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Low Carbon Building Design on Naxos Island

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ABSTRACT

In recent years, research focuses on different passive techniques able to decrease energy consumption and CO_2 emissions of buildings, with a view on mitigating climate change. This project concerns the importance of low carbon buildings in Greece and investigates the potential for low energy building design on the Greek island Naxos. The paper begins with a review of low carbon regulations worldwide and nationwide, and continues with a description on architectural and climatic characteristics of Naxos. The core of the paper focuses on the dynamic thermal modelling of two buildings: one existing non-domestic air conditioned hotel; and one not yet constructed dwelling (free running). The energy savings resulting from the integration of passive design strategies are significant and are compared with existing benchmark figures.

Keywords: low carbon, energy consumption, passive design, Greek island

1. Introduction

The Kyoto Protocol for the Climate Change determined for the first time legally binding targets for the reduction of GHG (greenhouse gas) emissions and it confirms the need of collaboration within the international community in subjects that concern such a major environmental problem. In contrast, the spread of low energy building concept in Greece is in a minor level.

Greek buildings account to 40% of the total CO_2 emissions in the country, as a result of their high energy consumption (HMD, 2004). In the line of the European Buildings Directive, the Greek Regulation on building energy efficiency, named "KENAK", sets specific limitations and minimum requirements of energy efficiency concerning the design and the construction of various building types.

1.1 Purpose of the Study

This research study investigates the potential of low carbon building design in Greek islands and specifically in the island of Naxos. Two different building types, a non-constructed residence and an existing hotel, are modelled and simulated in IES software. Passive design interventions are implemented in order to achieve reduction in energy consumption by also maintaining thermal comfort and CO_2 levels of the rooms in acceptable values.

1.2 Greek Cyclades Islands (Naxos) Characteristics

Architectural Characteristics: The architecture of Cyclades islands is unique, characterised by white-washed compact building shapes that reduce heat absorption. The dominant building shape is the two-storey dwelling with ancillary spaces on the semi-underground floor. The external walls of stone or concrete are plastered and whitewashed. Few narrow wooden openings protect the interior from the strong winds, although they provide adequate sunlight to the spaces (Naxos Net, 2012). Main decorative characteristics of the islands are the balconies, the wooden shading structures (‘pergolas’) and the arches (‘volto’) which connect the main entrance with the courtyard.

Climate Characteristics: The Greek climate is typical Mediterranean with mild and rainy winters and relatively warm and dry summers. There are extended periods of sunshine throughout most of the year. The average monthly air temperature on the islands ranges for the warmest months (July, August) from 26-28°C, while the average maximum temperature does not exceed 31°C. During this time the high temperatures are dampened from the north winds blowing mainly in Aegean, known as 'Etesian' (Hellenic National Meteorological Service, 2012).

2. Methodology - Buildings Description

The first building studied, the residence, consists of two storeys (ground floor and first floor) and a semi-underground floor, connected by a stairwell, with total floor area of 186.033 m^2. The ground floor layout includes a large living room, a kitchen, a bathroom and a semi-outside area at the front of the kitchen. The first floor has three bedrooms and one bathroom and the semi-underground floor ancillary spaces.

The hotel unit studied, has two upper ground floors and one underground floor, consisting of 17 en-suite double bedrooms, kitchen, gym, office spaces, a large living room-restaurant-reception area, etc. The floors of the building are connected by stairs and lifts. In front of the entrance there is a semi-outside area with arches on the walls. The total floor area of the building is 1422.821 m^2.

Apart from the double-glazed windows, the materials of the walls, floors, roofs, are also chosen for their high insulation properties.

2.1 Modelling Assumptions - Profile Patterns

Occupancy profile: The occupants' profile for the purpose of the simulations was based to the typical **residence** of 4 occupants. The highest occupancy of the day is at lunch time and at night-time. The summer occupancy profile is set from 20 May till 30 September and the winter for the rest of the year. For the **hotel** the daily, the weekend and the holiday profiles are considered the same, operating on maximum in summer period. The percentage of the hotels' occupancy is based on the maximum occupancy, deriving by the total beds of the rooms plus the total working staff. The summer occupancy profile is set between mid May and mid September.

