Study of the Impact of Cool Roof on Urban Thermal Comfort in Hot Arid Climate, Biskra – Algeria

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Abstract

The Uncontrolled urban sprawl and the unadopted building to the environment are the main causes that generate the urban heat island (UHI) phenomenon. This phenomenon contributes to the degradation of the environmental quality of the interior and exterior spaces and increases the energy demand of buildings. In hot and arid regions, the cooling needs of space during the hot season are much greater. This situation imposes the use of electrical air-conditioning equipment for longer periods, which leads to a drastic consumption of electrical energy, implicitly, rise the greenhouse gas emissions, which in turn accentuate the phenomenon of the urban heat island. In this context, one of the most effective strategies to moderate heat stress at the urban scale is the adoption of the cooling roof technique "cool roof”. In fact, solar reflectivity (SR) and high emissivity (IE) of cool materials allow them to absorb less solar energy than conventional concrete roofs, reducing the amount of heat transferred to the atmosphere. This research aims to evaluate the impact of cool roof on the mitigation of the urban heat island phenomenon and to investigate its effect on the reduction of energy consumption. Experimental work was carried out in Biskra — hot and arid climate — in the form of a simulation using the ENVI-met V4 program to evaluate the minimizing of urban temperatures. The results obtained show that the cool roof strategy is indeed advantageous for the hot climate, an air temperature reduction of 1.24 ° C to 2 ° C, moreover, they confirm the environmental effectiveness of the "cool roof" technique. Because of its impressive contribution to the achievement of thermal comfort by the reduction of the urban ambient temperature (UHI).

Keyword: Cool roof, outdoor thermal comfort, ENVI-MET V4, energy efficiency, urban heat island.

1. Introduction

Energy and environment are two key terms in the today’s modern architecture. Currently, about 52% of the world’s population lives in urban areas and according to United Nations (2014) it is expected to increase to 66% by 2050 (Vardoulakis, Karamanis, and Mihalakakou 2014). The uncontrolled urbanization due to rapid unexpected population growth, human activities and the adoption of standard materials had serious effects on urban quality increasing the risk of overheating in cities (Macintyre and Heaviside 2019). Modifying the land use and replacing vegetation with bituminous surfaces, such as buildings, roads, and other paved areas has led to an elevation in urban temperatures that exacerbate the phenomenon of urban heat island (Macintyre and Heaviside 2019).

Algeria like developing countries is especially exposed to climate change effects, it has been classified like the third largest CO_2 emitter in Africa (Bouznit, Pablo-Romero, and Sánchez-Braza 2018). in 2014, the total emissions were estimated to 147 MT CO_2. Many factors are responsible for UHI, including anthropogenic heat release, surface coverage optical proprieties, climatic conditions, and air pollutants (Pigeon et al. 2009)and, according to OKE (2003), UHI can be up to 10-15 ° C under appropriate conditions.

In hot arid climates, during summer days, building and pavements with concrete base materials exposed to solar radiation are prone to absorb and store an important amount of solar radiation resulting in heat release increasing the ambient temperature and outdoor discomfort (Di et al. 2017). In this context, the roof is the building element that represents a serious part in the accumulation of the heat gain (50% of the total heat gain in buildings) and being exposed to direct sunlight for almost the entire day (Suehrcke, Peterson, and Selby 2008). Furthermore, they constitute about 20–25% of urban surfaces (Roman et al. 2016).

The heat flow through built-up horizontal surface increase the demand for cooling energy to ensure indoor comfort affected by the outdoors. In this respect, occupants use mechanical cooling systems for longer periods resulting in a drastic consumption of electrical energy. In parallel, it exacerbates human health problems, pollution levels (greenhouse gas emissions) and decreases the ecological footprint of cities (Santamouris et al. 2016). For each 0.5°C rise in urban temperature, cooling energy demand for summer period arise by 1.5–2% (Akbari and Sezgen 1992).

