Solar applications in buildings in Greece

Nikos Papamanolis
Department of Architectural Engineering, Technical University of Crete
El. Venizelou 127 (former French School), 73133 Chania, Greece
Phone +302821037106; E-mail: npapama@arch.tuc.gr

Abstract

The work records, classifies and describes the main applications of exploitation of solar energy in buildings in Greece, a country in a region where high values of solar radiation are recorded. The study focuses on systems and practices that are applied to residential and commercial buildings following the prevailing design and construction practices in the country (conventional buildings). At the same time however it examines relevant applications in other categories of buildings as well as in buildings with increased ecological sensitivity in their design and construction (green buildings). It studies the effect of the respective applications in the energy and environmental behavior of buildings. It also investigates the room for improvement of efficiency and broadening of the scope of the relevant applications in buildings in the country and, where applicable, it proposes measures towards these directions.

1. Introduction

Greece, with an overall land area of approx. 132,000 km^2, consists, by the four-fifths of its mainland, of mountainous terrain. Greece is also a maritime country with numerous islands and a coastline of over 15,000 km in length. The bulk (i.e. about 59%) of the country's population according to the last census (2001) stands at about 11 million lives in urban areas [1]. Most urban centres and the largest of them -including the conurbation of the capital- Athens, with its population of about 4 million, lie on the coast.

Greece has a Mediterranean climate [2]. According to the relevant climatic data, the annual cycle can be divided into a cold and rainy season (October to March) and a warm and dry season (April to September). Temperatures on the Greek mainland present intense contrasts mainly due to seasonal and geographic factors. Greece is between the average annual isothermal of 14.5 and 19.5 °C. Extreme temperatures are close to -25 °C (during winter in the mountainous and northern regions) and +45 °C (during heatwaves on the mainland). The mean relative humidity ranges from 65% to 75%, according to location. It displays a simple annual fluctuation, with the maximum occurring during the winter months. In Greece, the general circulation of the atmosphere and the prevailing synoptic systems in the wider area contribute to the prevalence of western and northern wind components and fairly moderate speeds. However, in interaction with them, the complex relief of the country plays an important role in determining the prevailing wind direction and speed in many regions.

Greece is also a very sunny country. The average annual rates of incoming solar radiation, moving from north to south, range from 5000 to 6100 MJ/m^2 [3]. The month with the greatest amount of sunshine is July. During this month the average rates of incoming solar radiation range from 727.1 to 824.1 MJ/m^2. In contrast, the month with the least amount of sunshine is December, during which the average rates of incoming solar radiation range from 152.3 to 209.9 MJ/m^2.

The climatic conditions in Greece have the effect that the buildings in large part of the country should be heated for approximately four months of the year and be cooled for some other four months. This fact introduces a series of challenges in their design and construction. The challenges, indeed, are even greater with reference to green buildings. At the same time, the enhanced sunshine and high values of incident solar radiation allow the use of solar energy in a variety of applications. In fact, Greece is one of the countries which records relatively high percentages of exploitation of solar radiation in energy applications [4]. Among these, solar systems in buildings present an increased interest. Similar systems serve needs for natural lighting and of both heating and cooling. The contribution of the solar systems in the energy balance of the buildings in the country is only approximately measurable.

In Greece, the basic architectural and constructional characteristics of buildings display notable similarities. In the urban environment, in particular, which covers the vast majority of buildings, these similarities are pronounced and clearly visible [5]. As a result, these similarities extend to a large degree to the elements that determine the environmental and energy behaviour of the buildings concerned, whether these elements relate to design choices or constructional ones. This study identifies and examines these elements in buildings in Greece with reference to the management of solar energy and, insofar as the available data permits it, investigates their impact on the behaviour patterns of these buildings. Furthermore, in cases where it discovers shortcomings in the application of these elements, it draws attention to them and emphasizes the importance of developing more rational approaches and practices in order to overcome them.

2. Solar energy application in conventional buildings in Greece

2.1 Passive systems

The main applications of solar energy in buildings are related to natural lighting and heating.

The natural lighting of a room, for given solar radiation conditions, depends primarily on the size and orientation of the openings on the shell. Additionally, it depends on the permeability of the openings, the geometrical characteristics of the indoor space and the texture of the internal surfaces.

