Effect of High Aged Albedo Cool Roofs on Commercial Buildings Energy Savings in U.S.A. Climates

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Abstract- Cool roofs may reduce the temperature of a surface exposed to the sun and decrease the energy consumption inside buildings. This type of technology works under two different principles; solar reflectance and thermal emissivity and there is a wide variety of products in the market with different initial and aged reflectance and emissivity values. Reflectance is the fraction of solar energy that is reflected by the roof, and this value decreases over time. Roofs with high initial reflectance and low aged reflectance are currently the most common scenario. In this paper, energy simulation software, Energy 3D and Oak Ridge Cool Roof Calculator were used to determine energy savings when using high albedo cool roof technologies with albedo values fewer than 70%. For this study, we selected the cities with the most solar radiation in the U.S.A. and those with rebates and incentives available and approved by the Cool Roof Rating Council (CRRC). Results show a significant difference between the values of solar reflectance and suggest supporting the application of high albedo coatings for substantial energy savings.

Keywords Buildings, roof coatings, energy savings, commercial buildings, albedo roofs.

1. Introduction

Today's buildings in developed countries consume a significant portion of the total primary energy. It is well known and documented that one of the urban effects is urban warming [1]. Urban warming has negative effects on human comfort, health, and well-being. Scenarios with an increase in the maximum temperatures and longer summers will represent a higher risk for the population and will create a demand for air conditioning. The energy consumption of air conditioning is the most critical factor that affects the electricity consumption in residential buildings [2-5]. More air conditioner units generate more heat, which has an adverse impact on the climate and human comfort and increases the need for air conditioning even more. Studies showed that decrease in the roof temperature improved the energy efficiency of buildings [6].

Albedo is an expression of the ability of surfaces to reflect sunlight (heat from the sun). High-albedo roof coatings or cool roof coatings can maintain high solar reflectance (SR) and infrared emissivity when compared to standard roof coatings for their service life and can be used to reduce building cooling loads and maximize energy savings [7]. These roofs reflect more sunlight and absorb less heat than a standard roof and thus reduce the temperature of the roof dramatically, which in turn results in the following advantages compared to normal roofs:

- Reducing electricity consumption by decreasing the demand for air conditioning to cool the buildings
- Improving human comfort in spaces with a lack of air conditioner.
- Extending the life of the roof through protection against the sun heat

Cool roofs may decrease the ambient temperatures in the cities during the summer, helping to slow down ozone formation and increasing human comfort in addition to indirect benefits such as cooling outside air while improving the efficiency of air conditioner equipment, reducing greenhouse emissions, decreasing smog and cutting pollution from power plants [8-13].

Several studies reported estimated energy savings with cool roof coatings for different locations around the world with focuses on parameters such as albedo, weather, location, humidity, indoor and outdoor air temperatures and solar radiation etc. [14-34]. It was shown that when compared to more traditional roofing systems, cool roofs have demonstrated energy savings ranging from 2-40%, with average savings of about 20%. It was also found that when cool roofs are used, the heating penalties during winter or night are not severe and the cooling load reduction surpassed the heating penalty. The requirements for a high-albedo roof coating material to maximize energy savings are high solar reflectance, high infrared emissivity, and the ability to maintain these properties over the years [1]. One main issue with cold roofs is the change in properties of the coating materials with aging. For example, Table 1 shows the initial and aged solar reflectance index (SRI) in 3 years for some commercially available roof coatings [27]. A standard white surface has an initial solar reflectance of 0.80 and initial thermal emittance of 0.90.

It can be noticed from the table that there is a considerable decrease in reflectance after three years for high Albedo coatings. When all the available products (~2992) in the Cool Roof Ratings Council database were analyzed, it was founds that only 60 products (or 2% of total products) maintain an aged reflectance of 0.80 or higher for their lifetime, which means only a small percentage of products may claim cool roof benefits. Because the research was intended to understand aged albedo performance under U.S. climates, a commercially available formula was used [34]. For the analysis, the Equation 1 was used.

$$SR_{3yrs} = 0.2 + 0.7(SR_i - 0.2) \quad (1)$$

High reflectance saves energy by reflecting incoming solar radiation back towards space. Maximum reflectivity is normally achieved with white roof products. There are also cool roof products which look dark in the visible spectrum but still reflect most of the heat, providing the more traditional roof color options as well as the potential energy savings.

