Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 90 (2016) 200 – 208

Energy Procedia

5th International Conference on Advances in Energy Research, ICAER 2015, 15-17 December 2015, Mumbai, India

Performance of Building Roofs on Energy Efficiency- A Review

Arna Ganguly[a], Debashish Chowdhury[a], Subhasis Neogi[a,]*

[a]*School of Energy Studies, Jadavpur University, Kolkata, India*

Abstract

The steep increase in energy demand mainly during the summer season for tropical humid climates has gained significant importance in this scarce condition of fossil fuels. This paper presents a review on different roof technologies performed with an aim to reduce the cooling loads during summer thus helping in energy conservation. Firstly it deals with green vegetated roof carried out in regions of hot humid climates. The green roof performance was explored by evaluating its effect on temperature fluctuations and heat fluxes during summer. The results showed that the presence of plants led to a decrease in temperature in the presence of green roof. The water usage and tolerance to stress at times of prolonged drought were also assessed for several types of plants suitable for extensive green roof systems. Other cooling strategies are use of reflective paints also called cool paints. The impacts of the application of reflective paint on a standard bare roof were analyzed by mainly monitoring reduction of roof surface temperature at different case study locations. Further performance of three kinds of cool paints and even cool black paints are studied for going deeper into the facts of cool paint potentials and limitations. Eventually comparative analysis between these two solutions is assessed by taking into account the several parameters that affect the final energy performances.

Peer-review under responsibility of the organizing committee of ICAER 2015

Keywords: Green Roof; Cool Roof; Cool Paints

1. Introduction

The intensification of the urban heat island effect has led to development of issues like global warming, greenhouse gas effect etc. The building sector being directly involved to such effects and thus adequate solutions needs to be provided at energy and environmental levels. Roofs in particular are envelope components for which

* Corresponding author. Tel.: (+91) 033 2457 2907; fax: +0-000-000-0000 .
E-mail address: neogi_s@yahoo.com

Peer-review under responsibility of the organizing committee of ICAER 2015
doi:10.1016/j.egypro.2016.11.186

advanced solutions can lead to significant energy savings in any building with air conditioning facilities or improve indoor thermal conditions in buildings without such facilities. Green roofs are one such building element, providing various benefits where water availability does not restrict their implementation. Green roofs are generally classified into two major categories: (a) extensive green roofs, which may be established on a very thin layer of soil and are designed to require minimal maintenance and (b) intensive green roofs, which have a soil layer of 20 cm or more and can support a large variety of plants. On the other hand cool roof strategies are progressively drawing the attention of the scientific community and the market due to their effective role in reducing building energy requirements and also mitigating urban heat island effects. A cool roof technology generally consists of a roof system with a coating characterized by high solar reflectance and high thermal emissivity. When the roof is exposed to solar radiation, these two characteristics reduce the roof's external surface temperature. The same roof with lower reflectance and thermal emittance has a much higher roof surface temperature. Consequently in the former case, solar heating load entering the indoor thermal zone is decreased. This technique for improving thermal comfort inside the buildings is of low cost, much effective, easy to implement, energy efficient and helps in mitigation of Urban Heat Island (UHI).The necessity for cool non-white coatings arose because heat absorbing darker colours, which are often preferred from aesthetic point of view, contribute to UHI. This led to the development of cool paints of darker colours, but with special pigment that still reflected solar radiation. For aesthetic and energy efficient considerations, organic and complex inorganic black pigments with good spectral reflectivity have drawn attention. Complex inorganic pigments are less expensive and generally exhibit high durability properties like weathering, temperature, chemical resistance and UV scattering.

2. Green Roof

Natural cooling techniques have been used over the centuries. The introduction of mechanical air conditioning systems although came with a huge thermal comfort but it had to deal with a huge amount of energy expenditure. The benefits of green roof natural cooling system have not only shown huge potential in reducing the building energy consumption but also had been a large contributor in mitigation of the urban heat island effect. According to A. Niachou et. al. foliage protects the buildings from solar radiation, controls the temperature and humidity of the indoor building environment [1]. The plants for their biological functions such as photosynthesis, respiration, transpiration and evaporation absorb a significant portion of solar radiation. Moreover, the solar radiation, external temperature and relative humidity are reduced as they pass through the vegetated part covering the roof, hence protecting the integrity of the underlying bare roof. Selection of plant species plays an important role. Plant species exhibiting a strong ability to store water in their leaves and drought resistant are suitable for green roof plantation.

