8. These issues would impact the thermal performances of the wall and cause a diversified thermal response. During summer in Sicily, the external temperature was much higher than 20 °C (the lowest temperature reported on the wall), and especially in the most evident plaster cracks, temperatures up to 3–4 °C higher, have been found.

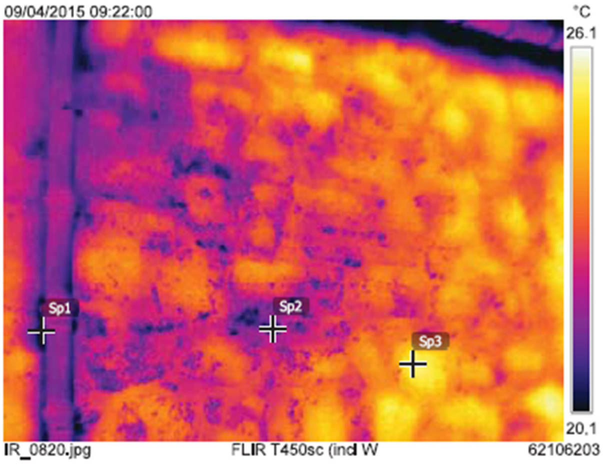

Figure 7. Exterior wall, North-East oriented.

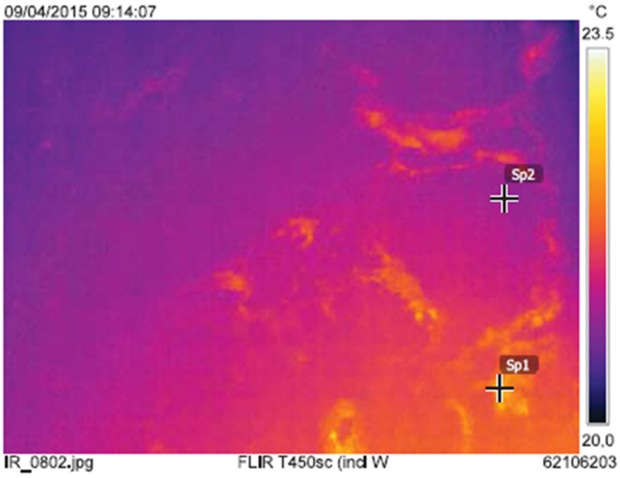

Figure 8. Internal wall, North-East oriented.

An application of an external/internal insulation retrofit action was therefore highly recommended to reduce thermal bridges and greatly improve the thermal insulation of the building.

The use of the building is non-residential, around 50 occupants at maximum can be present inside the building simultaneously. Work times are from 7:30 a.m. until 2 p.m. every day from Monday until Friday, and on Wednesday from 7:30 a.m. until 6 p.m. Lighting is based on fluorescent tubes of different sizes.

Internal gains are mainly based on office equipment, mostly personal computers (27 in the whole building) and printers (25 in the whole building). Working schedules for lighting and appliances closely follow the occupancy pattern in the building. The principal intended use of the building is for office activities, and due to the presence of a conference room, sometimes the Sanfilippo House can be used for events.

The building is conditioned through an air-water heat pump and fan coil units. The fan distribution is a function of geometrical and thermal characteristics, and is based on the number of occupants. The HVAC system works from 1 December to 31 March in heating mode, and from 10 June to 10 September in cooling mode. The building is considered unoccupied from 10 to 20 August.

The operating period, for climate Zone B in Italy is from 1 December to 31 March. The building is conditioned from Monday to Friday from 7: 30 a.m. to 2 p.m. except on Wednesdays when the system works from 7:30 a.m. to 6 p.m.

The cooling period is from 10 June to 10 August and from 20 August to 30 September; the system is switched on from Monday to Friday from 7:30 a.m. to 2 p.m. except Wednesday from 7:30 to 6 p.m.

The lighting system is characterized by fluorescent tubes of different sizes.

2.2. Modelling

The modelling of the building was performed in the TRNSYS environment.

The heat pump was modeled as with a fixed Coefficient of Performance (2.92) and Energy Efficiency Ratio (2.4) with 27 °C and 18 °C as cooling and heating setpoints, respectively.

Internal loads for lighting are calculated to be 5 W/m^2 for the whole building, following the occupation profiles. Similar values can be identified for non-residential buildings in [28]. Lighting power density was assessed following a detailed audit, with regards to power, typology, and number of lighting elements, as well as in depth light use patterns and habit. Internal loads for personal computers were assumed equal to 72 W, while for printers, the value input to simulation was 50 W.

