Cooling the Future: Bridging architectural aspects from the past with modern energy efficient paints

Prokopis PERDIKIS[a*]

[a]*Abolin Co, Athens, 12462, Greece*

Abstract. This paper presents the importance of building's envelop protection, the role of the building materials, the technologies and approaches involved and how the development and the use of modern high albedo coatings, based on traditional and mineral binders, could have a significant contribution in Mediterranean building's energy performance.

A number of inorganic, white and coloured, high solar reflective and breathable coating materials, based on natural and traditional binders (.i.e. waterglass, lime, natural pozzolans), synthetic and natural pigments (.i.e. burnt sienna) and/or unlimited resources (i.e. sand) have been developed.

The use of such coatings in built environment and especially on building's envelope, as a passive cooling technique, enable the improvement of indoor thermal comfort conditions and the reduction of cooling loads, driving to lower carbon dioxide emissions and to significant energy savings.

Keywords: High solar reflectance, passive cooling, vernacular architecture, functional paints, historic buildings, urban heat island, energy savings, thermal comfort

1 Introduction

The protection from unfavorable, harsh climatic conditions and achieving comfortable microclimate are the primal objectives of architecture. The Mediterranean traditional architecture evolved to produce buildings that would be in harmony with the harsh climates of its various regions (D.Serghides, 2010). Vernacular architecture adheres to basic green architectural principles of energy efficiency and utilizing materials and resources in close proximity to the site. These architectural principles capitalize on the native knowledge of how buildings can be effectively designed as well as how to take advantage of local materials and resources (Sarah Edwards, 2011).

2 Building envelope and passive cooling

Envelope design as a means of passive cooling is an integrated part of building design form and materials as a total system to achieve optimum comfort and energy savings

* Prokopis Perdikis. Tel.: 0030-210-5575568
E-mail address: abolin@abolinco.com

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(E.M. Okba, 2005). The building envelope is considered the selective pathway for a building with climate-responding ability with respect to cooling, ventilation and natural lighting needs. In hot and dry climate and because of heat gain due to solar effects, significant amount of energy is consumed to sustain comfortable indoor environment (Projacs Academy, 2013).

The materials surrounding the occupants of a building are of prime importance for protection against heat and cold. Great care must be taken in the choice of the wall and roof materials and their thickness with respect to their physical properties, such as thermal conductivity, resistivity and transmission and optical reflectivity.

There are many types of roofs in traditional Egyptian vernacular architecture, constructed from local materials and with traditional techniques. In hot-arid regions the dome, the vault and the flat roofs are considered traditional roof shapes. The modern construction method, in which a 10 to 15 cm exposed concrete slab is created, is considered the worst possible roof for this climate, because the surface temperature of the inner slab can reach up to 60°C, which is stored till late in the evening (P. Gut, D. Ackerknecht, 1993).

As the roof is a critical part of the building, high solar reflective and emissive materials are required for long-wave radiation, as well as thermal insulation. Apart from the fact that insulation is essential for concrete flat roofs, they also need an additional and expensive, robust skin that protects the insulation layers from damage caused by the sun (Mostafa El Gamal, 2012).

3 Buildings' envelope traditional construction materials

Building envelope in traditional architecture was constructed of local building materials that were appropriate to ambient environment whether in physical properties to climatic conditions or the construction techniques employed by the society that produced this architecture. Traditional building materials, such as brick, stone, palm trunks, and wood are usually natural, so they are generally low in embodied energy and toxicity. Often, traditional building materials are local and better suited to climatic conditions; thus, they create comfortable internal environment passively and naturally. Generally speaking, they are low embodied energy, recyclable, reusable, energy efficient and environmentally sustainable.

Building materials strongly influence vernacular building traditions also. It should be noted that many vernacular dwellings observed combine massive walls with lightweight roofs, most frequently thatch roofs. As the climate becomes hotter and more humid, lightweight building envelopes and construction materials become more prevalent. In hot-arid regions the vault, the dome and the flat roof are the traditional roof shapes.

