Assessment of the sustainable redesign of existing buildings in Greece in the context of an undergraduate course: Application of passive solar systems in existing, typical residences

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Abstract. Residential buildings in Greece form an important part of the existing building stock. Most of them were built prior to the first Thermal Insulation Code (1981) and thus are characterised by poor energy performance and increased heating and cooling consumption. The 6th semester undergraduate course of the NTUA, School of Architecture “Special Topics on Environmental and Bioclimatic Design” attempts to educate students on assessing the thermal characteristics and the environmental performance of existing buildings and then propose and quantitatively evaluate the effect of low-tech and low-cost interventions with the use of energy simulation software (Design Builder®). The paper presents the teaching methodology for the application of passive solar systems -with and without thermal insulation of the building shell and openings- to existing, typical residences built after 1920, which are found mostly in suburban areas and settlements all around Greece, and the assessment of the diurnal thermal performance during the heating period. The results of the study are two-fold and involve, primarily the teaching outcome of the course and secondarily the assessment of simple bioclimatic interventions to existing buildings’ energy performance and thermal comfort conditions during the cold period of the year.

1. Introduction
One of the basic pre-requisites of sustainable design is the preservation and upgrade of existing buildings. As Elefante [1] so eloquently put: “the Greenest Building Is... One That Is Already Built”. The demolition of existing buildings and their replacement with new, environmentally-friendly ones is neither an economically, nor an ecologically or socially sound alternative. In Greece, more than half of all the residential buildings (55%) have no thermal insulation, as they were constructed prior to the first Thermal Insulation Code (1981). From the total of residential buildings, 2.5% was built before 1919, 5.0% in the period up to the 2nd World War (1919-1946) and 48.0% between 1946-80 [2]. Consequently, the refurbishment of these buildings is a “one-way street”, as it not only helps preserve the energy initially embodied in them, but can also contribute to important energy savings for heating, cooling and lighting and, at the same time, significantly improve overall comfort conditions and quality of life.

Single-family residences (monokatikies) form an important part of the existing building stock and are far more energy-intensive than multi-storeyed residence buildings (polikatoikies) [3]. As far as residences in suburban and rural areas are concerned, their plot arrangement and design is, in most of
the cases, free of many of the constraints, which exist in urban centers. As a result, the application of a number of bioclimatic features is fairly easy, and particularly favors, depending on the terrain and the orientation, the exploitation of the sun, as a means of passive solar heating, and the prevailing winds, for passive cooling. This paper attempts to assess the contribution of passive solar systems to the thermal performance of typical residences built between the years 1920 and 1980 (application of the Thermal Insulation Code), which are found mostly in suburban areas and settlements all around Greece. The assumption is based on two key issues. While savings and impact reductions may seem small when considering a single building, they can be substantial when scaled across the building stock of a city, or even a country [1]. Furthermore, the refurbished buildings can function as prototypes for architects, engineers and the general public on issues related to energy conservation, and climate responsive architecture. The afore-mentioned key issues are within the context and teaching goals of the 6th semester undergraduate course of “Special Topics on Environmental and Bioclimatic Design” in the School of Architecture of the National Technical University of Athens, Greece, and for that reason, the present research was performed within its framework.

2. Special Topics on Environmental and Bioclimatic Design course

2.1. Course description

The discussed course is a 6th-semester elective course that follows a building technology core course (5th semester) on climate responsive design and further elaborates on the topics of sustainability, climatology, thermal comfort, daylighting, renewable energy sources and eco-friendly systems and energy refurbishments. The incorporation of all these parameters and systems in the design (or refurbishment) process is a key issue for the final architectural and constructional result.

Throughout the semester, the topics covered by the lectures are correlated with simple calculations and software tools that help the students quantitatively assess the various aspects of passive and low energy systems. The main aim is to consolidate the acquired knowledge on sustainable, environmental and climate responsive design, by introducing the students to thermal simulation analysis and parametric energy performance design. The selected simulation and modelling tool is the Design Builder® software [4].

2.2. Teaching goals

The main purpose of the course is to familiarize students with the impact of small scale/minimal interventions to the thermal properties and energy performance of the building envelope. While the key component variables (thermal insulation and relatively simple passive elements) that are investigated are standard and small-scale, the study presents new potentials as it tries to attract students’ attention on existing and architecturally rather uninteresting buildings, which, nevertheless present a numerically important part of the existing building stock and in some cases may possess qualitative characteristics that may enhance their thermal performance.

