Proposal of Indicators Dedicated to the Analysis of Contribution of Urban Projects to Urban Heat Island

ATHAMENA KHALED[1], MUSY MARJORIE[1], BOUYER JULIEN[1]

[1]CERMA – UMR CNRS 1563, Ecole nationale supérieure d'architecture de Nantes, Nantes, France

ABSTRACT: The radiative characteristics of buildings' envelops and their geometrical arrangement in the city play an important role in the urban heat island (UHI) phenomenon that modifies buildings' energy consumption. We focus on one parameter of direct relevance to UHI: the albedo. The albedo of a city or a district depends on surfaces' arrangement, materials, and solar position. We study these dependences through the calculation of the albedo for urban blocks in the case of a real urban project in France. After having regrouped the radiative characteristics of materials used in this project, we computed solar fluxes over a day, at several dates in a year with the SOLENE software to obtain albedos. This study, can be used to increase the awareness of urban planners, designers and decision makers on the importance of the choice of coating, paving and roof materials related to their effect on local climate and on energy consumption of buildings. Materials' albedo should be chosen differently in function of surface's location. For these urban blocks, morphological parameters are evaluated and correlations researched between them and calculated albedos to propose an indicator that characterizes the contribution of a district (real or at planning stage) to UHI.
Keywords: urban heat island, albedo, urban project, simulation, indicator.

INTRODUCTION

In most countries, tools have been established to control buildings' energy efficiency. Thermal regulations dictate buildings' energy consumption and sometimes, minimum requirements for the thermal performance of walls. We also dispose of efficient techniques adapted to climate and to architectural culture. Buildings' envelops are designed to better insulate indoor climate from outdoor one, to control heat and mass transfers that occurs between them.

Though, these practices omit to consider the indirect effect that envelop has on building's energy consumption. Indeed, the radiative characteristics of the buildings' envelop and their geometrical arrangements in the city play an important role in the urban heat island (UHI) phenomenon. UHI modifies buildings' energy consumption, because of the increase of air and surfaces' temperature, besides it leads to uncomfortable and unhealthy situations for inhabitants in summer.
The causes and effects of urban climates and heat islands are diverse [1, 2 and 3]:

- less evapotranspiration because of mineralization of cities,
- more solar energy absorption due to lower albedo,
- less infra-red loss in night due to density,
- less convection because of reduced air velocity caused by higher rugosity,
- higher anthropogenic loads partly due to conditioners' rejects.

Their interactions are complex and the effect of the different parameters that play a role in these phenomena, in particular urban form, can be contradictory. In this paper, we focus on one parameter of direct relevance to urban heat island phenomenon: the surface albedo.

The prediction of the urban energy budget and mesoscale climate involves the study of radiative exchanges within an urban canopy Miguet et al [4]. Because these calculations cannot be carried in detail at mesoscale, taking into account real materials and urban forms data, the equivalent surface albedo is used in mesoscale models. This is the main application of the urban surface albedo. Usually, this value is determined very roughly or using albedo calculation models as the one proposed by Chimklai [5]. However, it is difficult to use this kind of model to evaluate albedo of real urban fabrics that are not like checked frames.

Starting from the results obtained by Groleau [6] and the validation of the calculation performed with the SOLENE software [4, 6], we propose to use this software to calculate albedo for every kind of urban form. This is applied to a recent project that takes place in France.

For these urban blocks, several morphological parameters have also been evaluated and correlations are researched between these parameters and calculated albedos.

Our idea is to propose simple indicators that can be used to characterize the contribution of a district (real or at planning stage) to urban heat island effect. These indicators, due to their simplified formulation, are dedicated to decision help at previous stage of projects. They allow comparing different projects with objective criterions, eventually in a multicriterion approach.

URBAN SURFACE ALBEDO CALCULATION

The simulations are carried out in SOLENE software.
The first stage is to make a model of the district of which we wanted to evaluate the albedo. The 3D model represents, as set or polygonal planar facets, the external surfaces of the urban site: roofs, façades, courtyards and streets. A triangular mesh is applied to these facets and calculations take place at the barycentre of each mesh element. When modelling academic cases (e.g. canyon streets), this stage is quite easy, but it implies first compromises when modelling real project. The second one is to assign radiative characteristics to surfaces, what implies also compromises.

