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International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16

A Study on the Impact of Changes in the Materials Reflection Coefficient for Achieving Sustainable Urban Design

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Abstract

A lot of geographers, scientists believe that the current climate has changed. Especially, since the rapid increment of world's population. Indeed, rapid urbanization led to an increased demand of basic facilities, such as public transport services, hospitals, housing &, etc. Accordingly; the urban areas of cities have been expanded compared to rural areas, and many modifications and changes have been happened on their surface's materials. These modifications made our cities hotter than the Countryside, UHI effect phenomenon now well-known. One of the main reasons behind these changes is construction materials in both buildings and urban spaces, which play a major role in affecting the urban temperatures, precisely near-surface air temperatures positively or negatively, which depend mainly on the behaviour of the surface with solar radiation and how the energy is reflected, emitted, and absorbed. Thus, the current study aimed to investigate the direct and indirect impacts of materials reflection coefficient on the environmental performance and external urban surface temperature; by using the SOLENE-microclimate model tool (developed by the laboratory CRENAU - ENSA Nantes); which is a direct effect on external air temperature in terms of sustainability in the urban context. This study applied on one of the most important residential complexes in Mosul city - Iraq as a case study. The results were proved that when used a material with high reflectivity; Comparing low albedo Scenario (1) with high albedo Scenario (3); it can improve the thermal behaviour of building and urban surfaces, where the surfaces temperature of rooftop, walls, urban spaces, road have been changed by, respectively, 25°C, 18 °C, 20°C, and 18°C. As well as changed the urban air temperature by 11°C. However, the results showed that in some cases the surface temperatures increased slightly even when reflectivity increased in the scene, (comparison scenario 3 and scenario 5) where the change of albedo value of external walls surfaces have affected increasing the average urban spaces & pavement temperature about 2°C. The tool that is used in this study (SOLENE-microclimate) has effectively helped in achieving all the analysis required successfully, which it represent the most specialized tool in this field.

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1. Introduction: Previous studies, Aims, Focus and Research Questions

Over the centuries, the world has witnessed a growth in its cities over different time periods. Although some cities now experience slow growth or decline, such as New York and London, still other Asian and African cities are suffering very rapid growth now and are expected to continue at this pace [1] & [2]. As reported by UN, today 54% of the world's population lives in urban areas [3]. This growth and increase in urban inhabitants have led to, sequentially, expansion the cities and presence of dark colored surfaces, absorption of solar radiation during daytime and its re-radiation as heat during the night by buildings' envelope and pavements, replacement of forests, natural soils and green spaces with natural vegetation by residential buildings, and increased commuting distances [4]. Therefore, the inevitable results of these changes are higher surface temperatures of buildings/urban spaces, and then higher near-surface air temperatures, increased energy consumption and induced emissions. Therefore, and finally our cities are warmer than rural areas, phenomenon now well-known as the urban heat island (UHI) [5]. UHI is gradually increasing in urban areas, changing their microclimate and increasing energy demand in summer [6]. All of these changes will harden the sustainability challenges on cities. The possibility to achieve sustainability in the urban context is still controversial [7]. Van Staden M. and Musco F (2010) said, "Any urban activity cannot be considered as sustainable if it satisfies only one area of sustainability (environment, economy, and society)" [7]. For example, any environmentally friendly project is not sustainable if needing high costs and limited to only a certain segment of population. Accordingly, this work represents an attempt to provide suggestions to change any project to be compatible with the basic principles of environmentally friendly (sustainable environment), the basic principles of energy efficiency (sustainable society) with minimum cost (sustainable economy).

1.1. Literature review

Numerous studies have been carried out regarding high reflective surfaces and how energy is reflected, emitted, and absorbed, which have varied approaches as summarized in table 2. From previous studies, it has been observed that there are differences in the results and final conclusions. They are due to differences in methods, regions' types and characteristics, performance standards, climatic conditions, and scales/type of the studied scenario, etc. Accordingly, it is difficult to extrapolate a certain result on all projects. This conclusion agrees with the findings of Yang Jiechi et al (2015) in their study, which summarized most of the literature related to the relationship between albedo value and surface temperature, air temperature, and energy consumption [8]. Therefore, we can conclude a range of important points as table 1.