The use of thatch appears to be especially prevalent. The most common application of thatch in recent European traditions is for roofs, but many cultures, including prehistoric Britons, used thatch for the entire structure. Roof materials in vernacular dwellings included stone (slate), tile, thatch, bark, skin, felt, wood or turf. Tile roofs are a common site in vernacular architecture, but have very poor insulting quality. Thus, tile roofs are combined with thick wood, masonry or earthen layers except in cases of mild environments like the Mediterranean where terracotta tiles were developed by the Romans in conjunction with mortar (Paul T. Nicholson, 2000).

3.1 Traditional building materials examples

The use of natural building materials such as stones and mud bricks has always been an essential element of vernacular architecture. The mud bricks were produced by mixing the mud with sand and chopped straw, a technique still used today. Mud bricks were used in the construction of many Pharaonic tombs and houses (Zhiqiang Zhai, 2010). Natural stones are another common material of traditional vernacular architecture, recognized for their durability and high thermal capacity (Baran Tufan, 2014).

Lime and gypsum mortars were used extensively in various structures, employed mainly as plaster coatings. The chemical composition of lime and gypsum binders is identical to that of the corresponding natural rocks, although their microstructure is different. In the Levant (Syro-Palestine coast), Anatolia and Greece, lime plaster was almost exclusively the material of choice. Recent studies have shown that in ancient Egypt, lime was also used in this region (J.W. Shaw, 2009). The need to increase the poor resistance of quicklime mortars and improve hardening, even in water (e.g., for the construction of support foundations for bridges and aqueducts) led Roman builders to develop mortars containing pozzolana or other materials which behaved in a similar way (e.g., brick dust): these were the forerunners, by more than 2,000 years, of a material similar to today's Portland cement (J.D. Friedman, 1971). These mortars can be manufactured by mixing lime with pulverized clay materials called pozzolans (natural or artificial). When finely ground, the pozzolans react with lime at normal temperatures in the presence of water or moisture to form stable calcium silicate/aluminate hydrates. The hydraulic character of such mortars is due to the reactions between the pozzolanic material and the lime binder (Carlo Giavarini, 2010).

For many years the use of traditional lime-based paints was restricted to those involved in the conservation industry, but more recently these paints have enjoyed a renaissance. The basic material of limewash, lime, is derived from limestone or chalk (both are forms of calcium carbonate) which is 'burnt' in a kiln to form quick lime (calcium oxide). To make limewash this material is then further diluted with water to form a thin paint of brushable consistency (Maria Philokyprou, 2010). Limewash has always been, and remains, a most effective way to protect, maintain and beautify the surface of historically-significant structures (Peter Mold , 2005).

Other known painting technologies that have been used, involve chalk, casein (non-fat milk curds), animal or vegetable glues (i.e. Egyptian gum), and oil. Traditional distemper paints are also generally known and appreciated for their soft luminous appearance.

4 Colours, pigments, renders, paints and coatings

4.1 Colour

Isidore of Seville (560 – 636), scholar in the early middle ages described paint as "captured sunlight". Thousands years later, a number of technical standards describe the measurement of colour as follows: "Colour is the property of an area in the field of view that seems to have no structure and which allows this area to be differentiated, on viewing with one unmoving eye, from a similar structure-less area bordering on the original and seen at the same moment".