The first calculation stage is based on geometric procedures to determine the visibility between mesh elements or between a mesh element and a sun location or a sky patch of our geodesic sky model, considering mask and shadow effects. It results in form factors between mesh elements and sky form factor for each element. The second one calculates the solar energy (visible and near infrared) received by each mesh element. The sun and sky irradiation are computed separately. The direct component is evaluated, over time, for each sunlit element. The sky contribution is calculated using realistic, non isotropic model for the sky radiance distribution, according to a type of sky (clear, overcast or other) and location of the sun at the considered time. The time-dependant global solar energy received on each mesh element the second result.

Then, by a radiosity method, the inter-reflections between surfaces are calculated (only wavelengths in our case). What leads to the knowledge of net flux received by each facet, the reflected flux to make a budget on the whole district surface, Miguet et al [7]. The net received and reflected fluxes can't be summed directly because the flux reflected by a surface can have been intercepted by another surface, and for surface albedo definition, we need to determine what is globally lost. Two solutions are available: to pound the reflected fluxes by the sky view factor of each facet or to use the absorbed flux.

At the end, the district effective albedo is :

$$\alpha_{district} = 1 - \frac{\Phi_{absorbed}}{\Phi_{received}}$$

APPLICATION

We choose to apply our calculation to a real project because it is important for us to verify we are able to carry out these calculations for real configurations i.e. real urban forms and materials.

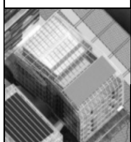
The SOLENE simulation is applied on two urban fabrics will be the subject of this experiment. It is a question of the first phase of the Lyon Confluence quarter (completed in 2015). In the frame of the European program CONCERTO, designers have paid a great attention to the energy consumption of these buildings but the thermal study has not been considered at district scale. In the same district, we also study the city garden, residence that dates from 70 years.

The 3D vegetation (trees) was not taken into account in these simulations but grass and green roofs are be represented by their optical characteristics.

Facades and roofs albedo calculation The following table shows the albedo values for the facades and roofs of the northern part of the block A. These values were obtained from the database of physical characteristics and solar materials [8, 9, 10, 11 and 12]. As regards the albedo and photovoltaic solar panels, studies conducted by the Thermal Center of Lyon have shown that the reflection and emissivity coefficients are respectively 0.05 and 0.95. The reflectance of single glazing is 0.08 while the reflectance of double glazing is 0.15 [13]. For facades composed of two or more materials with different albedo values, we use an equation to find an intermediate value so as to simplify our simulations:
$\alpha = A_1 \times P1 + A_2 \times P2$
Where; P1, P2, are the percentage of occupancy of materials in the façade, and A_1, A_2 is reflection coefficient of every material that composes facades.
The resulting albedos are presented in table 1.

For some material due to the lack of values in bibliography, we had to do assumptions. For the stainless steel, we use a reflectance value of 0.95 because it is considered as a highly reflective material (more reflective than aluminium). Polycarbonate plates were compared to double-glazing. After this comparison, we suggest a reflection value of 0.20. For the massive larch wood, we proposed a reflection coefficient of 0.40, similarly to natural wood.

Table 1: Calculation of the albedo of facades (F) and roofs (R) for the block A North (Fig. 1).

	Facades	A_1 and A_2	% P	α (F)	Roofs	α (R)
	Single glazing + Metal diaphragm	0.08 0.35	0.72	**0.16**	Solar Collectors	**0.05**
	Single glazing + Metal diaphragm	0.08 0.35	0.72	**0.16**	Solar Collectors	**0.05**
	Single glazing + Metal diaphragm	0.08 0.35	0.72	**0.16**	Solar Collectors	**0.05**
	Single glazing + Rough Concrete	0.08 0.35	0.42	**0.16**	Green roof	**0.33**