In spite of all this awareness, the usage rate of low albedo materials is still higher than the usage of high albedo materials at the level of building and urban form in many cities. This is due to many reasons such as often the cost, lack of experience of the decision makers, and lack of awareness about the importance of using high-reflectivity materials on the thermal behaviour of building and energy needed [19].

Table 1. The general conclusion of previous studies.

Rooftop	Pavement and road	Building envelope
All previous studies confirm that high-albedo and high emissivity roof materials (white color material, or another material with another color after change their chemical composition) can play an important role in enhancing the thermal behaviour of a roof, indoor/outdoor air temperature, and energy consumption. The appropriate rooftop albedo value is 0.8 for all types of building.	Most of the studies explained the advantages of using high-albedo pavement and road, but still there are some visual problems. Therefore, many others studies proposed some alternative's ideas to reduce the brightness of high reflective pavement with sustain high level of reflectance. Studies showed that the pavements also can help to improve the urban thermal environment through their effect of the air temperature near ground surfaces. Studies did not propose optimum albedo values for pavements and roads, but they suggested some strategies to reduce the surface	Employing high albedo coatings on the building exterior wall is an active and effective approach to improve the urban buildings' micro-heat environment.

brightness with sustain high level of reflectance.

Table 2. Reflection coefficient studies approaches (previous studies).

1.1. Effect of reflective materials on rooftop

Akridge and James M (1998) have stated that the conventional dark and impervious roofs can store much heat compared to high albedo materials which contribute directly to: Global urban environmental problems such as UHI effect; Higher summertime energy consumption rates for cooling [9]. Simpson and McPherson (1997) have said the increasing only the albedo of a building surface may not be always effective in reducing its temperature, for example the silver roof was more reflective than the grey roof, but their temperatures were similar due to the difference in emissivity [10]. Gaffin S. et al (2006), have proven that the appropriate rooftop albedo value is 0.8 for all types of building [11]. Therefore, thermal emittance or thermal emissivity is another important factor work together with surface albedo effecting rooftop temperature and the best-performing construction materials for surface temperature, cooling load, air temperature reduction has both high albedo and high emittance. Generally almost all the previous studies related to the high-reflectance roof have shown that high-albedo materials can influence greatly the surface temperature through shed heat by re-radiation, regardless of percentage of temperature reduction that is provided by high albedo rooftop [8].

1.2. Effect of reflective materials on Interior air temperature

Bansal et al. (1992) have studied "the effect of external surface colour on the thermal behaviour of a building". Investigations were done under different conditions; completely light building, effect of doors' openings and of an overhang on the window for complete shading throughout the day. This study found "the black painted enclosure was a maximum of 7 °C higher temperature than the similar white painted enclosure during hours of maximum solar radiation (daytime), while during the night the two enclosures showed nearly the same temperatures (being the light weight constructions)". This study has shown that there was a significant effect of external building envelope colour on the indoor building room temperature [16]. Cheng and Givoni (2005) have added another factor working together with the reflectivity that can affect indoor temperature: the 'thermal mass' of the building envelope. This study was applied on test cells with different specifications, black and white. It reports that there was a difference in the internal temperature of the cells: the air temperature inside the black test cell was about 12°C higher than that of the white cell, as well as the air temperature inside the white cell was 2–3 °C higher than the outdoor one. Finally, it concludes that the use of lighter surface colour and thermal mass can reduce maximum indoor temperatures [17].

