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NATURAL STONE WALLS IN VERNACULAR ARCHITECTURE: WHAT CONTRIBUTION TOWARDS RURAL nZEB CONCEPT?

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Abstract
Rural housing, with its vernacular characteristics related to landscape, constitutes a heritage resource and plays a key role in the cultural and physical production of countryside identity. This paper explores the energy performances of a traditional rural house with granite stone walls, located in Cova da Beira, Portugal. The analysis on thermal properties of granite walls and energy consumption patterns and the simulation of potential solar energy supply have been performed using Autodesk® Ecotect®. Findings show that the zero energy balance of rural housing can be achieved by means of some energy efficiency improvements and solar energy integration. This research aims to stimulate the debate about «(re)thinking» the background of existing vernacular architecture, reflecting the need and benefits of improving global energy performances and give an outlook towards a new "Nearly Zero-Energy Building" (nZEB) concept for rural areas.

Keywords
energy efficiency, solar energy, rural housing, granite wall, vernacular architecture, nZEB

Résumé
L'architecture rurale, avec ses caractéristiques vernaculaires liées au paysage, constitue un patrimoine et joue un rôle clé dans la production culturelle et physique de l'identité de la campagne. Ce document explore les performances énergétiques d'une maison rurale traditionnelle avec des murs en pierre de granit, situé à Cova da Beira, Portugal. On a effectué l'analyse sur les propriétés thermiques des murs de granit, les modèles de consommation d'énergie et la simulation du potentiel électrique de l'énergie solaire en utilisant le logiciel Autodesk® Ecotect® Analyse. Les résultats montrent que l'équilibre à énergie zéro des bâtiments ruraux peut être réalisé grâce à quelques améliorations de l'efficacité énergétique et à travers l'intégration de l'énergie solaire. Cette recherche vise à stimuler le débat concernant la «(ré)formulation» du background de l'architecture vernaculaire existante, manifestant la nécessité et les avantages de l'amélioration des performances énergétiques globales des maisons rurales afin de jeter un coup d'œil vers une nouvelle conception de "bâtiments à énergie quasi zéro - Nearly Zero-Energy Building" (nZEB) pour les zones rurales.

Mots-clés
efficacité énergétique, énergie solaire, maison rurale, mur de granit, architecture vernaculaire, nZEB

I. INTRODUCTION

In the EU-28, predominantly rural and intermediate regions represented 90% of the territory and 57.4% of the population in 2010 (European Commission, 2014). In such pathway, the attention to meet economic, environmental and social challenges, that face modern societies in the 21st century, is shifting to rural development, promoting a resurgence of initiatives. According to Europe 2020 strategies and the overall Common Agricultural Policy (CAP) objectives, energy emerges as one of the most important factors that contribute to the sustainability of European countryside, playing a crucial role for achieving adequate levels of rural development and quality of life. However, the current framework for energy issues in rural areas focuses mainly on supporting agriculture, forestry and agri-food sectors, combining energy saving and renewable energies.

In line with urban energy challenges, energy efficiency and microgeneration solutions to upgrade rural housing stock, can play a key role in achieving the combined objectives of decarbonisation, resource efficiency and competitiveness (FREE, 2012). Overall, the strength of this position is supported by an essential evidence: rural areas present much lower energy consumption patterns when compared to urban areas and offer a higher degree of flexibility in the deployment of renewable energy sources (EREC, 2005). The underlying interest within this framework is to direct an analysis towards the architecture of rural housing, that, with its vernacular characteristics related to landscape, tradition and social values, constitutes a heritage resource and plays a key role in the cultural and physical production of countryside identity. Indeed, it is necessary to pay special attention to rural housing if the global objective is to stop depopulation in countryside, promote regional and local developments and contribute to the sustainability of these territories (Brezzi & Piacentini, 2008; European Commission, 2008). To do this, vernacular architecture has to prove energy efficient buildings for the future, integrated within its natural and cultural environment and in consonance with the axiomatic thought of the Portuguese landscape architect Telles, (2004): “Bringing the countryside to the city without bringing the city to the countryside” (Firmino, 2004).

Understanding energy balance concept of a building is an essential starting point. The European Directive 2010/31/EU (EPBD recast) promotes the improvement of energy performance of buildings within the Union, taking into account outdoor climatic and local conditions, as well as indoor comfort and cost-effectiveness. Within the framework of this directive, the definition of ‘Nearly Zero-Energy Building’ (nZEB), leads to a building that requires a very low amount of energy, which should be covered to a very significant extent by energy from renewable sources produced on-site or nearby (D′Agostino, 2015). Although, most aid effort related to these issues are focused on cities, the implementation of nZEB could be considered as an opportunity and a target priority for traditional or new rural housing, as it is already the case for urban areas.

According to the OECD classification, in Portugal, 81.3% of the continent is predominantly rural and recently, activities like tourism, gastronomy and landscape, are creating conditions to raise coutyard attractiveness and competitiveness (European Commission, 2013). The selection of traditional construction materials and techniques reflects the traits of each different region, constituting a great ethnographic value and a significant touristic potential: two essential premises to promote rural development and retain population to these territories (Firmino, 2004). The link between stone walls and rural regions is a strong one in Portugal: from the famous terraces supported by stone walls in the Douro Valley (Firmino, 2015) to the promotion of tourism in the historic stone villages in the Centre Region of Portugal (Silva, 2009).

Considering the aforementioned framework, this paper explores the energy performance of a traditional rural house with granite stone walls, located in Cova da Beira, Portugal. Analyses on thermal properties of granite wall and energy consumption patterns and simulation of potential solar energy supply were performed using Autodesk® Ecotect® Analysis software. Findings show that the zero energy balance of rural housing can be achieved by means of some energy efficiency improvements and solar energy integration. In this way, the present research aims to stimulate the debate about «(re) thinking» the background of existing vernacular architecture, reflecting the need and benefits of improving global energy performances of the rural houses in order to give an outlook towards a new “Nearly Zero-Energy Building” (nZEB) concept for rural areas.

II. BACKGROUND

At the present, the interest of countryside itself is reflected in a profusion of policies (see, for example, CAP-Common Agricultural Policy, EU Rural Development Policy), programs (see, for example, RDP-Rural Development Program 2014-2020, CLLD-Community Led Local Development) and initiatives (see, for example, LEADER- Liaison Entre Actions de Développement de l’Économie Rurale, ENRD - European Network for Rural Development), trying to make sense of sustainable development and struggling to make rural areas attractive for the establishment of enterprises, places to live, tourism, and recreation businesses (Virchow & Braun, 2001). European rural landscapes are such a complex historical mosaic fashioned by humankind and nature over the centuries, it is not different from the architectural heritage that has long been protected by national and international instruments (Council of Europe, 2001). An overall approach to countryside is needed to maintain landscape features such as vernacular buildings terraces, hedges, stone walls or other and ensure that traditional housing stock preserves those materials and construction systems inherited from the past (Council of Europe, 2002; Domingues, 2001). Since the start of vernacular as an academic and professional discipline in the nineteenth century, there has been strong emphasis on studying and preserving historical rural buildings and traditions, considering them the most "authentic" buildings (JA Al-Qawasmi, 2013). This is the real value of rural architecture in Europe: to be original and European at the same time (Council of Europe, 2001).