Ventilation: The typical room of the Greek islands has windows with two sashes and opening shutters. The window and balcony door sashes slide horizontally (about 180 degrees) and also tilt vertically by 30 degrees. Ventilation profiles are created for both of the buildings after interview conduction in the form of questioners with residents of the island. In winter, all the windows are tilted by 30%, for natural ventilation only when the temperature is between 20-24^{o}C (24hours in the dwelling, between 10am to 2pm in the hotel). In summer, the profile changes for the warmer hours of the day, having a window opening of 50% and up to 100%.

Heating and Cooling: The **residence** has mechanical heating system only, operating during the occupied hours, from early October till end of May. For the **hotel** unit, the heating is set on continuously from 30 September until 31 May, with room temperature below the setpoint. The cooling (air conditioning) is set on continuously from end of April until end of October, with room temperature above the setpoint. According to the Greek Regulation on the Energy Efficiency of Buildings the setpoint temperature for the heating in a building should be 20^{o}C and for the cooling 26^{o}C (Technical Chamber of Greece, 2010). The heating operates in all rooms of both buildings (using radiators) and the cooling only in specific rooms (bedrooms, living room, kitchen, gym and offices) using split air conditioning units.

2.2 Internal Gains

According to CIBSE Guide A (CIBSE, 2007), different internal gains based on the occupants' activities and use of the space are set in each room.

3. Base Case Simulations and their Results

DXF files from architectural drawings are used to create the models of the buildings in IES Virtual Environment software, version 6.4.0.7 (2011). Once a model was completed, information about dimensions, materials, internal gains, weather and location, were set. In both models, arches on the external walls assist the natural ventilation of the semi-outside areas. Mechanical ventilation is applied in underground spaces of the hotel (kitchen and the gym). The Figure 1 and Figure 2 show perspective views of the building models in IES software.

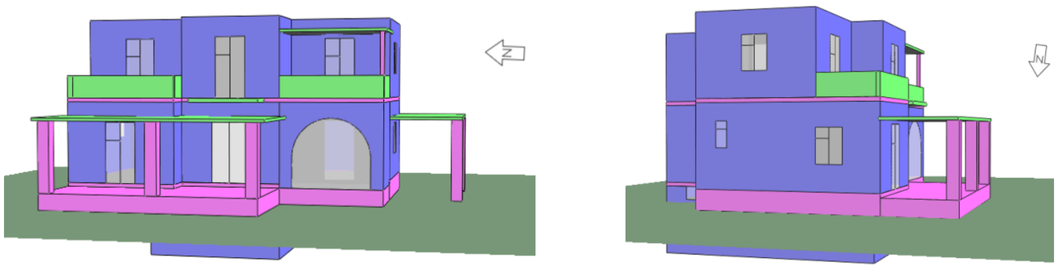

Figure 1. Front and side view of the residence in IES.

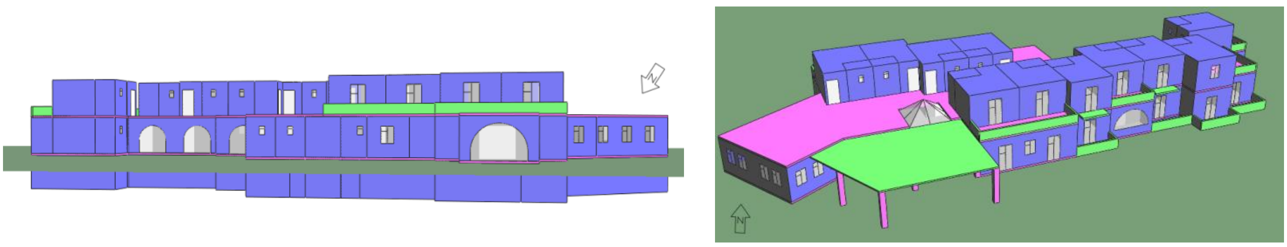

Figure 2. Front and aerial view of the hotel in IES.