1.3. Effect of reflective materials on outdoor air temperature

A. Dimoudia et al. (2014), starting from the certain idea which is "paved surfaces contribute to sunlight's heating of the air near the surface, depending on their ability to absorb, store and emit radiant energy, which has effect on urban microclimate", this study conducted a comparison between the thermal behaviour of typical construction materials and cool material in an urban center at Greece. CFD simulations results showed that cool materials, accompanied by other mitigation techniques in the area lead to reduce of the mean surface temperature of streets and pavement by 6.5°C. This temperature reduction will have a big influence on the microclimate

1.4. Effect of reflective materials on energy consumption

According to the change of buildings' external walls albedo, Yu B. et al (2008), have analyzed energy savings for two building models under certain meteorological conditions in different seasons by using Laplace integral transform method. The internal and external microclimate parameters were measured. The results show that, when the albedo changed from 0.21 to 0.86, the indoor air temperature reduction was up to 4.7°C with the average daytime temperature decrease up to 3.5°C in summer, and the increase was up to 2.8°C in winter. The results indicate that the wall-facing materials with high albedo have the function of heat-protection and heat-insulation and could reduce by 150.3 W per day the buildings' cooling load in summer and 69.5 W per day the heating load in winter.[12]. Yang J et al (2015) said that reflective materials have advantages in energy summer consumption but it can increase heating loads during winter [8].

1.5. Effect of reflective materials on Building envelope

Song B. and Park K. (2015), have conducted a study on a single residential area and commercial complex with high densities of artificial cover materials, before and after changes related to the development of green areas and increase in reflectivity of coating materials. It is found that the cooling effect has a positive correlation with the peak solar radiation intensity in which the surface temperature decrease as reflectivity increased. However, the results show that the reflectivity increase not always leads to decrease the temperature of the surface. It mainly depends on the distance between the buildings, where the reflected radiation energy was absorbed by the surrounding buildings and was consequently re-radiated to the surface from the building, consequently increasing the surface temperature. While in the park (without buildings) low surface temperature were observed. Finally, it is concluded that in order to improve the thermal environment of complex urban areas, it is necessary to improve green-area development and to use high-reflectivity ground and building cover materials, while taking into account the spatial characteristics of land-use types and their surrounding areas [15].

1.6. Effect of reflective materials on Pavements and roads

Kinouchi T. et al (2003) have put forward a range of views concerning albedo value, "It is not difficult to raise the albedo of the building roof as it can be attained by bright coloured painting but for pavements, the brighter surface is not allowable for reasons of driving safety and visibility of white line". Therefore, a new type of pavement satisfying both high albedo and low brightness was developed by introducing the paint coating technology. It is found that the paint-coated asphalt pavement experiences around 15°C lower surface temperature than that of the conventional one at the maximum. Even in the nighttime, the surface of the paint-coated asphalt is cooler for more than 2°C. In the winter. Therefore, this new technology has contributed to reduce pavement temperature and sensible heat flux and thus have contributed to reduce the air temperature near the ground and the longwave radiation emitted from the pavement surface [13]. Synnefa A. et al (2011) have analysed the thermal performance of five colour thin layer asphalt samples in comparison to the conventional black asphalt. CFD simulations

of the area, the outdoors thermal comfort as well as affect indoor conditions and buildings' cooling loads [18].

results showed that the coloured thin layer asphalt are described by higher values of solar reflectance; therefore, their surface temperature was lower compared to conventional asphalt as a result of their high near infrared solar reflectance. The maximum temperature difference was recorded for the off-white sample and it was equal to 12 °C [14].

1.2. Aims and Research Questions

Hence the importance of the present work, where little or no studies related to effect of increased albedo value of building envelope, roofs, and urban spaces compatible with the climate conditions and construction materials available in Iraq generally and Mosul city especially. The appropriate albedo selection can effect on achieving sustainable urban typology design (building envelope and urban spaces) through reducing external/internal surface temperature, maintenance indoor thermal comfort and reducing energy consumption. Thus, the study aims to investigate the direct and indirect impacts of materials reflection coefficient on the environmental performance and external urban surface temperature, which is direct effect on external air temperature in terms of sustainability in the urban context. The research questions of this work are specified as following:

- (i) Is the change in the materials reflection coefficient is affect: a. Decreasing surface temperature, b. Sustain the thermal comfort of occupants?, c. Achieve the requirements of energy efficiency ? of the scenario study of the present work.
- (ii) Is SOLENE-microclimate is an appropriate tool which can be used to achieve the objectives of this study?