Climatic conditions, topography, and available building materials influence the typological, structural and morphological solutions of rural housing and led to various configurations which reflect the specific habits, needs and the way of living of the local (Philokyprou, Savvides, Michael & Malaktou, 2014). Vernacular architecture studies have given rise to a large number of publications, notably in the second half of the 20 the Century. Within this field, the pioneering works of Rudofsky (1964), Oliver (1969) and Rapoport (1969) established links between vernacular architecture and the complexity of societal and cultural processes (Asquith & Vellinga, 2006). As Oliver (2006), commented in a most recent publication: "all forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them". In some way, this is precisely the perspective that responds to the notion of sustainability. Looking at the experience of vernacular architecture, local materials to provide thermal comfort, building forms to ensure natural lighting and sun radiation, traditional construction and technologies adapted to suit local environment and cultures, offer an interesting understanding of the lessons that can emerge from its study. Indeed, scientific literature which relates vernacular architecture and energy performances, has been reinforced in recent years, especially considering rural housing types and materials.

On this reading, the focus of the research is thermal comfort, which is defined by ASHRAE (1966) as "that condition of mind which expresses satisfaction with the thermal environment" (Hall, 2010:128). The study of Martín *et al.*, (2010) on two traditional houses, respectively made of local stone and adobe and one modern in prefabricated wooden, shows that the thermal behaviour of traditional houses is definitely better than the new one, due to the high thermal inertia of exterior walls. The research and intervention on the rehabilitation of rural houses, according to Lanzinha & Castro-Gomes (2010), may be done under a perspective of sustainable construction, especially in order to improve the thermal and hygrometric indoor comfort and combine traditional heating systems with new heating solutions, more ecologic and with renewable power supply (particularly geothermal and solar power). In line with Lanzinha and Castro-Gomes 'studies (2010) of thermal rehabilitation, Moradias, *et al.*, (2012), discuss the need to improve traditional house with stone masonry wall (granite) envelopes and prove the better contribution of the thermal resistance of pinewood, comparatively to plaster, which is in accordance with the thermal conductivity of each of these materials. By means of energy performance simulations, Alev *et al.*, (2014) observe that different alternatives, such as the renovation of thermal envelope, heating and ventilation systems, can be used to make historic rural houses more energy efficient and to improve the indoor climate. Creating a base geometry and set of thermal characteristics for detached Irish traditional dwellings, the approach of Ahern *et al.*, (2013), and their methodology, constitute a significantly contribution for fabric improvement measures related to heat loss due to envelope surface areas, glazing, thermal bridging and ventilation loss.

With respect to on-site renewable energy technologies, literature available on rural housing highlights the use of solar collectors for DHW and PV-panels (Alev *et al.*, 2014; Martín *et al.*, 2010; Missoum, Hamidat, Loukarfi, & Abdeladim, 2014). Nerveless, the concern to preserve vernacular architecture and landscape aesthetic values is open to argument. On the face of it, the installation of solar systems in vernacular buildings, whether old or new, implies a balance between technology impacts and historic and cultural value (Moran & Natarajan, 2015). With the emergence of nZEB paradigm, the recent experience of the Hope House in Molesey, Surrey, introduces the new concept of RuralZED. Hope House is a prefabricated kit house that was built using locally-sourced materials and combining microgeneration technologies with high standards of energy efficiency (Dunster, Simmons, & Gilbert, 2007). In line with BedZED (Beddington Zero Emission Development), the UK's largest mixed-use zero-carbon community, the Hope House is the first model of detached house suitable for rural location (Dunster *et al*., 2007).

Inspired by the aforementioned framework on energy efficiency, solar energy and nZEB concepts, this paper aims to deepen the approach to zero energy balance buildings, by studying vernacular architecture characteristics and the positive contributions provided by stone walls with high thermal inertia. Focusing on building construction systems and materials, Beira Interior and Cova da Beira regions show a predominantly rural housing stock with stone wall (Lanzinha & Castro-Gomes, 2010). This kind of thick exterior wall, with high thermal inertia, provides comfortable indoor environment inside traditional rural housing with less energy consumption than new buildings (Martín *et al*., 2010). Furthermore, the high levels of solar radiation in Portugal represent an excellent condition to implement photovoltaic and solar thermal system in rural buildings (Carvalho, Wemans, Lima & Malico, 2011). In this perspective, the present research discuss the relationship between natural stone walls and energy performances in vernacular architecture, in order to promote energy efficiency improvements and microgeneration integration into existing and new rural buildings, towards a new Rural nZEB concept.

III. METHODOLOGY

The nZEB concept aims to produce high energy performance buildings that reduce the specific demand for heating to a minimum, reduce the primary energy consumption for heating, cooling, ventilation, domestic hot water and lighting and cover the overall primary energy demands with renewable energy resources (ECEEE, 2014). The three aforementioned nZEB principles, represent the theoretical background that has inspired the research question of this study: "Natural stone walls in vernacular architecture: what contribution towards Rural nZEB concept?"

The proposed approach is not strict linear but it integrates qualitative and quantitative methodologies. In this framework, the methodology is structured in three phases: conceptual, experimental and synthesis that have to be taken into account to derive reliable answers. The conceptual phase deals with the identification of basic parameters, which relate to each of the three nZEB principles with building components and appliances (Table 1).

Table 1. Basic parameters relating nZEB principles and building components and appliances

nZEB PRINCIPLES	PARAMETERS
Reduce heat demand	Building orientation Thermal mass envelope U-Value (walls, roof, ground floor, glazing) Heating systems Ventilation/air change and infiltration (windows, doors)
Reduce the primary energy consumption	Thermal mass envelope U-Value (walls, roof, ground floor, glazing) Window size Appliance power consumption and use Heating systems (fuels) Water heating systems
Cover primary energy demands with renewable energy resources	Solar radiation Wind speed High temperature geothermal resources

The experimental phase carries out analysis on a case study in order to understand the relationship between the basic parameters and the building energy performances. It is important to use a tool able to perform full thermal, solar and energy analysis. As a variety of coupling simulations and data visualizations are possible, Autodesk® Ecotect® Analysis software has been adopted, developing an approach for building performance analysis and simulation (Figure 1).