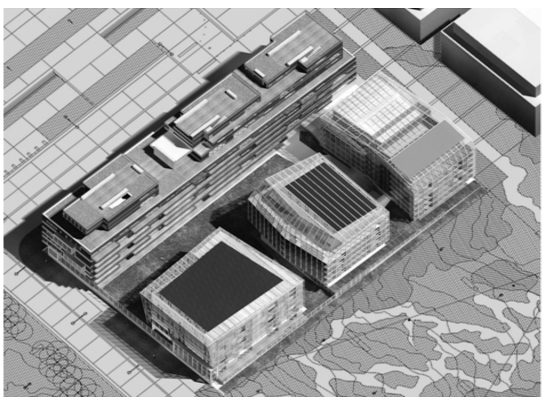


Figure 1: Seen perspective of the block A North

Blocks's equivalent albedo The albedo of a surface is the ratio between the global short wave flux reflected and the corresponding incident flow. It takes account into the direct and diffuse components of these fluxes.

As part of our work, both absorbed and global incident flows were measured for three different days. The first day is the summer solstice (June 21), equinox (March 21), winter solstice (December 21). The choice of these 3 simulation dates aims at computing the albedo of different geometries and measuring the impact of solar azimuth on the amount of energy reflected by the blocks of the district selected.

The first step of the experiment is to select the data required by the software so as to run simulations. First, we open the geometry for simulation. Secondly, we define solar properties (absorption and reflection) of the various materials of faces and roof for the geometry chosen in the base materials of the software.

Once complete, the material is attributed for each side. A phase of triangulation is applied to any geometry over the ground (Fig. 2), using a mesh parameter of 3 meters so as to decrease computation time. Then the albedo is computed after having proceeded to solar calculations explained in previous part.

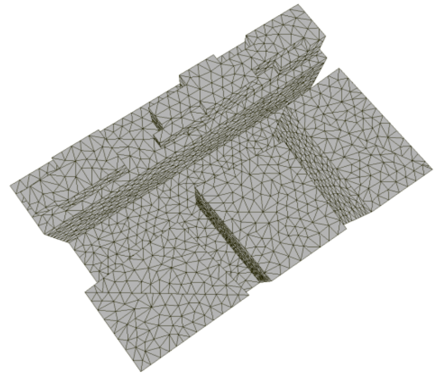


Figure 2: the meshing of the Block A North

Typically, the equivalent albedos of urban surfaces are included between 0, 20 and 0, 30 but in certain case, these values can be exceeded. These results corresponds to of the other one studies led by Taha [14] in certain city European and North American.

The analysis of results shows that:
• In summer, the horizontal surfaces, including roofs participate fully in the reflection of sunlight. According to materials they are keys to decrease the UHI.
• In order to better exploit the benefits of the UHI during the winter period and in particular in reducing energy consumption. It is advisable to use little reflective coatings for the facades of buildings with albedos between 0.3 and 0.45.
• Depending on the case study, the solar height can play a role in reducing or increasing the values of albedo. The results show that when volumes are coated with different materials with heterogeneous reflection coefficients, the results of the impact of solar height depend on the orientation of the facades (Fig. 6). However, when the materials of the facades are homogeneous, then the solar height plays a less important role on the values of albedo.
• The percentage of glazing in the facades reduces considerably the values of surface albedo (Fig. 7). This is a capital parameter. The results show that the greater this percentage is, the lower the albedo is. To limit this phenomenon, vertical break sun for West facades and horizontal for South constitute solution.
• The shaded surfaces have a reflexion power less important than the light surfaces.

Table 2: Values of Incident energy solar, energy absorbed and the albedo of the different blocks. Detailed results for block A Nord in Fig. 4 and 5.

The different blocks	Simulation date	Global Energy incident (KWh)	Energy Solar Absorbed (KWh)	Albedo
North Bloc A	21-6	1834	1570	**0.14**
	21-3	1192	1024	**0.14**
	21-12	446	380	**0.15**
South Bloc A	21-6	1947	1341	**0.22**
	21-3	1259	922	**0.19**
	21-12	475	374	**0.19**
North Bloc B	21-6	3563	2574	**0.27**
	21-3	2083	1501	**0.28**
	21-12	562	389	**0.30**
South Bloc B	21-6	2694	1675	**0.37**
	21-3	1785	1011	**0.43**
	21-12	668	355	**0.50**
C block	21-6	4589	3561	**0.22**
	21-3	2822	2181	**0.23**
	21-12	871	671	**0.23**
Lyon confluence	21-6	11101	8656	**0.22**
	21-3	6202	4713	**0.24**
	21-12	2001	1524	**0.24**
Garden city	21-6	6356	4943	**0.22**
	21-3	3770	2914	**0.24**
	21-12	1146	871	**0.26**