Table 1. Products with highest initial albedo, sort by initial reflectance. Source: CRRC, 2017

Product	Initial SRI	Aged SRI
APOC 256 X	0.94	0.75
AcryShield A179 High Reflectance White	0.92	0.81
AcryShield A590 High Reflectance White	0.92	0.87
Alkorplan F35276 Alkorbright 2001–1.5mm	0.91	0.76
Alkorplan F35276 Alkorbright 1920- 1.5mm	0.91	0.73
APOC 256 FR White	0.91	0.81
United Coatings EnergyCote^{TM} Roof Coating (White)	0.91	0.78
Metacrylics APOC 232 White	0.90	0.80
Inopaz H2O	0.90	0.77
Gacoflex A3800 HH White	0.90	0.81

Table 2. Products with highest initial albedo, sort by aged reflectance.

Product	Initial SRI	Aged SRI
AcryShield A590 High Reflectance White	0.92	0.87
NXT Cool Coat White	0.90	0.86
Adgreencoat ES	0.85	0.85
Centimark 913	0.88	0.84
Davlin Sunshield 3800	0.88	0.84
NP 913	0.88	0.84
Aqua-Fast Finish White – Bright White	0.87	0.83
Aqua-Ply PW White	0.87	0.83
ECO-THERM 2500 Elastomeric White	0.87	0.83
Pro-Grade 988 Silicone White Roof Coating	0.88	0.83

The energy saving benefits of cool roofs were documented and studied many times, particularly in locations with a high solar radiation. However, they do not provide general answers for the effect of aged solar reflectance on energy savings. In the above works, energy simulations have been done using a low solar reflectance, and savings were estimated using low albedo values. Also, many of these methods appear to be limited to the potential savings of cool roof technologies with no consideration of utility strategies. Utilities in certain states have rebates, incentives, loans and tax benefits for the use of cool roof technologies. Due to the increasing use of cool roof technologies all over the world and particularly in the US, it is timely and essential to establish the real benefits of a cool roof in the US according to the current policies and available programs within the utilities and government. In this study, energy savings of different cool roof coatings were investigated in the states where utilities are available (e.g., southwestern parts of the United States). Available rebate programs offered by the utilities in the US play a fundamental role in determining the cost-benefit of the cool roof technologies for stakeholders. Hence, the effect of high albedo roofing on energy savings in the states with the rebates is analyzed.

2. Hypothesis and Methodology

The simulation considered different variables:

- Building insulation R-20, R-10
- Solar reflectance of 80 and 50

In order to obtain net savings and total annual energy + demand savings:

- Net Savings [\$/ft² per year] relative to a Black Roof for R-20 and R-10
- Total Annual Energy + Demand Savings [\$/ft² per year] corresponding to a Black Roof for R-20 and R-10

A total of 8 different results per state in the U.S were obtained. Therefore, the study explored how products with differed aged reflectance affected energy savings by estimating energy consumption of different places.

We used a two-way ANOVA (analysis of variance) to determine if the means of a group are statistically different when there are two categorical factors. The steps in the statistical procedure for this research are described below:

1. State the null hypothesis (H0): The null hypothesis for the main effect is that the response mean for all factor levels are equal. The null hypothesis for an interaction effect is that the response means for the level of one factor does not depend on the value of the other factor level.

2. State the alternative hypothesis (H1): The alternative hypothesis for the main effect is that the response mean for all factor levels are not equal. The alternative hypothesis for an interaction effect is that the response means for the level of one factor depend on the value of the other factor level.

3. Establish the significance level: Significance level (α or alpha) of 0.05 was chosen, which indicates a 5% risk of concluding that an effect exists when there is no actual effect.

4. Experiment and observe the outcome: Perform a normality test to see if data fits under a normal distribution. Perform a two-way ANOVA to obtain a p-value.

