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# Investigating Thermal Performance of Residential Buildings in Marmari Region, South Evia, Greece

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Received: 17 December 2019; Accepted: 10 February 2020; Published: 26 February 2020



**Abstract:** In recent decades, the steady increase of energy consumption from building construction and operations cause atmospheric pollution and significant financial burden, mainly due to the high costs imposed from energy production. This study examines ways under which modern designs of a building can be applied on construction and domestication while following conventional methods of construction, compared to a building that has been constructed and domesticated under bioclimatic architecture. Particularly, two buildings were investigated in terms of the energy consumption incurred, being built on the same seaside area and period of construction and at adjacent plots of the same distance from sea for ease of comparison. The first building (A1) was constructed under the principles of bioclimatic architecture, being also facilitated with green and smart technologies. The second building (A2) was constructed under conventional construction techniques. The energy efficiency of both buildings was calculated by the “TEE KENAK” software, while specific parameters were recorded. Energy classifications of both buildings were valued and a proposed scenario and interventions unveiled the energy classification upgrading from A2 to A1. Our analysis revealed, as also found in the literature, that during thermal energy oscillating conditions, corresponding relative humidity stresses were observed, indicating that the vapor pressure handling should be taken into account towards comfort. The preliminary incremental cost evaluation and comparison of A1 and A2 energy upgrading under the criterion of simple payback period were critically discussed.

**Keywords:** thermal performance; building energy use; indoor environmental quality; energy classifications; microclimatic monitoring; green technologies; smart house; Mediterranean climatic zone; energy performance of buildings directive–EPBD; European standards

## 1. Introduction

In recent decades, economic growth and technological development accelerated the excessive use of conventional forms of energy, resulting in increased emissions and leading to the ongoing destruction of the natural environment and its accommodated ecosystems. At the Mediterranean basin, in general, and in the Greek context, in particular, a developed, vivid, and extensive literature has been developed on the impacts of energy consumption and possible policies to plan and control energy consumption to alleviate the environmental pollution caused by the ongoing overexploitation

of fossil fuels for energy production [1–5]. In the built environment of the Mediterranean basin, it is noteworthy that predictions made by bioclimatic indices differ from actual thermal pleasure, thus, research has been focused on assessing such commonly-used bioclimatic indices that unveil human thermal pleasure, mostly identifying simulated thermal pleasure in a Mediterranean urban environment [6]. Field surveys, weather measurements, and different microclimatic characteristics in Athens, Greece, all unveiled a significant correlation between predicted and actual thermal pleasure, indicating a strong correlation when indices classes were taken into account [6]. Another index that has been utilized in the relevant literature, specifically for two cities in Brazil, was that of the effective temperature index resulting from the wind effect (ET<sub>v</sub>) that ranged from partially comfortable to uncomfortable, with a thermal sensation of 27–28 °C in the hours between 12:00 and 14:00 [7]. It was signified that the level of differentiation between the two months, January and June, of the year for the two cities of Patos and Teixeira revealed the perceptions of local citizens in which they preferred a colder thermal environment in winter (January), which further indicated the necessity of maintaining shading and ventilation [7]. From an international viewpoint, such an indicative index, namely universal thermal comfort index (UTCI) has been deployed at China, in alignment with the geographic information system (GIS) grouping analysis, to investigate the spatial pattern of seasonal and daily changes in air temperature, mean radiant temperature, vapor pressure, and wind speed [8]. It was proven that vapor pressure played a determining role in either intensifying or mitigating the thermal stress in summer [8]. The role of humidity in improving thermal comfort in urban spaces has been also experimentally studied with the UTCI through an overhead water mist cooling system, in order to improve the comfort and liveability of urban open spaces during the summer days. It was denoted that clouds of droplets reduced the temperature and the UTCI by 8.2 °C and 7.9 °C, respectively, against a 7% mean humidity premium [9]. Besides, perception and preferences in terms of solar radiation, humidity level, and wind all improved within the droplet mist, while optimum design conditions were that of a steady light breeze (1–2 m/s), in highly irradiated sites and suspended at 1.2–1.5 m above the average height of users [9].

The examined modification of wind, temperature, and humidity over rural economies has been related to the reduction in wind speed and relative humidity over developing economies, posing a threat to human and animal comfort and the environment at large, by considering that urbanization alters an urban center's land use and land cover, modifying the climate of the urban setting [10]. Under such an evolution in urban settings, it has been reported that solar radiation and the specific urban design of buildings and streets' orientation can greatly affect thermal sensation and improve microclimate conditions more than wind velocity, both in the summer and winter seasons [11]. In investigating the human thermal discomfort caused by elevated temperatures in a city center compared to the suburbs and rural areas in another Asian country, that of India, which assessed outdoor thermal comfort using a physiologically equivalent temperature (PET) index [12]. The microclimate parameters measured were that of air temperature, wind velocity, relative humidity, globe temperature, and mean radiant temperature unveiling that spatial variations in temperature measured at various sites were all under the stress condition as per the PET scale for sub-tropical climate zone, enabling urban planners and designers to create safe and pleasant spaces to live, work, and commute [12]. In a similar study deployed in the Chinese context, it was proven that urbanization can increase urban temperature and decrease relative humidity and wind velocity. Therefore, while urban thermal comfort and discomfort days greatly changed in northeast China from 1990 to 2015, such changes for different cities across different climate zones are inconsistent. It was also shown that urbanization especially for social economic activities can have a significant influence on the PET index, unveiling that the changing patterns of urban thermal comfort in Chinese cities under rapid urbanization can support central government to take some effective measures to improve urban thermal environment [13].

In a similar research area in the Mediterranean basin, a wide spectrum of initiatives and policies in the field of energy saving at the building sector were investigated, focused on Cyprus, in order to improve the energy performance of societies. The reduction of the energy consumption of dwellings

becomes more important when social housing buildings are discussed, not only due to the fact that they constitute a major part of the European building stock, but also because the main concept of these buildings is that they are used by low income or vulnerable social classes [14].

In terms of energy performance of buildings, the EU has developed powerful and long-structured legislative instruments to promote the energy performance of buildings and to boost renovation within the EU, which are in the energy performance of buildings directive (EPBD) and the energy efficiency directive. The first-issued to 2002/91/CE was followed by that of 2010/31/EU, supporting consumers to make informed choices upon both energy and money savings in changing trends in the energy performance of buildings. Taken into consideration that buildings of today are consuming only half of that (buildings) of the 1980s, evolving energy efficiency requirements necessitate the issue of the revised EPBD of 2018/844/EU, which partially amended that off the 2010 EPBD. Taken into consideration that the building sector sustains a vast potential to contribute to a carbon-neutral and competitive economy, the revised EPBD covers a wide spectrum of policies and supportive measures to support national governments in the EU to boost energy performance of buildings and envisage a decarbonized building stock by 2050, accelerate cost-effective renovation of existing buildings in both a short and long-term perspective, and introduces new elements, as well as to support the mobilization of investments [15].