Convection coefficients used in the simulation were: 11 $kJ/(h \cdot m^2)$ (internal) and 64 $kJ/(h \cdot m^2)$ (external).

Although using detailed monitored data to perform an adequate calibration of the model is the preferable approach to building simulation, in this case on-site monitoring activities were out of the scope of the work. Therefore, a standard weather data file for the city of Agrigento was used for the simulation.

Natural ventilation and infiltration were modeled through TRNFLOW [29], establishing a pressure network in the model. The nodes represented the rooms and the building surroundings [30]. In the baseline model, windows were considered to be closed throughout the year.

The TRNSYS model outputs were compared with the energy bill monthly information to validate it critically. Results are shown in Figure 9.

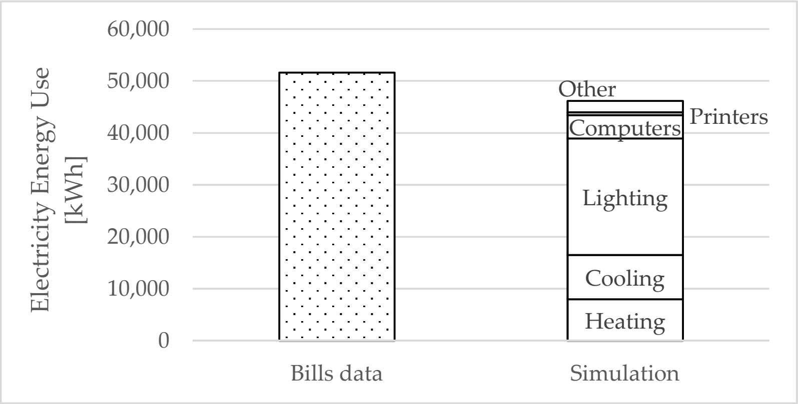

Figure 9. Validation of the simulation, annual data.

Heating represents 17.34% of the total electricity consumptions, and cooling is also very close to this value (18.38%), while the highest contribution to the total is electrical equipment and lighting (64.28%). Lighting in particular is the cause of around 48% of electricity use in the building.

On a yearly base, the simulated results report a deviation from bills data lower than 9%. While this is usually the threshold accepted worldwide in several standards [31] for validation of models, a more in-depth analysis will allow us to relate these results to some contingent issues.

The analysis on Figure 10 shows some differences between energy bills data and simulations in some months and results were nearly identical in others. These differences were connected to some behaviors of the occupants, unexpected use of portable cooling devices in summer, different work hours during summer and early autumn, and the use of a standard weather file during the simulation.

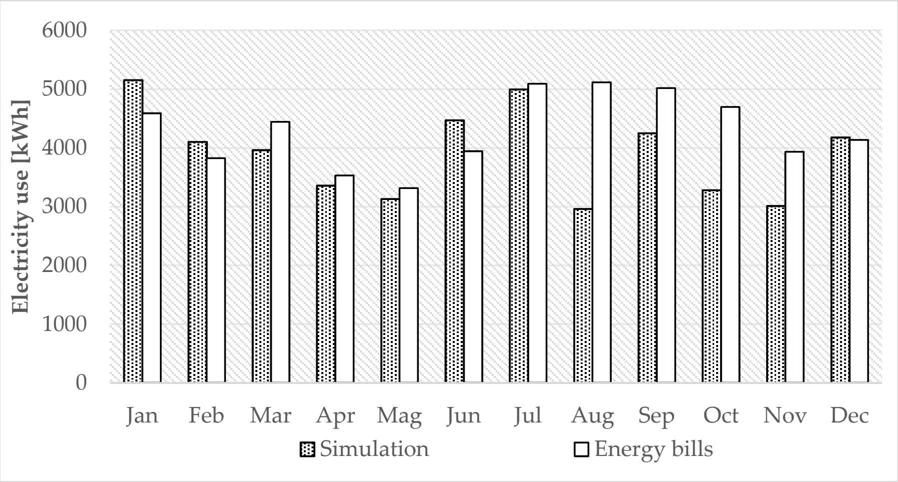

Figure 10. Validation of the simulation, monthly data.

The model was however able to reproduce the general trend with moderate differences in the energy bills, and as such, was considered appropriate for the development of the building redesign studies.

3. Results

From the analysis of the building and of the results, it was possible to define some retrofit actions to improve the energy performances of the building and reach the Net Zero Energy target.

The context in which to operate is bound by non-technical constraints. As such, the approach was to target first the easiest and simplest reductions in energy uses with no structural interventions, while only afterwards progressively including more invasive retrofit actions. In this section of the paper, the energy efficiency and retrofit solutions proposed are reported and briefly discussed, separately from the energy generation options identified.