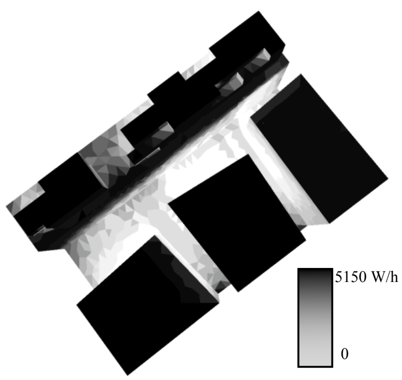


Figure 4: Global solar incident, 21-3 of Block A North

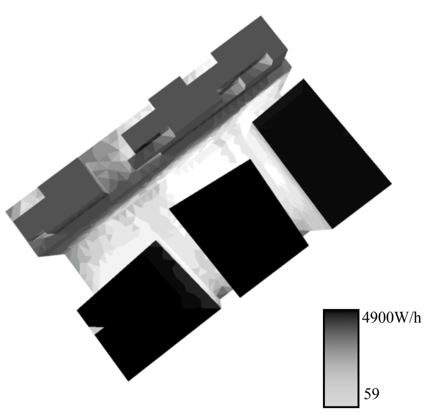


Figure 5: Energy solar absorbed, 21-3 of Block A North

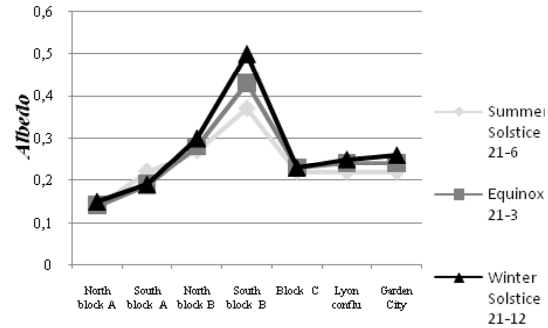


Figure 6: Impact of sun height on the albedo of surfaces

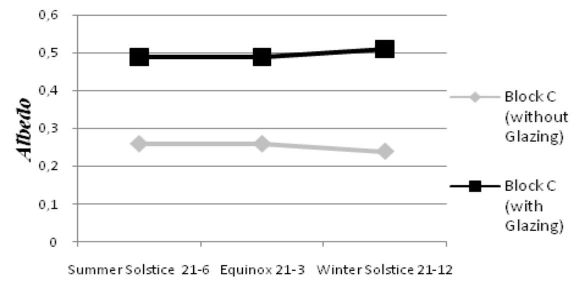


Figure 7: Impact of the glazing on the albedo of surfaces

Sky view factor Sky View Factor (SVF) expresses the relationship between a surface and sky, thus introducing the concept of opening or closing the space. This helps to highlight the exchange areas between the considered surfaces and the sky. Its value ranges between 0 and 100%. This descriptor is evaluated from the maximum and minimum values of each tissue mainly computed by the number of reported contours to the surface. Weighted values for each descriptor allow a comparison between the urban fabrics.

The computation of SVF was made for every geometry of the blocks on the one hand and the horizontal and vertical surfaces of these separate volumes on the other hand. A triangulation step is applied to any geometry over the ground; this step is needed to run the simulation. This triangulation was made on a grid of about one meter. The sky model used has 1024 faces. Geometries masks were taken into account. The results of our experiments are presented in the table 3.

The histogram analysis (Fig. 8) shows clearly that the horizontal surfaces and particularly roofs have a large percentage of visible sky. A geometry that presents a large ratio of horizontal surface, including a large proportion of roof shows quite large SVF.

We also remark that the vertical surfaces have almost similar SVF than the whole blocks, except for A north and C blocks. This is probably due to the size of their roofs compared to other blocks. Therefore we conclude that the vertical geometry ratio greatly affects the SVF: The greater this ratio, the lower the SVF factor is.