It is noteworthy that according to the former directive 2002/91/CE and the recent versions of 2010/31/EU and 2018/844/EU, energy saving in buildings is obligatorily achieved consistently with indoor environmental quality, e.g., in alignment with the standards of EN 15251:2007 and European Committee for Standardization (CEN) 16,798. Therefore, it is very important for research to conjugate the indoor environmental quality (IEQ) with energy saving, according to the aforementioned directives and international standards in force.

### *1.1. Literature Background upon Building Energy Use in Europe and Worldwide*

In a worldwide context, the building sector is considered among the most environmentally-burdened anthropogenic activities, since buildings contribute to the depletion of about one-sixth of the global resources. Particularly, the building sector consumes about 40% of global energy and 16% of global water reserves, resulting in the emission of 70% of sulfur oxides and 45–50% of carbon dioxide (CO<sub>2</sub>), at a global level of analysis [16]. Therefore, it is imperative for building designers to direct the principles of the building sector toward ecological dimensions/valuations for design and construction patterns. In this respect, energy consumption of buildings depends mainly on what is being designed, at the phase of construction, as well as at the lifetime of house occupants [17], where the common principals of bioclimatic architecture of the buildings are that of: architectural structure, location, plot–orientation, and the exterior profile of the surrounding area [18].

Regarding the exterior profile of the surrounding area, especially in urban parks, it is noteworthy that various planting designs are function in different ways on the microclimate and thermal comfort due to the distinct features of the vegetation type and ratio. Such urban designs have been reported in cities' divisions into local climate zones (LCZs) in order to access differences in intra-urban thermal comfort thermal while employing air temperature and relative humidity data [19], as well as by introducing models to study the influence of open surface water cover, its size, spatial configuration, and temperature in urban design. In such a modelling of urban design, it was proven that when the water is warmer than the air temperature (during autumn or night), the water body has an adverse effect on thermal comfort. Therefore, the water body eventually limits the cooling and thermal comfort in the surrounding city [20]. As such, the measurement of temperature, relative humidity, and wind velocity in terms of various scenarios in planting design, types, and ratios of vegetation showed that in a scenario of evergreen trees, humidity was relatively high while temperature and wind velocity decreased. However, simulated grass covered parks and deciduous trees showed higher temperature and wind velocity [21]. The authors stressed the possibility of improvement of winter thermal comfort when considering a proper planting design as an important step in order to achieve citizens' satisfaction in terms of thermal comfort [21].

The evaluation of thermal comfort conditions and energy consumption in specific housing types under a severe summer climate has been from literature related to occupants' actions to control thermal pleasure [22], since as it is aforementioned, energy saving in a building has to be consistent with indoor environmental quality. Therefore, national regulations should define different retrofitting targets based on certain climatic and socio-economic conditions prevailing [22] including: geographic location, typology, construction, and functional characteristics of buildings in alignment with the assessment of energy performance by means of onsite data collection, monitoring, construction, and calibration of energy models [23]. Another important aspect of comfort resides to the fact that the Mediterranean climate is characterized by extreme calculation conditions (overcast sky in winter and clear sky in summer); therefore, the evaluation of the comfort variations—being caused by changes of building position—can be implemented by a series of lighting and thermal numerical indicators that are applied to a set of simulation models, generating a complete analysis to determine optimal positions for the air exchange in an indoors environment [24].

In reference to the relevant legislative framework on bioclimatic architecture, an overview of policies and directives that have been launched by the European Parliament and European Council is given below: Firstly, the EU Directive 2002/91/CE on the Energy Performance of Buildings (EPBD), under the issued Green Paper, each Member State had to be into force by January 2006. The Directive contained general principles and a common methodology for calculating the energy performance of buildings. Moreover, this legislative framework contained minimum energy performance standards for buildings, classifications of energy performance in terms of certification systems, as well as the inspection of heating and air conditioning systems. Subsequently, the European Committee for Standardization (CEN, French: Comité Européen de Normalization) undertook the initiative to create 31 technical standards for the energy performance of buildings in directive supportiveness. Upon implementing the aforementioned directive, the first report was published in March 2007, having assured that the majority of EU members also applied it successfully within the timeframe of the (preceding) year, 2006. While the aforementioned EU Directive 2002/91/CE clearly established regulations for the thermal insulation of buildings for saving energy in winter, the summer strategy was described by a few qualitative provisions. Therefore, upon national requirements, the high insulation of the building envelope can be considered as the principal strategy to control energy consumption, even in summer, regardless of the different climates [23].

### *1.2. Literature Background upon Indoor Environmental Quality and Building Energy Use*

A sustainable building design and operation requires a serious modification of the way we design the buildings and systems by taking into account the binomial indoor environmental quality (IEQ)—building energy use. As a consequence, project teams need to be multi-disciplinary and be able in an integrated design process to simulate energy performance. The binomial thermal comfort-energy saving approach has been established at the EU through the Energy Performance of Building Directive (EPBD), and its instruments towards reducing the energy consumption of existing buildings and achieving nearly zero energy buildings (nZEBs). Presently, the compliance to the nZEBs requirements upon energy and environmental performance at the building sector are commonly dealt with pilot or modelled levels of analysis, such as the use of the smart energy systems with particular regard to the heat sharing systems, as well as the effect of the window retrofit on indoor air quality [25].

The theoretical production upon binomial thermal comfort-energy saving approach consists of an ongoing challenge to improve building energy efficiency without compromising indoor environmental quality. From the 1990s onwards in Europe, energy and climate policies started to take shape culminating with the ambitious 20-20-20 climate goals and the Low-Carbon Europe Roadmap 2050. The general belief was that the energy performance optimization of buildings required an integrated design approach and cross-disciplinary teamwork to optimize a building's energy use and quality of indoor environment while satisfying the occupants' needs [26]. These authors proceeded in an integrated and cross-disciplinary approach to building design through state-of-the-art of the building sector and

educational initiatives in the participating countries in the EU project of IDES-EDU: “Master and Post-Graduate education and training in multi-disciplinary teams” [26].

In two earlier studies, EPBD: 2002/91/EC introduced various obligatory requirements intended to achieve the reduction of use of energy resources in buildings. It was proven that the relationship between the EPBD and milder climates experienced in the Mediterranean is considered to be of great importance, particularly since world temperatures are slowly rising [27,28]. Burman et al. [28] introduced a methodology to calculate energy performance of buildings, with its theoretical performance using calibrated thermal modelling, under standardized operating conditions. The reported energy performance gap is determined by the intended vs. actual energy performance that can be established under identical operating conditions. Once the energy performance gap is determined with reasonable accuracy and the root causes identified, effective measures could be adopted to remedy or offset this gap [28].

However, in these earlier studies [27,28], it was also acknowledged that insufficient research has been carried out on the energy performance of buildings, at least among the Mediterranean basin countries. Therefore, Abela et al. [27] investigated the existing legal structures that had been put into place to implement the EPBD and the effectiveness of this implementation to date (year 2013) to define the methodology for the calculation of the energy performance of buildings [27]. Later, Wang et al. [29] demonstrated that energy performance of buildings can be valued under the indoor environment quality in buildings with the passive house (PH) standard, considering parametric sensitivity studies and including effects of diverse parameters on PH building performance [29].