Based on Bloom's Taxonomy of Learning Domains [5], at the end of the course, students are able to:

- Acknowledge the main issues related to bioclimatic and sustainable design.
- Understand the fact that passive heating and cooling systems require, apart from qualitative, quantitative documentation (experimental) concerning their efficiency.
- To be able to apply analytical and/or experimental procedures for the calculation of the optimum energy performance of passive heating and cooling systems.
- To quantitatively analyse the contribution of the systems of bioclimatic design to the improvement of thermal comfort conditions and energy performance of buildings.
- To have the ability to perform a synthesis of all the parameters involved within the framework of architectural design.
- To evaluate the systems of bioclimatic and environmentally friendly design with the use of appropriate software tools.
Based on the above, the course tries to make the issues of the environmental crisis that are immediately linked to the built environment (conventional energy consumption for heating, cooling and ventilation, as well as preservation and upgrade of existing buildings and materials) an integral part of the architectural education process. Only then can the long-standing phenomenon of these issues being a “marginal issue in academic discourse” [6] be overturned.

As a result, the educational goal is dual: firstly, to emphasize on the need to maintain and upgrade the existing building stock, irrelevant of its architectural and/or heritage values and secondly, to educate students on the necessity to assess simple passive design strategies, with a combination of quantitative and qualitative analysis of the basic environmental parameters (temperature, relative humidity, heat gains and losses, etc.). For this reason, the performance modelling of given, typical residences, namely given / conventional buildings was favored over more complex architectural design projects.

3. Teaching methodology

The course is set up as a semester workshop, based on the facts that knowledge is acquired through practice [7], that students themselves prefer coursework, and that the quality of learning is proven to be higher in assignment-based courses [8]. Furthermore, the semester project is split into different assignment-based sections that correspond to the different scenarios that are investigated (see 3.2 Parametric investigation) and the work of each sub-project is presented in class, assessed and feedback is sent back to the students, acknowledging its powerful influence on the learning process [8], as well as its help for students to prepare for or improve their work prior to the final summative assessment at the end of the semester [9].

3.1. Course-work structure

The coursework is formulated in an array of consecutive steps and work-packages. The students work alone or form groups of two or three. Each student or group is assigned a location from each climatic zone of Greece (A, B, C, and D) to perform a thorough climatic analysis with the Climate Consultant® software [10]. Inevitably, only cities with an available weather data file (.epw) are applicable. Depending on the total number of attending students, more students or groups of students may be assigned the same city (climatic zone), so the part of the climatic analysis is done by a group as teamwork.

After the completion of the first stage of the semester project, the typical buildings that will be analyzed are selected and assigned. During the academic year of 2016-2017, two typical, one-storey houses were selected to form the base-case models, one with a pitched and one with a flat roof. The selection was based on the fact that these two building types are representative and largely found in various parts of Greece. The simplest possible design typology and form were selected for educational purposes, despite the fact that more complex variations of these building types also exist.

The building characteristics of the base-case model were typical; conventional construction system with reinforced concrete frame baring structure (U-value = 3.00 W/m²·K, for 25-cm thick elements) with brick masonry infill walls (U-value = 1.30 W/m²·K, for a double-leaf brick wall with a 5 cm air gap in between) and timber or aluminum frame, single-glazed windows (U-value = 6.0 W/m²·K). Additionally, heavy-weight construction with 60 cm-thick, stone masonry walls (U-value = 2.0 W/m²·K), was also studied, as it is commonly found in suburban and rural areas around the country.

With the completion of the design of the base-case model(s), which also completes the second stage/work-package, each student and/or team moves on to perform thermal simulation analyses of the parametric investigation scenarios described in the following section (3.2) with the use of the Design Builder® software. The number of different parameters that are simulated depend on the number of students that participate in the course. The results of the simulations and analyses for all the scenarios are compared to each other in order to draw relevant, comparative conclusions on various parameters such as energy efficiency, diurnal and most importantly inter-seasonal performance, etc. Comparisons of the efficiency of the same system in different climatic zones, as well as of different systems in the
same climatic zone are encouraged, but are, unfortunately, not always feasible. The course is concluded with the students giving a presentation of their semester project and receiving final comments and feed-back, in order to submit their final report, which consists of the presentation file.

The continuous shifting from individual to teamwork and back is deliberate, based on the strategy that each member is individually accountable for. In order for each group to advance the project and complete the assignment, co-operative input is needed [8], while individual learning of the group members is assimilated within the group work.

3.2. Parametric investigation

The parameters that were investigated in the study are presented in Table 1. For various, applicable combinations of these parameters, the following four scenarios were defined and simulated:

- Scenario 0: Base-case (as is)
- Scenario 1: Application of thermal insulation on walls, ground floor and roof and double-glazing to the windows.
- Scenario 2: Application of passive solar and/or passive cooling system(s).
  2.a Application of passive systems to the uninsulated house of Scenario 0.
  2.b Application of passive systems to the insulated house of Scenario 1.