Buildings in Greece are characterized by many and large openings on their shell. It is significant that in multi-storey apartment buildings, which are the most common buildings in urban environment, prevail as openings on the shell balcony-doors with dimensions of approximately 3 m^2 [5]. According to the until recently valid in the country Thermal Insulation Code for buildings, as regards the normal for the most contemporary buildings´ opening frames, with double glazing, with gap 6 or 12 mm, results that in a typical balcony door with surface of approximately 3 m^2 should correspond masonry of approximately 7.5 m^2, in the case of a metal frame and of 6 m^2, in the case of synthetic or wooden frame. We can approximately construe these calculations as one balcony door per room, ratio which, where applied, indeed exhausts the margins of the Code as regards normal construction and conventional window and door frames [6].

In addition, the orientation of the openings toward to the sun is considered privileged, irrespective of the use of space where they belong. As a result, in cases where there are margins of choices, we are seeing more and larger openings of buildings to be oriented towards the side of the sun (mainly southern orientations) while, where the corresponding margins are limited (e.g. in densely-built urban environment), the preference for the orientation toward to the sun is manifested by giving it to uses that are considered to be more significant (like living room). These choices, despite the advantages they have, are not judged as always advisable. The climatic data of the country indicate cases where the southern orientation of openings has negative results for the conditions in the interior of buildings, like overheat at the hot period and mist [7].

The buildings in Greece are generally small in size. This comment applies also for the multi-storey apartment buildings forming the prevailing building type in urban environment. This makes it easier to the sunlight to reach the core of their internal space, despite the dense arrangement of internal partitions which normally characterizes them. The internal surfaces of the buildings are usually simply plastered and painted with emulsion paints. As for the choice of colour, light colours are the most common, usually ochres, blue, beige, orange or green.

In residential buildings, all rooms of main use have external openings. Even in densely-built urban environment, where sometimes buildings have only two free sides, the living room, the bedrooms and the kitchen in every apartment have external openings for natural lighting and ventilation. A formal relationship of opening to the room surface is approximately 3 m^2 of opening to 10 m^2 of room surface. With these data, for south orientation of the opening, the average illuminance inside the room exceeds the value of 650 lx. In addition, in such type of rooms, if they correspond to upper floors in multi-storey buildings, there is normally direct access to balconies, which allows the residences to have direct benefit of the solar radiation and of conditions that happens (when it happens) to be more favourable in the environment [8]

The exploitation of solar radiation for passive heating of buildings depends mainly on the absorbency of the external surfaces and on the thermal properties of materials of their shell. The exterior surfaces of the buildings in Greece are, as a rule, plastered and painted, as the internal, with light colours, which decreases the absorbency of solar radiation. On the other hand, buildings are constructed with materials and methods that contribute to increased prices of thermal mass. Reinforced concrete for example, which is used in big quantities so that it lends the required for the data of region antiseismic property of the buildings, is a structural material with high specific heat capacity, 0.88 kJ/kgK. Similarly, the bricks which with the plaster supplement the basic structural materials of the shell, are also materials of high specific heat capacity. This fact allows the storage of solar thermal energy in the elements of the shell and its following exploitation for smoothening the differences of temperature in the interior of the buildings.

With regard to the thermal conductivity of the shell, it is worth reporting two of the most common cases of walls in conventional buildings. In the first case the external wall is built with a double row of bricks, each 9 cm wide, with internal insulation consisting of a 5 cm-thick layer of expanded or - at best - extruded polystyrene. Such a wall, if the layer of plaster on each side - approx. 2 cm thick - is included, is nearly 27 cm thick, while the mean thermal transmittance coefficient is approximately 0.45 W/m^2K and the Thermal Time Constant approximately 54.6 h. For the second case, thermal insulation is applied to the vertical elements in the envelope of the supporting structure by fastening 3 or 4 cm-thick tiles of expanded or extruded polystyrene onto the external surfaces. In this case, the mean thermal transmittance coefficient of a typical wall 32 cm thick (25 cm-thick concrete slab + 3 cm-thick insulation + 2 cm-thick plaster on each side) is approximately 0.72 W/m^2K and the Thermal Time Constant approximately 130.7 h. Thermal insulation is also applied to the flat roof, as well as the floor of the first storey, if this lies above an open-sided parking area. The prevailing practices of application of thermal insulation on the shell of buildings in Greece, often do not take into consideration the thermal capacity of its elements, more specifically, with regard to the heat from the solar radiation [9]. It is noteworthy for example that cool roofs, which are considered to be appropriate for the climatic conditions in the country, are not often used in conventional buildings.

The above facts regard the contribution of constructional data in the configuration of the behavior of the shell toward the solar radiation. With regard to the designing contribution, we realise that the exploitation of the thermal mass of the shell seldom engages the designing of conventional buildings in Greece. It corresponds to a parameter that a lot of engineers do not feel capable to manage sufficiently and also does not occupy the tenants insofar as they do not comprehend its importance in the energy behavior of their buildings. On the contrary, for most of them, the exploitation of sun for passive heating of buildings becomes perceptible via the direct entry of solar radiation from the openings on their shell.