In recent times, the need for energy efficiency building is represent an issue in the scientific community and pushing towards for insulated envelope. For this, the adoption of reflective materials in the urban fabric constitute a significant passive intervention widely employed to mitigate urban heat island and reduce energy peak demand (Castaldo et al. 2017). Cool products are characterized by high values of solar reflectivity (SR) and high thermal emissivity (TE) which provides materials the ability to keep surface temperature very low under the sun by minimizing solar irradiation absorption and increasing the amount of reflected one (Kolokotroni, Gowreesunker, and Giridharan 2013a). The roof is the appropriate area to apply this type of cooling intervention as largest area receiving the major incident solar radiation. cool roof presents some significant advantages; at urban scale it helps mitigating the urban outdoor overheating effects (Santamouris, Synnefa, and Karlessi 2011)and, at building scale, high albedo on roof can reduce the amount of inward heat flux into indoor spaces, therefore, ensuing energy saving for cooling loads during overheating times (Di et al. 2017). Moreover, cool roof can be easily applied on existing buildings besides that it is the most economic, cost effective environmentally -friendly and exceed the roofs life time (Santamouris et al. 2011; Zinzi 2010).

A huge research effort has been registered towards the integration of cool roof, for this, several numerical investigations tested the introduction of cool products or reflective materials on urban roofs to prove their effectiveness for both reduction of cooling loads and mitigation of the UHI effect.
Castaldo et al (2017) analysis of the potential of innovative cool materials in the context of a historical urban canyon located in central Italy. The results show the huge potential of the proposed innovative cool materials in mitigating the local microclimate of the historical urban canyon. MOCI was reduced up to 0.15 and 0.30 is detected by applying cool coatings. Zinzi, Carnielo, and Agnoli (2012) proved that high albedo of existing roof decreases the outdoor surface temperature about 2°C.
Another important study conducted by Santamouris et al. (1999) investigated the surface albedo and air temperature distribution in Athens. A difference up to 19 ° C was detected in warm weather between the two opposite facades and a stratification of air temperature up to 33 ° C was detected. Taha et al. [21] showed that the white elastomeric coatings used in urban surfaces (ρ= 0.72) during the summertime could reach 45 ° C cooler than black coatings (ρ= 0.08). The reduction in air-conditioning electricity consumption was measured between 11% and 43% with an average saving of 9.2 kWh / day, and the reduction in peak demand of 0.4-1kw when applying reflective coatings (Parker et al. 1998). Synnefa, Santamouris, and Livada (2006) found that increasing the solar reflectance of the roof reduces cooling loads from 18 to 93% and cooling peak demand from 11 to 27%.
This topic stems from the need to put forward innovative sustainable solutions, hence, the aim of this work is to evaluate the impact of the use of "cool roof" in minimizing the heat stress in urban environment and conserving energy by reducing summer peak demand for electricity while maintaining comfortable indoor conditions. To achieve this purpose, a numerical simulation was conducted using Envi-met software in order to evaluate a canyon located in dense fabric in Biskra city, Algeria. The final results of this research confirm that passive reflective roof techniques have

the advantage of minimizing UHI effects, Implicitly, the energy consumptions during the hot month in summer period.

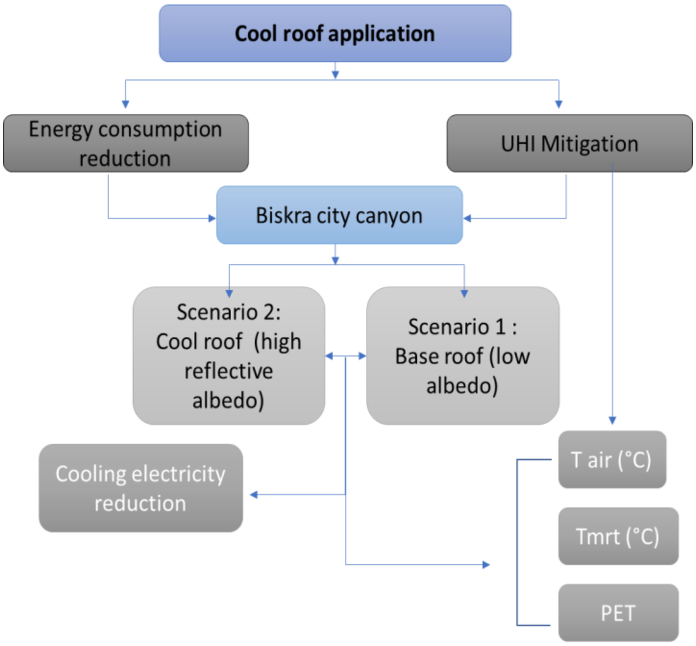


Figure 1. Structure of the Study (Developed by Author).