THE PROPOSED INDICATOR

Our purpose is to propose a simple indicator that can be used to characterize the contribution of a district (real or at planning stage) to urban heat island effect. These indicators have to be simple enough to be dedicated to decision help at previous stage of projects.

The results of the crossing analysis between the surface albedo, geometrical and morphological indicators, we identified the factors that most impact the value of albedo: the average reflection coefficient of the urban fabric and the SVF.

The Albedo Indicator, denoted A, is defined as follows:

$$\frac{\sum(\alpha_i \psi_i S_i)}{\sum(\psi_i S_i)} \qquad A = \frac{\sum \alpha_i \psi_i S_i}{\sum \psi_i S_i}$$

with α_i, ψ_i, S_i: Average reflection coefficient, SVF, area of each facet in the geometry.

As shown in Fig. 9, the indicator represents correctly the variations of calculated albedo for the cases we studied.

The indicator that we propose widens the role of solar material characteristics and the urban form in the evaluation of the phenomenon of UHI. It will operate a kind of pre-diagnosis of the quality of the elements of urban form that will be complemented by computer simulations of physical phenomenon.

Table 3: SVF for horizontal, vertical surfaces and blocks

The different blocks	Surface	S.V.F
North block A	Whole Blocks Vertical surfaces Horizontal surfaces	**0.43** **0.34** **0.82**
South block A	Whole Blocks Vertical surfaces Horizontal surfaces	**0.41** **0.36** **0.68**
North block B	Whole Blocks Vertical surfaces Horizontal surfaces	**0.37** **0.30** **0.71**
South block B	Whole Blocks Vertical surfaces Horizontal surfaces	**0.36** **0.29** **0.78**
Block C	Whole Blocks Vertical surfaces Horizontal surfaces	**0.46** **0.32** **0.94**
Lyon Confluence	Whole Blocks Vertical surfaces Horizontal surfaces	**0.36** **0.36** **0.81**
Garden city	Whole Blocks Vertical surfaces Horizontal surfaces	**0.38** **0.28** **0.93**

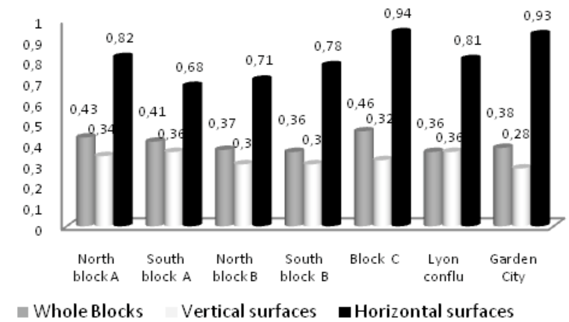


Figure 8: Histogram SVF for all the blocks

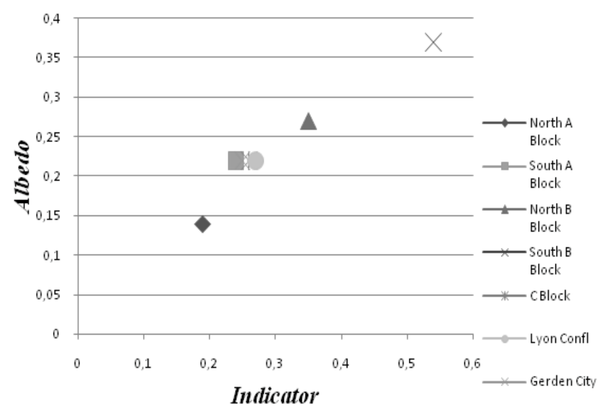


Figure 9: Comparison of A and calculated equivalent albedo for all block (summer solstice)

In its simplicity it is easily applicable to urban complex geometries. It is enough for it to have a database of solar materials and identify the different materials of buildings' envelops.

To proceed to the numerical calculation of the indicator, a software that allows to calculate SFV and aggregate results (pounded means), as Solene can be used.

DISCUSSION

During this research several approximations were necessary. They are imposed by the tools used. These approximations involve simplifying assumptions at some levels of urban space.