The reduction of energy consumption in buildings is a determining aspect of European instrumentations and strategies ensuring that future climate and energy targets are reached [30]. These authors devoted their research to stress the inconsistencies and critical issues upon progressing nZEBs implementation in Europe, and comparing the distinct EU-NZEBs and US-NZEBs definitions. Particularly, there is a contentious debate of nZEBs to: firstly, distinguish between energy and primary energy, and between energy sources and energy carriers; and secondly between metrics and primary energy conversion factors, to define primary energy factors for energy carriers produced from renewable energy sources on site; thirdly, clarify the definitions among “plus” buildings: type of energy index to interpret incentives for buildings and to overcome the questioning on the “negative” primary energy index; as well as to conceptualize the nominations of near zero, zero, and plus energy buildings under an integrated discussion that does not uniformly implement them [30].

From an operability viewpoint, the conceptualization of nearly zero energy buildings (nZEB) is a tool that contains qualitative and quantitative indications of energy efficiency concerning the EU 2020 carbon targets specified for the European construction sector [31]. The advantageous features of nZEBs are the economic challenges, the technical challenges upon renovating the existing residential building stock and adding newly constructed high performance buildings, as well as the strategy planning and the local governance for nZEB market penetration. However, the main shortcomings of nZEB, especially for its applicability in southern European countries, are that most southern European countries are poorly prepared for nZEB implementation, especially for retrofitting existing buildings. nZEBs in southern Europe lack climate adapted metrics and concepts, and European nZEBs guidelines are biased towards cold climate conditions. Therefore, the main recommendations are that of: actions to shift the identified gaps into opportunities for future development of climate adaptive high performance buildings; creating a common approach to further develop nZEB targets, concepts and definitions in synergy with the climatic, societal and technical state of progress in regional level of analysis; and proposing performance thresholds for regional-referred nZEBs [31].

In a Mediterranean context, Lopez-Ochoa et al. [32] investigated the regulation of energy savings in buildings in Spain that has evolved in parallel with the, aforementioned, EPBD: 2018/844/EU. The authors deployed a complete case study, in which the improvements introduced with respect to previous regulations, being checked against the new renewable energy contribution requirements for the production of domestic hot water, energy demand limits, and energy consumption limits of the

Basic Document on Energy Saving of the Technical Building Code (CTE-DB-HE 2018). Under this legislative instrument (CTE-DB-HE 2018), nZEBs can be addressed for the first time, including both new buildings and renovated buildings. Authors stressed the ways that energy consumption of the residential building stock is expected to be reduced and how policies that favor building energy rehabilitation can be encouraged to achieve the European goals for 2020 and 2030 [32].

Taking into consideration that contemporary legislation is directed for indoor environmental quality, thermal comfort is one of the most important aspects due to its impact on well-being, people's activities, and buildings' energy requirements. In this respect, advanced design and operation of a building's and heating, ventilating, and air conditioning (HVAC) systems should be taken into account towards achieving thermal comfort fundamentals. Indeed, shortcomings of research upon such thermal comfort systems are that of wrong or incomplete input data on design and verification, while design input values from standards are often considered as universal values, rather than recommended values to be used under specific conditions. Therefore, it is recommended that the selection criteria of proper comfort indices and criteria for the design and assessment of thermal comfort be established, enabling standardization propositions to improve indoor environmental quality and energy saving [33].

This topic has only recently stirred the interest of researchers and policy makers in facing the necessary challenges upon energy performance of buildings, in alignment with the potential benefits for making the historic buildings of heritage cities non-polluting and energy efficient [34]. In southern Europe, most of these buildings are residential and are mainly listed with low grades of protection, allowing for significant transformation. In this respect, Caro and Sendra [34] quantitatively evaluated the indoor environment and energy performance of the residential heritage building stock under severe summer conditions characteristic of the Mediterranean climate zone, showing that in most examined cases, reducing the mechanical cooling demand would not require intrusive physical interventions, but would largely rely on suitable window shading and nightly natural ventilation when outdoor conditions allow [34].

## 2. Energy Consumption and Environmental Conditions in the Construction Sector in Greece

Energy consumption is an issue of utmost importance in Greece urging for a solution, since the existing buildings are responsible themselves for approximately 36% of the nation's total energy consumption. Besides, considering that the majority of the buildings were built before 1980, they do not have the latest niche technology from the construction sector. Therefore, these old buildings are unavoidably energy intensive in the phases of construction and operation, compared to today's energy requirements, which are completely different and much more energy-friendly to homeowners. In the context of environmental policy, the EU has launched a wide spectrum of initiatives aiming to increase the use of energy efficient tools, as it has pledged to reduce energy consumption by 20%, compared to the growing forecasting levels of CO<sub>2</sub> emitted to the atmosphere from 2020. In Greece, CO<sub>2</sub> air emission levels have risen significantly over the past two decades. Specifically, for the year 2011, CO<sub>2</sub> emissions per person in Greece corresponded to 7.56 tons. According to the data, this increase in emissions is 151.2% above the levels of 1980 and a 756% increase from the levels of 1960. Therefore, the building sector consumes the largest amount of energy in Greece, thus constituting the most important source of CO<sub>2</sub> emissions. Subsequently, energy upgrading the building sector produces multiple benefits, such as reduced energy consumption and alleviation of adversely burdensome air pollution [35–37].

From a legislative viewpoint, two noteworthy studies examining the adaptability of legislative systems to bioclimatic principles showed the following: Sakiyama et al. [38] examined two different Mediterranean climates, that of Palermo and Valencia, and the influence of these bioclimatic principles at the building thermal performance was evaluated upon cooling and heating degree-hours indicator, showing that modelled materials of the building shell can increase its thermal inertia, thus reducing the temperature variation in the internal environment and improving its interior comfort, especially during the warmest seasons [38]. In another study, it was stressed that the building shell has a high potential

to reduce the energy consumption of buildings, according to the International Energy Agency (IEA), because it is involved throughout the building process: design, construction, use, and end-of-life [39]. These authors tested earth-based construction systems that consist of rammed earth walls and green roofs, being adapted to contemporary requirements by reducing their thickness. Subsequently, it was denoted that sustainable construction systems can behave similarly or even better than conventional ones under summer and winter conditions, while thermal behavior is strongly penalized when rammed earth wall thickness is reduced [39].

According to compliance with the aforementioned European Directive 2002/91/EC on the energy efficiency of buildings, Greece stated that it could not incorporate the directive before the end of 2007, but intended to put it fully into effect in 2009. Moreover, Greece's compliance with Directive 2002/91/EC on new buildings, as well as extensive renovation of old buildings, was initiated under problematic conditions in October 2010. As a result, on 27 July 2007 EC brought legal action against Greece (along with Estonia and Poland) for not applying the directive. Following this, Greece was convicted by the European Court of Justice (Decision C-342/07, 17-1-2008).