Green roof installation is characterized by a number of layers. According to A. Spala et. al. the lowest point before the original bare roof consists of a water proofing membrane in order to protect the building from leakages [2]. Similar scenario was also shown by Dominique et. al. where there were both a water proofing membrane and drainage layer and also other protecting layers summing up to a total depth of 120mm between the green roof (GR) and the bare roof surface [3].

2.1. Effect on roof surface temperature

Green roofs help to decrease the roof surface temperature significantly. According to Dominique et. al. the extensive green roof installed in Reunion Island which was mainly characterized by tropical humid climate, showed a significant decrease in temperature of the roof surface. While the maximum temperature of the reference bituminous roof surface reached about 73.5 ±1.4 °C, the roof covering the three succulent plant species namely *Plectranthus neochilus*, *Kalanchoe thrysiflora* and *Sedum reflexum* only reached an average maximum temperature of 34.8 ±0.6 °C. Similar things were reported by A. Spala et. al. where the green roof system in Athens, Greece showed a decreased temperature after its installation as recorded in the space thermograph. Similarly A. Niachou et. al. reported that lowest temperatures of the green roof ranged from 26°C to 29°C and were measured in places dominated by thick dark green vegetation. The highest temperatures were between 36°C and 38°C and were measured in spaces covered by sparse vegetation. While the temperature of green roof cover of insulated building varied from 28.7°C to 32.5°C at different positions, the temperature of green roof cover of non-insulated building varied from 28.9°C to 42.6°C at similar positions. There were no significant temperature variations between the external surface of the insulated building with or without implementation of the green roof while the temperature reduction due to existence of green roof on the exterior surface temperature of non-insulated building was of the order of 10 °C. Thus the impact of green roof of non-insulated building was favourable.

2.2. Contribution to thermal comfort

Green roofs induce to decrease temperature fluctuations thus contributing towards thermal comfort. According to Dominique et. al. the average values of temperature differences between GR surface and GR surface at a depth of 120mm were 6.8±1.4 °C for *Plectranthus*, 6.5 ±0.9 °C with *Kalanchoe* and 6.7 ±0.1 °C for *Sedum* . Thus a significant ability to decrease temperature fluctuations was being observed due to the presence of green roof. According to A. Niachou et. al. thermal comfort was recorded for insulated building with green roof where the average maximum indoor air temperature was 29°C with green roof while it was 31°C without green roof. The temperature fluctuation was also lesser with green roof showing an average daily temperature width of 4°C while it was around 7°C without green roof. Orna Schweitzer et. al. reported that all the four plant species namely, *Pennisetum clandestinum, Apentia cordifolia, Sesuvium verrucosum* and *Halimione portulacoides* showed a significant cooling effect mainly during the warmest hours of the day (temperature difference with and without green roof being 3.1K – 4.4 K), the most effective being *P. clandestinum* and *S. verrucosum* [4].

2.3. Shading effect of vegetated roof

Sun-shading capability of the plant species plays a very important role in effecting the performance of a green roof. According to Dominique et. al. on typical three days of January, 2011 when the mean maximum solar radiation was 1165.7±43.3 W/m^2 ,the maximum heat flux transferred through *Plectranthus* green roof surface was 27.7 ±2.2 W/m^2 , for *Kalanchoe* the value was 28.8 ±2.7 W/m^2 and 16.6±1.7 W/m^2 for *Sedum.* Higher performance of *Sedum* was due to its higher sun-shading effect and its higher ability to grow more quickly than the other two species used in the experiment. Similar things were observed by Orna Schweitzer et. al. which showed comparable temperature difference between the planted roof layer and the insulation layer of (three) test cells equipped with (three) different kinds of vegetation and that of a test cell with moist soil cover. The effect of moistening the soil showed much smaller cooling effect than any of the planted green roofs. Thus the shading effect of the vegetated roof proved to be much more efficient than the evaporative cooling mechanism of the moist soil.