5. Draw conclusions: Based on p-values obtained, draw conclusions on the significance.

Hypotheses for each simulation are as follow:

1. Net Savings [\$/ft² per year] relative to a Black Roof:

a. R-20, SR-80, and SR-50

$$H_0 = \mu_{SR80=}\mu_{SR50} \quad (2)$$

$$H_a = not\ all\ \mu\ are\ equal \quad (3)$$

b. R-10, SR-80, and SR-50

- Use Equation 2 and 3

2. Total Annual Energy + Demand Savings [\$/ft² per year]

relative to a Black Roof:

a. R-20, SR-80, and SR-50

- Use Equation 2 and 3

b. R-10, SR-80, and SR-50

- Use Equation 2 and 3

The objective of the present study is to simulate energy savings under two different scenarios: customer charge and energy charge. Energy charge refers to the cost allocation where there is a low fixed price, and the majority of the cost is attributed to the energy consumption on a particular period (usually month by month). Customer charge refers to the cost allocation where there is a high fixed price computed according to the utility politics, which allows the utility to have a fair profit. This customer charge is convenient for customers with high electricity consumption but inconvenient for the counterpart. On the other hand, customers who are charged according to the energy demand prefer the energy charge strategy.

In order to gain further insight into cooling roof energy savings, this work attempts to explore beyond how products with a high aged reflectance increase energy savings and benefit communities and buildings as follows:

- Estimate energy consumption of different places to understand how insulation or R-Value affects solar load in buildings. This estimation will help to validate results from the simulations considering differences in solar reflectance.

- Evaluate energy savings in states where there is any support for cool roofs, based on information available on the CRRC

The methodology used for the analysis is shown in figure 1. To meet the above objectives, we first looked for rebates, incentives, programs, tax deductions, loans and any support available in the U.S. Next, we selected states with rebates available and classified them according to the type of support stated by CRRC. In-depth research was conducted on each incentive to understand the most common scenarios regarding insulation, solar reflectance, energy savings, and price per kWh (all the variables needed as input for the simulations). Next, we utilized the 3D Energy software created by NFS, to perform energy consumption simulations on the cities previously selected. Then we used the Roof Savings Calculator from Oak Laboratory to perform a simulation on energy savings. Two variables were created on solar reflectance or albedo: 80% and 50%. Finally, cities were grouped according to each state, and average savings from each group were estimated. We computed the difference between savings for 80% and 50% of solar reflectance with each insulation value.

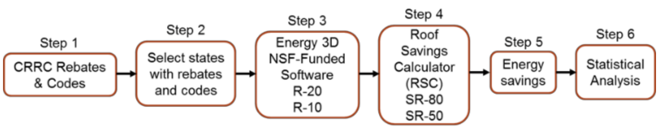

Fig. 1. Methodology Proposed

2.1 Annual energy consumption

For the first simulation, the Energy 3D software was employed. Energy 3D is a simulation-based engineering tool for designing green buildings and power stations that harness renewable energy to achieve sustainable development. The following values were used for each simulation on the 75 different cities:

- Time
- Latitude
- Temperature
- Sunshine
- Roof Area = 141.93 m2 / 1527.72 ft2
- Rise = 0
- R-Value = 10 / 20
- Thermostat = 20 □/ 68□

The second simulation estimated cooling and heating savings for flat roofs having non-black surfaces. Using the CRRC incentives database as a filter for the cities, the remaining cities were introduced into the software. For the third simulation, Oak Ridge Cool Roof Calculator was utilized to estimate energy and peak demand savings for flat roofs with non-black surfaces.

Table 3. Parameters used for the simulations

Parameters
Roof Area= 141.93 m^2 / 1527.72 ft^2
Rise = 0
R-Value = 10 / 20
Thermostat = 20 °C / 68 °F

However, for more accurate results, specific modifications were made to consider the location and weather conditions (i.e., there are some locations where solar panels are not viable and/ or insulation is not used).

- Area = 123 m2 / 1323.96 ft^2
- Height = 7.8 m / 83.95 ft^2
- Window/floor area ratio = 0.364
- Number of windows = 8
- Number of walls = 4
- Number of solar panels = 0

To avoid bias in the research, average values were used for all the energy consumption simulation.