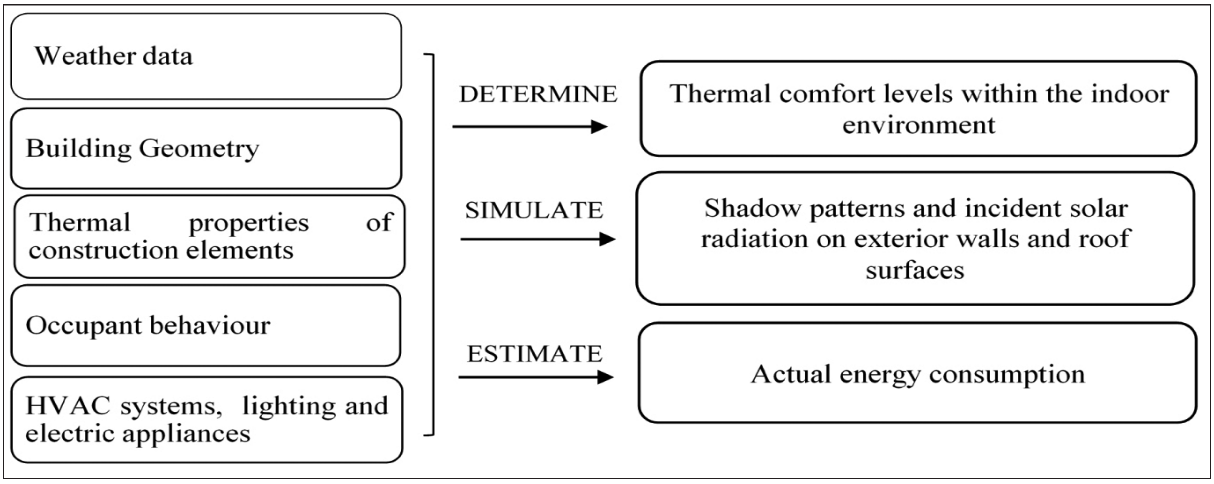


Figure 1. Proposed approach for building performance analysis and simulation

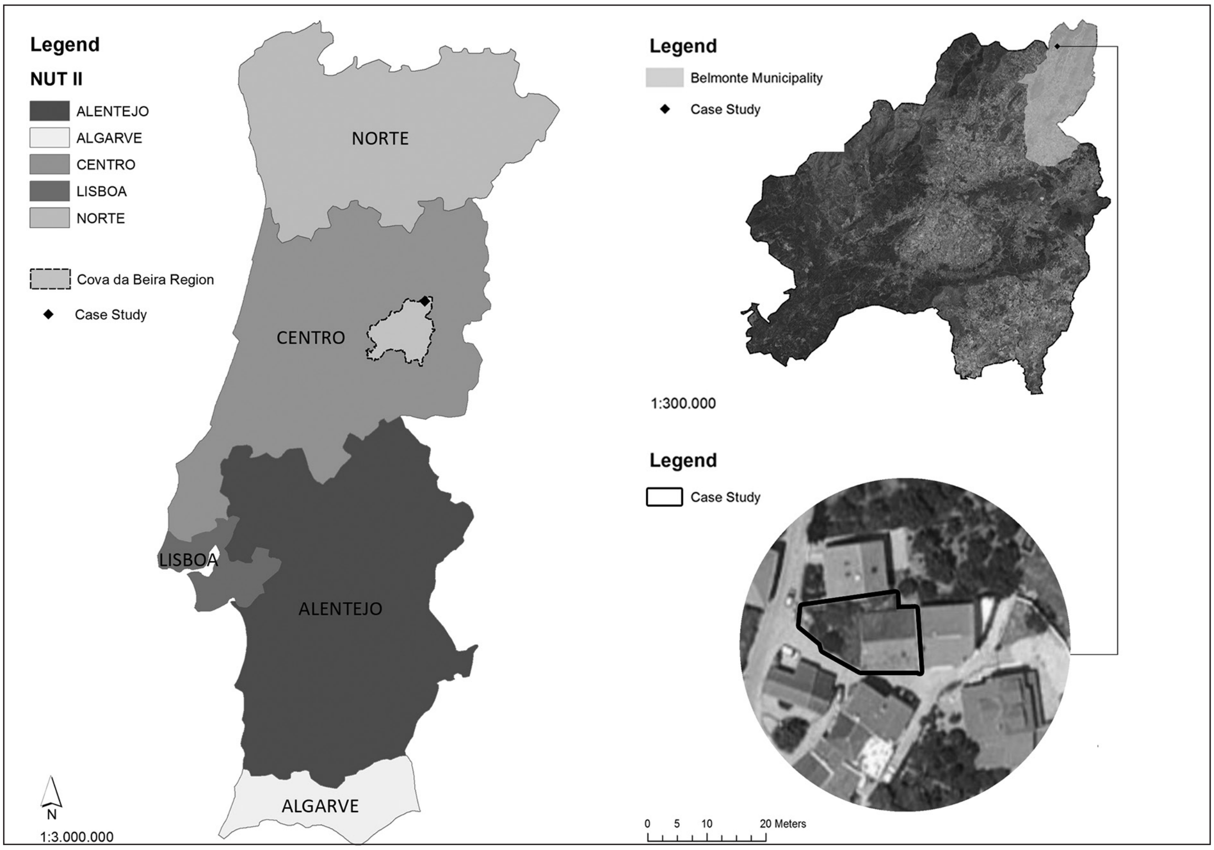


Figure 2. Location of the case study (Cova da Beira, Portugal)

The synthesis phase compare the obtained results from the case study with the nZEB requirements, reflecting then a formal definition of the Rural nZEB concept.

IV. CASE STUDY

The ambition of the case study is to reflect on a representative case of building in order to introduce the nZEB concept into vernacular architecture, with particular regard to the use of stone wall in traditional rural housing. The criteria used for the selection of the case study are the following:
- Geographic location – rural regions where local stones are traditionally used as construction materials;
- Climate conditions – temperate climate with dry and/or hot summer, large daily temperature variations and high level of solar radiation throughout the year;
- Vernacular architecture – viewed as a local rural context asset, with particular regard to the use of stone wall in traditional rural housing;
- Socio-economic profile of occupants – existence of residential or tourist-recreational activities related to historical centres and their religious heritage, archaeological sites, cultural landscapes, natural parks and places of traditional or ethnic significance;
- Typology of building – traditional one family rural house;
- Constructive system and materials – existence of traditional exterior stone walls and available roof area for PV installation facing south.

Beira Interior and Cova da Beira are rural regions where traditional one-family house with exterior stone wall, is the predominant typology of residential building (Moradias, 2012). According to the aforementioned features, the case study is established in the village of Colmeal da Torre, just north of Belmonte municipality, in Cova da Beira region (Figure 2).

Climate conditions

According to the Koppen Climate Classification, Belmonte holds a warm and temperate climate (Csa) with an average annual temperature of 13.7 °C. The temperatures are highest on average in August, at around 22.4 °C, while the lowest average temperature of the whole year is in January at around 6.2 °C. In a year, the average rainfall is 1006 mm with the least amount of precipitation in July, with an average of 9 mm and the most amount in January, with an average of 150 mm. The climate conditions are obtained from (CLIMATE-DATA, 2016) (Figure 3).

Vernacular architecture

High levels of thermal mass are common in rural houses of this region where, local sources bulk materials such as granite and schist stone, are easily available. The case study has relevant features and challenges with respect to study its energy performances:
- First, the traditional exterior walls of granite, which due to their thermal mass, maintain constant the indoor temperature across the year.
- Second, the south orientation of the pitched roof,

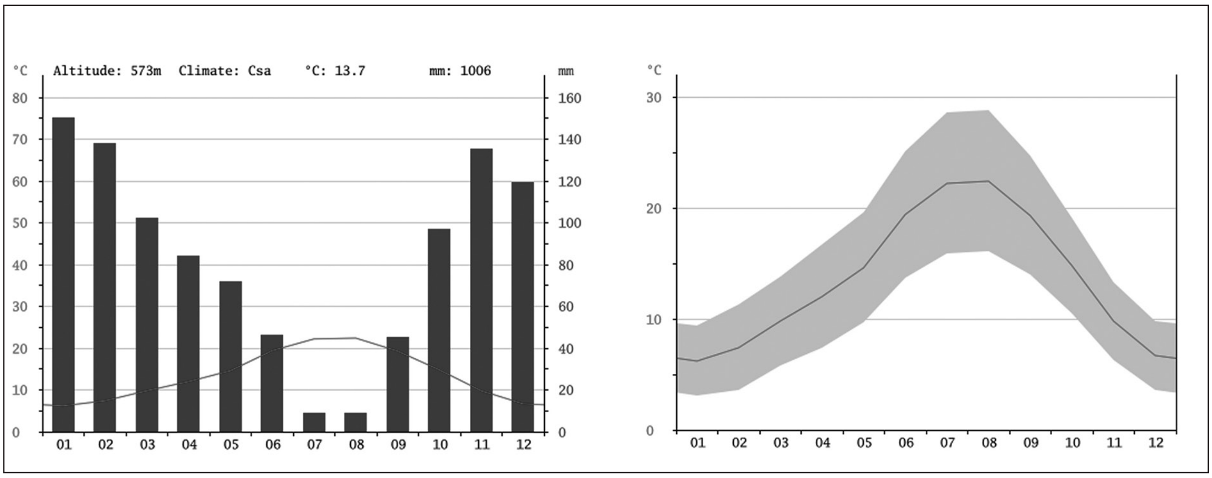


Figure 3. Climate and temperature graphs (CLIMATE-DATA, 2016)

which provides an optimal surface for solar energy system installation.
- Third, the occupants' behaviour in rural houses, which shows different patterns in the countryside compared to the city, regarding energy consumption for heating and cooling requirements.