Contrary to the aforementioned disadvantageous legislative obstacles, Greece issued the Energy Performance of Buildings Regulation (KENAK), which came into force on 1 October, 2010, after the country's over-indebted and time-consuming compliance with its obligations in terms of energy efficiency of buildings. Specifically, KENAK was adopted in a regulatory framework for the full implementation of the ground of L3661/2008, which transposed the directive into its national law system. KENAK currently incorporates the concept of integrated energy design into building construction, aspiring to contribute to the improvement of energy efficiency, saving energy, and environmental protection. The key aspects of the KENAK are: (a) the obligation to submit a Building Performance for Building in order for owners to obtain the construction license, and (b) the obligation to conduct an energy inspection of buildings, including boilers as well as installation of heating and air conditioning systems.

KENAK is applicable to all energy buildings with a number of exceptions. By the end of 2019 (at the latest), all new buildings should satisfy their energy needs with renewable-based energy systems. To this end, a relevant software tool named "TEE-KENAK" was developed that is a common benchmark for the calculation of energy performance for buildings in Greece. This software implements the necessary algorithms for the calculation of energy performance for buildings in Greece and is based on the methodology from European standards as well as relevant national standards and the corresponding guidelines issued by technical committees [40–42].

The aforementioned software is introducing data upon the geometrical and the technical characteristics of the building shell (including thermal and physical properties of building elements and shades) as well as the technical characteristics of the necessary electrical and machinery installations for the calculation of the energy efficiency and the abiding energy classification of the building. The data and the results of the calculations are printed in appropriate software reports, thus contributing to the proper deployment and compliance with the "TEE-KENAK" targets.

### 3. Buildings' Description Materials and Methods

The two examined houses are located in Lykorema and Marmari, on the island of Evia in central Greece. The municipality of Marmari belongs to the prefecture of Evia, being specifically located at the southern peninsula of the island of Evia between the municipalities of Karystos and Styra. Lykorema is pristine land, ranging from the sea and extends about 1.5 km from the provincial road. Both examined houses have been built in the same period in adjacent plots, having the same distance from the sea, thus being exposed to the same weather conditions. What unmistakably distinguishes them is that one building (A1) is constructed on the principles of bioclimatic architecture while combining both green technologies with embedded smart devices that make it environmentally friendly, unlike the second building (A2) being constructed by conventional techniques. The differences are analyzed both within the narrative and the data included in Table 4.

### 3.1. Meteorological and Climatic Data—An Overview

Prior to presenting the meteorological and the climatic data for the examined region, it is noteworthy to succinctly introduce the European standards, their structure, and their scopes. In particular, the ISO 7730 (and some elements of the old EN 15251) as well as American Society of Refrigerating Engineers (ASHRAE) specifications cover the selection of appropriate meteorological data for the assessment of the long-term mean energy use for the heating and cooling of buildings. The main shortcoming of structuring such a standard is that the simulation of building performance is bounded by the appropriate mean values of the meteorological parameters, but also on the frequency distributions of individual parameters and the cross correlations between them. Subsequently, the use of longer periods, extended up to ten years, or even more) of hourly meteorological data is recommended. Under this framework, long spells of unusually warm or cold weather, lasting several months, are eliminated in the construction of a reference year. Another limitation of such long runs of hourly and full meteorological data is considered expensive and impossible to monitor for many areas. Therefore, annual sets of data that can be used to represent the long-term mean performance of buildings are generated once from long runs of expensive data and then distributed in a more costless manner. In a general context, other methods are possible to develop reference years for specific purposes, including those methods that are based on an analysis of general weather situations [40].

While the conventional perception of ideal living conditions is the comfort upon the joint conditions of humidity and temperature, later research approaches are concerned about the needs of various materials and laboratory studies to provide optimal values of temperature and relative humidity for the proper conservation of each material, or artefacts composed for various materials. The contemporary approach of evaluation microclimatic conditions is that of acclimatization, under which it is assumed that if a particular material or artefact is exposed for a long, over one-year, period to the influence of certain conditions, it can experience cracks and irreversible deformations at the building-shell. Acclimatization causes can cause a catastrophic response to the microclimate, since the materials may have exceeded its capacity of deformation, which can ultimately lead to total losses. Based on the past conditions, the concept of “proofed fluctuations” was defined by Michalski, showing that by setting the target of the fluctuations experienced by the object in the past, it is assumed that if the largest past fluctuations are not exceeded in the future, then the risk of new mechanical damage will be extremely low [43].

Based on the aforementioned framework, the meteorological and climatic data for the Marmari location, upon these two examined homes, are summarized at Table 1. In a detailed description of the site studied, the following climatic conditions were reported:

**Table 1.** Climatic data upon the homes examined.

| Parameter                  | Explanation (Descriptive or Numerical) [43]           |
|----------------------------|---|
| Climate                    | Mild Mediterranean, with mild winters and hot summers |
| Average annual rainfall    | 750 mm  |
| Rainy season               | Between November and March                            |
| Average annual temperature | 17.5 °C   |
| Average winter temperature | 12.0 °C   |
| Average summer temperature | 26.5 °C   |

#### 3.1.1. Temperature

In the relevant literature, environmental monitoring for understanding the natural microclimate of an old building at a temperate climate was conducted with the aid of a set of sensors at regular time intervals and manual records. As reference variables for annual average fluctuations, seasonal variation fluctuations (based on a moving average of 30 days) and short-term fluctuations; the latter were calculated by the difference between the instantaneous measures and a moving average. In the relevant literature, the specific selection of the study of Entradas Silva and Henriques [43] was made due to

the very close proximity of temperature and relative humidity—varied at  $\pm 2$  °C and  $\pm 3\%$ —to the corresponding average annual values reported in our research study. This literature approach can be used both for temperature and relative humidity, assuming that: if future variations do not exceed the higher past values, the mechanical damage risks are low [43]. The co-presentation of seasonal temperature variation between both this study and our study are presented at the following Table 2.

**Table 2.** Indoor temperature and relative humidity profiles.

| Variable                                | [43]           | [own Study, Greece] |
|---|----------------|---------------------|
| Reference                               |                |                     |
| Seasonal minimum temperature (°C/month) | 13.2/February  | 7.4/January         |
| Seasonal maximum temperature (°C/month) | 24.9/September | 30/July             |
| Average annual temperature (°C)         | 19.1           | 17.5                |
| Average relative humidity (%)           | 63.6           | 66.6                |

In our study, the southwestern plain of Karystos is the warmest area of Evia. The average annual temperature is 17.5 °C, the average maximum temperature 21.5 °C (in July it reaches 30 °C), and the average minimum temperature is reported at 14.3 °C (in January the minimum average temperature drops at 7.4 °C).

### 3.1.2. Humidity

In our study, high humidity levels were reported. Specifically, the relative humidity for the indoor annual average was measured as 66.6%. It is noteworthy that even in (the certainly dry month of) July, relative humidity did not drop below 56% (compared to the relative humidity of Attica, the capital of Greece, which is about 35%), which is almost 40% lower than that of the Evia at the same month of July.