2. Methods and Materials

2.1. Scenario study

This study has an in-depth search to find the appropriate materials reflection coefficient (albedo value) for all urban components (buildings and urban spaces) on an important residential complex in Nineveh city –Iraq, with respect to climate conditions, geographical location, and a group of characteristics associated with that region. This complex includes 56 residential buildings (504 apartments) and a group of services buildings e.g. primary school and two secondary schools, shopping center, mosque, and a health center. In addition, this project has been provided with a set of internal roads, squares, and gardens (see Figure 1).



Fig. 1. Al Hadba Residential Complex.

2.2. Methodology and approach

This study uses the Solene-microclimat as a tool to achieve simulations regarding to the objectives of this paper. Solene-microclimat provides a range of abilities in relation with geometries: it can create any geometry 'real', as well as the ability to change any parameters related with location, climatic conditions, walls and roofs design (e.g. thickness, number of layers, finishing), and construction materials of the urban area or natural surfaces (water or vegetation).

2.3. Meteorological model: The SOLENE-microclimat model

The SOLENE-microclimat model is described with details in MALYS L. (2012) [20]. SOLENE-microclimat is the new version of solene software that includes new sub-models that provide it with many additional possibilities (see Figure 3). Generally, SOLENE-microclimat has three main models: the thermo-radiative model, the thermo-radiative model of a building, and the thermo-radiative model coupling with other codes e.g. Code_Saturne (CFDSimulation), (see Figure 2) [20]. This study uses the thermo-radiative model of a building to investigate the indoor air temperature, external surface temperature (building facade, roof, and urban open spaces), and amount of energy needed to maintain the thermal comfort level. To find the outdoor air temperature, the energy balance equation described in MALYS L. (2012) [20] is used.

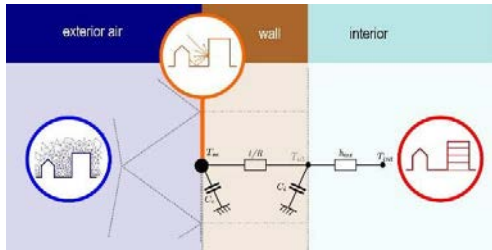


Fig. 2. The SOLENE-microclimat model types [20].

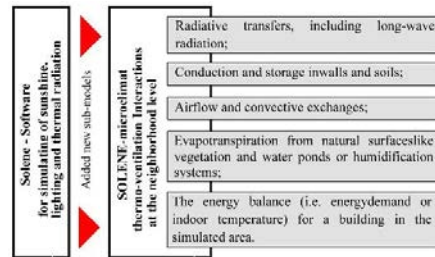
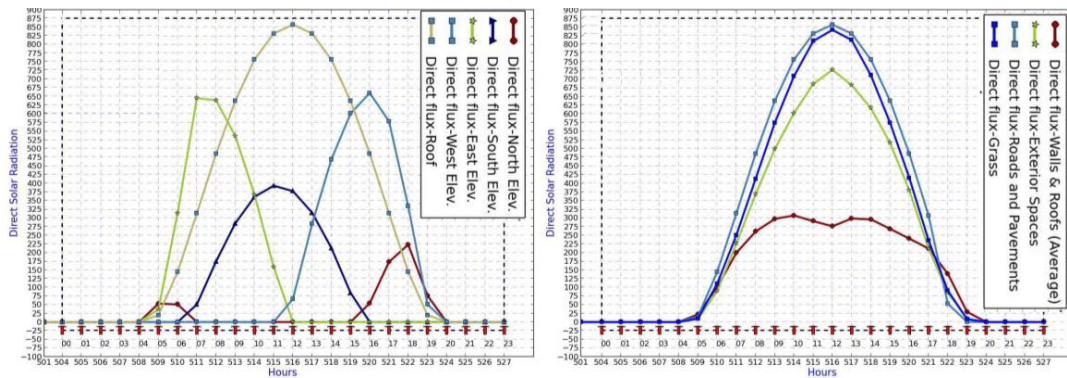


Fig. 3. The new sub-models of Solene [21].