Socio-economic profile of occupants

The global socio-economic profile of this rural region reflects three different social classes: the residents, the second homeowner and the tourists. In particular, the expansion of second homes in older and single-family buildings located in rural areas, with attractive natural and cultural landscape, shows percentage greater than 20% in Centre Region of Portugal (Instituto Nacional de Estatística, 2012; Loureiro de Matos, 2013). According to J. Oliveira & Costa (2012), the majority of second home owners are residents in Lisbon metropolitan area, followed by Portuguese emigrants and foreigners. These groups differ in frequency of use of second homes, given that residents in the Lisbon metropolitan areas and emigrants are mostly economically active couples with children, while foreigners are predominately retirees (Oliveira & Costa, 2012). In this context, the profile of the occupants of house is a middle-class one-family household with two sons who are 25 and 20 years old.

Description of the typology of building

The case study is an example of traditional rural house, with exterior granite walls dating back to the 1920s. On the other side, the roof and the windows have been recently replaced due to bad state of conservation. The type of the building is one-family house, presenting a rectangular plan with a rather simple interior room subdivision (Figure 4-Figure 5).

Constructive system and materials

The constructive system is composed by exterior granite stone walls with a thickness on the order of 0.6 m. The roof was reconstructed in the last decade, according to the original timber roof structure and Marseille clay tile covering. In order to separate the occupied zones of the house from the unoccupied roof zone, it was necessary to provide a system of concrete columns and beams to support a new ceiling. The occupied zone is subdivided by internal partitions of single 0.1 m brick on a ground floor that consists of a 0.1 m concrete slab plus ceramic tiles. All the aforementioned elements have no insulation materials. On the other side, the old timber windows were replaced with PVC double glazing.