### 3.1.3. Water Precipitation

The study area sustains plentiful rainfalls. The average annual rainfall is 704 mm and the average monthly is 58.4 mm; the maximum is reported in December (144.1 mm) and the minimum is reported in August (3 mm). It is also apparent that rainfall in Karystos and Marmari exceeds that of other large cities of central and south Evia, including that of Chalkida (384.4 mm) and Aliveri (513.1 mm), but it falls short of Kymi (1040.2 mm) and the mountainous areas of Steni and Makrikapa.

### 3.1.4. Wind profile

High north-facing winds are prevailing in the region examined. Besides, high winds often blow in the winter (December, January, February) and during the summer months of July and August.

### 3.1.5. Microclimatic Monitoring According European Standards

In understanding the hygrothermal behavior of a building, it is important to understand both the internal microclimate, but also its relationships with outdoor conditions. It is obvious that the definition of optimal values covering all materials and all locations is an impossible task. Besides, the definition of the ideal microclimate is an ambiguous issue, despite the importance of limiting the cycles of temperature and relative humidity abiding to short-term fluctuations and the relevant study site/area conducted. Therefore, it is significant to keep the conditions stable and consistent with the past, while a target microclimate has to be considered and taken into account for the future in order to ensure the preventive conservation of the objects and materials studied. The historic microclimate can be adequately defined upon the most frequent T and RH values and their variations. These values are defined in order to specify the levels that limit the physical damage caused by the microclimatic

fluctuations in organic and hygroscopic materials conserved for long-term (certainly more than one year) in a specific environment [43].

### 3.2. The Green and Smart House A1

#### 3.2.1. Structural Characteristics

The walls were built with Thermoblock™ (Heat flow density =  $10.6 \text{ W/m}^2$ , U-value =  $0.41 \text{ W/m}^2\text{K}$ ) equipped with an external thermal facade. They were placed as external insulation to the balconies in order to avoid thermal bridges. The external coatings applied with decorative colored plaster finishes (named “Sto plaster”) that has composition that combines improved aesthetics, protection, and mechanical properties, ensuring high elasticity, (waterproof) resistance to moisture and microorganisms, high breathability, as well as advantageous hygric and mechanical protection to all surface types. These advantageous properties are important due to adverse climatic conditions, such as intense air and rainfall episodes in winter, high solar radiation at summer, and discomforting salty conditions of the nearby seaside, thus accelerating the wearing deterioration of both houses’ building-shells and their indoor environments.

#### 3.2.2. Windows

Energy windows are the new generation of the window frames industry, being used throughout the building. The installed windows have metal frames with a 12-mm thermal break, twin glass with 12-mm air gap, and low emissivity coating which all jointly achieve high thermal transmittance and sound insulation. The thermal transmittance value of the frame,  $U_f$ , of the aluminum metal is  $3.5 \text{ W/m}^2\text{K}$ , and the  $U_g$ , of the glass panel is  $1.8 \text{ W/m}^2\text{K}$ . The total losses from windows were  $67.20 \text{ W/K}$ .

#### 3.2.3. Cooling

Inverter air conditioners have been installed on the ground floor’s living room and within the space of the studio house. Such air conditioners are characterized by high energy class with internal temperature sensor on the remote control and an air purifier. It is noteworthy that both air-conditioners are not used for cooling due to the location and proper cooling that takes place inside the house by the current generated during ventilation. These two air conditioners are mostly used for house heating, since underfloor heating is not used.

#### 3.2.4. Heating

For heating purposes, the house interior is heated by using electric underfloor heating via thermal cables from the Norwegian company NEXANS (Oslo, Norway). The building is domesticated as a holiday home, therefore, during summertime there is no need for house heating. Therefore, air-condition is mostly used in case of raising the temperature. The preference of one type of floor heating over another—such as heat pumps, steam, oil, or gas—was made by the owner’s very specific desire for the system selected, although this is not an optimum energy saving system.

#### 3.2.5. Solar Water Heater

A solar water heater has been used to provide hot water to the building. This heater is installed on the top roof, at the south side of the building. The trademark of Celsius Solar CE-X 160, low profile, was chosen, which is ideally serving for small families, small homes, and cottages. Specifically, the 160 L tank is facilitated with a specified type of collector offering the joint advantages of cost effectiveness and maximum efficiency. The stand is a long-evolved niche product of Celsius Solar’s R&D department and it has obtained the European Certification CE-Solar keymark-ISO 9001/2008. Due to its low height structure, the heater minimizes the nearby visual pollution, while its 160lt boiler is mounted in the utility room of the house, thus, offering economic savings as it is not directly exposed to outdoor weather conditions.

### 3.2.6. Housing Automation–Central System of Vacuum Cleaner

It is a common sense that today homeowners spend 80% of their time indoors, mainly in areas of reduced ventilation and as such, inhale more chemicals. Inappropriate indoor environments are the main cause of many indoor-blamed diseases, such as asthma and allergies. Therefore, in the green house examined, among its construction facilities, the manufacturer installed a central vacuum cleaner. The functionality of this housing automation enables the absorption of dirt, dust, dust mites, pet hair, as well as filtering the polluted air, removing away all these pollutants from the main residential area, and refurbishing the indoor conditions to a much cleaner environment. The Figure 1, below, depicts the operating system of this housing automation, from the broom slot to the central bin.



**Figure 1.** Housing profile upon the central system of vacuum cleaner.

Particularly, each housing area supports its own collapsible tube system, which allows homeowners to pull the vacuum tube to the desired length by simply connecting the vacuum cleaner. Each pipe is installed inside the house-walls, while the central absorption unit is installed in the engine room of the house. This system was chosen for its ease of maintenance and due to the fact that there is no contact with dust when emptying the bin [44].

### 3.2.7. Exploration of Other in-House Interventions

Among the most important parameters of investigating the thermal and the energy performance of buildings in the Mediterranean climate are the natural ventilation conditions using advanced building energy simulation tools [45]. In this study, several multi-zone simulations were carried out and it was concluded that the stack effect plays an important role in the ventilation and that it is commonly outperforms the wind effect. Besides, sizing permanent openings according to the standard guidelines can be adequate in providing the expected ventilation rates targeted [46]. In wider bioclimatic perspectives, comfort models include the variability of occupants' behaviors based on the external climate conditions. The latest adaptive comfort methods consider outdoor temperature not only as a steady variable, but also as the representation of occupants past thermal history. While different models have been implemented, some are included in current technical standards, whereas some other are still experimental [47]. A critique developed for the effectiveness of the interventions proposed by researchers refers to the "over insulation" of buildings, which runs the risk of reducing the effectiveness of traditional passive cooling strategies (thermal mass, air permeability of the roof covering, roof ventilation), thus adversely effecting internal comfort. Therefore, the ways under which an increase in insulation thickness reduces the effectiveness of traditional passive cooling strategies (as an effect of the thermal decoupling between the interior and the upper layers of the roofs), can be further investigated [48].

