The role of materials in the energy efficient retrofitting of traditional buildings

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Considering the characteristics of the European cities, energy efficiency in historic and traditional buildings stands out as one of the main problems for urban policies farsighted. Historic buildings (pre 1945) form the core and reflect the most predominant profile of many European cities, consisting the 10% of the building stock in Europe [1]. However they urgently need refurbishment and renovation to upgrade their energy efficiency standards in order to reach those of the EU. Nevertheless any retrofitting measures must respect the features and the cultural values inherent in the historic and traditional buildings. In this chapter the exemplar of a traditional building in a university campus in the city centre of Limassol, Cyprus is studied. The study focuses on the design of the building, its construction characteristics and the role of materials for energy efficient retrofiting.

Keywords: energy efficiency, retrofitting, historic and traditional buildings.

1. Introduction

The European Union considers climate change as the greatest long-term challenge facing the human race. It is therefore its priority to reduce the carbon dioxide concentrations, which are one of the main contributors to the climate change. The sustainability in the built environment is based on three pillars: sustainable materials and construction, sustainable energy use and waste management. The energy efficiency in buildings is the most important and fundamental step towards sustainable-energy buildings [2]. It is critical for the researchers to establish the energy performance characteristics of traditional buildings before and after the application of energy efficient retrofitting measures, since they have more demands than contemporary buildings. However, many retrofitting concepts are common for both modern and old buildings. Nevertheless the strategies and techniques to be adopted to create comfortable indoor environments and energy efficiency must at the same time respect their traditional style. The challenge for researchers, engineers and architects is to consider the traditional building aspects such as wall insulation, window improvement, shading devices and installation of renewable energy sources, without altering their unique character. The renovation of the existing building stock and energy efficiency improvement of historic buildings is a priority in the European research agenda. The standard CEN/TC 436 which is now under development, refers to the energy conservation of cultural property [3]. This standard will outline guidelines for improving energy efficiency of architecturally, culturally and historically valuable buildings while preserving their inherent cultural heritage value.

Nowadays the buildings are responsible for the 40% of the world energy. The need to design energy efficient buildings arises from a variety of factors and external pressures such as legislation, emissions of ozone depleting gases and public awareness of the pollution of our planet [4]. There is a great need, among public and private sectors, to improve the energy performance of existing public buildings. Specifically indoor air quality, energy efficiency and thermal comfort conditions are the three main considerations for the good performance of buildings [5,6]. The Directives 2002/91/EC and 2010/31/EC are the main legislations reference for the buildings' energy performance in Europe [7,8]. The directive has as its main objective to promote the improvement of the energy performance of buildings and the historic or traditional buildings are not excluded from the Directive. Also the energy performance rating and the certification are the main requirements as quoted in Article 7 of the Directive [9]. Energy auditing in buildings is an imperative process on which the energy efficiency is based. Benchmarking standards for the energy performance of educational buildings already exist in many EU countries [10,11,12].

In order to upgrade the existing buildings in nearly zero energy buildings (NZEB) the first priority is to investigate all available measures for conserving energy. These measures include building insulation, window improvement, shading devices, low-energy light bulbs, heating controls and users' behaviour. The renewable energy sources such as photovoltaics installed on the buildings, could contribute enormously in providing alternative energy and at the same time being environmentally friendly.

Most traditional buildings were not originally designed to incorporate insulation. In selecting the most appropriate insulation materials it is important to ensure that it will last and continue to perform for many years to come. Although for the Mediterranean region the most appropriate insulation is its application externally, for the traditional buildings this might not be possible since the preservation of the character of the facades is equally important. It can be carried out successfully in traditional and historic buildings if it is approached with care and consideration for the special circumstances. For instance insulation on the inside of an inclined roof is one of the easiest and cheapest methods of improving building’s energy efficiency. However on a flat roof the external insulation is most effective [13]. Regarding
windows, double glazing is now introduced in all new homes and whenever replacement of windows is required. While it will take many years to get a return on the cost of new windows, simply from the savings in energy costs, they can improve a home’s overall indoor comfort level by reducing cold draughts. If the replacement of the existing single windows with double glazed is not possible, the addition of a secondary glazing panel is a good alternative. With this technique the existing windows are retained and therefore the character of the external elevations is preserved. While secondary glazing cannot achieve the same level of performance as a new double glazed window unit, it offers considerable improvement in heat retention over single glazing [13]. Referring to shading devices, the window shutters of the Mediterranean traditional buildings contribute enormously to the reduction of solar radiation during summer. The replacement of the existing shutters with automated ones could serve well especially during the hot summer period.