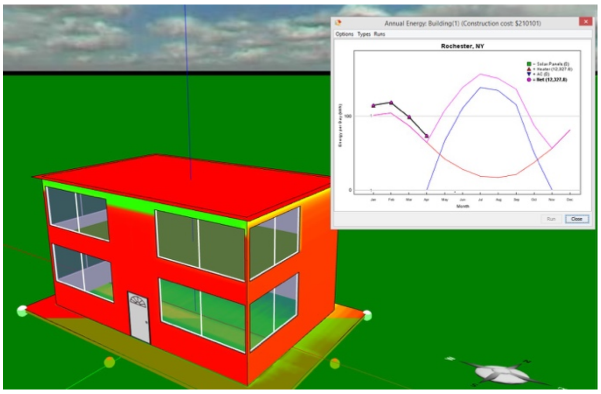

Fig. 2. Flat roof annual energy consumption in Rochester New York. Source: Energy3D, 2017.

3. Results

An intensive parametric study (about 900 annual simulations) was performed to investigate the impacts of these fundamental parameters on energy demand and human comfort. The criteria used for evaluating the effect of cool roofs on building include annual energy consumption, initial solar reflectance, aged solar reflectance, winter penalty, peak demand, and HVAC system size. Prototype models have a white roof, and the simulations were carried out with gas-heating and electricity-cooling systems. In calculating the overall expenses, average values of electricity and natural gas expenses were used for input. An aged solar reflectance of 80% was used for simulations. Tables 4 and 5 show simulation results for average saving from each state whose cities are grouped into it. Although small in magnitude, the results show noticeable improvements in energy savings for all the states.

To evaluate the statistical significance of the result, a statistical analysis was performed. First, a probability plot was created with a confidence interval of 99% (p-value of 0.01) to check that the data fits a normal distribution. Probability tables (Tables 6-9) show that the data pass the normality test and no significant departure from normality was found. A two-way ANOVA was then conducted to determine whether the main effect and interaction effect are statistically significant.

The analysis was done for both "Net Savings" and "Total Annual Energy + Demand Savings" relative to a black roof (Tables 6-9). Small p-value (<0.01) indicates substantial evidence against the null hypothesis, and thus the tested effect is statistically significant. Therefore, we reject the null hypothesis and conclude that the levels of solar reflectance (SR) and thermal resistance (R-Value) are associated with different strengths. The p-value of the interaction indicates that the interaction is not statistically significant.

	Annual Energy Consumption (kWh)				**Net Savings [$/ft² per year] relative to a Black Roof**				**Total Annual Energy + Demand Savings [$/ft² per year] corresponding to a Black Roof**			
	Heating		**Cooling (AC)**		**R-20**		**R-10**		**R-20**		**R-10**	
	R-20	*R-10*	*R-20*	*R-10*	*SR-80*	*SR-50*	*SR-80*	*SR-50*	*SR-80*	*SR-50*	*SR-80*	*SR-50*
AZ	11733	13283	62580	71769	0.05	0.03	0.11	0.07	0.10	0.06	0.23	0.14
CA	8123	9195	49569	57005	0.03	0.02	0.06	0.03	0.08	0.05	0.17	0.10
LA	6332	7168	46478	53451	0.05	0.03	0.12	0.07	0.07	0.04	0.16	0.09
NM	13947	15790	45530	55334	0.04	0.02	0.09	0.05	0.07	0.04	0.16	0.09
TX	7261	8219	49511	56869	0.05	0.03	0.12	0.07	0.08	0.04	0.17	0.10

Table 4. Simulation results using different software and albedo values.

	Highest cooling energy consumption (kWh)		**Net Savings [$/ft² per year] relative to a Black Roof**				**Total Annual Energy + Demand Savings [$/ft² per year] relative to a Black Roof**			
Insulation	*R-20*	*R-10*	*R-20*		*R-10*		*R-20*		*R-10*	
Reflectance			*SR-80*	*SR-50*	*SR-80*	*SR-50*	*SR-80*	*SR-50*	*SR-80*	*SR-50*
	HI	AZ	HI	HI	HI	HI	HI	HI	HI	HI
	AZ	HI	FL	FL	FL	FL	FL	FL	FL	FL
	FL	FL	TX	TX	TX	TX	AZ	AZ	AZ	AZ
	CA	CA	LA	LA	LA	LA	AL	AL	AL	AL
	TX	TX	AL	AZ	AL	AZ	GA	GA	GA	GA
	LA	NM	AZ	AL	AZ	AL	SC	SC	SC	SC
	NM	LA	GA	GA	GA	GA	CA	CA	CA	CA
	GA	GA	SC	SC	SC	SC	TX	TX	TX	TX
	AL	SC	NM	NM	NM	NM	NM	NM	LA	LA
	SC	AL	NC	KY	KY	NC	LA	LA	NM	NM