2. Cool roof concept

Roofs affect the thermal performance of the building, the surface temperature can reach 37°C above the ambient temperature in hot dry climates (Borge-Diez et al. 2013). To this, controlling the incident solar irradiance on roof heating the building with the adoption of “cool” materials is considered as the best passive solution that assists in reducing the building’s envelope cooling energy demand, besides its effects on outdoor heat stress (Di et al. 2017; Parker et al. 1998). According to Sailor and Dietsch (2007), mitigation of the urban heat island effect can be achieved by two parameters: increasing the reflectivity/ albedo of urban surfaces and increasing the evapotranspiration.(Figure.2). Rejecting the sunlight radiation is the main objective of passive cooling systems. In this issue, cool roofs are surfaces that are able to reflect sunlight and emit heat more than dark roofs, in a sunny sky, from 20% to 95% of solar radiation is absorbed by the surface (Suehrcke et al. 2008). The high solar reflectance values are ranging from 0.1 (for very black colors) to 0.85 (for very white colors). The thermal emissivity of cool materials was about 0.9 which gives the high ability to radiate heat in infrared wavelengths (Zinzi 2010). Cool roofs have a range of albedo value depending on the type of coating or membrane (Santamouris et al. 2011; Synnefa et al. 2006).Typically, this technique is done by applying a liquid material (white paint, elastomeric, acrylic coatings….), or by using single ply product (Chlorinated Polyethylene, Thermoplastic Polyolefin……) (Santamouris et al. 2016). Most of cool materials are white or light-colored as the most effective colour that reflects between 55% and 80% of incident sunlight (Akbari, Pomerantz, and Taha 2001). A black surface with 0.05 albedo registers a temperature about 50ºC higher than ambient air temperature, while when applying a white color coating with 0.85 albedo, the temperature rises about 10ºC (Santamouris et al. 2016).

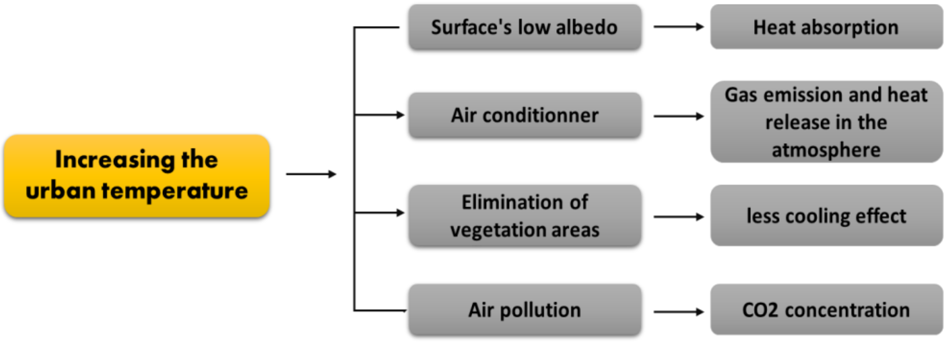


Figure 2: Urban Heat Island formation; (Sailor,2007)

There are many benefits of cool roof application: at urban level, reflective horizontal surfaces reduce the formation of urban smog and air temperature helping also to mitigate the UHI (Akbari et al. 2001; Kolokotroni, Gowreesunker, and Giridharan 2013b; Synnefa, Saliari, and Santamouris 2012). At building level, they enhance the indoor thermal comfort reducing the consumption for cooling demand needed by air conditioners (Borge-Diez et al. 2013; Romeo and Zinzi 2013).