### 3.2.8. Electrical Infrastructure

One of the key features of this home type is the house automation system, commonly referred to as “smart home” by the trademark TEXET TECHNOLOGIES SA. The Smart-Bus home automation system enables user to easily and safely control all home lights (indoors and outdoors), heating, air conditioning, and security (alarm) system. The “smart home” system consists of keyboards having LCD (liquid crystal display) screens, which are installed in the compartments of the living room, bedroom, and guest-house, where users can distinctly or altogether control lights with open, close, and dimming modes. The aforementioned keyboards are also thermostats that can control (increasing or decreasing) the temperature and the speeds of air conditioning and heating. In this context, the creation of various scenarios is the most important feature of the “smart home” ensuring energy saving for the building. A typical scenario that the homeowner uses is that of “Exit”, where upon leaving the house, with the touch of a button, all lights are switched off, the heating levels are adjusted to the desired level, the alarm system is activated, and the shutters are closed. Another scenario is that of “Good Morning”, where it is activated by the bedroom keypad in the morning time. At this mode the alarm status is deactivated, the heating level is adjusted to the desired temperature, and the shutters are opened. All the aforementioned and scenario-based functions can be remotely controlled from all types of PCs or smart phones, in alignment with the appropriate automation control system.

### 3.2.9. Lighting Appliances

Nowadays, there is a developed active research interest in linking architectural design with lighting design [49–51]. This research is further oriented to sustainable and environmentally friendly lighting systems [52,53]. Specific research orientations of these systems select efficient luminaires, lighting control, or embody more efficient lighting design or daylight [54–56]. In our study, the lighting design was directed to save energy, which is in compliance with the ongoing legislative and technological interest in energy saving policies, devices, and applications. Under this research framework, lighting of the smart home was delivered by low energy lamps. The lights were low-power lamps, while in the bedroom and in the guest-house the lighting had a dimming function. Indoor house lighting was delivered by spotlights with LED lamps. The overall lighting of the smart home was directly linked to the aforementioned smart home scenarios, which all contributed to house’s energy saving. The average consumption on lighting is rated at 25 W.

### 3.2.10. Temperature Measurements

The temperature measurements were made on 5 April, 2014, where the climatic conditions were measured indoors and they were taken by a infrared precision thermometer, given in the following Table 3. The meteorological data at the time of measurement were: humidity 87%, wind speed 5 km/h, sensation temperature 10 °C, outdoors temperature 15 °C. Infrared thermometer and thermocouple type K sensor were used with  $\pm 0.2\%$  accuracy.

**Table 3.** Temperature profiles measured at the ground floor and at the basement at the green and smart house (A1).

| Ground Floor   | °C | Basement       | °C |
|----------------|----|----------------|----|
| Floor          | 20 | Floor          | 19 |
| Ceiling        | 20 | Ceiling        | 20 |
| Interior walls | 22 | Interior walls | 21 |
| Exterior walls | 17 | Exterior walls | 16 |
| Glazing panels | 19 | Glazing panels | 19 |

### 3.2.11. Energy Consumption

The electricity bill was considered for the period of 8 May, 2013 to 5 September, 2013, and showed that the energy consumption was 1177 KWh. For the other months, energy consumption was 200 KWh—from the outdoor lighting and alarm system.

Unfortunately, this PPC (Public Power Corporation) account can neither be used as a credible point of reference upon residential consumption, nor as a comparable criterion between the conventional house and the green house. Indeed, while both houses are used as second homes, the green house is constantly occupied during the summer months. (May to September), while the conventional house is occupied for a total of 20–25 days, in the period of May to September.

Therefore, due to the fact that the two houses are occupied at different timeframes, no common ground of comparability/references is given. In this respect, in this study, the Energy Efficiency Regulation (KENAK) software was applied in order to unveil the specific energy class at which these buildings are ranked, which further implies their energy consumption. Subsequently, interventions and proposals can be targeted upon the outcomes yielded and the classification rankings, respectively.

## 4. Results and Discussion

### 4.1. The TEE KENAK Software at the Green House

TEE-KENAK special software is a widespread and known benchmark for the calculation of the energy performance for buildings in Greece. This software tool runs necessary algorithms to calculate the energy performance of buildings in Greece based on the methodology of recently issued European standards, as well as the relevant national standards and the (nationally-issued) Technical Guidelines of the Technical Chamber of Greece (T.O.T.E.E).

The functionality of this software was based on the introduction of data upon the geometrical and technical characteristics of building shells (including thermal and physical properties of the building elements and shadows), as well as the technical characteristics of the necessary E/M installations for the calculation of the energy efficiency and the abiding energy classification of the buildings. The numerical data resulted upon calculations were then printed in relevant software reports. In this study, data entries and parametric modeling were inputs of the software, and the corresponding outputs are collectively presented in Table 4.

**Table 4.** Profile of the reference building's requirements (according to the National Technical Standards) and the A1 building regarding the energy consumption per domestic use.

| Final Use                  | Reference Building B<br>(in kWh/(m <sup>2</sup> Year)) | Green and Smart<br>Building/Conventional (A1/A2)<br>(in kWh/(m <sup>2</sup> Year)) |
|----------------------------|--|--|
| Heating                    | 42.50  | 29.20/48.20  |
| Cooling                    | 24.50  | 19.80/27.60  |
| Hot water for domestic use | 15.20  | 7.70/21.90   |
| Total                      | 82.30  | 56.70/97.70  |

### 4.2. Energy Consumption of the Green House

The electricity bill was considered for the period of 8 May, 2013 to 5 September, 2013, and showed that the energy consumption was 1020 KWh. For the other months, energy consumption was 446 KWh—from the outdoor lighting, alarm system, and closed circuit monitoring.

As has been mentioned before, this PPC account can neither be used as a credible point of reference for residential consumption, nor as a comparable criterion between the conventional house and the green house. Indeed, while both houses are used as second homes, the green house is constantly occupied during the summer months. (May to September), while the conventional house is occupied for a total of 20–25 days, in the period of May to September. Again, the KENAK software was applied in

order to unveil the specific energy class in which these buildings are ranked, which further implies their energy consumption. Subsequently, interventions and proposals can be targeted upon the outcomes yielded and the classification rankings, respectively.

#### 4.3. TEE KENAK Software at the Conventionally-Constructed House A2

In applying the TEE KENAK software, it was calculated that the conventionally-constructed house's (A2) classification is C, counting for the energy consumption of 97.70 KWh/(m<sup>2</sup> year). Upon the aforementioned profiles of energy consumption between the two types of building examined, it can be denoted that energy consumption of the green house (A1) is about 40% lower than that of the conventionally-constructed building (A2), respectively.

In applying the TEE KENAK software, it was calculated that the green house's (A1) classification counts for 56.70 KWh/(m<sup>2</sup> year) of energy consumption lower than the reference building's requirements from the National Technical Standards. The contributors of the derived difference are also depicted.