Based on the previous mentioned energy saving measures, the present study focuses on the energy efficiency of a building in a university campus. Variables of the building elements are examined through parametric simulations using the software iSBEMcY. The building simulations calculate the energy consumption of the building and conclude to its energy performance certificate which states the energy categorization of the building. Based on the energy classification of the building five retrofitting scenarios are studied in simulations. The scenarios include the building’s insulation, the windows’ replacement, the shading devices and the installation of photovoltaic panels on the building roof. Following these and through comparative studies the optimal scenario for energy conservation is concluded and the most energy efficient techniques which at the same time preserve the historical character of the building are adopted for retrofitting.

2. Methodology

In order to define the role of materials in the energy efficient retrofitting of traditional buildings a methodology is developed. The building design and specifically its construction characteristics are selected through field inspections and are examined through parametric simulations using the software iSBEMcY. This is the official governmental software used for the categorization of energy efficiency in buildings and the calculation of CO2 emissions according with the European Directive 2002/91/EC [7,9]. The software calculates the energy consumption of the building and concludes to its energy performance certificate which states the energy categorization of the building. All the European member countries have similar softwares in order to examine the energy classification of their buildings. Energy rating of a building can provide useful information on its energy consumption and it’s performed through standard measurements under a specific experimental protocol.

The energy auditing on the building under study investigates the aspects which affect its energy efficiency and its conservation. Initially the simulations conclude to the energy consumption of the existing building. Consequently five scenarios with different energy saving techniques are developed and through simulations with the iSBEMcY and the optimal solution is selected. The aspects which are examined in the simulation are the elements of the building envelope such as insulation levels, window design and shading devices. Furthermore the contribution of the installation of photovoltaic panels is studied.

3. Case study

This building carries on his back about 100 years of history. Originally it was built from economically donations for a girls’ school. In 1954 the English court moved there and from 1979 is used as a public office. The last 5 years after a restoration this historic building operate as an auditorium, teaching classrooms and computer lab for the Cyprus University of Technology. The building’s facade adorns a porch with four Ionic columns [Fig. 1]. A modern oval amphitheater added in the current traditional building and fitted perfectly with the old part of the building.

![Fig. 1 Lectures’ building](image)

The building is situated in the coastal area of Limassol. Limassol is the second largest city of Cyprus with extensive building development. The meteorological data in this location are 8m altitude, 34° 41’ latitude and 33° 03 ’ longitude. According to the Meteorological Service of Cyprus the mean daily minimum air temperature for Limassol is 8.5oC in February and the mean daily maximum temperature is in August 33.3oC. There is a diurnal fluctuation between eight to
ten degrees Celsius, with increased moisture content during the early morning hours. The city of Limassol and Cyprus in general enjoy long hours of sunshine throughout the year [14].

The building is located in the centre of the university campus and attracts the majority of students every day from 9:00 am to 18:00 and for most evenings of the week is used for the university events. These are entered in the building simulations using the iSBEMcy software and the energy certification of the building is concluded. The energy performance certification shows the energy consumption of a building in kWh/m² per year and the emissions of CO₂, in kg per m². Although the building has been recently renovated is not insulated and all the windows are single glazed. The building has a south orientation with extensive glazing surface. The envelope of the building consists of traditional stone of 50cm thickness. The electromechanical system consists of split units, VRV and chillers for heating and cooling with a central control system.

4. Current energy categorization of the building

The energy categorization of the building derived from the simulations is in the lowest energy class G [Fig. 2,3a]. Its’ total annual energy consumption is 669 kWh/m² without the use of any renewable energy sources. Its’ annual emissions of carbon dioxide amount to 196.78 kgCO₂/m².

Through the energy performance certificate (EPC) further results are also obtained. Annual consumption details showed that the highest amount of energy is consumed for electricity with the cooling system covering the 66% and the 13% for lighting. The heating system consumes only 6% of the total annual consumption [Fig.3b]. A possible reason for this low figure is the south orientation of the building and its high thermal mass due to the traditional stonewalls. Moreover the cold period in Cyprus is relatively short and the demand for heating is low. On the other hand the demand for cooling is very high during the summer. The most energy demanding months during the year are the summer months with a pick of energy consumption during July.

![Fig. 2](image1.png)  
**Fig. 2** Energy rating of the building

![Fig. 3](image2.png)  
**Fig. 3** a) Energy performance certificate of the building b) Energy consumption analysis of the building
5. Retrofitting scenarios for energy improvement

The energy performance of the building is assessed through the energy auditing and the building is concluded as an intensive consumer with very low energy efficiency and high running costs. For this reason the research continues with the simulation of energy improvement scenarios. In order to upgrade the energy performance of the building and reduce its energy consumption five different retrofitting scenarios are examined in building simulations. Following these and through comparative studies the optimal scenario which adopts the most energy efficient combination of techniques for energy conservation is concluded.