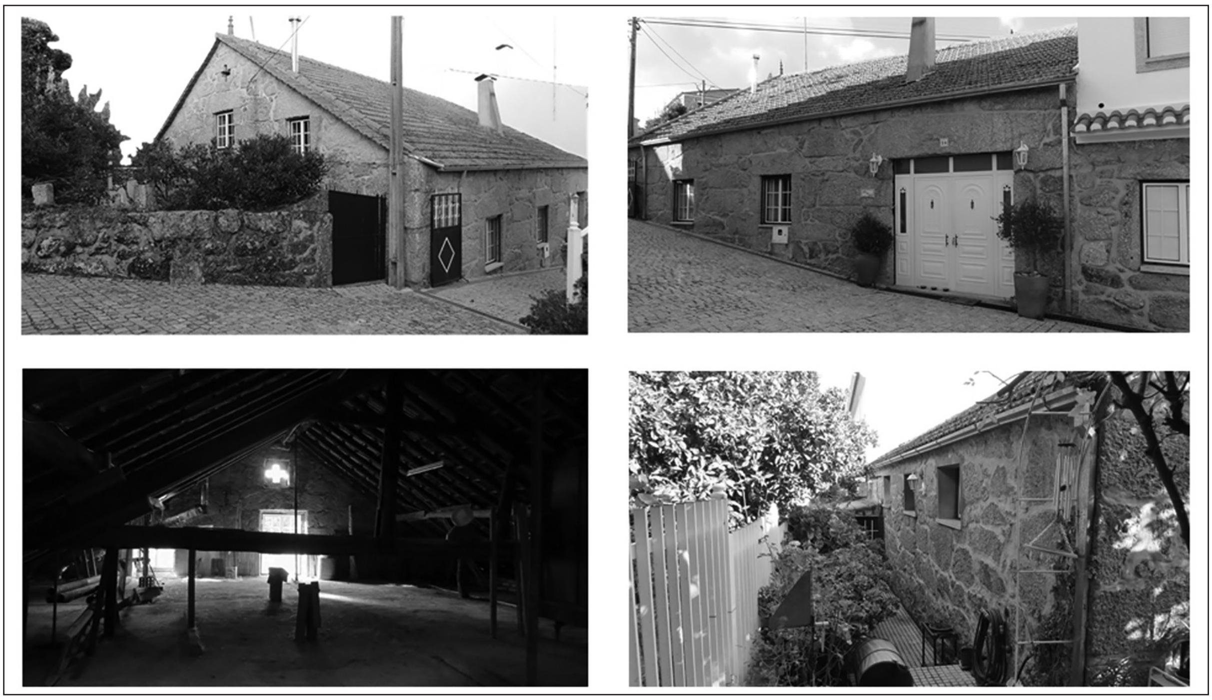


Figure 4. Images of the building

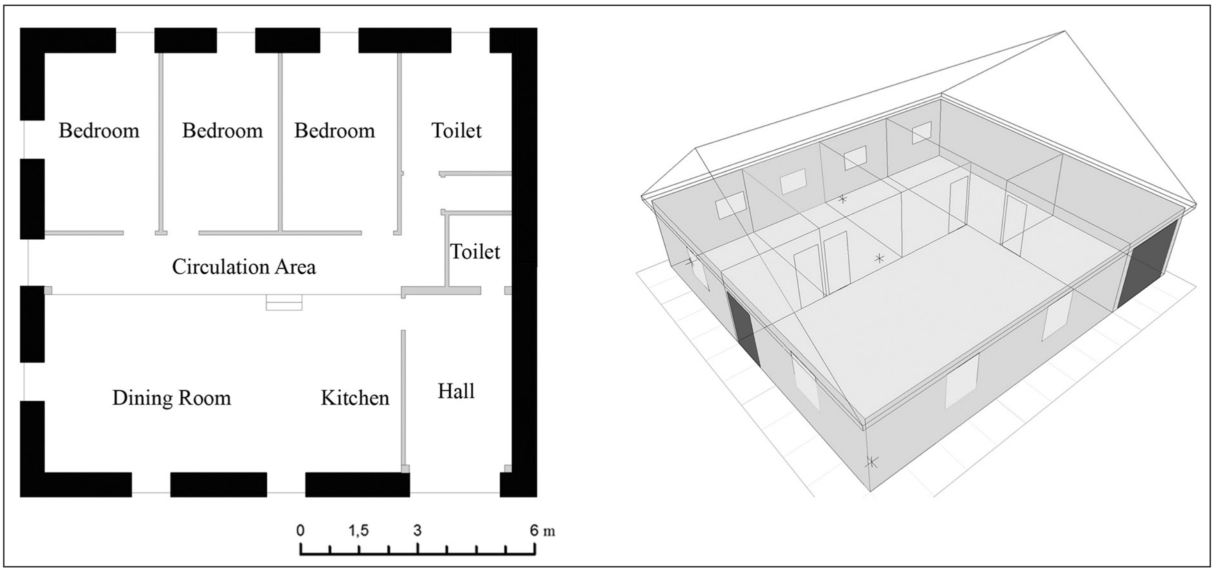


Figure 5. a) Floor plan; b) 3D model by Ecotect® Analysis

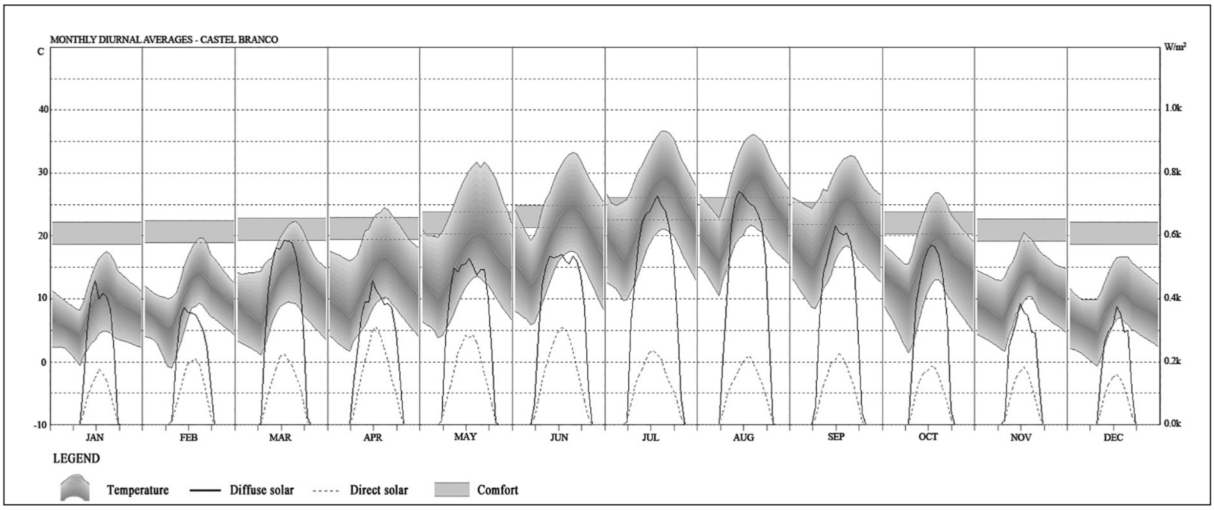


Figure 6. Climatic data (Source: meteorological station of Castelo Branco)

Weather data

The weather data used in this research was collected from the meteorological station of Castelo Branco (348m above sea level; N 39° 49’ W 7° 28’) and synthetized by means of Ecotect® Analysis, as shown in Figure 6.

Thermal analysis

The present analysis combines local climate data, geometrical and thermal parameters and the occupants’ behaviour patterns in order to assess the indoor comfort and the heating and cooling loads of the building. Table 2 reports the geometrical and thermal parameters which result from the modelling and calibration of the building in Ecotect® Analysis.

From the perspective of energy performances, the building wall envelope is the most influent construction component. Thermal transmittance data of many traditional materials is simply not available and calculations at present are based upon idealised, homogenous walls. In this framework, the U-Value of the external granite wall has been identified, using the results of Rodrigues and Pina dos Santos‘s research (2009), on construction solutions for old buildings. Considering the mortar joints percentage and their composition with regards to

Table 2. Technical description of the building

Geometric data	Thermal conductivity of the envelope U (W /m^{2}C)
Number of floors 1	External granite walls (600mm) 2.1
Built in volume 312 m^3	Double glazed windows with aluminium frame 2.7
Exposed area 578 m^2	Concrete floor on ground plus ceramic tiles 0.9
Floor area 112 m^2	Concrete ceiling 2.5
South roof area 81 m^2	Interior partition with brick and plaster 3.1