3. Methodology

In order to achieve the stated objective, a strict methodology has been put in place based on (Figure.1):

1. Case Study selection: An urban canyon located in a dense area that represents the typical morphology of a desert city. This district consists of modern self-built up residential buildings in Biskra.
2. Simulation period: analysing the climate data of Biskra’s city, July is the month of study period chosen as the hottest month in summer season (determined by the "design month" method).
3. Reflective product: a white cool coating was used in the simulation. This paint is inexpensive, easy to set up and available in the Algerian market.

3.1 Case study

A representative urban context to serve as a reference case for simulation was selected. It represents a typical morphology of Biskra’s city, Algeria (Figure.3).

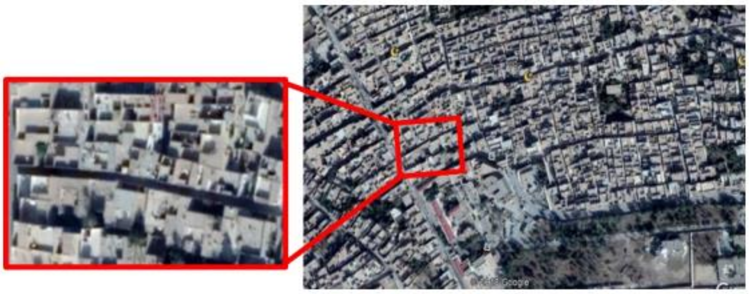


Figure 3: Case Study presentation, (Author, 2019)

The town portion is located in old part of Biskra, and characterized by a high-density typical urban pattern of the most olden parts. It includes: contemporary self-built individual buildings (middle rise and high rise (6m to 9m)), a ratio h / L = 3.50m for street distance representing a dense fabric with roofs as the large exposed area to the intense solar irradiation. The selected area was meshed into a grid with 1x1x2 m dimensions of the cells to simplify the buildings geometry modelling in Envi-met V4 software (Figure.4). The simulation was carried out during the hottest summer month, in 11th July 2017 presenting the hottest day. The meteorological framework set for the simulations is presented in Table 1.

Table 1. Input details for conventional case in Envi-met simulation

General condition of simulation	
Localisation	Algeria, Biskra (34.8°N; 5.73°E)
Climate type	Hot and arid
Simulation day	11 July 2017
Starting time	From 6 am to 6 pm (every 2h)
Wind speed	0.7 m/s
Wind direction	135 South- East
Temperature	38.5
Relative humidity	16%
Roofs albedo	20%

3.2 Simulation

Our study focuses on analyzing the effect of albedo or cool roofs on outdoor thermal comfort in urban fabric under the effect of particularly hot and arid climatic condition. More specifically, the analysis focuses on heat gains released from rooftops in the ambient atmosphere. The model was created in ENVI-met software using an orthogonal geometric grid (x, y, z) (Figure.4). Materials of houses envelope are brick for the walls reinforced grey concrete for roofs. The simulated time interval extends over a period of 6 hours in a typical summer day (11/07/2017).