3.1. Natural Ventilation

Benefits from promoting the use of natural ventilation in mixed mode buildings range from an increase in the air quality of the offices to a substantial reduction in energy use [32].

Use of natural ventilation in the building was modeled by implementing a mixed-mode building control in the simulation, that included the manual opening of the windows when overheating occurred (Tindoor > 26), and while the external temperature was below 26 °C as well. If internal temperature rose higher than 27 °C, the standard cooling equipment would be operating.

Although cooling was not the highest contributor to energy uses in the building, this solution could allow the savings of nearly 20% of the whole cooling energy required during the year (1650 kWh), equal to 5.50% of total energy savings.

3.2. Adaptive Comfort Considerations in the Use of Cooling Equipment

As a complimentary measure to the previously discussed one, this scenario investigated the benefits of a variable cooling set-point towards the reduction of energy uses.

Under the premises of UNI EN 15251 [33] and its future revision prEN 16798-1 [34], it is possible to associate the concept of the adaptability of subjects living in a considerably hotter environment to the capability of perceiving a higher indoor temperature as comfortable. Although adaptive comfort in mixed-mode buildings still needs further research, this scenario included a higher setpoint temperature for the activation of cooling systems, while allowing the opening of windows while the temperature was below it. The setpoint was calculated as based on the equation of the comfort temperature reported in the UNI EN 15251 [Equation (1)]; if the indoor temperature is higher than 29 °C, however, windows would close and the cooling system would be activated.

$$T_{co} = 0.33 \cdot T_{out} + 18.8 \tag{1}$$

This scenario forecasted a 55% reduction in cooling energy use (5650 $\mathrm{kWh_e}$) and an overall reduction of nearly 10% in overall energy use.

3.3. Substitution of Lighting Elements with LED

The largest source of potential energy efficiency actions in the building is the lighting system (nearly 50% of overall consumptions). The existing fluorescent tubes can be substituted throughout the building into light-emitting diode (LED) elements, guaranteeing higher visual comfort and higher electricity savings.

The modeling included a variation in the power installed, while guaranteeing the same illuminance levels to the indoor environment.

This solution could guarantee a reduction of up to 60% of the lighting consumptions and of nearly 30% of total electricity uses in a year, and proved to be the most impactful solution out of the whole set of retrofit actions.

3.4. Substitution of Windows and Frames

Another potential source of inefficiencies in building energy management are the windows, since most of them are single-glazed. Double glazing windows could allow a reduction of heating requirements to the whole building, due to both the reduction of infiltration airflow and transmittance values.

This scenario included the substitution of single glazing windows with double ones, having glass U = 1.26 $\mathrm{W/(m^2 \cdot K)}$, overall U = 1.8 $\mathrm{W/(m^2 \cdot K)}$, solar transmittance g = 0.548 and visible transmittance Tv = 0.769.

This scenario could reduce energy use for heating by roughly 6%, but as a drawback could increase cooling energy requirements by 2%. Overall electricity use reduction on a yearly base would not be higher than 1%.

3.5. Internal Insulation

The transmittance values for all opaque structures are above the normative limitations in Italy for new buildings (roof = U = 2.55 $\mathrm{W/(m^2 \cdot K)}$, vertical opaque elements U = 0.74 $\mathrm{W/(m^2 \cdot K)}$).

The retrofit intervention studied would add internal insulating coatings to the vertical opaque structures and the roof. Although it would be more beneficial to the energy performances of the building to actually use an expose thermal mass towards the inside, altering the facades in such a significant way was not considered to be a viable option.

By adding internal insulation, the U values for both the opaque vertical structures and for the roof would be reduced respectively, to 0.343 $\mathrm{W/(m^2 \cdot K)}$ and 0.29 $\mathrm{W/(m^2 \cdot K)}$. In the first case, the insulation of opaque structures could reduce the energy use during the year by 1.70%, cooling can be reduced up to 2.3% and heating by 7.4%.

Higher values were reported for the insulation of the roof, that could reach 8% of the overall yearly electricity use reduction, and of both heating (62%) and cooling (51%) energy requirements. All the new wall compositions were been tested through the Glaser method and are not expected to suffer for any condensation phenomena.

3.6. Energy Generation

In order to achieve the Net Zero Energy target, it was mandatory to select some renewable energy solutions to achieve the necessary on-site energy generation. Several solutions were analyzed jointly with the authorities of the Valley of the Temples. Although wind turbines had been initially taken in consideration, this idea was later discarded due to the high visual impact which was not tolerable in the context of an historical archeological site.