Table 5. Summary of states with the most impact from cool roof applications

Table 6. The Analysis of Variance R-20, SR-80, and SR-50

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SR	1	0.033814	0.033814	21.89	0.000

R-Value	1	0.075494	0.075494	48.87	0.000
SR*R-Value	1	0.004953	0.004953	3.21	0.074
Error	296	0.457290	0.001545		
Total	299	0.571551			

Table 7. Model summary for savings

S	R^2	R^2 (adj)	R^2 (pred)
0.0393052	19.99%	19.18%	17.81%

Table 8. Analysis of Variance Demand R-20, SR-80, and SR-50

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SR	1	0.1261	0.12608	37.24	0.000
R-Value	1	0.2807	0.28066	82.90	0.000
SR*R-Value	1	0.0182	0.01819	5.37	0.021
Error	296	1.0020	0.00339		
Total	299	1.4270			

Table 9. Model summary for savings based on demand

S	R-sq	R-sq(adj)	R-sq(pred)
0.0581847	29.78%	29.07%	27.87%

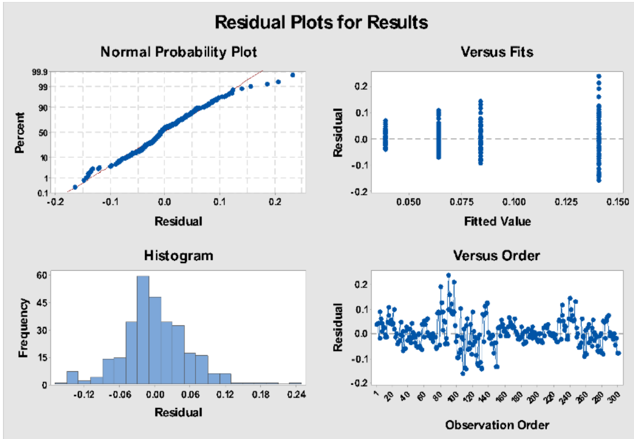

Figure 3. Probability Plot for savings based on demand

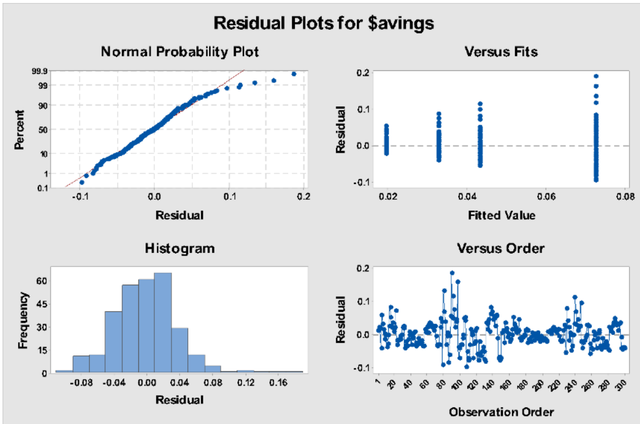

Figure 4. Residual plot for savings. R-20, SR-80

The main results of the analysis were summarized as follows:

- The null hypothesis H0 for the main effect was rejected, which indicates the response means for all factor levels are not equal.
- Results do not depend on the interaction between solar reflectance and thermal resistance (R-Value) for savings.
- For savings based on demand, however, results depend on the interaction between solar reflectance and R-Value.
- Results show 40% more energy savings on facilities with an SR-80 and R-10 base on-demand consumption.
- Results suggested that cool roofs, combined with insulation, provide the most significant overall benefit regarding urban heat mitigation and energy transfer into buildings.