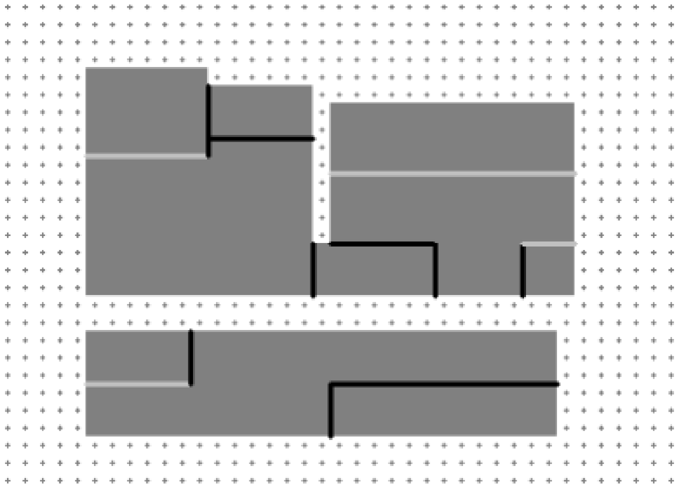


Figure 4: Case Study modeling

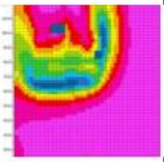
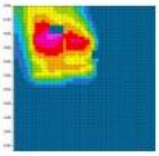
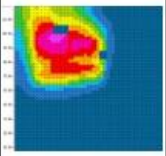
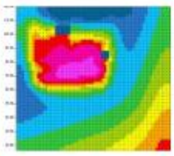
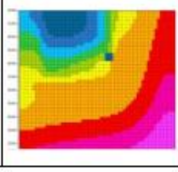
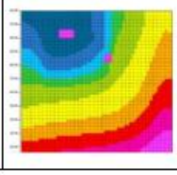
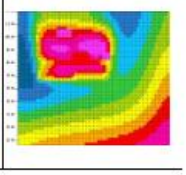
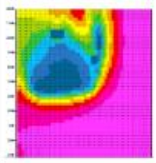
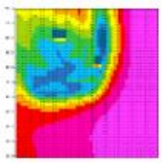
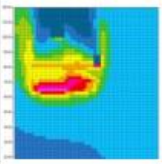
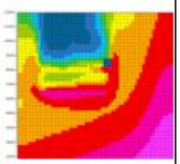
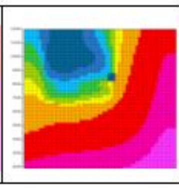
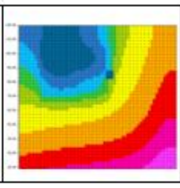
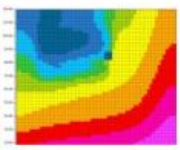
Scenarios of study:

To evaluate the impact of cold coatings or the albedo of roofs on the urban microclimate, two different configurations were considered: the first with an ordinary roof (base case) and the second with high reflective white coating (case of cool roof).

- Basic case: the model is defined with standard values (concrete). The radiative properties of the building are: roof albedo = 0.2; albedo of the walls = 0.3.
- Cool roof case: all roofs have been covered with high-reflectance "Cool Paint". Which gives: roof albedos = 0.90; albedo of the walls = 0.3.

The calculated parameters include: room temperature and average radiant temperature (TMR) over a height of 2m above the roofs Table 2.

Table 2: Ambient air temperature during the month of July for both cases

Cas de base							
Temps	6 :00	8 :00	10 :00	12 :00	14 :00	16 :00	18 :00
Temp ambiante °C							
Cas de cool roof							
Temp ambiante °C							

4. Results and discussion

4.1 Outdoor air temperature (Tair ° C):

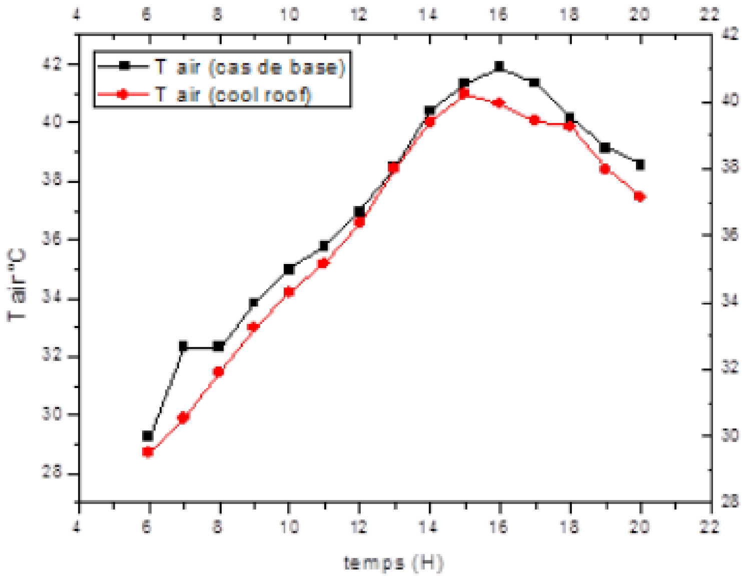


Figure 5: air temperature variation profiles in both cases during July; (Source: Author, 2019)

The air temperature is a variable parameter in space and difficult to estimate due to the multitude of factors that affect it. Figure 5 illustrates a graph of air temperature fluctuation in both cases (case of a fabric with conventional roofs and a fabric with Cool Roofs). we found that the basic case registers a minimum Tair about 29.25°C at 6am and a maximum 41.89 ° C at 6pm where the heat stored in the horizontal parts of buildings over time propagates in the outside air by convection.