The parametric investigation derived from the basic climatic characteristics of each climatic zone (A, B, C, and D) and the corresponding basic bioclimatic design principles. In the present paper, only the results involving the application of passive solar systems (C.1 in Table 1) are presented.

Table 1. Parameters investigated during the study.

| A. Residence types | 1. Single-floor, compact form with pitched roof ✓
| | 2. Single-floor, with semi-open space with flat roof |
| B. Construction | a. Conventional construction, no thermal insulation ✓
| | b. External thermal insulation ✓
| | c. Light-weight structure ✓
| | d. Heavy-weight structure ✓ |
| C. Bioclimatic design | C.1 Passive solar systems |
| | C.1 a. Direct gain (south-facing openings) ✓
| | C.1b Indirect gain
| | - Mass wall
| | - Trombe-Michel wall
| | - Sunspace
| | - Sunspace with opaque roof |
| D. Climatic zones | A – Southern Greece (Crete, Cyclades and south Peloponnese)
| | B – Central Greece ✓
| | C – Northern Greece (Epirus, Macedonia and Thrace)
| | D – NW Greece |

Note: The tick sign (✓) denotes the parameters of the study that are included in the present paper (Section Presentation of the study / results).

The main emphasis was on interventions on the building shell, mainly on its thermo-physical properties (Figure 2), with the application of external thermal insulation and double glazed windows being the first and most common strategy, continuing with shading and followed by less “popular” strategies, such as solar spaces or Trombe-Michel walls. More drastic interventions, such as alterations to the window to wall ratio and advanced solutions, such as cool roofs and/or phase-change materials, which are discussed in relevant studies [11], were discussed in class, but omitted from the semester project for reasons of simplicity and time limitations.
3.3. Assumptions

As the primary goal of the coursework is to familiarize the students with the simulation of the passive performance of simple bioclimatic interventions, a series of assumptions were made (Table 2), so as to minimize the various, defining parameters and to ensure that the achieved results are mostly due to the proposed interventions on the building shell. All the calculations were normalized by floor area, for the whole building (roof zone included) and the building without the roof zone (occupied zones only).
Table 2. Assumptions for the different parameters (tabs).

| Tab          | Assumptions                                                                 |
|--------------|-----------------------------------------------------------------------------|
| Construction | Definition of the appropriate construction details                           |
| Lighting     | Lighting Template NONE                                                       |
|              | General & Task Lighting OFF                                                  |
| HVAC         | HVAC Template NONE                                                           |
|              | Mech. ventilation / Heating / Cooling / DHW / Nat. Ventilation OFF           |
|              | Nat. Ventilation ON (in the cases of summer passive cooling)                 |
| Activity     | Activity Template House                                                      |
|              | Different rooms templates: According to use                                  |
|              | Computer / Office equipment OFF                                               |

4. Presentation of the study / Results

4.1. Coursework results concerning the heating period

The students followed the proposed course-work structure (Section 3.1) and parametric investigation (Section 3.2) and initiated the project work with the base-case (as is) scenario. As expected, the development for this, first stage of the course-work took the largest amount of time. This was due to several reasons: the students used the first model practically to familiarize themselves with the modelling tools of the software, as well as with all the necessary settings and the available analyses and simulations and tried to understand how it works in order to continue with the input of different parameters and test the proposed strategies.

The heating period calculations were generated from the ‘Heating Period’ tab in Design Builder®, whereas the diurnal and seasonal variation of the various data were generated from the ‘Simulations’ tab. For the cold period of the year, the results of the simulations actually validated the data, which the students had qualitatively assumed during the relative core course of the 5th semester, as well which they had heard during the course lectures.

For the Base-case (Scenario 0) (Figure 3), they concluded that:

- Both the conventional and the stone wall construction without insulation, have comparable thermal losses that are mainly dependent on their U-value. Furthermore, the diurnal and inter-seasonal internal air temperature variation in the two different constructions presents many similarities due to the fact that the conventional construction is actually quite heavyweight itself.
- The roof zone presents considerable heat losses, which affects inter-zonal heat losses of its underlying rooms.
- The uninsulated ground floor has a positive contribution to the winter thermal balance (due to the higher, compared to the air, ground temperature).