4.2 Paints and coatings

Colours in all shades are used to decorate buildings. Paint does not, however, simply add colour, but is also a structural component, providing protection against the weather, moisture, water and against atmospheric, chemical, biological, mechanical or other influencing factors. In addition, paint has a decorative element. The term "coating", which includes the traditional terms paint, varnish and lacquer, today also includes a large number of protective systems including filling compounds and floor coatings. Coating materials as defined in modern technical standards – paints and varnishes – are liquid to pasty, or powdered materials, which consist of binders, pigments or other colouring matters, fillers, solvents and other ingredients. Paints or coatings in general, consist of binders, solvents, fillers, pigments and auxiliary substances. These ingredients, which are added and mixed in the solid or liquid state, determine the colour and above all the properties of the paint. Binders can be divided, according to their origins, into vegetable, mineral, animal and synthetic binders. EN 1062 lists the following binder groups: acrylic resin, alkyd resin, bitumen, cement, chlorinated rubber, epoxy resin, slaked lime, oil, polyester, water glass, silicone resin, polyurethane, vinyl resin.

4.3 Plastering/rendering

Plastering/rendering, as defined in many standards, is a single - or multi-layer coating of plastering or rendering mortar applied to walls or ceilings with a defined thickness. Its final properties develop only after hardening. Mineral binders can be divided into the following groups: lime binder, calcium silicate binders, calcium aluminate binders, calcium sulphate binders and silicate binders. Beyond mineral plasters, synthetic plasters based on organic binders are available also. Synthetic resin plasters are coatings which look like plaster. They are made of organic binders and fillers/aggregates in the form of a polymer dispersion or solution (Alexander Reichel, 2004).

4.4 Pigments and colorants

Ever since the prehistoric time, mankind took delight in coloring the objects of daily use by employing natural pigments of vegetable, animal, and mineral origin. These coloring substances, known as natural dyes, are the chemical compounds used for coloring fabrics, hair, leather, plastic, paper, food items, cosmetics, and medicines, etc., and to produce artistic colors and inks for paintings and printing (Har Bhajan, 2014).

Natural dyes have been used in most of the ancient civilizations of the world, like India, China, Mesopotamia, Egypt, Greece, Aztec, and others. The discovery of red ochre in very ancient burial sites indicates that the use of natural dyes for aesthetic and other purposes is at least 15,000-year old. The art of dyeing cloth is believed to have been known since 3000 BC in China and 2500 BC in India. At relatively the same period (2000 BC), dyeing of cloth in yellow, red, blue, and green was also practiced in Egypt.

Earth pigments are naturally occurring minerals, principally iron oxides that people have used in paints for thousands of years for their natural color. These natural pigments are found in rocks and soils around the world, where different combinations of minerals create vibrant colors that are unique to the regional landscapes. Some earth pigments are roasted in order to intensify their color. Earth pigments include ochres, sienna, and umbers. Ochres come from naturally tinted clay containing mineral oxides. Ochres are available in a range of yellows, golds, and reds. Sienna is a form of limonite clay. The pigment was first used in Italy in prehistoric times. The unique color is derived from ferric oxides. Umber, is a clay pigment that contains iron and manganese oxides. The name is said to be derived from the Latin word umbra (shadow) or from the mountainous Italian region of Umbria, where umber was originally extracted. Umber is darker in color than ochres and sienna. Colors range from cream to brown, depending on the ratio of iron and manganese compounds. Mineral pigments are pigments that are created by combining and heating naturally occurring elements. Mineral pigments made by heating sulphur, clay, soda. They include ultramarine and spinel pigments.

5 Cooling Mediterranean homes naturally and affordably

5.1 The concept of high albedo materials

Keeping cool indoors when it is hot outdoors is a problem. The sun beating down on our homes causes indoor temperatures to rise to uncomfortable levels. Air conditioning provides some relief. But the initial costs of installing an air conditioner and the electricity costs to run it can be high. An alternative way to maintain a cool house or reduce air-conditioning use is natural (or passive) cooling. Passive cooling uses non mechanical methods to maintain a comfortable indoor temperature.

Dull, dark-colored typical home exteriors absorb 70% to 90% of the radiant energy from the sun that strikes the home's surfaces. Some of this absorbed energy is then transferred into the home by way of conduction, resulting in heat gain. In contrast, shade trees and bushes can reduce this heat gain and typical light colored surfaces can reflect most of the heat away from the surfaces (Cooling Your Home Naturally: DOE/CH10093-221 FS 186, 1994).