3. Results



3.1. Description of the initial state of the scenario study simulation and results

3.1.1. The period of simulation

Detailed simulations were performed in the Al-Hadba Residential Complex, in the hottest day which represents the most frequent days over the hottest months in the year. Therefore, and in order to ensure the validity of the results, the simulation was conducted during the 22th of June - 13th of July with concentrated to 13th of July. The hottest month in Mosul city was July where the average temperature reached 35.5 °C at the highest level, while the most frequent hottest day over July is 13th of July. All these days were clear and the direct solar radiation for both buildings envelopes and urban spaces as shown in figure 4-a, and 4-b.

Building envelope components				Urban spaces components			
	Direct Flus W/m2	Time of day	Period		Direct Flus W/m2	Time of day	Period
North elevation	Close to 55	4h00-7h00	3 hours	Roads	Close to 855	4h00-20h00	16 hours
	Close to 220	15h00-20h00	5 hours				

South elevation	Close to 390	15h00-20h00	5 hours	urban spaces and	Close to 750	4h00-20h00	16 hours
East elevation	Close to 645	4h00-12h00	8 hours	Pavements	Close to 840	4h00-20h00	16 hours
West elevation	Close to 660	11h00-20h00	9 hours	Green area			
Roof	Close to 855	4h00-20h00	16 hours				

Fig. 4, a- Direct flux of building envelope and Roofs, b- Direct flux of urban spaces.

3.1.2. Types of materials selection

The task related to materials type's selection has been achieved in X previous study. A search string was developed to find appropriate materials for building external walls, which are manufactured in France and are suitable to use in Iraq. Groups of manufacturers of construction materials and specialized research centers who deal with developing properties of construction materials were contacted for guidelines and technical assistance to select materials types that have an effect on indoor/outdoor microclimate and cooling energy use compatible with the climate condition in the Middle East generally and Iraq, especially. Finally, we selected one type of the vast range of materials according to standards commensurate with a whole range of factors, summed up the price, and environmental performance, endurance and others. It is pumice block materials, which is produced at one of the construction companies in France and Italy, which is Ciments Calcia

3.1.3. Materials reflection coefficient selection for building, roofs, and urban surfaces

Seven scenarios of reflective coatings were proposed, differing in the reflection coefficient of rooftop, external walls, roads, urban spaces and pavements as in table 3. This work considered is the second step after selecting the appropriate building materials with respect to physical thermal properties of materials.

Table 3. Materials reflection coefficient scenarios of this study.

Scenarios	North Elevation	South Elevation	East Elevation	West Elevation	Roads	Pavements and urban spaces	Roofs	Green area
Scenario ONE	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.28
Scenario TWO	0.25	0.25	0.25	0.25	0.25	0.25	0.8	0.28
Scenario THREE	0.8	0.8	0.8	0.8	0.6	0.7	0.8	0.28
Scenario FOUR	0.8	0.8	0.8	0.8	0.25	0.25	0.8	0.28
Scenario FIVE	0.25	0.25	0.25	0.25	0.6	0.7	0.25	0.28
Scenario SIX	0.7	0.7	0.7	0.7	0.6	0.7	0.8	0.28
Scenario SEVEN	0.6	0.6	0.6	0.6	0.6	0.7	0.8	0.28

3.2. Description the results of simulation

Table 4 summarizes the results of the simulation for all scenarios.

Table 4. Summary of simulation results.