Table 1. Comparison of the base case results for the residence with the benchmarks.

	Total annual energy consumption (kWh/m^2)
Residence Base Case	173.86
Benchmark Label A+	Total Energy < 60
Label A	60 ≤ Total Energy < 80
Label B+	80 ≤ Total Energy < 110
Label B	110 ≤ Total Energy < 140
Label C	140 ≤ Total Energy < 155
Label D	155 ≤ Total Energy < 175
Label E	175 ≤ Total Energy < 215
Label F	215 ≤ Total Energy < 255
Label G	Total Energy ≥ 255

Table 2. Comparison of the base case results for the hotel with the benchmarks.

	Total annual energy consumption (kWh/m^2)
Hotel Base Case	248.93
Benchmarks:	
Rated 2 star	209.9
Rated 3 star	199.5
Rated 4 star	185.6
Rated 5 star	169.4

The results of the two base case simulations are gathered from IES and compared with the benchmarks in Tables 1 and 2. The energy performance of the buildings is considered insufficient; the residence is classified energy label D (almost E) and the hotel is below the lowest level of the benchmarks and the target of **195 kWh/m²**.

The thermal comfort for heating and cooling periods for both buildings, ranges between 20-26°C. For the free running months (residence in summer) the thermal comfort range is calculated by the equation $T_C = 13.5+0.54\ T_O$, where Tc is the comfort temperature and To the monthly mean outdoor air temperature (Santamouris, 2005), and also by the suggested acceptable temperature range (3K for new buildings) (Nicol and Pagliano, 2007). The results of the base case simulations show that thermal comfort is not acceptable only during July and August for the residence. Therefore, the above thermal simulations indicate that the need for passive interventions on both buildings is emerging.

4. Energy Interventions and their Results

A combination of passive interventions implemented on both the dwelling and the hotel of the project, intending to improve the energy performance of the buildings are described below:

Residence: First of all the summer ventilation profile of the windows is changed and now set later in the year and the heating profile is set off for the months May and October, considered unnecessary. Extra windows are added on both living room and bedroom, in order to gain additional solar gains in winter time. Furthermore, insulated concrete forms (ICFs) replace the materials of the over-ground external walls. The cast concrete placed between two layers of polystyrene foam insulation, offer higher insulating values and air tightness levels, assisting the reduction of the energy requirements for heating and cooling. Afterwards, a buffer space is added in front of the living room to reduce the high heating loads by passively preheating the incoming air through an arch at the front of the main entrance and a glazed arch at the front of the balcony door (closed only during winter). Changes were also made in the artificial lighting profiles, where fluorescent triphosphor lamps of 300 lux illuminance replace the existing lamps, creating new internal gains of 7 W/m² as directed by CIBSE Guide A (2007).

In order to improve the thermal comfort of the building during summer, shading devices ("pergolas") are designed on bedroom walls. The three bedrooms and the kitchen will be ventilated in night-time through the balcony doors in July and August (the two months with insufficient thermal comfort). The idea is that the building is cooled during the evening and night hours by cross ventilation and so the heat absorbed during the day can be dissipated during the night when the air temperature is significantly cooler than during the daytime. During daytime openings remain closed and the heavy building mass retains the indoor maximum temperature lower than the outdoor maximum. The windows of the balcony doors remain open between 8pm and 8am. In addition, the assumed continuously opened window shutters of the models were set to operate respectively with the operation of the openings.

Hotel: Firstly, the materials of the external walls (over-ground) of the hotel are replaced with insulated concrete forms (ICFs). A way to reduce the cooling load of the kitchen and the gym, which are underground, is to set night-time stack ventilation. Thus, outside air comes into the spaces with the help of a stack, at daytime in winter and at night in summer. Also shading and ventilation changes are implemented in different rooms. At the staircase-corridor of the ground floor, the previously open side of the space is now being glazed, with operable windows only during summer (100% opened), in order to reduce the high heating loads of the space. Also, the summer ventilation profile of the living spaces (bedrooms, living room, and restaurant) is changed. The 50 % window opening percentage is replaced by 100 %, in order to reduce the cooling load. In addition, an extra shading device ('pergola') is designed and the size of the existing one is increased, in order to minimise the direct solar gains in summer. Same changes on the ventilation profile were made at the accountancy office. At the managers' office an extra internal window is added on the common wall with the accountancy office, creating cross ventilation, operating the same respectively with the external windows of the building.