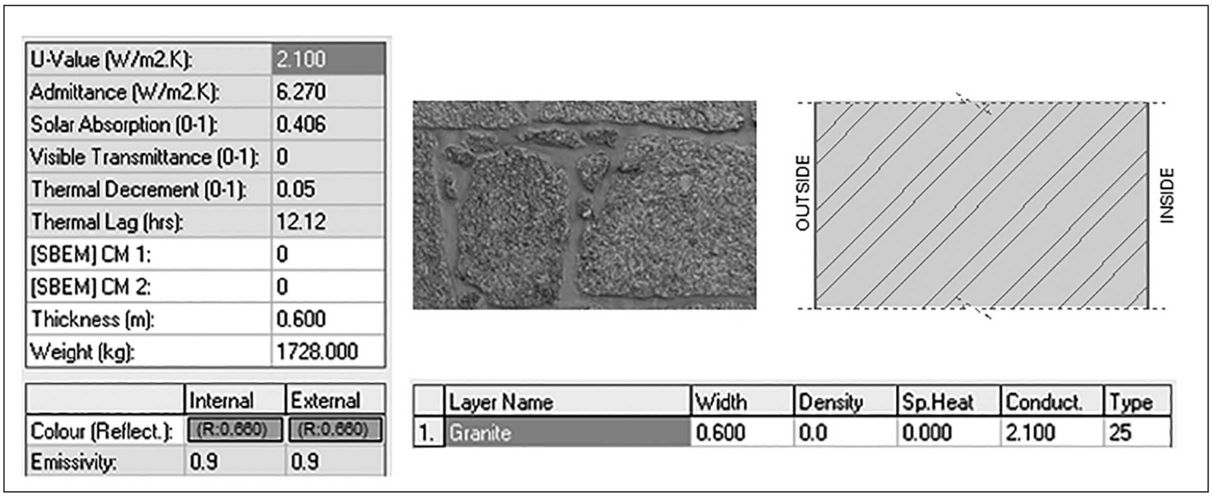


Figure 7. Granite wall description

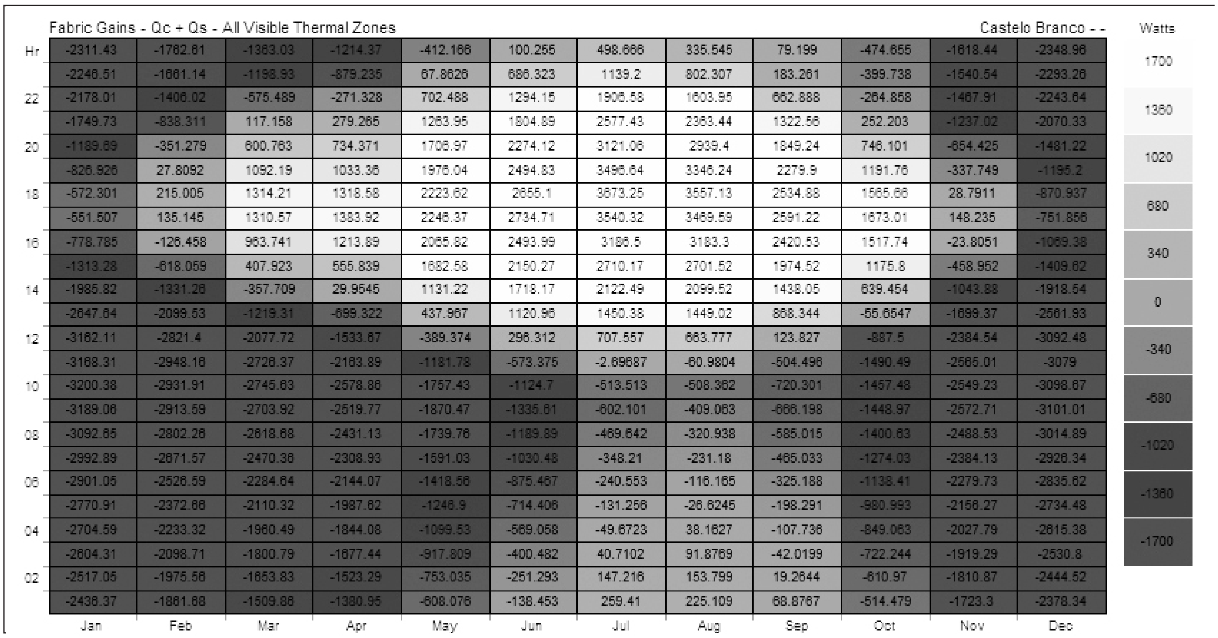


Figure 8. Simulation of the stone wall heat gains and losses (Watts)

total wall surface, the mean value between 2.4 W / m^2K and 1.8 W /m^2K has been adopted (Figure 7).

The thermal mass performances of the granite stone wall is then obtained by simulating the heat gains and losses (Watts) on an average day each month. The graph of Figure 8, with months along the horizontal axis and hours of the day along the vertical, shows a matrix where each grid square represents the heat gains from the exterior stone walls, due to both external temperatures and incident solar radiation.

Thus, it is possible to observe that from May to October, heat gains occur from 12am to midnight, showing the positive long term effects provided by the high thermal mass of the stone walls. In winter, heat gains occur mainly from about 15pm to 21pm and just during the months of December and January heat is lost through the exterior stone walls. Additionally, the thermal comfort analysis confirms that the indoor environment of the building achieves good percentages of satisfaction in the dining room and kitchen zone, due to the wide area of south-facing stone wall and the use of a fireplace as heater system. On the other hand, the same results do not occur in other zones of the building where the heat gains are negatively influenced from the north-facing orientation of the stone wall (Figure 9).

Electricity consumption

In relation to the energy consumption, the house is occupied by four active inhabitants who work and study during the day. The occupants use a fireplace, burning 4Kg of wood charcoal per hour, to heat the dining room and kitchen zone. The bedrooms are heated by means of electrical appliances, especially during the winter nights. Besides, the thermal mass of the walls provides a natural comfortable indoor environment, so no cooling system is used, during the summer. Data, obtained from a questionnaire survey of appliances and heating systems, show that the total electricity consumption is 5462 kWh/ year (Table 3).

The house is not cooled and the load is slightly higher in winter than in summer because of the need to run additional heating systems such as an electric appliance in each bedroom.

Solar energy generation

If the nZEB goal is to produce as much electricity as the annual demand, solar energy represents a key element to face electricity consumption patterns by means of photovoltaic (PV) and solar thermal collectors (STC) systems. The environmental and economic value of these technologies make them significant for both existing and new housing deve-

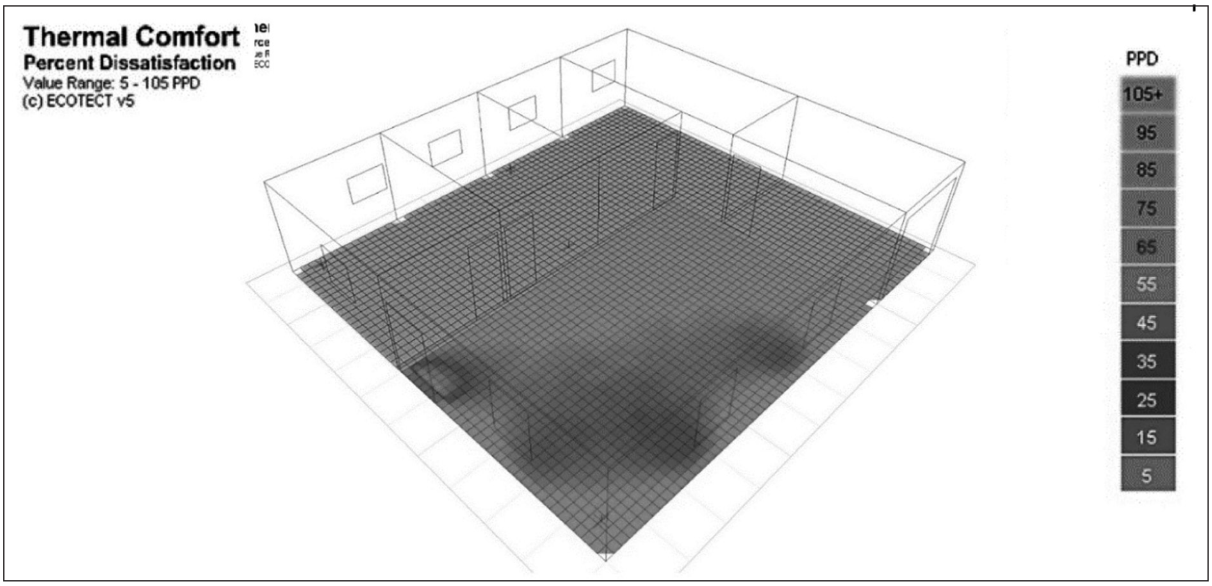


Figure 9. Thermal comfort of indoor environment of the building

Table 3. Electricity consumption by appliances and heating systems

Appliances	Watts	Hrs/Wk	Wh/Wk	Annual operating schedule
Dishwasher	1400	2	2800	
Iron	1000	2	2000	
Laptop Computer	35	10	350	
Microwave	1000	1	1000	
Refrigerator	150	168	25200	48 weeks
TV: 25 Color	150	25	3750	
Vacuum cleaner	700	1	700	
Washing Machine	500	3	1500	
30 Energy Saver Lights (20W)	600	5	3000	
3 Electric heaters	6000	21	126000	28 weeks
Subtotals	**Watts**	**Hrs/Wk**	**Wh/Wk**	**kWh/year**
Appliances	5535	217	40300	1934
Heating systems	6000	21	126000	3528
Totals	11535	238	166300	5462

lopments. In this section, a solar radiation analysis on the case study has been carried out in order to identify suitable surface for PV or STC system. By performing the shadows range and solar radiation simulations on the building, it is possible to verify that the south orientation and inclination of the roof provide a wide surface with high level of incident insolation and which is not overshadowed from the surrounding building (Figure 10-12).

As a gas boiler is used to supply hot water to the house, the PV system installation on suitable roof area is studied in order to estimate the potential electricity supply. Figure 12 reports the framework of parameters that determine the potential electricity supply, if the house was equipped with a PV system of 42 m^2.