A difference of 1.24 at 2 ° C was recorded between the two scenarios. This difference is explained by the fact that the adoption of reflective materials at the roof level contributes at reducing of the heat absorbed and emitted later in the air. The information to be learned from these results is that: the more the roof is reflective, the lower is the air temperature, and therefore the lower the UHI intensity. These results were found by Romeo, Zinzi, and Marinelli (2007) who demonstrated by simulation that the application of high solar reflectivity materials on roofs of existing buildings positively affects the urban heat island phenomenon, decreasing the outdoor temperature of about 2 ° C.

4.2 Mean Radiant temperature (Tmrt)

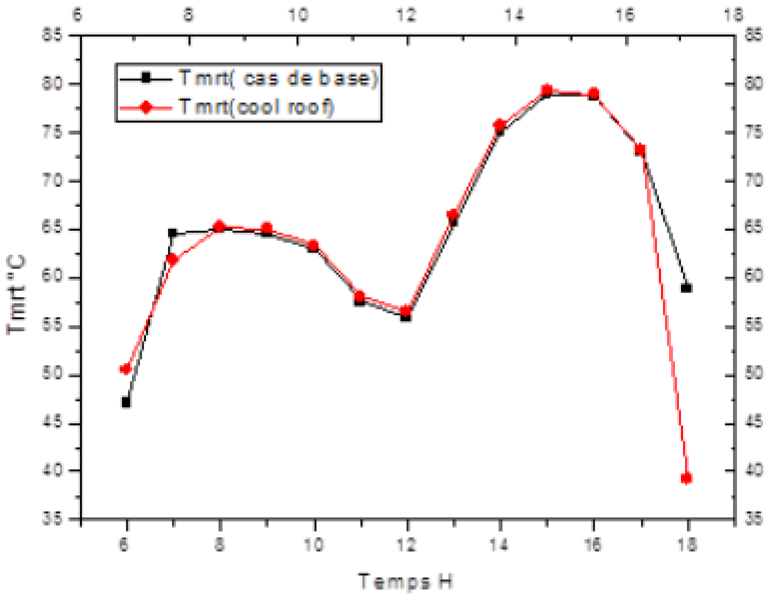


Figure 6: Mean radiant temperature variation profiles in both cases during July; (Source: Author,2019)

The mean radiant temperature Tmrt includes all of the short-waves (direct, diffuse and reflected.) and long-waves radiation emitted by the built-up surfaces (Matzarakis, Rutz, and Mayer 2010). The Tmrt is directly related to the albedo value of materials that increases with high reflectivity. According to the different researches, the Tmrt is a very important parameter to evaluate the outdoor thermal comfort. Figure 6 shows that the Tmrt for the cool case is higher than that of the base case, from 6 am to 5 pm recording a difference of 0.83 ° C, this is due to the thermophysical properties (high solar reflectivity) of the cool white paint, and it decreased from 10 am to 2 pm from 62.92 ° C to 55.95 due to the shadow of neighboring buildings. This confirms, once again, its effectiveness as an urban heat island mitigation strategy in a hot arid climate.