Photovoltaics, on the other hand represent one of the most interesting solutions for on-site energy generation from renewables in Italy. The connection to the grid allows for a two-way energy flow, guaranteeing the possibility for energy import from the grid when energy uses are higher than generation, and via some feed-in tariffs when the energy generated is higher than use, it can be sold to the energy grid. Thanks to a wide campaign of public incentives in the last years photovoltaic applications have seen a large growth in Italy [35].

Photovoltaics (PV) on the building façade and roof appeared to be the best choice, but it suffered the same issues of visual impact. The possibility of installing photovoltaics in the building façade was discarded, since it was not advisable to alter the façades of an historical building to such an extent.

Thus, the attention of the authors was re-directed to the Valley of the Temples close by.

Another option under analysis was one of high integration with the tourist's structures, the offices of the Valley, and in the coverings of the excavating sites. An example of the structure imagined for the application is reported in Figure 11.

Its main aim was covering of the excavating sites, with the structure based on a gabion filled with rocks, and the covering based on wood. PV panels would be fixed upon the south oriented layers.

Figure 11. South orientation of one of the location designed to host the PV system.

The idea was nevertheless rejected after some discussion with the management authorities of the park, since it could have had a direct or indirect (installation of cables, additional equipment etc.) impact on the historical value of the Valley of the Temples.

The only practical and deployable solution, identified after a discussion with the local authorities and according to the regulations on heritage buildings, was found when looking at a very close space used for car parking for the tourists (See Figure 12). The area, around 100 m × 65 m large, houses mostly open spaces that could be partly occupied by PV shading groups for the parking spots.

Figure 12. Plan of the parking area and of the PV shading structures.

The system was simulated in the TRNSYS environment, using the well-known five parameters and one diode module. Typical 240 W commercially available modules were modeled. Although the area available for the application was larger, in order to achieve the Net Zero energy target, a surface of around 214 m^2 was considered for nearly 35 kW_p and 145 modules installed. The simulated PV generation reached 48.7 MWh in a year and was roughly equal to the simulated electricity consumption.

3.7. Redesigned Building

As a summary of all the solutions identified up to now is now following in Table 1. All the redesign solutions examined are reported in detail, one by one from Scenario 0—the building as it currently is—to scenario S6 that includes all the scenarios analyzed and the PV applications discussed in Section 3.6.

Scenario 7 was conceptually the same scenario if compared to the sixth that instead used a much lower PV area, able to cover the largely reduced electricity consumption.

Table 1 includes the percentage reductions in energy uses—distinguished by Heating, Cooling, Lighting and the total, due to the retrofit actions and the Net Zero Energy Balance.

Table 1. Summary of the results for the retrofit solutions.

Scenarios	**Heating**	**Cooling**	**Lighting**	**Overall**	**NZEB Balance (MWh)**
S0—Building as it is	-	-	-	-	−0.30
S1—Natural Ventilation	-	19.20%	-	5.50%	2.68
S2—Adaptive comfort considerations in cooling setpoints	-	54.81%	-	9.92%	4.83
S3—LED Lights	1.39%	−6.25%	59.10%	30.02%	14.62
S4—Windows and frames	5.94%	−2.01%	-	0.66%	0.32
S5.1—Vertical structures insulation	7.41%	2.28%	-	1.70%	0.83
S5.2—Roof Insulation	62.02%	51.10%	-	7.86%	3.83
S6—Complete retrofit	78.60%	90.36%	59.10%	44.46%	21.65
S7—Complete retrofit: lower PV area scenario	78.60%	90.36%	59.10%	44.46%	0.95

All values represent decreases in energy use for each category. In the case of negative values, it indicates an increase in energy. NZEB: Net Zero Energy Building.

Several methods and assumptions are available in literature and regulations to calculate use phase energy balances. For the sake of clarity and since the only energy carrier of significance to this application was electricity, a simple load-generation balance with no weighting was adopted in this case [36].

Thus, Equation (2) was adopted in the calculation of net zero energy balances [37]:

$$Energy\ balance = G - C \tag{2}$$

where G stands for the total electricity generation during a year and C is the electricity consumed during the same time span. In Figure 13, all retrofit options investigated are compared on a standard $G - C$ graph, in order to assess whether the identified retrofit solutions would reach the desired Net Zero Energy target. The PV generation was considered as constant for all scenarios from S1 to S6.