The application of thermal insulation (Scenario 1) to the base-case model, led to the following remarks:

- The adding of thermal insulation considerably reduces fabric heat losses.
- For the openings, the replacement of single glazing with double, offers a relatively small thermal losses reduction, due to the fact that the typical houses had a relatively small total glazing area.
- For the roof, thermally insulating the ceiling slab practically reduces these losses in half.
- For the ground floor, the positive effect of the higher temperature is offset by the application of thermal insulation to the slab on ground.

The application of passive solar systems (Scenario 2) to the uninsulated house (Scenario 2a) and to the insulated model (Scenario 2b) was assessed by the students through the comparison of representative software outputs of the same parameters (Figure 4), as well as with their own, original graphs (Figure 5).
Figure 3. Presentation of the results of the base-case scenario [D.Timagenis, 2017]

Figure 4. Comparative presentation of the results of the study concerning air temperatures [S.Skarmalioraki, 2017]
The application of passive solar systems (Scenario 2) (Figure 6) to the uninsulated house (Scenario 2b) and to the insulated model (Scenario 2b), revealed the following (Figure 7):

- All the passive solar systems have a similar contribution to the air temperatures of the house.
- During cold period, the main positive effect is on the lower, night-time temperatures.
- Overall, the contribution of the investigated passive solar systems on the whole building air temperature is limited, in both the non-insulated and the insulated models. The insulated models have about 2.0 °C higher air temperature compared to the uninsulated ones. This is probably due to the high thermal mass of the buildings.
- At the beginning of the winter, when external air temperatures remain high, passive solar systems that do not have shading may have a negative contribution and lead to overheating. On the contrary, at the beginning of spring passive solar systems, in combination with the adding of thermal insulation can result to a free-running building, even without internal gains (occupancy, lighting and equipment).
4.2. Lessons learned

The presented research involves the academic year 2016-2017, when the proposed teaching methodology was applied for the first time, and is applied, with modifications and amendments, until today. The splitting of the assignment in distinct work-packages and the intermediate presentations upon the end of each work-package contributed to its timely completion. Furthermore, the workshop function of the course ensured that all the students participate in the class, cooperate with each other and tutors as the semester project progressed and succeed in submitting complete and comprehensive final reports and presentations.

The drawbacks are mainly related to the limited semester time and students’ small experience with research and simulation software. One relates to the semester time limitation prevented students from fully exploiting the features of the software and as a result, the more “ambitious” goals of the project, which mainly involved the comparisons of the efficiency of the same system in different climatic zones, as well as of different systems in the same climatic zone, were only superficially achieved, in the form of oral observations during the final presentation. Another is the students’ lack, at the middle of the 5-year study period, of basic knowledge of research and comparisons, such as the simple fact that all relevant graphs should be plotted with a locked y-scale in order to directly and easily spot the differences caused by the different interventions. As a result, many of the graphs, even in the same project had different scales. Based on this observation, in the years that followed, the students received detailed and precise instructions on y-axis ranges and were encouraged to talk to each other in order to select the ranges that would accommodate the results of all four climatic zones.

5. Conclusions

The results of the study are two-fold and involve mainly the teaching outcome of the course, as well as the assessment of simple bioclimatic interventions to existing buildings’ energy performance and thermal comfort conditions.

In relation to the teaching outcome of the course, similar to previous research [12], it was clear that as building simulation tools are not fully adapted to standard design studio practice, the students take up considerable time to learn how to use the simulation software, and especially how to set up the model layout and configuration. As a result, it was proved difficult to run all the necessary simulations and reach qualitative and synthetic conclusions, within the time constraint of the regular 13-week semester. Moreover, it is clear that students at this level, given their small experience on such matters, have not yet developed the necessary criteria and knowledge to exploit all of the software’s
possibilities and always conclude to accurate observations. The applied teaching methodology (coursework done throughout the semester with the different stages regularly presented in class, assessed and provided with feedback) (Section 3) has proven, since 2014-2015 (the year the course was introduced), to be largely accepted by the students and to contribute to the timely completion of the project and the fulfilment –as far as possible- of the course’s the teaching goals. Finally the number of participating students is another critical parameter for the successful development of the course, as it’s nature dictates no more than 20-25.

Concerning the results of the study, it is clear that the application of commonly used passive solar systems to existing buildings of high thermal mass have a rather small contribution to the interior air temperatures during the coldest days of the year, their effect being more pronounced in the lower, night-time temperatures, which is rather important. On the other hand, window replacement with more efficient ones, especially in the spaces with large glass areas, is more effective. Furthermore, it is worth noting that most of these low impact interventions that basically refer to the building envelope, do not interfere with the users’ activities and compensation and thus may demonstrate an improvement on the building thermal performance and energy use, especially due to the geometry of the building.

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