4.3 Equivalent physiological temperature

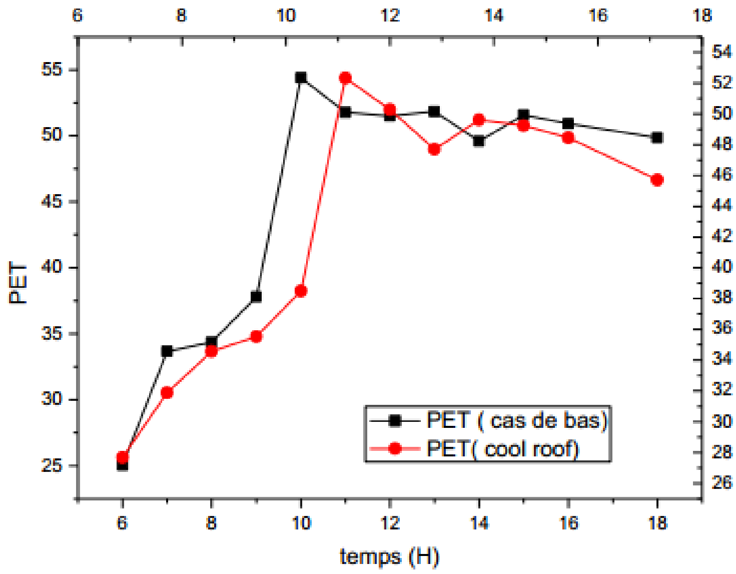


Figure 7: PET profiles for case study before and after cool paints application; (Source: Author, 2019)

The analysis of outdoor thermal comfort is based on the Equivalent Physiological Temperature (PET). PET takes into consideration the impact of Tmrt on human comfort. Figure 7 illustrates the variation of PET in the simulated urban fabric demonstrating that the values are not in comfort range (18 ° -29 ° C) , while this situation has very high heat stress (< 41 ° C extremely hot) but with a cool roof, a difference of 0.8 ° C was registered comparing to the basic case, proving that cold materials have a very important impact on human comfort especially if they were applied on roads and sidewalks.

5. Conclusion

It has been agreed that the roof is one of the building parts that is the most difficult to protect. This paper presents the main results of an investigative work devoted for an optimization of thermal performance of an outdoor environment in a typical residential fabric by the application of "a cool roof" or "reflective roof" technique under hot and arid climatic conditions of Biskra.

The results of the simulation carried out by ENVI-met showed that the use of "cool roof" by adopting a cold white paint on standard concrete roofs, substantially reduces the roof surface temperature which in turn affects the ambient air temperature. A difference of 1.24 ° C to 2 ° C was detected between the reference case and the cool roof case, so a non-negligible overall attenuation of the local microclimate in the canyon, typically characterized by a low factor to the sky.

To conclude, the results obtained validated, by simulation, the investigations underlying this research and demonstrated the effectiveness of the Cool Roof technique as a strategy to attenuate the urban heat island effect and improve the thermal quality of local urban air.

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References

Akbari, H., M. Pomerantz, and H. Taha. (2001). “Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas.” *Solar Energy* 70(3):295–310.

Akbari, Hashem and Osman Sezgen. (1992). “Analysis of Energy Use in Building Services of the Industrial Sector in California: Two Case Studies.” *Energy and Buildings*.

Borge-Diez, David, Antonio Colmenar-Santos, Clara Pérez-Molina, and Manuel Castro-Gil. (2013). “Passive Climatization Using a Cool Roof and Natural Ventilation for Internally Displaced Persons in Hot Climates: Case Study for Haiti.” *Building and Environment* 59:116–26.

Bouznit, Mohammed, María P. Pablo-Romero, and Antonio Sánchez-Braza. (2018) . “Residential Electricity Consumption and Economic Growth in Algeria.” *Energies* 11(7):1–18.

Castaldo, Veronica Lucia, Federica Rosso, Iacopo Golasi, Cristina Piselli, Ferdinando Salata, Anna Laura Pisello, Marco Ferrero, Franco Cotana, and Andrea De Lieto Vollaro. (2017). “Thermal Comfort in the Historical Urban Canyon: The Effect of Innovative Materials.” *Energy Procedia* 134:151–60.

Di, Elisa, Marianna Pergolini, Francesca Stazi, Elisa Di Giuseppe, Marianna Pergolini, and Francesca Stazi. (2017). “ScienceDirect ScienceDirect ScienceDirect Numerical Assessment of the Impact of Roof Reflectivity and Building Numerical Assessment of the Impact of Roof Reflectivity and Building Envelope Thermal Transmittance on the UHI Effect Envelope Thermal Transmitt.” *Energy Procedia* 134(2016):404–13.

Kolokotroni, M., B. L. Gowreesunker, and R. Giridharan. (2013a). “Cool Roof Technology in London: An Experimental and Modelling Study.” *Energy and Buildings* 67:658–67.

Kolokotroni, M., B. L. Gowreesunker, and R. Giridharan. (2013b). “Cool Roof Technology in London: An Experimental and Modelling Study.” *Energy and Buildings* 67:658–67.