2.4. Water consumption

Water consumption, tolerance to stress and tolerance to salinity are the three important parameters to be taken into account in case of green roofs located in arid climatic conditions where water consumption is an important factor, as shown by Orna Schweitzer et. al where the experiment took place in Tel Aviv which has practically no precipitation during summer. It was observed that the daily evapotranspiration was lowest for *A. Cordifolia* at a wind speed of 2m/sec hence showing most economic water consumption.

2.5. Tolerance to stress and salinity

Green roofs installed in a water scarce region might have to withstand prolonged periods of stress. Thus two factors that come into play are: (i) the response of the plant species to a complete removal of irrigation for one month and (ii) use of brackish water instead of potable water, with different levels of salinity. According to Orna Schweitzer et. al. *Apentia cordifolia* survived the extended drought conditions with a fairly good health among the four species of plants selected for the experimental study. On the other hand S.verrucosum and H.portulacoides watered with solutions of 100mM and 150mM of salt showed a much better performance in terms of tolerance to salinity than the other two plant species.

2.6. Effect on U-value

According to Dominique et. al. the U-value, K-value and R-value of the green roof were evaluated based on the obtained results of temperature fluctuations and heat flux variations. It was observed that Sedum had a U-value of 2.15 ± 0.22 W/m^2.K which was significantly lower than the other two plant species. Consequently Sedum showed a greater value of thermal resistance also, which was 0.47 ± 0.05 m^2.K/W. Similar results were observed in case of K-value hence showing better energy performance of Sedum compared to Plectranthus and Kalanchoe. According to A. Niachou et. al. the U-value of non-insulated roof ranged from 7.76 W/m^2.K to 18.18 W/m^2.K while the ones with green roof varied from 1.73 W/m^2.K to 1.99 W/m^2.K. Thus it directly shows that the heat transfer through non-insulated roof is greater than through non-insulated roof with green roof. Furthermore in case of moderately insulated roof the U-value varied from 0.74 W/m^2.K to 0.80 W/m^2.K while the same with green roof had a U-value of 0.55 W/m^2.K to 0.59 W/m^2.K, hence the difference of thermal conductance co-efficient was almost equal to 0.2 W/m^2.K. Similarly the same was observed for well insulated roof in which the bare roof had a U-value between 0.26 W/m^2.K to 0.4 W/m^2.K while the same bare roof with green roof above had a U-value ranging from 0.24 W/m^2.K to 0.34 W/m^2.K, hence having an estimated difference of 0.02 W/m^2.K to 0.06 W/m^2.K. Thus while the contribution of green roof had a significant effect on the thermal performance above the non-insulated building, on the other hand it was negligible in case of well-insulated buildings.

2.7. Effect on energy consumption

Energy consumption is reduced to a great extent in case of buildings equipped with green roof. According to A. Spala et. al. the percentage cooling load reduction for the whole building varied from 15% to 39% while for the floor just beneath the roof, the effect was much more significant showing a reduction up to 58% during summer. During winter small increase as well as decrease of heating load was found in both the cases. Moreover the observed decrease of heating load fluctuated between 2% to 8% for whole building and between 5% to 17% for the floor just beneath the roof.

2.8. Energy saving capability

Orna Schweitzer et. al. showed that *A. Cordifolia* provided an optimum performance both in terms of water consumption and cooling efficiency (cooling efficiency taken as a ratio of reduction in sensible heat in test cell to amount of water supplied to the roof) which were 4.5 L/m^2 and 5.5% respectively. A. Niachou et. al. showed that energy saving percentage of the compared roofs (with and without green roof) for heating ranged from 9% for well-insulated roof while it was 45% for non-insulated roof. Estimated values with similar comparison for cooling loads showed zero energy saving in case of well-insulated building and about 45% for non-insulated building. Similarly, energy saving percentage in non-insulated buildings during summer varied from 54% for 4 air change per hour and 61% with 10 air change per hour. The corresponding values in building with moderate insulation ranged from 9% (4 ACH) to 12% (10 ACH). On the other hand, for well-insulated building the energy saving for cooling was almost zero for each alternative scenario of night ventilation. The results thus explained the fact that during summer period the green roof contributed to low air temperature during the daytime and high air temperature during the night.