The price of exploitation of solar radiation for lighting and heating of buildings in Greece is the need for measures for sun protection particularly during the hot period of the year. Sun protection in Greece is necessary for all the openings that are exposed in direct solar radiation. A great part of sun protection of openings is achieved by constant projections – as a rule, projections of balconies [9]. The corresponding projections, for reasons of simplicity in the designing and construction of buildings in which they belong, are usually paraded in columns with the openings. As a result, each projection provides sun protection in the amenable opening. The breadth of constant projections seldom exceeds 2.5 m. The balconies function as elements of solar protection and, moreover, mediate with a lot of ways in the absorption of thermal energy of beams of the sun from the elements of the building shell [8]. Additional sun protection is achieved with mobile projections. A very common category of mobile projections in buildings in Greece are the operable awnings. It is rolls made of durable cloth or of thin metal venetian blinds that are fixed on the lower side of the above opening projections and open and close under bent, at will, with a manual mechanism.

In addition, in residential buildings, solar protection of the interior is also provided by adjustable shutters on doors and windows. Shutters have followed a similar course of development to door and window frames. Wooden frames had French-style shutters. Early aluminium frames had external sliding synthetic blinds or rolling shutters with synthetic slats hung in a wooden case fixed to the top section of the frame. In contemporary frames (aluminium or synthetic) the shutters usually take the form of synthetic rolling shutters hung in a case joined to the top section of the frame. Also, for sun protection reason internal curtains constitute a necessary supplement to all openings in residential buildings. Awnings, shutters and curtains, as manually operable systems, have the advantage to be activated when is needed, an attribute with particular importance for the shifting climatic and environmental in general conditions that prevail in Greece [10]. Reflective or absorbing glasses are rarely used and only in commercial buildings where the internal blinds constitute the prevailing equipment to control incoming solar radiation.

Trees and plants in general are welcome and suitable for the climatic conditions in the area solar control means. The unpleasant is that in urban environment the limited space does not allow the development of plants and, most of all, they do not extend high enough to overshadow the higher floors of multi-storey apartment buildings.

In dense building conditions, which characterize many areas in urban centers of the country, it is likely that a part of sun shading is non-deliberate and resulting in the screen of solar rays from neighboring buildings and other obstructers. Even more, in similar circumstances, appears the phenomenon of activating the measures for sun control for pursuing privacy. In other words, keeping closed shutters or folded curtains is done not for the avoidance of solar rays but to prevent the view within their territory from residents of apartments on the other side or passersby. The phenomenon, which, based on dubious validity student research work, may exceed in some areas in urban centers of the country the 20 % of the time of activation of the sun control measures, is worthy of thorough study.

2.2 Active Systems

The application of active solar systems in Greece started in mid 70's. The use of electric heaters in almost every Greek household, in combination with the oil crisis, and the rising price of electricity during this period, provided the background for the solar market to develop (EBHE - the Greek Solar Industry Association - was created in 1978). Until 1987, the market was steadily rising. In 1984-1986 a large advertising campaign supported by the Greek government, combined with financial incentives, boosted the sales of glazed solar collectors up to 218,000 m^2. It was estimated that there were about 300 manufacturers of solar systems at that time. The campaign of '84-'86, as well as a new one performed in cooperation with the Public Power Corporation in 1995, helped the solar systems to penetrate considerably in the residential sector. Trying to support the application of central solar systems in the tertiary and the industrial sector, the Operational Programme for Energy (1996-2000) supported a significant number of solar systems in Hotels and Industry by financing up to 50% of the capital cost [11].

Since then, the production of solar heaters increases continuously up to 2008 when 300,000 m^2 of solar collectors were produced. In 2009, despite the important, at 31%, fall in production (206,000 m^2 of solar collectors), Greece, with installed solar collectors of surface 4,074,200 m^2 or 2,851,940 kW(th) cumulative installed capacity in operation is found in the third, after Germany and Austria, place of classification in the EU based on the per capita installed solar thermal capacity (43.6 kW(th) per 1000 capita) [12].

Solar water-heating systems for domestic use are typically small units of closed circuit type, with average collector's surface 2.3 - 2.5 m^2, with storage tank capacity from 100 to 200 l, covering the needs for hot water of a single family. Their fitting on terraces of buildings, and even multi-storey apartment buildings, is made by metal bearing construction which ensures the proper slope and orientation of the collector. More rarely, in buildings without terrace, we encounter the metal bearing construction adjusted to sloping roofs. Even more rarely we encounter the unit of solar collector integrated in the aesthetics of the building or established at a distance from the building.