4. Conclusion

Building energy consumption has been increasing, and is an important cause of the incremental rise in temperature and demand for more air conditioning units. Continued population and society growth will demand more buildings and thus more energy. Construction of sustainable buildings and restoration of existing building could decrease the energy demand and bring positive consequences to the coming generations. The information obtained from the present research promotes further use of cool roof technologies in the US and the world and help concerned decision makers to take steps to achieve building's energy efficiency as follows:

1. Support policy development by showing the potential energy savings and creating the best scenarios for customers, utilities and the environment.
2. When a public utility in a particular state sees a cost-benefit for its and customer's interest, it is essential to remove market barriers and allow the emerging cool roof technologies to become part of the energy efficiency solutions portfolio.
3. Update the existing legislation, codes, permits, and standards to support the use of cool roof technologies.
4. In the areas where the benefits of cool roofs have been proven, the legal enforcement of cool roof adoption should be a priority for governments.

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References

[1] Grimmond, S. "Urbanization and global environmental change: local effects or urban warming", The Geographical Journal, Vol. 173, Issue 1, 83-88, 2007.

[2] Lalit Kumar, A., Romana, H. K., and Malik, R. K. "Energy consumption attributes in residential building- A case study of replacing conventional electrical applicances with energy efficient appliances", International Journal of Renewable Energy Research, Vol. 7, No. 5, pp. 1950-1955, 2017.

[3] Abhinaya, .S., Kumar, R., and Krishnaraj, L. "Assessment and remodelling of a conventional building into a green building using BIM", International Journal of Renewable Energy Research, Vol. 7, No. 4, pp. 1675-1681, 2017.

[4] Huat, N. B., and Akasah, Z. A. B. "Reliability and validity of a new energy – efficient building performance survey framework in hot and humid climatic regions: a review", International Journal of Renewable Energy Research, Vol. 2, No. 4, pp. 702-711, 2012.

[5] Tarigan, E. "Simualtion and feasibility studies of rooftop PV system for university campus building in Surabaya, Indonesia", International Journal of Renewable Energy Research, Vol. 8, No. 2, pp. 895-908, 2018.

[6] Kumar, V., and Mahalle, A. M. "Investigation of the thermal performance of green roof on a mild warm climate", International Journal of Renewable Energy Research, Vol. 6, No. 2, pp. 487-493, 2016.

[7] Bretz, S. E., & Akbari, H. "Long-term performance of high-albedo roof coatings" Energy and Buildings,Vol. 25, Issue 2, pp. 159-167, 1997.

[8] Akbari, H., & Levinson, R. "Evolution of Cool-Roof Standards in the US". Advances in Building Energy Research, Vol. 2, pp. 1-32, 2008.

[9] Santamouris, M., Synnefa, A., & Karlessi, T. "Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions" Solar Energy, Vol. 85, Issue 12, pp. 3085-3102, 2011.

[10] Coutts, A. M., Daly, E., Beringer, J., & Tapper, N. J. "Assessing practical measures to reduce urban heat: Green and cool roofs". Building and Environment, Vol. 70, pp.266-276, 2013.

[11] Xu, T., Sathaye, J., Akbari, H., Garg, V., & Tetali, S. (2012). "Quantifying the direct benefits of cool roofs in an urban setting: Reduced cooling energy use and lowered greenhouse emissions" Building and Environment, Vol. 48, pp. 1-6, 2012.

[12] Akbari, H., & Matthews, H. D. "Global cooling updates: Reflective roofs and pavements" Energy and Buildings, Vol. 55, pp. 2-6, 2012.

[13] Akbari, H., Levinson, R., & Rainer, L. "Monitoring the energy-use effects of cool roofs on California commercial buildings" Energy and Buildings, Vol. 37, Issue 10, pp. 1007-1016, 2005.

[14] Rosenfeld, A. H., Akbari, H., Romm, J. J., & Pomerantz, M.. "Cool communities: strategies for heat island mitigation and smog reduction" Energy and Buildings, Vol. 28, pp. 51-62, 1998.

[15] Levinson, R., Akbari, H., Konopacki, S., & Bretz, S. Inclusion of cool roof in nonresidential Title 24 prescriptive requirements. Energy Policy, Vol. 33, Issue 2, pp. 151-170, 2005.