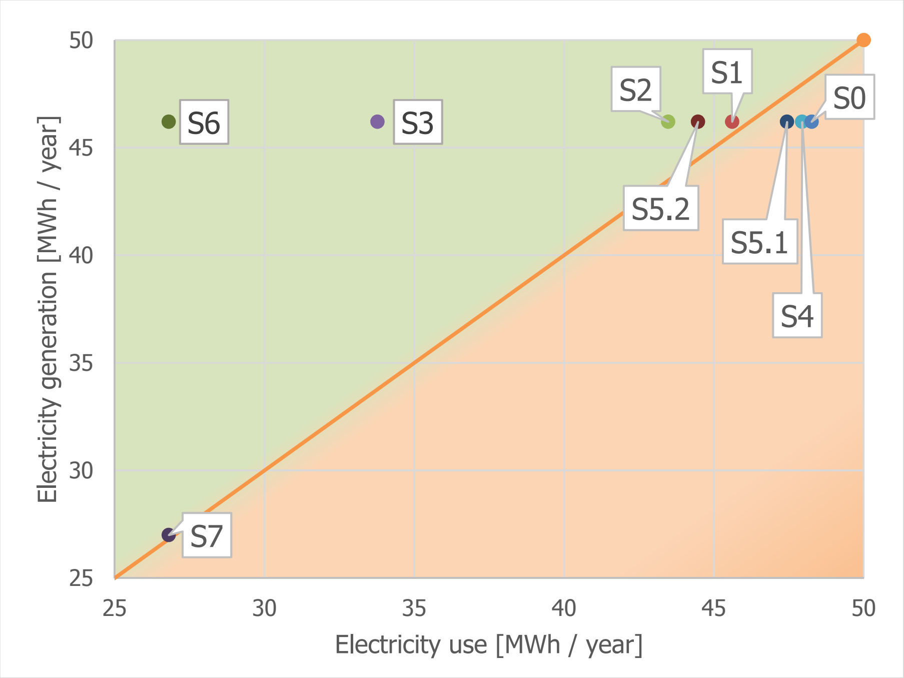

Figure 13. Net Zero Energy Balances for the retrofitted building.

The most impacting solution proved to be light bulb substitution, that reaching a 30% overall electricity use reduction. The other solutions identified lower impacts ranging from 0.66% electricity reduction in S4, to 9.92% by adaptive comfort applications. The Net Zero Energy Balance was achieved in all cases except from the building as it is.

In S7, the NZEB target was achieved as well, while the PV peak power installed was reduced to 20 kW_p from 35 kW_p, due to the large reductions in energy use achieved by the retrofit studies.

The same retrofit solutions were analyzed one by one from an economic point of view in Table 2, whereas a simple payback time was calculated. For the sake of simplicity for the cost of energy, a single value of 0.166 Euros/kWh was used. Null payback times were obviously found for the passive solutions S1 and S2, while the LED lights scenario and the roof insulation proved to be the solutions with the lowest payback time.

Table 2. Summary of the results for the retrofit solutions—economic analysis.

Scenarios	Energy Savings (kWh)	Specific Cost	Payback (Years)
S1—Natural Ventilation	2839.60	0 Euro	0.00
S2—Adaptive comfort considerations in cooling setpoints	5121.60	0 Euro	0.00
S3—LED Lights	15,499.03	1.5 Euro/W	2.13
S4—Windows and frames	340.75	600 Euro/m^2	182.66
S5.1—Vertical structures insulation	877.69	10 Euro/m^2	37.09
S5.2—Roof Insulation	4058.04	15 Euro/m^2	3.79

The results can be expressed also by means of a standard NZEB graph, where the NZEB levels are represented by the orange line with a 45° slope. Ranging from the S0 scenario—the building as it is—all the retrofit scenarios move ideally from right to left, or from higher to lower energy use levels. The last step from S6 to S7 is on a vertical direction since it implies the reduction of unnecessary PV power.

4. Discussion

The analysis has presented a large range of potential retrofit actions. Some of them were more effective than others, however the real point was that their effectiveness was compared to their invasiveness and the potential risk for the historical value of the building.

This is the reason why some retrofit solutions were investigated at first but not included in the final redesign in the end, due to their overly invasive nature with regards to the features of the environment and of the building itself.

This was the case for wind turbines that would disrupt the visual impact of the historical park, as well as photovoltaic systems that would require complete reworking of the facades and appearances of the rural building under study. The proposed photovoltaics application instead was a perfect example of how to merge renewable generation needs to actual practical applications.

The idea, therefore, was to choose and rank the redesign solutions by both their effectiveness and the invasiveness on the historical background of the building.