#### 4.4. Critique Upon Buildings Adaptation to European and Temperate Microclimatic Conditions

The accruing number of microclimatic studies in recent years enhanced our knowledge upon the influential factors of climate to the built environment. Indeed, this wider standardizing applicability in cold climates justifies the fact of the short-term fluctuations over seasonal cycles, since it is expected that the buildings in cold climates are fully equipped with heating systems and better isolation from the surroundings; thus, more stable seasonal cycles and less dependence on the external conditions. However, it is assumed that the heating systems do not run continuously and short-term fluctuations are often increased.

In temperate climates, the aforementioned approach may not be completely suitable, since it is undemanding in the case of seasonal cycles and it does not impose any limit. Nevertheless, it is important to study the evolution of temperatures because they have a direct influence on RH. In addressing issues surrounding the fluctuations aforementioned, it is important for research to be deployed and compared to other regions, where unheated or intermittently warmed conditions (e.g., at sites running along the Mediterranean climatic zone) are applied. However, it can be noted that buildings located in colder climates, and where the internal variations are strongly dependent on external factors such as heating, lighting, and human presence, the short-term fluctuations amplitudes are substantially higher than in the temperate climates [43].

It is noteworthy that the consideration of relative humidity in microclimatic monitoring is the main factor of analysis in cases of climate control systems, but in cases where buildings are not equipped with such a systems, it is further necessary for a systematic consideration of temperature, since it can directly influence the relative humidity and contribute to its stability. In our study, where the examined buildings have been built in temperate climate and in the absence of acclimatization systems, microclimatic monitoring depends largely on the seasonal outdoor variations, since short cycles are lower and more stable, which justifies a careful analysis and regional identification. This approach can effectively handle problems relating to changes in the short-term, but does not contribute to limiting the seasonal cycles and does not specify limits for temperature [43].

From a methodological viewpoint, the computation of microclimate monitoring aims to limit the seasonal cycles and lightens the short-term fluctuation limits. In the case of temperature, there is no concern of limiting the target according to human comfort, since this factor is not considered dominant in the satisfaction of occupants to a particular place of reference. In this respect, a statistical analysis based on historical data is commonly fitted to both variables of temperature and relative humidity. Therefore, in addition to the seasonal values, the annual average is also an important factor of analysis. From the computational results, it can be signified that the higher seasonal cycles of temperature and relative humidity should be limited in relation to the annual average. This limit is defined by the 10th and 90th percentiles of the values obtained by the subtraction of the annual average from the moving average, in an attempt to limit seasonal variations and make the most stable indoor climate [43].

This method can be easily applied in various areas, since it is based on the climate of the building itself and no empirical or specific values are defined for certain climates. The generalized applicability of this methodology necessitates that obtaining reliable results is necessary to smooth the data recorded. Microclimatic monitoring extreme values of temperature and relative humidity can occur and may not necessarily correspond to reality for several reasons, such as changes in energy. However, it is impractical for a manual and point-to-point analysis, thus, smoothing data can be achieved by excluding 1% of the highest positive and negative extremes; a safe range is extended from 0.5 to 99.5 percentiles [43].

## 5. Proposed Improvements

The research outcomes yielded from the energy-directed analysis, in alignment with the applicability of the TEE-KENAK software, enabled the development of an intervention scenario towards moderating the energy consumption of the buildings examined. In this scenario, the parameters modified were that of: heating, cooling, and hot water for domestic use. However, the parameters of lighting and renewable contribution to energy production were excluded from the analysis, having also null contribution to the break down profile to the “reference building”.

### 5.1. Interventions at the Green House and Conventional House

The energy consumption of the A1 house based on green and smart embedded technologies can reach up to 56.7 kWh/(m<sup>2</sup>year). In this case, no need for immediate priorities was recommended to be followed by the homeowners. Compared with the reference building, the annualized initial and operating cost of the green and smart house (A1) is about 30% less than the retrofitted conventional one (A2).

#### 5.1.1. Interventions in the Conventionally-Constructed House

On the other hand, the energy consumption of the conventionally-constructed house calls for further retrofitting interventions to achieve the required consumption at the range similar to the A1 house. As shown from Table 4, the A1 building drops to the range from 50% to 75% of the reference building (about 40%), while the conventional building exceeds the probability range of the latter and belongs to the range from 100% to 141%. The upgrading scenario, the economics, and the simple payback period to achieve the A2 energy consumption transition (about 40% of the reference building) to the range of A1 is depicted in Table 5. The primary energy savings regarding this scenario and the simple payback period are also presented. The scenario includes replacement of petroleum fuel with biomass in order to reduce energy consumption.

**Table 5.** Economics profile and payback period for the scenario applied to A2 house.

| Parameters of Cost Reduction                                | Reference Building | A2 Building | A2 Building (Retrofit) |
|---|--------------------|-------------|------------------------|
| Operational cost (in euro)                                  | 1691.8             | 2605.0      | 1203.1                 |
| Initial cost of investment (euro)                           |                    |             | 6000.0                 |
| Primary energy savings (kWh/m <sup>2</sup> )                |                    |             | 3.8                    |
| Primary energy savings (%)                                  |                    |             | 3.6                    |
| Cost of energy savings                                      |                    |             | 4.9                    |
| Reduction of CO <sub>2</sub> emissions (kg/m <sup>2</sup> ) |                    |             | 10.0                   |
| Payback period (yrs).                                       |                    |             | 7.0                    |

#### 5.1.2. Interventions at the Indoors–Outdoors Environment

In-house interventions are not adequate to achieve familiar microclimatic conditions per se. Therefore, these microclimate conditions are related to side-by-side interventions. From a literature viewpoint, there is a widespread applicability of green roofs that are perfectly adaptable to the Mediterranean climate. Green roofs provide a number of environmental advantages like increasing

urban biodiversity, reducing pollution, easing burdens on drainage systems, and lowering energy costs thanks to thermal insulation [46]. Moreover, green roofs are considered passive construction systems which can reduce the energy demand of buildings and achieve: European goals of nearly-zero-energy buildings, energy reduction for existing buildings in warm climatic conditions, as well as improvement of the thermal performance of extensive roofs with different substrates, compared to traditional gravel ballasted roofs [47]. It has been reported that annual reductions of energy gains and losses upon applied green roofs can achieve annual average reductions of 66% and 63%, respectively, compared to traditional roofs. These advantageous outcomes are related to the composition of the substrates, their capacity to retain water and the quantity of vegetation in each plot [47].

In terms of substrates' composition, typical species planted in green roof installations are that of *Frankenia laevis*, *Dymondia margaretae*, and *Iris lutescens*. It has been stated that the most influential factors registered for such species planted are the relationship between air and water in the substrate and the interaction between green cover and substrate, respectively, for the seasons of summer and winter [46]. In investigating the impact of green roofs on the improvement of urban heat performance in the Mediterranean climate, the key parameters of investigation are that of: experimental site, air and surface temperature profiles, and various measurement points at the level of the modules chosen [57]. It is noteworthy that green roofs can play a decisive role in improving the thermal performance of the surrounding microclimate and energy performance of buildings, being a feasible intervention choice against urban heat island effect, not only for Mediterranean cities but also for other areas [57]. In a wider context, it is stressed out that vegetal systems in facades can contribute to the reduction of the buildings' energy demand, the attenuation of the urban heat, and the filtration of pollutants present in the air. The effect of a vegetal finishing (formed by plants and substrate) on the thermal energy performance of an insulated facade under summer conditions is very positive, particularly in the warmer hours of the day [58]. Therefore, vegetal facades can be used as a passive cooling tool to reduce the energy consumption and improve the comfort conditions to the homeowners [58].