Photovoltaic systems are very promising for energy applications in Greece. At present, a few small photovoltaic power plants are in operation or in planning (Their total capacity in electricity production reached 17 MW in 2009) [13]. Yet, their integration in the energy design of conventional buildings remains hesitant. The reasons for this are the high costs of installation in conjunction with their limited effectiveness, the incomplete information and the problematic or even unclear so far legislative and administrative regime governing their installation in buildings.

3. Solar energy application in energy conscious buildings in Greece

The systems that were described include the big majority of solar applications in buildings in Greece. We find more evolved systems in buildings with increased ecological sensitivity in their design and construction (green buildings). Most of them are passive, according to the prevailing choices, compatible with the rich potential of the country in renewable energy sources. They began to be applied in buildings from the mid 70's (The Greek Institute of Solar Technology established in 1980; The Greek Center for Renewable Energy Sources established in 1987) and include systems of indirect solar gain that cover all the range of relative choices: exploitation of the thermal mass of the shell, thermosyphonic panels (Trombe walls), attached greenhouses, solar chimneys, solar atriums. It should also be estimated that the sun, as the basic factor that mediates in the activities of interaction of the building with the environment, enters as a parameter into all the applications of systems of exploitation of renewable sources of energy into buildings in the country. Similar applications are found in residential buildings as well as in big private or even public buildings of various uses (Companies, Organizations, Schools, Hospitals etc.). Among the most interesting cases, with the additional value that it existed from the historically first important efforts of distribution of solar applications in the country, is the solar village in Lykobrysi in Attica. It is a group of 435 residences with roughly 1600 occupants that were completed in 1984 and which uses a big variety of passive and active systems of exploitation of solar and other renewable forms of energy [14].

Although such applications are supported by the State with different measures [15], it is true that they have not yet reached a satisfactory for the data of the country degree of dissemination. They remain sporadic, not widely known and with poor contribution to a shift toward more ecological design and construction practices in the country. Part of their limited response in the society is perhaps due to the fact that the Greeks have difficulty in understanding the effectiveness of respective applications or, worse, in some cases this effectiveness was proved inferior to the expectations that grown. For some of these cases, in accordance with the empirical knowledge of the writer, corresponding studies didn't manage to address successfully the cooperation between separate building energy systems. In other cases, these studies did not assess correctly the climatic conditions of the country, mainly by underestimating the need for cooling of the buildings during the hot period.

4. Conclusions

Sun is given in Greece. Consequently, it has always been a key factor in the design and construction of buildings in the country.

Among the solar systems we find in contemporary buildings in Greece, those applied in conventional residential or commercial buildings belong mainly in the category of passive. It is about applications that have to do primarily with dimensions and orientations of openings and arrangements of shading of openings. For Greeks, the southern orientation of openings is of high appreciation, even though for some cases this is not justifiable.

The buildings in Greece, because of the way they are constructed, have a relatively big thermal mass and big thermal inertia shell. However, the prevailing design and construction practices do not exploit this identity to the extent they should be.

In Greece all the openings directed to sun have sunshades. Very common measures of solar protection are the mobile, usually hand moving awnings that we almost systematically find in openings directed to the sun. Often, indeed, we find openings with multiple systems of shading (e.g. curtain and shutters and awnings).

Important effects in the environmental and energy behavior of buildings have the morphological elements of their facades. Among these, prevailing place, with multiple role in the management of solar radiation, have the balconies, which constitute a characteristic element of facades of Greek urban buildings.

In Greece, we find in great number of buildings solar heaters for the heating of water, mainly for domestic use. The country is found in a high place of classification as for the number of installed solar water heating systems and the produced from them energy. Still, growing is during the last few years the installation of photovoltaic systems for production of electric energy. Relative installations at the present moment concern mainly units of production of electric energy, while with regard to their extension in scale of buildings, it is found in an initial stage.

In buildings with increased ecological sensitivity in their design and construction we find great variety of solar energy systems, both passive and active. For some of these systems could be worded as criticism that the most appropriate for their application environment corresponds to more cool and more stable climates than this of Greece.

In Greece, the conditions for the application of technologies of exploitation of solar energy in buildings assist. Of course, the needs of buildings both in heating and in cooling support the exploitation of all spectrum of available technologies, and still more, technologies adjustable to the shifting climatic and environmental conditions. These conditions in some degree are developed. There are however scopes of improvements that could upgrade the energy behavior and the quality of interior environment of buildings in the country.

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