According to the analysis carried out with Eco-

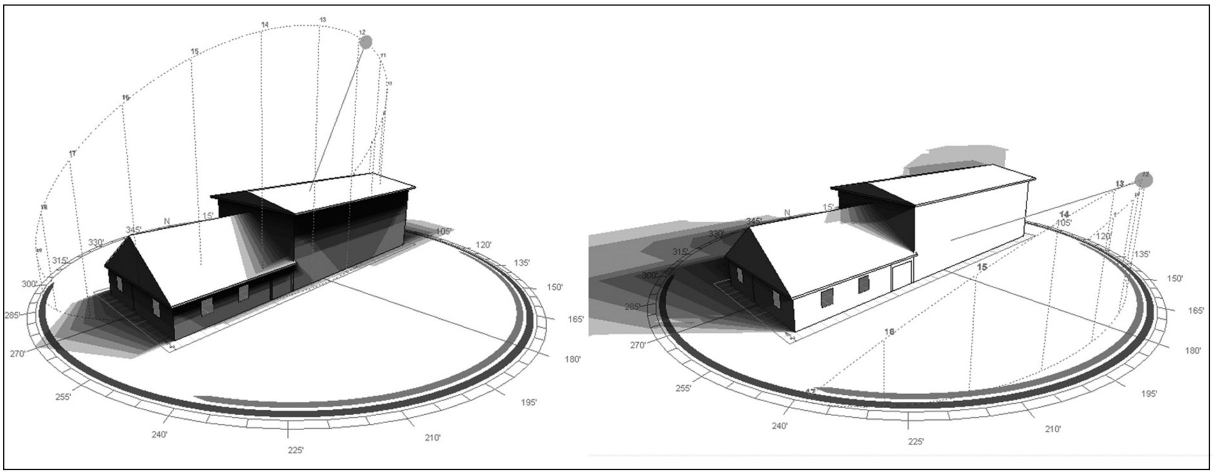


Figure 10. Shadows range; a) Summer solstice; b) Winter solstice

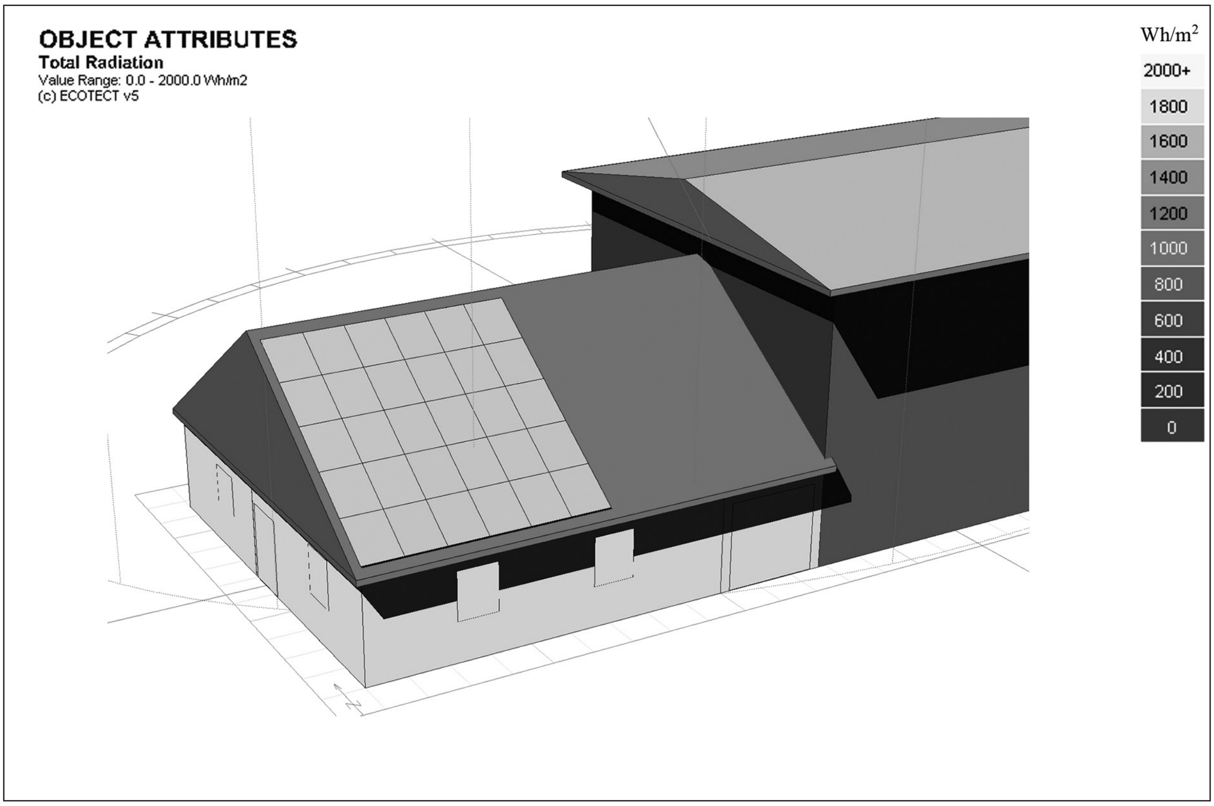
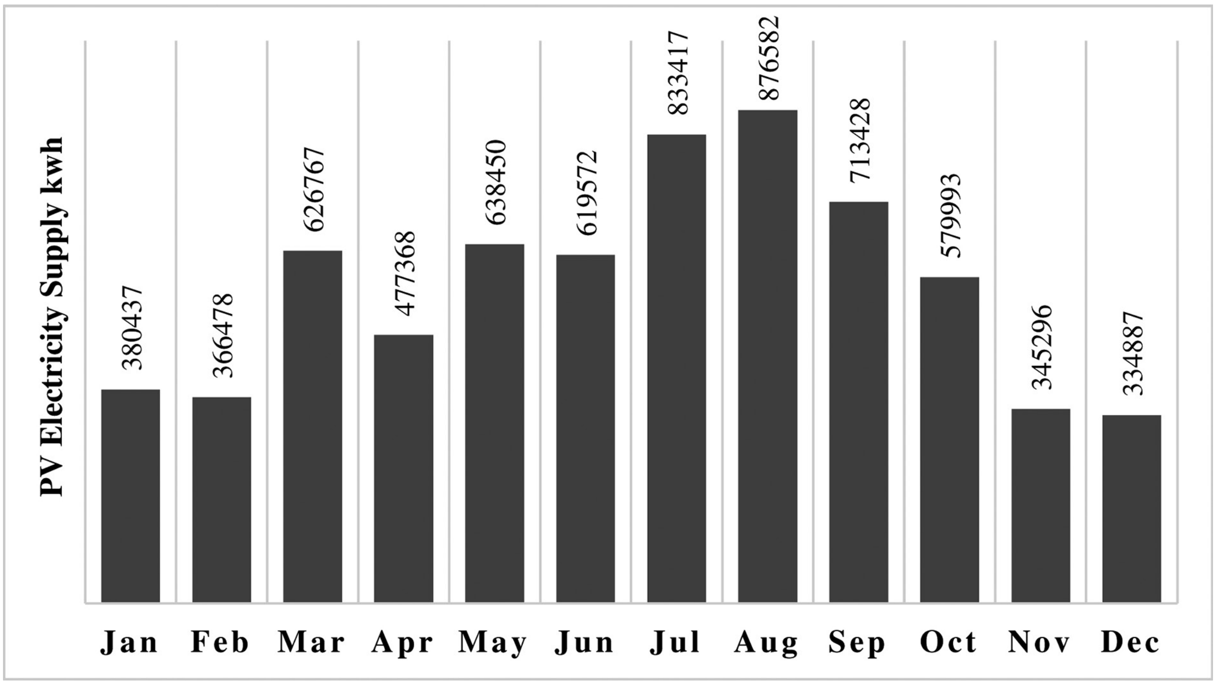