The most relevant retrofitting scenarios are the least invasive approaches that can guarantee the highest energy savings. From this perspective, the first two scenarios (natural ventilation use and application of variable setpoints) were perfect for such a building, since the only needed actions were better strategies for the management of the openings and of the HVAC system. These solutions highlighted relevant energy savings that could be achieved through the development of a more developed energy awareness by the occupants of the building, with no costs and a null impact on the historical value of the building.

The largest energy reduction was achievable through the substitution of the lighting elements with higher performance LED ones. Aside from the limited impact on heating and cooling, this scenario could guarantee a relevant increase in performance, with a modest impact on the building, with little to no invasiveness. This scenario, due to the specific nature of the energy consumption of the building, proved to be the best and most impactful solution, representing a very effective compromise between invasiveness and effectiveness.

The substitution of windows and frames had a very limited impact on the results, since the Sanfilippo House has less than 5% of glazed surfaces on all facades.

The solution has a very limited impact on the performances of the building. Achieving only a 6% reduction of overall heating consumption, while performing a moderate invasiveness retrofit action in a heritage building, would probably not be the best choice in this context. Moreover, allowing moderately higher infiltration values could help in having healthier conditions indoors, in a building that does not have high airflow interaction with the outdoor environment.

Applying internal insulation to the vertical elements and to the roof leads to different results, mostly in accordance to the difference in the original transmittance values in the two cases. Having a transmittance equal to U = 2.55 $W/(m^2 \cdot K)$, the retrofit of the roof leads to the best results, up to nearly 8% in the overall electricity use reduction, while for the vertical walls this value could reach only 1.7%.

Although these solutions could be performed even on a heritage building, while the retrofitting of the roof is necessary, since it could cut by more than 50% both heating and cooling, the vertical walls would have only limited positive impacts on the results, and as such could be considered to be removed from the final implementation, to preserve as much as possible the integrity of the historical value of the building.

With regards to energy generation, the proposed solution was one of good integration with the environment without relevant impacts on the heritage value of the building. This solution was the only one viable among all the others, since it could be located outside the physical boundaries of the building. Achieving similar solutions to respect the heritage value of the built environment is not always possible however, and site-specific studies are needful to identify them.

5. Conclusions

The study has presented a case study of a typical rural heritage building of Southern Italy, built close to the archaeological site of the "Valley of the temples" close to Agrigento, Sicily.

In the paper, a redesign study of an historical building in a heritage context was discussed, achieving the target of NZEB while being respectful of the historical value of the building itself and of the overall site at which the building is built. Several redesign options were approached, and their potential for energy savings and impacts on the heritage environment were discussed and evaluated to choose the most suitable ones.

The best performing solutions to be applied to a case-study like the Sanfilippo House were those regarding the management of the building, as in the case of natural ventilation and the HVAC setpoints, and those with very limited invasiveness, as in the lighting scenario.

The most invasive actions can only be justified in the case of high energy savings, as in the case of the insulation of the roof, otherwise they should be disregarded.

The NZEB was achieved in most scenarios, thanks to the availability of PV generation. However, this kind of target needs to be achieved through site-specific solutions, since in protected buildings it can be problematic to install renewable energy generation technologies.

Author Contributions: Maurizio Cellura and Sonia Longo conceived and designed the activity, performed the on-site energy audit and interacted with the local authorities responsible for the building. Giuseppina Ciulla modeled the building and performed a part of the simulations, Francesco Guarino has performed a part of the simulations and written most of the paper. All authors have integrated some sections in the paper and reviewed it.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tassinari, P.; Torreggiani, D.; Paolinelli, G.; Benni, S. Rural Buildings and their Integration in Landscape Management. *Agric. Eng. Int. CIGR Ej.* **2007**, *9*. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.565.3963&rep=rep1&type=pdf (accessed on 21 July 2017).
2. Tadeu, S.; Rodrigues, C.; Tadeu, A.; Frire, F.; Simões, N. Energy retrofit of historic buildings: Environmental assessment of cost-optimal solutions. *J. Build. Eng.* **2015**, *4*, 167–176. [CrossRef]
3. Bastian, Z.; Spiekman, M.; Troi, A. Energy retrofit of cultural heritage buildings. *REHVA J.* **2014**, 24–27. Available online: http://www.rehva.eu/publications-and-resources/rehva-journal/2014/032014/energy-retrofit-of-cultural-heritage-buildings.html (accessed on 21 July 2017).
4. Laustsen, J.; Ruyssevelt, P.; Staniaszek, D.; Strong, D.; Zinetti, S. *Europe's Buildings under the Microscope. A Country-by-Country Review of the Energy Performance of Buildings*; Buildings Performance Institute Europe (BPIE): Bruxelles, Belgium, 2011; ISBN 9789491143014.
5. Ascione, F.; De Rossi, F.; Vanoli, G.P. Energy retrofit of historical buildings: Theoretical and experimental investigations for the modelling of reliable performance scenarios. *Energy Build.* **2011**, *43*, 1925–1936. [CrossRef]