[16] Kolokotroni, M., Gowreesunker, B., & Giridharan, R. "Cool roof technology in London: An experimental and modeling study". Energy and Buildings, Vol. 67, pp. 1-10, 2013.

[17] Millstein, D., & Menon, S. Regional climate consequences of large-scale cool roof and photovoltaic array deployment. Environmental Research Letters, Vol. 6, pp. 1-9, 2011.

[18] Bhatia, A., Mathur, J., & Garg, V. "Calibrated simulation for estimating energy savings by the use of cool roof in five Indian climatic zones". Renewable and Sustainable Energy, Volume 3, Issue 2, pp. 1-15, 2011.

[19] VanCuren, R. (2012). "The radiative forcing benefits of "cool roof" construction in California: quantifying the climate impacts of building albedo modification" Climatic Change Journal. Vol. 112, pp. 1071-1083.

[20] Romeo, C., & Zinzi, M. "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 Journal, Vol. 67, pp. 647-657, 2013.

[21] Borge-Diez, D., Colmenar-Santos, A., Perez-Molina, C., & Castro-Gil, M.. "Passive climatization using a cool roof and natural ventilation for internally displaced persons in hot climates: a Case study for Haiti" Building and Environment Journal, Vol.59, pp. 116-126, 2013.

[22] Lapisa, R., Bozonnet, E., Abadie, M. O., & Salagnac, P. "Cool roof and ventilation efficiency as passive cooling strategies for commercial low-rise buildings-ground thermal inertia impact" Advances in Building Energy Research, Vol. 7, Issue 2, pp. 192-208, 2013.

[23] Santamouris, M. "Cooling the cities A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments" Solar Energy, Vol. 103, pp. 682-703, 2014.

[24] Dabaieh, M., Wanas, O., Hegazy, M., & Johansson, E. "Reducing cooling demands in a hot dry climate; simulation study for non-insulated passive cool roof thermal performance in residential buildings" Energy and Buildings. Vol. 15, 2015.

[25] Arumugam, R., Garg, V., Mathur, J., Reddy, N., Gandhi, J., & Fischer, M. L. "Experimental determination of comfort benefits from cool-roof application to an un-conditioned building in India". Advances in Building Energy Research, Vol. 8, pp. 14-27, 2014.

[26] Synnefa, A., Santamouris, M., & Akbari, H. (2007). "Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions". Energy and Buildings, Vol. 39, Issue 11, pp. 1164-1174, 2007.

[27] Suehrcke, H., Peterson, E. L., & Selby, N. "Effect of roof solar reflectance on the building heat gain in a hot climate". Energy and Buildings, Vol. 40, Issue 12, pp.224-2235, 2008.

[28] Berdahl, P., & Bretz, S. E. "A preliminary survey of the solar reflectance of cool roofing materials" Energy and Buildings, Vol. 25, Issue 2pp. 149-158, 1997.

[29] Pisello, A. L., Castaldo, V. L., Pgnatta, G., Cotana, F., & Santamouris, M. "Experimental in-lab and in-field analysis of waterproof membranes for cool roof application and urban heat island mitigation", Energy and Buildings, Vol. 114, pp. 180-190, 2016.

[30] Zingre, K. T., Wan, M. P., Tong, S., Li, H., Chang, V. W.-C., Wong, K. S., Leng Lee, I. Y. "Modeling of cool roof heat transfer in a tropical climate", Renewable Energy, Vol. 75, 210-223, 2015.

[31] Santamouris, M. "Cooling the cities A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments", Solar Energy, Vol. 103, pp. 682-703, 2014.

[32] Pisello, A. L., Piselli, C., & Cotana, F. (2014). Influence of human behavior on cool roof effect for summer cooling. Building and Environment, Vol. 88, pp. 1-13, 2015.

[33] Pisello, A. L., Rossi, F., & Cotana, F. (2014). Summer and Winter Effect of Innovative Cool Roof Tiles on the Dynamic Thermal Behavior of Buildings. Energies, Vol. 7, No. 4, pp. 2343-2361, 2014.

[34] Online available link: https://www.nps.gov/tps/sustainability/greendocs/doe_coolroofguide-sm.pdf (last accessed on 09-03-2019)