3. Cool Roof

The Urban Heat Island phenomenon is one of the main reasons behind the increase in urban air temperature. This primarily occurs due to the removal of natural vegetation and its replacement with buildings and paved surfaces. Building roofs are huge absorbers of heat being directly exposed to solar radiation, thereby increasing the roof temperature up to a great extent.

The use of highly reflective materials, also called “Cool materials” or “Cool Coatings” helps to maintain a much low exterior surface temperature. Cool materials are a particular category of paints that are characterized by high solar reflectance which tends to reduce the absorption of solar radiation when compared to conventional building materials and hence limiting the rise in roof surface temperature. These are also characterized by high infrared emittance that dissipates the accumulated heat without transferring it inside the building rooms.

3.1. Effect on roof surface temperature and internal ceiling surface temperature

Different case studies have been undergone showing the potential of cool roof. According to M. Kolokotroni et. al. the monitoring parameters included internal surface temperature, indoor air temperature, indoor relative humidity and roof surface temperature [5]. Every case study has a pre-application and post application period of cool paint condition in order to firmly point out the potentiality of a cool roof. According to M. Kolokotroni et. al. the case study that took place in an open office building in Brunel University, London consisted of a pre-application of cool paint starting from 1st May, 2009 to 1st week of June, 2009. Similarly it also included a post-application condition starting from 1st August, 2009 to last week of July, 2009. Every parameter showed a better performance from cooling point of view in case of roof after application of the cool paint. As shown by M. Kolokotroni et. al. on two particular days i.e 1st June,2009 and 16th August,2009 each having approximately similar external average temperature and average global radiation during daytime, showed that the roof surface temperature was higher on 1st June as compared to 16th August by a maximum of 7.7°C and an average of 6°C during working hours. Internal ceiling surface temperature was higher by a maximum of 3.1°C on 1st June. Surface temperature differences were also by calculated by deducting internal ceiling temperature from roof surface temperature during the pre and post painted months. It was observed that the pre-painted period showed a cooler roof surface temperature than internal ceiling surface during early morning while during midday just the opposite occurred. During the post-painted period the internal ceiling temperature always remained at a higher value than the roof surface temperature indicating the cooling effect of cool paint on the external surface. According to E. Bozonnet et. al. the case study building located in Poiters, France the mean external roof temperature was 30.2°C during pre-application of cool paint and 19.8°C during the post-application condition [6]. Similarly a study was conducted by C. Romeo et. al. in a school located in Trapani, a town on the west coast of Sicily that during the pre-application of cool paint the maximum roof surface temperature difference was 48°C and decreased to 26°C after application of the cool paint [7]. C. Romeo et. al. presented more detailed temperature profiles of twenty days in August,2009. It observed a difference of 20°C between the non-treated roof and air temperature; on the other hand the difference was never higher than 5°C between the cool roof and air. A cumulative distribution of temperature difference between the external roof surface temperature and external air temperature during the monitoring campaign showed a noticeable increase of the surface temperature higher than 10°C for more than about quarter of the period mostly during daytime hours. On the other hand in case of cool roof only for 6.6% of the monitoring period, surface temperature resulted in higher temperature difference than 3°C compared to air temperature. Similar results were found in the thermal modelling of the building of Brunel University as shown by M. Kolokotroni et. al. It was observed that the predicted hours of internal air temperature and internal operative air temperature (working hours) for the case study building during May, 2009 to September, 2009 remained above 25°C for 981 hours at a solar reflectance of 0.1 and 851 hours at a solar reflectance of 0.6 and greater than 25°C for 1045 hours at solar reflectance of 0.1 and 853 hours at a solar reflectance of 0.6 respectively, hence proving the positive sides of a cool roof.

3.2. Variation due to ventilation system

The performance of cool paint is affected by operational conditions like ventilation system of the rooms beneath the roof under experimental study. According to M. Kolokotroni the internal ceiling surface temperature of the open office area and the three office rooms showed a slight decrease on both the days that is 1st June, 2009(pre-application) and 16th August, 2009 (post application) with similar external average temperature and average global radiation. This slight decrease in temperature was observed on both days between 7am and 8 am due to increased ventilation rate by user's opening of windows as they came to the office. The same things were observed in the parametric analysis of the case study. Lower ventilation rates led to higher energy savings in case of air-conditioned building with the highest reduction indicated for a solar reflectance of 1.0, air change rate of 2 with summer and winter set-point temperatures being 25°C and 21°C respectively.