5.1 Scenario A: Insulation of the external walls

The first retrofitting scenario focuses on the building envelope and most specifically on the external walls with the addition of 5cm of extruded polystyrene internally. The insulation is added internally to preserve the traditional character of the building. The existing structure has already an insulated roof with rock wool. With the addition of internal insulation the heat transfer coefficient of the walls is lower than 0,85 W/m2K and it thus satisfies the Cypriot Decree based on the European Directive 2002/91/EC. In Figs 4,5a,b the simulation results of this scenario are presented. The walls’ insulation reduces the energy consumption of the building to 586kWh/m2 and its energy classification upgraded from class G to F. Energy savings occur both for heating and cooling. The heating consumption is reduced by 15.4% and the cooling consumption by 15.9%. The total annual energy savings are 12.5%.

5.2 Scenario B: Single windows replacement

The second scenario examines the replacement of single glazed openings with double glazed windows. The existing windows have single glazing with wooden frames. The wooden frames are retained to preserve the architecture.
character of the building. The heat transfer coefficient for the new openings is equal to 3.7 whereas the value of existing was 7 W/m²K.

After this measure the energy consumption of the building slightly decreases by 2%. The total energy consumption reduces from 669 to 655kWh/m². The energy consumption for heating reduces by 0.5% and the cooling by 3%. It is concluded that the replacement of single glazed windows with double is expensive and does not result to any significant reduction of energy consumption. Therefore the choice of the secondary glazing installation is cheaper and would reduce the thermal losses of this historical building.

Fig. 6 Energy rating of the building – 2nd Scenario

Fig. 7 a) Energy performance certificate-2nd Scenario   b) Energy consumption analysis of the building-2nd Scenario

5.3 Scenario C: Addition of mobile and automated external blinds

In the third scenario traditional designed mobile and automated external blinds replace the traditional window shutters. Following in Figures 8,9ab are the simulation results. The building is upgraded from class G to class F. With this alteration the energy consumption is reduced from 669 to 621kWh/m² with total savings up to 7.2%. The carbon dioxide emissions are also reduced by 7.2%. The energy consumption for cooling is reduced by 10.3% and the heating consumption to 2.5%. This implies that if the installation of the mobile automated shutters could reduce the energy demand then also the appropriate use of the traditional shutters could have the same results.
5.4 Scenario D: Installation of photovoltaic panels at the roof of the building

The fourth scenario studies the installation of 100m² of photovoltaic panels (PV) on the roof of the building. This intervention is suitable in case that the traditional or historic building has a horizontal roof and the PVs do not affect the facade and the unique design of the building. This pilot building has both types of roofs; parametrically has an inclined tiles’ roof and in the center of the building the roof is horizontal. Therefore the PV area is determined by the availability of the horizontal roof area. In order to maximize the energy efficiency the PV panels are install at appropriate angles and orientation. The selected photovoltaic panels consist of polycrystalline silicon since they are currently the cheapest in the market. The PV area of a 100m² on the roof of the building achieves the energy upgrading of the building and the replacement of 6.6% of the conventional energy with solar energy.
5.5 Scenario E: Combination of all the previous scenarios

This scenario involves the four previous retrofitting interventions of the building envelope; the internal insulation on walls, the double glazed windows, the shading devices and the installation of PVs. It is concluded that with a combination of simple and widespread energy saving techniques the total energy savings may reach 27.7%. The energy savings for heating is 13.4% and for cooling 28.3%.
6. Conclusions

In this study several retrofitting techniques are investigated through simulations with the official Cyprus’ government software for energy classification. The interventions are mostly applied on the building envelope. From the studies it is derived that the most energy efficient technique is the addition of thermal insulation on the walls with total annual energy savings of 12.5%. Although the addition of the insulation is on the internal side of the walls in order to preserve the historic character of the building, this measure has the most significant impact on its energy conservation. This is followed by the installation of shading devices with total savings of 7.2%. The installation of the mobile automated shutters reduces significantly the energy demand of the building; however, the appropriate use of the existing traditional shutters could have the same or similar results. The replacement of the single glazed windows with double glazed does not conclude to significant energy reduction and due to their increased cost they are not recommended. The installation of photovoltaic panels achieves the replacement of 6.6% of the conventional electricity with solar energy. The retrofitting scenario which involves the combination of all these proposed techniques is concluded to be the most energy efficient with total energy savings of 27.7%. However further techno-economic studies to examine the cost effectiveness and the payback period of the various scenarios must be carried out in future studies for the most cost effective solutions and for energy efficient retrofitting of historical buildings.

References