In terms of the design and operational conditions of green roofs, experimental investigations unveiled that the operating parameter of moisture content and the designing parameter of substrate thickness reduce the substrate temperature and heat flux through the green roof, thus, consistently reducing some of the negative environmental impacts of built environments [59], generating considerable energy savings, improving the thermal performances of buildings, as well as substantially improving the dynamic properties of traditional roof structures, especially in the case of roofs with limited dynamic performances [60].

In terms of occupants' behavior and thermal comfort, these are aspects considered of utmost importance for contemporary architectural interventions to convert original semi-open spaces into indoor spaces by adding movable glass dividers [61]. Therefore, the climatic adaptability of buildings shows that the window control patterns have a more prominent impact during the heating period. Besides, literature studies have verified the significance of cooling potential on night ventilation and have stressed the benefit of having energy-aware and engaged occupants. Moreover, conservation practices and occupants' behavior are bringing energy efficiency and comfort into the discussion about cultural heritage [62]. Considerable research has been performed in the bioclimatic building sector by taking into consideration new methods in respect to materials, processes, and technology for a clean strategic development [63–69].

In this study, the main interventions in the outdoor environment include: At the north side, the plantation of evergreen trees can protect the building frame from cold winds in winter. At the east side, the plantation of more deciduous trees can support sun protection in summer and solar radiation gains in winter.

In the south side, the plantation of evergreen trees and shrubs is proposed to provide shading and to function as windbreakers. At the west side with the open view of the seaside, there is no tree-planting area. However, low-height bushes can be planted, in order to enhance the appreciation of the natural landscape, an action which the homeowners have already made.

In a future timeframe, it is recommended that thermal insulation be valued as a necessary intervention for energy savings. External thermal insulation does not cause heat imperfections, such as heat escape bridges with respect to indoors heat losses, but it (the external thermal insulation) protects the building shell from damage/erosion. Thermal insulation can be extended throughout the building, which in alignment with energy-efficient windows, results in a high energy savings and reduction of heat losses.

The novelty of this study resides in the fact that the joint applicability of the aforementioned scenario, in alignment with the outdoors interventions proposed, is expected to achieve indoor thermal comfort for a wider geomorphologic profile of buildings in Mediterranean landscapes in warm summer and mild winter conditions. Such specific interventions in bioclimatic interest affect a wide spectrum of key parameters for the construction sector: thermal insulation, utilization of solar radiation, change of frames, change of fuel, appropriate plantation of trees, as well as construction techniques to achieve natural ventilation. Under advantageous ground stability and spacious availability, ventilation could be further accomplished through evaporative cooling achieved by the construction of a swimming pool. These specific interventions are of the utmost importance and are feasible for Mediterranean-sided buildings, commonly constructed just of the seaside. The study supports: firstly, considerable energy savings for heating in winter and for cooling in summer; and secondly, moderate payback periods for investment. This shows the scenario-based choices are cost effective and of promise applicability to similar regional and infrastructure plans.

### *5.2. Proposals to Microclimatic Monitoring*

In temperate climates, both rural houses and old buildings do not usually install HVAC systems and the interior climate is largely dependent on variations of the outdoor climate. Therefore, it is reasonable that short-term fluctuations are very controlled, although the seasonal and the outdoor cycles follow more significant variations. It is also apparent that when applying microclimatic monitoring in temperate climates, it is necessary to adapt all methodologies ensuring the reliability of these applications in temperate climates. Under this context, when proposing microclimatic monitoring, it is important for a researcher to effectively adapt their meteorological data, building materials available, geomorphologic specifications of the site/land uses, targeted energy savings, as well as economic criteria of cost-effectiveness and pay-back period of interventions. In this respect, the proposed microclimatic monitoring at the site examined was adapted to a method prepared at another neighboring Mediterranean country, Italy, and was based on ASHRAE specifications.

At the Mediterranean basin, short-term fluctuations are considered low; thus, it is possible to lighten their limit while the seasonal variations were limited. However, the risk of biological attack should be considered and the fact that some materials require greater stability conditions than others. Subsequently, there should be defined two distinct levels of analysis, one for less demanding/visiting/occupied buildings, and another for more demanding/visiting/densely occupied buildings. Specifically, a method of analysis should be focused on daily cycles of temperature and relative humidity, since this is a common type of analysis in the literature.

## **6. Conclusions**

From the above findings, it can be denoted that since changes of structural upgrading and energy savings to existing buildings are few and limited, it is not feasible that all proper changes be implemented upon bioclimatic principles. Besides, refurbishments and renovation of buildings are more costly, compared to interventions made upon construction. The place selection of a building's construction should ensure a south-facing orientation of its long facade, thus, maximizing the solar radiation in the winter and reducing the reluctant shading. In this study, both houses could not fully adopt the aforementioned interventions per se, but should adapt them, given the preferable location and view by homeowners, while utilizing the optimum inside volumes inside their homes as well as

the indoor environmental conditions. Overall, the proactiveness of energy and indoor environmental measures are more profitable than the post-treatment actions.

Another research remark is that bioclimatic architecture of buildings fosters: firstly, the harnessing of the energy consuming processes of buildings' construction and domestication; secondly, contributes to the improvement of human health by lowering the emission of harmful air pollutants; and thirdly, ensure the overall energy sustainability of the buildings. Upon comparing the two adjunct-located houses, which were built during the same period, it is noteworthy that—regardless of their differentiated features in terms of energy consumption, materials used, and technologies upon construction of each of the two homes—the research objective was to examine whether a conventionally-constructed building can be “modern and energy-competitive” without need of using “green” tools, compared to one that follows the principles of sustainability from its design and construction phase. The conditional comparison between these two houses was based on the applicability of the TEE-KENAK software, where inputs were received independent to the utilities behavior of the homeowners at each one house, where it was concluded that the green house consumes less energy, in terms of kWh/(m<sup>2</sup>year). Finally, in the widely islanded Greece, there are still misconceptions regarding the perception that green buildings cost more than traditional buildings and that the former do not achieve economies of scale and cost effectiveness within a reasonable time, due to high payback periods of investments. This attribution is worsened due to the current economic recession and market liquidity facing the Greek construction sector.

**Author Contributions:** A.E.K. and M.Z. organized the study, conducted the research design, analyzed the data, and contributed to the development of the interpretation of the outcomes and their concluding directions. G.L.K. and V.C.K. contributed to the deployment of the literature review, the structure of the research analysis, and the conclusions drawn. G.M. and S.S.M. were responsible for structuring the scientific framework of the research analysis, and supervised all phases of the research conducted. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** Thanks: are expressed to “Greek Dreams” Contraction Company that built the green house.

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

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