3.3. Effect due to different room orientation

Cool Roof potentials are also identified with rooms having different orientations. According to C. Romeo et al. one of the rooms in Trapani, Sicily which was mainly west oriented and was characterized by high thermal loads during the afternoon had a mean indoor air temperature 3.5°C higher than the ambient air, the two values being 27.9°C and 24.4°C. On the other hand after the application of cool paint the indoor air became 0.4°C warmer than the ambient temperature, the two values being 28.6°C and 28.2°C. Similarly the same results were observed for another room that was mainly east oriented, indoor air temperature was higher than outdoor during 96% of the time before the application of cool paint while indoor temperature was 2°C cooler than the ambient temperature during 50% of the time and only 13.6% of the time it was warmer.

3.4. Effect on thermal comfort

Thermal comfort is another factor which is significantly improved after the application of cool coatings. According to M. Kolokotroni et. al. maximum internal operative temperature was reduced by 2.2°C at a solar reflectance of 0.6 and average internal operative temperature was reduced by 2.5°C where operative temperature signified the internal room temperature during working hours (7am - 6pm). In the parametric analysis of the same case study internal operative temperature was greater than 25°C for only 30% of the hours thus increasing the thermal comfort. Similar results were shown by E. Bozonnet et. al. where in order to investigate more into the potentiality of cool roof it was compared with a non-insulated roof. A clear benefit was obtained in summer conditions with a maximum temperature of 41.4°C that is the internal operative temperature with initial non-insulated roof and only 32.1°C with cool painted roof. C. Romeo et. al. showed cumulative distribution of discomfort hours for the three school rooms in Trapani, Sicily with three reference operative temperatures of 25°C, 27°C and 29°C. The effect of application of the cool paint depicted a strong reduction of discomfort hours in two of the rooms and temperature was greater than 27°C for less than 15% of the period. Worse results were obtained for the room which was mainly west oriented, because of high solar gains through the wide open windows facing west in the afternoon. The operative temperature was higher than 27°C for more than 25% of the period and 29°C for 5% of the period. Cumulative distribution of discomfort conditions were also shown for insulated building which showed a clear benefit for temperature higher than 27°C, the number of hours was reduced by 20% in one room while by 30% for the other.

3.5. Effect on energy consumption

Cool roof has the advantage of decreasing the cooling demand during summer and the disadvantage of increasing the heating load during the winter. According to M. Kolokotroni et. al. the simulated heating and cooling energy demand for the case study in Brunel University before and after the application of cool roof showed that total energy demand without cool roof was 4211 kWh/year while 4031 kWh/year after the application of cool roof thus saving around 180 kWh/year. According to C. Romeo et. al. cool coating application on the roof is the best performing technology among several conditions like roof insulation, night ventilation ,external shading which were effective in cutting off at least 30% of the cooling energy demand, on the other hand the it was 54% in case of cool roof. Better performance is surely expected by integration of the cool roof system with other passive cooling solutions. According to C. Romeo et. al. the combination of cool roof with other energy measures led to a net energy demand reduction up to 78%. C. Romeo et. al. also showed that with increase in solar reflectance the roof leads to a reduction of 4.6% of the total net energy demand, the heating demand increased by 28.4% and the cooling demand reduced by 60%. Different results were obtained in case of insulated building. In this case the net cooling demand was always higher than the heating demand. The net total energy demand was reduced by 13%, while the heating demand increased by 23% and the cooling demand decreased by 32%.