6. Mazzarella, L. Energy retrofit of historic and existing buildings. The legislative and regulatory point of view. *Energy Build.* **2015**, *95*, 23–31. [CrossRef]
7. European Union. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). *Official Journal of the European Union*. 18 June 2010. L 153/13. Available online: http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32010L0031 (accessed on 23 July 2017).
8. European Union. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC (Text with EEA relevance). *Official Journal of the European Union*. 14 November 2012. L 315/1. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027 (accessed on 23 July 2017).
9. Presidenza Repubblica Italiana. *D. Lgs 192/2005, Attuazione Della Direttiva 2002/91/CE Sul Rendimento Energetico in Edilizia. G.U. n.222 del 23 Settembre 2005 S.O. n.158*. come modificato dal D. Lgs. 311/2006, G.U. n. 26 del 1 febbraio 2007 S.O. n. 26/L. 2007. Available online: http://www.camera.it/parlam/leggi/deleghe/05192dl.htm (accessed on 21 July 2017).
10. Martínez-Molina, A.; Tort-Ausina, I.; Cho, S.; Vivancos, J.L. Energy efficiency and thermal comfort in historic buildings: A review. *Renew. Sustain. Energy Rev.* **2016**, *61*, 70–85. [CrossRef]
11. Roberti, F.; Filippi Oberegger, U.; Lucchi, E.; Gasparella, A. Energy retrofit and conservation of built heritage using multi-objective optimization: Demonstration on a medieval building. *BSA 2015 Build. Simul. Appl.* **2015**. Available online: http://www.ibpsa.org/proceedings/BSA2015/9788860460745_24.pdf (accessed on 21 July 2017).
12. Polo López, C.S.; Frontini, F. Energy efficiency and renewable solar energy integration in heritage historic buildings. *Energy Procedia* **2014**, *48*, 1493–1502. [CrossRef]
13. Alev, Ü.; Eskola, L.; Arumägi, E.; Jokisalo, J.; Donarelli, A.; Siren, K.; Broström, T.; Kalamees, T. Renovation alternatives to improve energy performance of historic rural houses in the Baltic Sea region. *Energy Build.* **2014**, *77*, 58–66. [CrossRef]
14. Dalla Mora, T.; Cappelletti, F.; Peron, F.; Romagnoni, P.; Bauman, F. Retrofit of an Historical Building toward NZEB. *Energy Procedia* **2015**, *78*, 1359–1364. [CrossRef]
15. De Berardinis, P.; Rotilio, M.; Marchionni, C.; Friedman, A. Improving the energy-efficiency of historic masonry buildings. A case study: A minor centre in the Abruzzo region, Italy. *Energy Build.* **2014**, *80*, 415–423. [CrossRef]
16. Gagliano, A.; Nocera, F.; Patania, F.; Detomaso, M.; Sapienza, V. Deploy energy-efficient technologies in the restoration of a traditional building in the historical center of Catania (Italy). *Energy Procedia* **2014**, *62*, 62–71. [CrossRef]
17. Morelli, M.; Rǿnby, L.; Mikkelsen, S.E.; Minzari, M.G.; Kildemoes, T.; Tommerup, H.M. Energy retrofitting of a typical old Danish multi-family building to a “nearly-zero” energy building based on experiences from a test apartment. *Energy Build.* **2012**, *54*, 395–406. [CrossRef]
18. Rose, J.; Thomsen, K.E. Energy saving potential in retrofitting of non-residential buildings in Denmark. *Energy Procedia* **2015**, *78*, 1009–1014. [CrossRef]
19. Serghides, D.K.; Katafygiotou, M.C. The role of materials in the energy efficient retrofitting of traditional buildings. *Mater. Process. Energy. Commun. Curr. Res. Techonol. Dev.* **2013**, 978–984. Available online: http://www.formatex.info/energymaterialsbook/book/728-735.pdf (accessed on 21 July 2017).
20. Tagliabue, C.L.; Leonforte, F.; Compostella, J. Renovation of an UNESCO heritage settlement in southern Italy: ASHP and BIPV for a “Spread Hotel” project. *Energy Procedia* **2012**, *30*, 1060–1068. [CrossRef]
21. Zagorskas, J.; Zavadskas, E.K.; Turskis, Z.; Burinskiene, M.; Blumberga, A.; Blumberga, D. Thermal insulation alternatives of historic brick buildings in Baltic Sea Region. *Energy Build.* **2014**, *78*, 35–42. [CrossRef]
22. Guarino, F.; Athienitis, A.; Cellura, M.; Bastien, D. PCM thermal storage design in buildings: Experimental studies and applications to solaria in cold climates. *Appl. Energy* **2017**, *185*, 95–106. [CrossRef]
23. Beccali, M.; Cellura, M.; Fontana, M.; Longo, S.; Mistretta, M. Energy retrofit of a single-family house: Life cycle net energy saving and environmental benefits. *Renew. Sustain. Energy Rev.* **2013**, *27*, 283–293. [CrossRef]
24. Cellura, M.; Di Gangi, A.; Longo, S.; Orioli, A. An Italian input-output model for the assessment of energy and environmental benefits arising from retrofit actions of buildings. *Energy Build.* **2013**, *62*, 97–106. [CrossRef]