Macintyre, H. L. and C. Heaviside. (2019). “Potential Benefits of Cool Roofs in Reducing Heat-Related Mortality during Heatwaves in a European City.” *Environment International*

127(August 2018):430–41.

Matzarakis, Andreas, Frank Rutz, and Helmut Mayer. (2010). "Modelling Radiation Fluxes in Simple and Complex Environments: Basics of the RayMan Model." *International Journal of Biometeorology*.

OKE, TR. (2003). "The Energetic Basic of the Urban Heat Island." *Quarterly Journal of the Royal Meteorological Society*.

Parker, D. S., J. R. Sherwin, L. [Florida Solar Energy Center Gu Cocoa, FL (United States)], Y. J. Huang, S. J. Konopacki, and L. M. [Lawrence Berkeley National Lab. Gartland CA (United States)]. (1998). *Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings*. United States: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA (United States).

Pigeon, Grégoire, Aude LEMONSU, Valery MASSON, and Julia HIDALGO. (2009). "De l'observation Du Microclimat Urbain à La Modélisation Intégrée de La Ville." *La Météorologie*.

Roman, Kibria K., Timothy O'Brien, Jedediah B. Alvey, and Oh Jin Woo. (2016). "Simulating the Effects of Cool Roof and PCM (Phase Change Materials) Based Roof to Mitigate UHI (Urban Heat Island) in Prominent US Cities." *Energy* 96:103–17.

Romeo, C. and M. Zinzi. (2013). "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* 67:647–57.

Romeo, C., M. Zinzi, and E. Marinelli. (2007). "Energy and Comfort Benefits of a Cool Roof Application in a Not-Residential Building . A Sicilian Case Study." *Office* 2100:1970–77.

Sailor, David J. and Nikolaas Dietsch. (2007). "The Urban Heat Island Mitigation Impact Screening Tool (MIST)." *Environmental Modelling and Software*.

Santamouris, M., N. Papanikolaou, I. Koronakis, I. Livada, and D. Asimakopoulos. (1999). "Thermal and Air Flow Characteristics in a Deep Pedestrian Canyon under Hot Weather Conditions." *Atmospheric Environment*.

Santamouris, M., A. Synnefa, and T. Karlessi. (2011). "Using Advanced Cool Materials in the Urban Built Environment to Mitigate Heat Islands and Improve Thermal Comfort Conditions." *Solar Energy* 85(12):3085–3102.

Santamouris, Mat, Afroditi Synnefa, Denia Kolokotsa, and Dimitriou Vasillis. (2016). "Passive Cooling of the Built Environment – Use of Innovative Refl Ective Materials to Fi Ght." *International Journal of Low Carbon Technologies (2008) 3(2) 71-82* (January).

Suehrcke, Harry, Eric L. Peterson, and Neville Selby. (2008). “Effect of Roof Solar Reflectance on the Building Heat Gain in a Hot Climate.” *Energy and Buildings* 40(12):2224–35.

Synnefa, A., M. Saliari, and M. Santamouris. (2012). “Experimental and Numerical Assessment of the Impact of Increased Roof Reflectance on a School Building in Athens.” *Energy & Buildings* 55:7–15.

Synnefa, A., M. Santamouris, and I. Livada. (2006). “A Study of the Thermal Performance of Reflective Coatings for the Urban Environment.” *Solar Energy* 80(8):968–81.

Vardoulakis, Eftychios, Dimitrios Karamanis, and Giouli Mihalakakou. (2014). “Heat Island Phenomenon and Cool Roofs Mitigation Strategies in a Small City of Elevated Temperatures.” *Advances in Building Energy Research* 8(1):55–62.

Zinzi, M., E. Carnielo, and S. Agnoli. (2012). “Characterization and Assessment of Cool Coloured Solar Protection Devices for Mediterranean Residential Buildings Application.” *Energy and Buildings* 50:111–19.

Zinzi, Michele. (2010). “Cool Materials and Cool Roofs: Potentialities in Mediterranean Buildings.” *Advances in Building Energy Research* 4(1):201–66.