The artificial lighting profile of the spaces, apart from the offices, the gym and the kitchen, changes to 300 lux illuminance with new internal gains of 7 W/m^2. Finally, nocturnal ventilation is enforced in all spaces in order to reduce the cooling loads, with windows operating between 6pm until 8am.

The results in number of the interventions made in both buildings are presented in Tables 3 and 4.

Table 3. The final results for the residence.

	Total annual energy consumption (kWh/m^2)
Residence Final Case	173.86 → **108.24 (37.74% energy reduction)**
Benchmark Label A+	Total Energy < 60
Label A	60 ≤ Total Energy < 80
Label B+	80 ≤ Total Energy < 110
Label B	110 ≤ Total Energy < 140
Label C	140 ≤ Total Energy < 155
Label D	155 ≤ Total Energy < 175
Label E	175 ≤ Total Energy < 215
Label F	215 ≤ Total Energy < 255
Label G	Total Energy ≥ 255

Table 4. The final results for the hotel.

	Total annual energy consumption (kWh/m^2)
Hotel Final Case	248.93 → **177.65 (28.63% energy reduction)** < 195 (main target)
Benchmarks:	
Rated 2 star	209.9
Rated 3 star	199.5
Rated 4 star	185.6 ACHIEVED
Rated 5 star	169.4

The occupied hours were calculated to be less than 5% out of the **thermal comfort range**, successfully complying with the guidelines. The **CO_2 concentration levels** of the main occupied rooms of the dwelling range between 435ppm and 588ppm, indicating high indoor air quality based on the benchmarks (CIBSE, 2007). Almost the same CO_2 levels were found in the double bedrooms and the kitchen of the hotel (444ppm to 707ppm). Satisfactory levels were calculated it the gym (971ppm being <1000ppm) and moderate in the offices (1167ppm and 1203ppm), which although considered acceptable according to ASHRAE (2010).

5. Conclusions - Future Work

All the simulation results proved that it is feasible to achieve a significant reduction in the energy consumption, in comparison with the benchmarks, by maintaining the acceptable thermal comfort conditions and CO_2 concentration levels. The ventilation patterns proved to be remarkable for that kind of buildings. The nocturnal ventilation created notable results. Also, the characteristics of the architecture of Naxos island, such as the semi-outside areas with the arches on the external walls and the shading devices, and also the efficient lighting, contributed to the energy performance improvement of the buildings. In contrast, it was found difficult to adequately ventilate the underground floors without mechanical ventilation, and consequently reduce the energy consumption.

It is possible through software improvement in the future to be able to overcome all the limitations of IES program, or the interventions can be set to a different thermal simulation program and check the similarity of the results. In addition, the energy performance of the same buildings, before and after the interventions, has to be checked in the future climate of Naxos.

Since the operation of opening, shutters and heating thermostats depends on occupants' behaviour, instructions to them are required, in order to achieve significant energy results; although, this is not entirely feasible with the short staying occupants of the hotel unit. That's why a good suggestion is to give practical benefits to the visitors, such as to provide discounts for the customers, who will implement the ventilation strategy of the building (or who will not use air conditioning in the bedrooms) simultaneously imposing penalty fares on the visitors who consume too much energy, in order to make them more energy conscious.

The achievement of the project is the significant reduction of the energy consumption of two building types on a Greek island, without making radical changes and without implementing renewable energy systems, such as photovoltaics, biomass, heat pumps, etc. This is substantial because it proves that small scale (low cost) changes on the building envelope, on the operation of the systems (window opening, lighting and heating devices) and also implementation of passive cooling and ventilation strategies, can improve occupants' thermal comfort while reducing energy consumption. The changes made on the domestic and the non-domestic buildings are considered applicable and feasible in similar building types of the same climate.

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