25. Beccali, M.; Cellura, M.; Mistretta, M. Environmental effects of energy policy in sicily: The role of renewable energy. *Renew. Sustain. Energy Rev.* **2007**, *11*, 282–298. [CrossRef]
26. Moschella, A.; Salemi, A.; Lo Faro, A.; Sanfilippo, G.; Detommaso, M.; Privitera, A. Historic buildings in Mediterranean area and solar thermal technologies: Architectural integration vs preservation criteria. *Energy Procedia* **2013**, *42*, 416–425. [CrossRef]
27. Pisello, A.; Petrozzi, A.; Castaldo, V.L.; Cotana, F. On an innovative integrated technique for energy refurbishment of historical buildings: Thermal-energy, economic and environmental analysis of a case study. *Appl. Energy* **2016**, *162*, 1313–1322. [CrossRef]
28. *ANSI/ASHRAE/IES Standard 90.1-2016—Energy Standard for Buildings Except Low-Rise Residential Buildings*; American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.: Atlanta, GA, USA, 2016.
29. Transsolar. TRNFLOW: A module of an air flow network for coupled simulation with TYPE 56 (multi-zone building of TRNSYS). 2009. Available online: http://trnsys.de/docs/trnflow/trnflow_uebersicht_en.htm (accessed on 21 July 2017).
30. Weber, A.; Koschenz, M.; Dorer, V.; Hiller, M.; Holst, S. Trnflow, a New Tool for the Modelling of Heat, Air and Pollutant Transport in Buildings within Trnsys. In Proceedings of the Eighth International IBPSA Conference, Eindhoven, The Netherlands, 11–14 August 2003.
31. ASHRAE. *Measurement of Energy, Demand and Water Savings*; ASHRAE Guideline 14-2014; ASHRAE: Atlanta, GA, USA, 2014.
32. Guarino, F.; Longo, S.; Tumminia, G.; Cellura, M.; Ferraro, M. Ventilative cooling application in Mediterranean buildings: Impacts on grid interaction and load match. *Int. J. Vent.* **2016**, 1–13. [CrossRef]
33. European committee for Standardization. *EN 15251: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings—Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics*; CEN: Brussels, Belgium, 2007.
34. European Committee for Standardization. *prEN 16798: Energy Performance of Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics—Module M1-6*; CEN: Brussels, Belgium, 2015.
35. Decreti, Delibere e Ordinanze Ministeriali. Attuazione dell'art. 25 del Decreto Legislativo 3 Marzo 2011, n. 28, Recante Incentivazione Della Produzione di Energia Elettrica da Impianti Solari Fotovoltaici (c.d. Quinto Conto Energia). Available online: http://www.gse.it/it/Conto%20Energia/GSE_Documenti/Fotovoltaico/02%20Normativa/Decreto_5_luglio_2012_Quinto_Conto_Energia.pdf (accessed on 9 June 2017).
36. Sartori, I.; Napolitano, A.; Voss, K. Net zero energy buildings: A consistent definition framework. *Energy Build.* **2012**, *48*, 220–232. [CrossRef]
37. Cellura, M.; Guarino, F.; Longo, S.; Mistretta, M. Different energy balances for the redesign of nearly net zero energy buildings: An Italian case study. *Renew. Sustain. Energy Rev.* **2015**, *45*, 100–112. [CrossRef]