The most effective method to cool a house is to keep the heat from building up in the first place. The primary source of heat buildup (i.e., gain) is sunlight absorbed through the roof, walls, and windows. Secondary sources are heat-generating appliances in the home and air leakage. Reduction in roof heat gain means reduction in cooling demands, using air-conditioning so as to increase human indoor thermal comfort levels. This also has a positive impact on urban environmental quality. The performance of the roof depends mainly on its form, construction and materials. Generally when the roof surface is fully protected from the direct warming effect of solar rays, especially at noon, heat gain is minimal (Marwa Dabaieh, 2015).

Wall color is not as important as roof color, but it does affect heat gain and in some cases notably. White exterior walls absorb less heat than dark walls. Light, bright walls increase the longevity of siding, particularly on the east, west, and south sides of the house. Lower exterior walls surfaces temperatures, will gradually affect the buildings' interior temperature also. When the wall internal surface temperature is lower than the indoor air temperature, it will have cooling effect. This reduction of the wall internal surface temperature is beneficial to improve the body's radiation heat transfer and enhance the indoor thermal comfort effectively in summer. Therefore, the cooling effect of the internal surface temperature may reduce the air-conditioning running time, to achieve the goal of energy saving.

Albedo indicates the fraction of incident radiation, including the invisible ultraviolet and near-infrared parts of the spectrum that is reflected. Planet Earth now has an average albedo of 0.3 that is. It reflects about 30% of the sunlight that lands on it (Tina kaarsberg, 2006).

The albedo of a surface is defined as it's hemispherically and wavelength-integrated reflectivity. This definition applies to simple uniform surfaces as well as to heterogeneous and complex ones. Typically, urban albedos are in the range 0.10 to 0.20 but in some cities these values can be exceeded. North African towns are good examples of high albedo urbanized areas (albedos of 0.30 to 0.45) whereas most US and European cities have lower albedos, from 0.15 to 0.20 (Haider Taha, 1997).

High albedo materials drive to lower temperatures of the surfaces exposed to solar radiation than those characterized by more traditional materials, thus having a lower temperature characterizing the environment (Ferdinando Salata, 2015).

Cool roofs, or high albedo roofs, reflect a large portion of the sun's heat, and have a greater ability to emit, or radiate away, any heat that is absorbed. The ability of a cool roof to perform these functions is measured in terms of solar reflectance (also known as albedo), thermal emittance, and Solar Reflectance Index (SRI).

Cool roofs can help reduce the heat island effect and also help improving the energy performance of the buildings. A cool roof can reflect the sun's heat and emits absorbed radiation back into the atmosphere at a higher rate than standard materials. The cool roofs technology has been used for more than 20 years (EPA, 2012). The cool roof basically helps in reflecting sunlight and heat, thus reducing the temperature of the roofs. 20---25% of the urban surface is reported to be occupied by roof surface.

This provides huge scope of providing passive cooling to enhance energy performance of the modern buildings (Zinzi & Angoli, 2012).

5.2 The concept of coloured high solar reflective coatings

A number of coloured high solar reflective coating materials (Fig 1) have been developed which allow architects and buildings' energy consultants to take benefit of lower surface temperatures, without sacrificing aesthetic options in building's design. The technology involved enables the creation of dull, dark-coloured even surfaces, with significant higher solar reflectance and infrared emittance values, in comparison to standard materials of the same colour.