Scenarios	Rooftop °C	External walls °C	Roads °C	Urban spaces and pavements °C	Green area °C	Indoor air temp. °C	Aver. outdoor Air temp. °C
Scenario ONE	55 - 13h00	40 - 14h00	68 - 12h00	58 - 12h00	25 - 12h00	22 - 18h00	26
Scenario TWO	30 - 13h00	40 - 14h00	69 - 12h00	58 - 12h00	25 - 12h00	21 - 18h00	25
Scenario THREE	30 - 13h00	30 - 14h00	50 - 12h00	40 - 13h00	25 - 12h00	19 - 18h00	21
Scenario FOUR	30 - 13h00	32 - 13h00	67 - 12h00	60 - 12h00	25 - 12h00	20 - 18h00	24

Scenario FIVE	30 - 13h00	38 - 14h00	60 - 12h00	38 - 12h00	25 - 12h00	21 - 18h00	22
Scenario SIX	30 - 13h00	32 - 14h00	50 - 12h00	40 - 12h00	25 - 12h00	20 - 18h00	21.6
Scenario SEVEN	30 - 13h00	34 - 14h00	50 - 12h00	40 - 12h00	25 - 12h00	20 - 18h00	21.9

Four comparisons were conducted to understand the effect of albedo changes in each component, as a following

A. Comparison One: between scenario 1 and 2: the difference between the two scenarios is only the rooftop albedo value, so that this comparison is performed to study the effect of high surface albedo of rooftop. The change of rooftop albedo value from 0.25 to 0.8 reduces its temperatures by about 25°C, the average outdoor air temperature by about 1°C, and indoor air temperature by about 1°C. It does not affect the surface temperature of the other components of urban topology (Urban spaces & pavement, Roads, External walls, Green area).

B. Comparison Two: between scenario 3 and 4: this comparison has been performed to study the effect of high surface albedo of roads, pavements, and urban spaces. Regarding road surface temperature, the change of road's albedo value from 0.25 to 0.6 reduces their surface temperatures by about 17°C, while the changes of urban spaces and pavement albedo value from 0.25 to 0.7 reduces their surface temperatures by about 20°C. These changes also affect the average external walls temperature by about 4 °C at 1:00 PM (Scenario 3 = 30 °C, Scenario 4=34 °C), but there is no effect on rooftop and green surface temperatures. The average outdoor air temperature is reduced by about 3°C, and indoor air temperature by about 1°C.

C. Comparison Three: between scenario 3 and 5: this comparison is performed to study the effect of high surface albedo applied to external walls surfaces. The change of the albedo value of external walls' surface from 0.25 to 0.8 reduces their temperatures by about 8°C, the average outdoor air temperature by about 1°C, and indoor air temperature by about 1°C. These changes have affected the average urban spaces & pavement surface temperature which increases by about 2 °C at noon (Scenario3= 40°C, Scenario5=38 °C), but there was no effect on roads, rooftop, green area surface temperatures.

D. Comparison Four: between scenarios 3, 5, 6, and 7: When changing the albedo of wall facing materials for all elevations (north, south, east, and west) from 0.25 to 0.6, 0.7, and 0.8, respectively, some elevations are greatly affected as west elevation, while the others are less affected as north elevation due to a lower amount of direct solar irradiation, (see Figure 5).