4. Cool Paints

4.1. Non-white cool paints

The use of highly reflective "cool" coatings helps to maintain lower exterior surface temperatures of roofs and consequently contributes to an increased indoor thermal comfort during summer which reduces the need for cooling. The necessity for non-white cool paints arose because of aesthetic reasons and also darker colours serve as a glare control. According to Kai L. Uemoto et. al. special class of non-conventional inorganic pigments are used to produce energy efficient coloured paints [8]. These are called Complex Inorganic Coloured Pigments (CICPs) or Mixed Metal Oxide (MMO) pigments. These special groups of non-conventional pigments are characterized by high reflectance in the NIR radiation. Kai L. Uemoto et. al. showed that colour co-ordinates of the conventional white, brown and yellow colour were approximately similar to the corresponding cool paints with white, brown and yellow colour. The tests was undergone in laboratory with reference to a standard unpainted specimen of fiber cement roofing sheet and were kept on a wooden device with thermocouples attached at different points and exposed to two 250W infrared radiation lamp. It was found that the cool paints significantly improved reflectance in the NIR range compared to unpainted standard sheet and to conventional paint of the same colour. Kai L. Uemoto et. al. presented that the application of the two types of white paint lowered both the outer and inner surface temperatures of the fiber cement roofing sheets, thus improving the thermal performance. The results also added that the brown paint presented a higher temperature than the unpainted standard fiber cement roofing sheet but on the other hand the cool brown paint reflected more in the NIR radiation than in the visible range thus reducing the surface temperatures. Significant improvement in thermal performance was similarly observed in case of sheet painted with cool yellow paint. It was also observed that cool white paint was most effective in reducing radiant heat flux transfer inside the wooden device and cool brown paint was more efficient in doing the same than conventional yellow although yellow is lighter in colour than cool brown.

4.2. Cool black paint

According to Jie Qin et. al. the use of conventional black roofs on buildings is most likely in various places because it meets the aesthetic requirement and has lower risk to moisture damage unlike the white roofs [9]. Here Jie Qin et. al. presented a "two-layered technique" where preparation of a black thin top coat pigmented with NIR-transmitting black colorants and a white basecoat with high NIR reflectance were done. They were then applied to substrates with low NIR reflectance. The conventional pigments used for black colour that is carbon black and copper-chromite black were compared with black colours pigmented with commercially available inorganic manganese ferrite black spinel, chromite iron nickel black, perylene black and dioxazine purple over white basecoat and aluminum alloy substrate. Black coatings pigmented separately with chromite iron nickel black and manganese ferrite black spinel were cooler than those of the conventional ones i.e. carbon black and copper chromite black but they were not eligible cool black coatings for building energy efficiency in China because the cool coating had lightness L* smaller than 40, NIR reflectance lesser than 0.4 and their solar reflectance was also lesser than 0.3. Jie Qin et. al. found that black colour pigmented with perylene black and dioxazine purple (with addition of inorganic yellow pigments to re-establish a true black colour) showed a much better performance with high solar and NIR reflectance and thus proved to be qualified cool black coatings. From cost and profit perspective, the application of black coatings pigmented with perylene black to the roofs of the buildings is of high cost. Thus the black coating pigmented with diaoxazine purple and yellow colorants was observed to be the most suitable coating contributing towards building energy efficiency.

5. Conclusions

The effects of global warming and climate changes are of relevant concern for ecological system. The global warming and the urban sprawl cause a number of environmental hazards, the urban heat island (UHI) being one of them. This phenomenon is defined as the air temperature rise in densely built environments with respect to the countryside surroundings. The main cause is the modification of the land surface in the urban area, where the vegetation is replaced by extensively built surfaces are characterised by high solar absorption. Roof surfaces of the building accounts for a large part of the total urban surfaces; hence they can be successfully used to reduce the air and surface temperature of urban area. Cool and green roofs are widely used to mitigate the UHI. These techniques have proved significant benefits on the energy performance of buildings, providing passive cooling to the built environment.

Green roofs use the foliage of plants to protect the building environment. The soil layer gives an added up insulation to the building roof while the water content increases the thermal inertia of the structure. On the other hand cool roofs are characterized by materials having high solar reflectance and high thermal emittance that helps in reducing the building energy consumption.