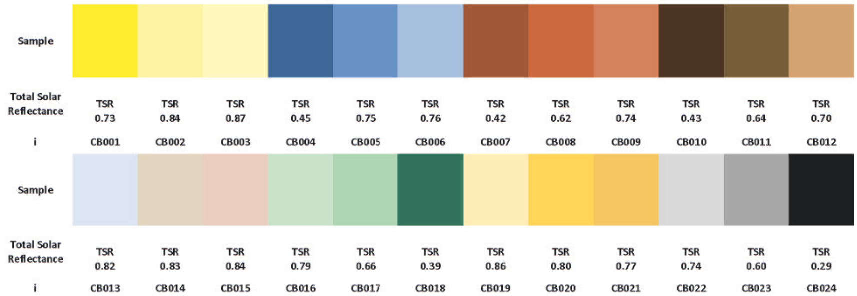

Fig 1. High Solar Reflective Colours Source: www.abolinco.com

While a typical black colour absorbs almost all thermal radiation the "cool" alternatives can even reflect the 30%. As a consequence, the use of such low heat build-up colours in the built environments can have a significant impact in lowering surface temperatures: driving into buildings' energy demand reduction for cooling and to better microclimatic thermal conditions. Typical applications of such coatings are not limited to commercial or residential buildings and urban superstructures.

Historic or cultural heritage buildings can also take advantage of such coating solutions. Even though historic buildings are currently exempted from most energy performance directives and requirements, there is a growing awareness that cultural heritage preservation and preservation of the natural basis of life are equally important goals.

Statistical data on historic buildings in Europe (Alexandra Troi, 2014) indicate that 14 % of the EU27 building stock dates from before 1919 and 12 % from between 1919 and 1945 (with considerable national differences), corresponding to thirty and fifty-five million dwellings respectively, with 120 million occupants. Finding conservation-compatible solutions for these buildings can thus contribute a significant share to the EU's CO_2 emission reduction goals.

5.3 The concept of "natural" binders and special pigmentation mix design

In respect to the well-performing of the traditional building materials since centuries, societal claims for greener technologies and taking into account recent technological developments and technical requirements, a number of high solar reflective coating materials based on minerals and/or hybrid binders have been developed. The result is breathable, yet water resistant, coating materials, which combine the inherent function, the characteristics and the intended scope of traditional construction materials, with novel and advanced performances and functionalities.

From another aspect, carefully selected formulations, managed to combine natural earth pigments with high performing non-toxic metal oxides and nanostructured raw materials. As a result, a number of high solar reflective colours are available, that have the same visual properties with traditional colours used, in many Mediterranean countries. The new high solar reflective coating materials are not limited to lime paints and stucco, natural pozzolanic mortars and silicates.

6 High solar reflective materials and energy savings

Several studies have been performed in the past to evaluate the impact of the high solar reflective technique on the energy performance of air- and not air-conditioned buildings (M Zinzi, 2010). Reducing the building's solar gains, the energy use for cooling and the peak electricity demand will be reduced also in summertime. This strategy will conversely lead to increased energy consumption during the heating months. Solar gains are reduced in this season, since the sun is low on the horizon, with a reduced length of day and sun radiation. These reasons make solar reflective technique an energy-efficient strategy, but several variables have to be taken into account in order to evaluate the counterbalance between cooling benefits and potential heating penalties. Such variables include:

- Climatic conditions: The warmer the building location, the higher the needs for cooling.
- The insulation level of the building. This aspect has to be connected with the climatic conditions.
- Building use.
- Building geometry and orientation.
- Installed energy systems.

7 Conclusions

Vernacular architecture in many countries within the Mediterranean area is a splendid example of how built space skillfully adapted to a harsh natural setting, taking advantage of local materials and techniques. The use of solar reflective building materials is a traditional, simple and cost effective technique, which, through proper design considerations, can drive to a clear benefit into buildings' energy consumption for cooling.

The development of novel, durable and coloured solar reflective coating materials, based on natural binding agents, who ''mimic'' the characteristics of the traditional material used for centuries in vernacular architecture and outperform their intended scope, can be a well suited technique in buildings' energy renovation works and especially into historic buildings applications.

Moreover, the benefits from the use of such materials can have a positive impact into microclimatic conditions (mitigation of urban heat island consequences) and be also an effective answer to global warming, which is critical in large urban areas.

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