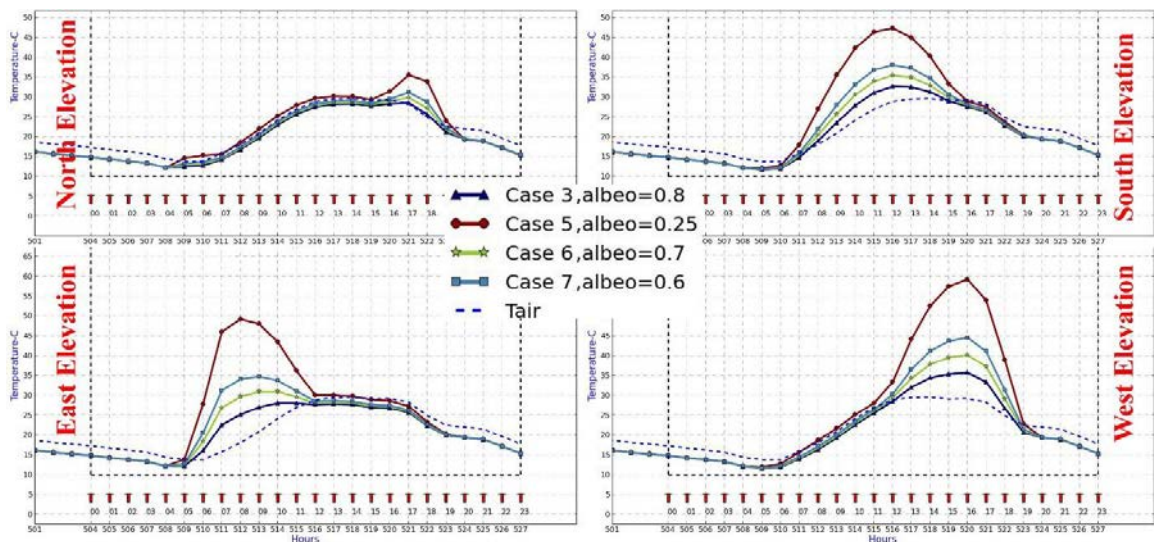


Fig. 5. Comparison between scenarios 3, 5, 6, and 7.

3.3. Results discussion

In light of these results and to answer the study questions, we can say that the changes in the materials reflection coefficient generally reduce surface temperature for all urban components (building envelope and urban space), as a result the urban air temperature has been locally reduced about up to 7°C (as scenario 3). Regarding the indoor air temperature, high albedo wall surface materials and type of the materials selection (pumice block) worked together to provide high level of thermal comfort with minimum cooling energy needs, which only reached about 100 W/m² per day in summer between 15h00 to 18h00. The SOLENE-microclimate model has effectively helped in achieving all the analysis required in this study.

4. Conclusions

Seven scenarios of reflective coatings were studied and it was found that the use of a appropriate reflection coefficients can significantly reduce surface temperatures, external/internal air temperature, and energy needed, or in a broader sense, achieving sustainable urban design in the environmental perspective. However, the results of the present study showed that in some scenarios the surface temperatures increased slightly even when reflectivity increased in the scene, this is evident in the third comparison between scenario 3 and 5 where the change of albedo value of external walls surfaces has increased the average urban spaces & pavement temperature by about 2 °C at noon (Scenario3= 40°C, Scenario5=38 °C). It is worth mentioning that high reflectance materials are not necessary white colors, where new technologies allow to increase the reflectance such as cool colored coatings.

As it was expected, for Al-hadba residential complex, white colored coatings of rooftop perform better than concrete grey color (existing materials), and reduce rooftop temperature by about 25°C. Regarding wall facing material, the study proves that there is a strong relationship between the direct solar radiation and appropriate reflection coefficient required, which depends mainly on the location and orientation of the building. For example as it receives about 55 W/m² direct flux, the north facing wall temperature was almost the same whether using albedo value of 0.25, 0.6, 0.7, and 0.8. On the contrary, the change of the facing west wall temperature; that received direct solar radiation about 55 W/m²; was higher when using albedo value of 0.25, 0.6, 0.7, and 0.8: the surface temperatures were respectively 35°C, 40°C, 44°C, and 59°C. Regarding the indoor air temperature, both high thermal insulation materials (e.g. pumice block) and high albedo wall surface materials worked together to provide high level of thermal comfort with minimum energy needs. Those only reach about 100 W/m² per day of cooling load between 15h00 to 18h00 (scenario 3). SOLENE-microclimate has effectively helped in achieving all the analysis required in this study.

Finally appropriate selection of materials and high albedo materials is the best strategy to achieve environmental gains in such a country like Iraq. Even if reflective materials can increase heating loads during cold periods, known as the "heating penalty of high albedo", this not applicable in Iraq where the energy sources vary depending on the season of the year. In summer, the electricity is considered as the main energy source to provide thermal comfort, especially for cooling loads, through used artificial cooling means. This source is considered fairly expensive. On the contrary, in winter where they are relying on the traditional petroleum derivatives energy sources, which is less expensive compared to electricity as a source of energy.

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