5.1. Comparative analysis on green roof and cool roof

According to M. Zinzi et al. the three typical locations chosen were Barcelona, Cairo and Palermo [10]. The north rim that is Barcelona is heating dominated for non-insulated buildings, while heating and cooling are both relevant in buildings in the centre of the Mediterranean region that is Palermo . The south rim that is Cairo is cooling dominated for any building thermal characteristics. In case of the row houses of Palermo best performances were obtained with the green roof always wet, with heating demand comparable with the conventional roof, but with the cooling demand reduced by more than half. The total energy savings were 24%. On the other hand cool roof reduced the cooling demand by 75%, but the increase of the heating demand lowered the total energy savings close to 12%. Energy savings were around 11% during winter, due to the higher insulation level of the roof, but low improvements were reached in the cooling season, because of the limited advantage of the dry vegetation layer.

Barcelona has a cooler climate than others, thus non -insulated envelope induced a high heating demand. The best result was obtained by dry green roof, because of the insulation effect produced by the soil layer in winter and the natural water content in summer. The total energy demand was reduced by 14%. In this case cool roof registered the worst performance, with 10% increase in total energy demand. In case of Cairo, cool roof led to 40% reduction in energy demand. High differences were found for the green roof configurations. The wet green roof proved to be the best performing solution. It led to 45% of the total energy savings. Actual rainfall and dry green roof performances practically gave the same results with 13% energy savings as compared to standard roof, with reduction of 10% in cooling demand.

According to M. Zinzi et. al. cool roof technique proved to be the effective solution for southern and central areas of the Mediterranean basin which were mainly cooling dominated areas. The non- insulated houses might have faced a penalty of excessive increase in heating demand but, on the other side, cool roofs practically nullified the installation of the cooling systems, because of the very low cooling energy demand.

Performances of the green roofs are strongly dependent on the water content of the system with the adopted model. A well wet green roof has good cooling performance, but relying on the rainfall does not ensure effective energy performances during the dry Mediterranean hot season, especially in the central and the southern rim of the basin. Nevertheless, green roofs improve the heating performances as well, when compared with the conventional roofs.

Thus both the techniques, the cool roof and the green roof come with their own advantages and disadvantages but both have their usefulness accordingly contributing highly towards the section of energy conservation of the built environment.

References

[1] A. Niachou, K. Papaknstantinou, M. Santamuris, A. Tsangrassoulis, G. Mihalakaku, Analysis of the Green Roof Thermal Properties and Investigation of its Energy Performance, Energy And Buildings 33 (2001) 719-729.

[2] A. Spala, H.S. Bagiorgas, M.N. Assimakopoulos, J. Kalavrouziotis, D. Matthopoulos, G. Mihalakakou, On th green roof system . Selection, state of art and energy potential investigation of a system installed in an office building in Athens, Greece, Renewable Energy 33 (2008) 173–177.

[3] Dominique MORAU, Teddy LIBELLE, François GARDE, Performance Evaluation of Green Roof for Thermal Protection of Building In Reunion Island ,Energy and Buildings 14 (2012) 1008–1016.

[4] Orna Schweitzer, Evyatar Erell, Evaluation of the energy performance and irrigation requirements of extensive green roofs in a water- scarce Mediterranean climate, Energy and Buildings 68 (2014) 25–32.

[5] M.Kolokotroni, B.L. Gowreesunker, R.Giridharan,Cool roof technology in London : An experimental and modeling study, Energy and Buildings 67(2013) 658-667.
[6] E. Bozonnet, M. Doya, F. Allard, Cool roofs impact on building thermal response: A French case study, Energy and Buildings 43 (2011) 3006-3012.
[7] C. Romeo, M. ZinziI,Impact of a cool roof application on the energy and comfort performance in an existing non-residential building. A Sicilian case study, Energy and Buildings 67 (2013) 647–657.
[8] Kai L. Uemoto, Neide M.N. Sato, Vanderley M. John, Estimating thermal performance of cool colored paints, Energy and Buildings 42 (2010) 17–22.
[9] Jie Qin, Jianrong Song,Jian Qu,Xiao Xue,Weidong Zhang, Zhongnan Song,Yunxing Shi, Lihong Jiang,Jingfang Li,Tao Zhang, The methods for creating building energy efficient cool black coatings, Energy and Buildings 84(2014) 308–315.
[10] M. Zinzi, S. Agnoli, Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region, Energy and Buildings 55 (2012) 66–76.