The first one concerns the topography: we considered that the hillside of the ground is flat.

The second one is relative on the assumptions made of solar the characteristics for some unidentified materials in the databases of materials available in bibliography.

The more significant one is imposed by SOLENE that is not yet able to represent directional reflections, so that we know that the albedo we calculate is certainly overestimated. This should be corrected in the future.

CONCLUSION

We have shown that, with some approximations, SOLENE makes it possible to evaluate the albedo of a urban project. We have proposed an albedo indicator that permits to compare different projects or districts with less computing time than when calculating albedo.
This study, that should be completed by site experiments, can be used to increase the awareness of urban planners, designers and decision makers on the importance of the choice of coating, paving and roof materials not only for their esthetical aspect but also in function of their effect on local climate and indirectly on energy consumption of buildings. Furthermore, materials' albedo should be chosen differently in function of surface's position.

The method and the indicators should be validated using more kinds of urban forms and materials arrangements, what will also constitute a references base, facilitating comparison with academic or well-known real cases.

We also propose strategies concerning materials' arrangements that can be adopted in function of surfaces' orientation, azimuth and shadowing to lower albedo in winter when it is interesting to take advantage of heat island effect and increase it summer to reduce its impact on comfort and energy consumption.

ACKNOWLEDGEMENTS. We thanks K. Lapray from TRIBU who gives us many information about the Lyon Confluence project.

REFERENCES

1. Santamouris, M., Papanikolaou, N., Livada, I.; Koronakis, I., Georgakis, C., Argiriou, A. & Assimakopoulos, D.N. (2001). On the impact of urban climate on the energy consumption of buildings', Solar Energy 70(3), 201-216.
2. Akbari, H., Pomerantz, M. & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas, Solar Energy 70(3), 295-310,
3. Oke, T.R. (1987). Boundary layer climates. London and New York: Methuen, Second edition (first edition 1978), p 435.
4. Miguet F., Groleau D., Marenne C. (1996). A combined sunlight and skylight tool for microclimatic analysis in urban architectures. In: Proceedings of the 4th European conference on solar energy in architecture and urban planning, Berlin, pp. 338-345.
5. Chimklai, P., Hagishima, A. & Tanimoto, J. (2004). A computer system to support Albedo calculation in urban areas, Building and Environment 39(10), 1213-1221.
6. Groleau, D., Fragnaud. F., Rosant, JM. (2003) Simulation of the radiative behavior of an urban quarter of Marseille with the SOLENE model, In; Proceedings of the Fifth International Conference on Urban Climate, Lodz, Poland.
7. Miguet F. (1996) Eclairements énergétiques et lumineux en milieu urbain. Nantes, Rapport CERMA, 67 p
8. Berdahl, P. & Bretz, S.E.; (1997). Preliminary Survey of the Solar Reflectance of Cool Roofing Materials, Energy and Buildings, Vol. 25, 149-158
9. Parker, D.S., McIlvaine J.E.R.,. Barkaszi, S.F, and Beal D.J., (1993). Laboratory Testing of Reflectance Properties of Roofing Materials, Report N°FSEC-CR-670-93. Florida Solar Energy Center, 300 State Rd. 401, Cape Canaveral, FL 32920.
10. Letter report from Atlas/DSET, August 4, (1999), Normal infrared emittance from ASTM E408-71, converted to hemispherical emittance using eqns. 4 and 5 provided by the National Fenestration Rating Council in NFRC 301-93. Solar reflectance from ASTM method E903, using the air mass 1.5 global spectrum of ASTM E892.
11. Lavigne P. et al. (1994). Architecture Climatique, une contribution au développement durable (Tome 1 : bases physiques), EDISUD, 183-188.
12. Mazria E. (1979). Le guide de l'énergie solaire passive, Parenthéses. 272-277.
13. Tsangrassoulis, A. et M. Santamouris (2003). Numerical estimation of street canyon albedo consisting of vertical coated glazed facades. Energy and Buildings 35(5), 527-531.
14. Taha, H. (1997). Modeling the impacts of large-scale albedo changes on ozone air quality in the South Coast Air Basin. Atmospheric Environment 31(11), 1667-1676.