Figure 11. Solar radiation simulation and suitable roof area for PV system



PV System Area m²	Total solar radiation kWh/m²	Mean global radiation kWh/m²	Predicted yield for PV systems kWh	PV electricity supply kWh/year
42.2	54081	1613	71345	6956

Figure 12. Monthly PV electricity supply on the suitable roof area (kWh)

tect®, it is evident that solar radiation is influenced by seasonal and monthly variations that depend from the effects of latitude and the amount of cloud cover. The mean global radiation, depending on the geographical location, shows a value of 1613 kWh/m^2 giving a positive feedback about the high level of solar energy potential on the roof surface (Amado & Poggi, 2012). The annual PV electricity supply value of 6956 kWh/year has been obtained by adopting the equation of (Bahaj & James, 2007):

$$\text{Annual PV energy production} = PR \times Me \times Vst \times (Gr) \quad (1)$$

- PR is the Performance Ratio that considers the energy losses in the balance of system (adopted value in (1) | PR=0.75);
- Me is the nominal module efficiency rating at standard test conditions: air mass AM 1.5, irradiance 1 kW/m^2, cell temperature 25ºC reported by the selected manufacturer (Martifer Solar, 2014) (adopted value in (1) | Me = 13 %);
- Vst is the solar radiation values at standard test conditions of irradiance: Vstc =1 kWh/m^2 reported by the manufacturer;
- Gr is the predicted yield for PV systems over a year (value obtained from Ecotect® simulation, see Figure 12).

V. RESULTS AND DISCUSSION

The energy balance, related to nZEB concept, puts forward the target that the differential between the overall energy demand for heat, hot water, electricity appliances and the renewable energy, produced locally, should be extremely low (almost zero).
In the present case study, the energy balance equation indicates that the actual electricity demand of the building can be totally covered by a PV system with $42m^2$ on the roof. Figure 13 reports the percentage difference comparison between PV electricity supply and electricity consumption and the differential of 11 % represents the electricity power surplus of 1494 kWh. It is also possible to note how heating systems accounts for 65 percent on total electricity consumption, constituting one of the most important aspects to improve.

In this context, it is important to refer that the initial investment cost, associated with a PV system of 42 m^2, can be high, requiring a long-term payback because of low electricity rates in the residential sector. It is therefore necessary, to increase energy efficiency levels of the building by means of some specific improvements which can provide significant energy and cost savings. According to the features of the case study, the energy efficien-

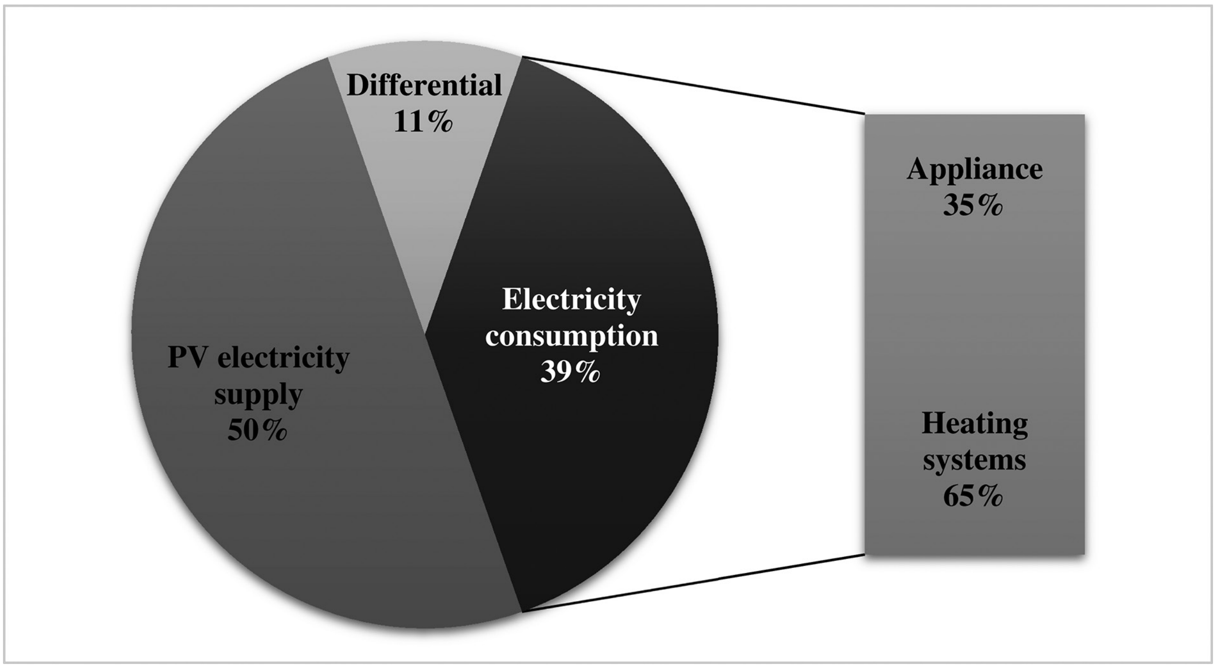


Figure 13. Percentage difference comparison between PV electricity supply and electricity consumption

cy improvements that can be adopted involve the followings aspects:
- insulate walls, floors, roofs, possibly introducing ecological materials for insulation such as, for example, cork which is largely produced in Portugal;
- repair and retrofit the original wood windows and add new interior or exterior removable glazing panels in order to protect the character of traditional building and respect the environment;
- replace the existing electric heating systems with an heat pump or an active solar heating system, which, considering the climatic conditions of the site, constitute an efficient solution;
- install a thermal solar system, to cover the domestic heat water demand of the building. In order to make the best use of the suitable roof area for the PV system, the solar collector and the storage water tank could be installed in the outdoor garden area within the lot;
- the existing energy saver bulbs are an efficient way for the general house lighting. Nevertheless, LED bulbs last longer and represent a better solution for the rooms that need directional light sources for reading, cooking, or working;
- replace electric appliances, especially those that account for major end uses of energy such as laundry, cooking and refrigeration, with more energy efficient appliances;
- adopt smart meters to put occupants in control of how much energy each appliance uses, allowing to reduce energy consumption.

VI. CONCLUSIONS

In a world where energy efficiency continues to be a predominantly urban challenge, this research shows as natural stone walls in vernacular architecture provide optimal levels of energy performances with regard to rural housing.

The promotion of local materials and traditional construction techniques represents a strategic vector to guarantee good energy performances of rural housing, reduce resources consumption and greenhouse gas emissions. Energy efficiency plays a key role in providing quality of "living in rural areas" which is an essential social aspect to be taken into account within the context of sustainable communities. On the other hand, the solar analysis performed in the case study, confirm the determinant role of PV systems for achieving the positive energy balance, which is the primary target of the nZEB concept. Due to climatic condition and site features, the implementation of solar power technologies for electricity and hot water supply is much simpler in rural areas than in urban ones. Nevertheless, it is always necessary to provide functional and efficient solutions, which don't affect vernacular architecture and landscape aesthetic values.

«(Re)thinking» the background of existing vernacular architecture, reflects the need and benefits of improving global energy performances of rural houses. In this sense, the Rural nZEB emerges as a theoretical model that, involving specific design principles, materials, renewable energy technologies and refurbishment guidelines, will be developed in order to preserve, protect and promote rural housing and thus contribute to the development of rural areas.

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