Evaluation of Smart Shading Structures in Mitigating Urban Heat Island in a district of a Hot Arid Climate City (Abu Dhabi).

Lindita Bande[1], Adalberto Guerra Cabrera[2], Afshin Afshari[3], Miguel Martin[4]

[1] *Polytechnic of Milan,* Piazza Leonardo Da Vinci, 32, 20133 Milano, *Italy,* lindita.bande@polimi.it

[2] *Masdar Institute of Science and Technology, Abu Dhabi, UAE,* agcabrera@masdar.ac.ae

[3] *Masdar Institute of Science and Technology, Abu Dhabi, UAE,* aafshari@masdar.ac.ae

[4] *Masdar Institute of Science and Technology, Abu Dhabi, UAE,* mmartin@masdar.ac.ae

Abstract

Nowadays we observe that the world population is concentrating in the cities converting natural areas into urbanized areas by changing the thermal properties also. As the cities evolve the local climate changes as well. And this change is shown perfectly in the urban heat island (UHI) phenomenon. Indirectly the UHI increases the energy consumption used for the cooling systems inside the buildings. This is translated in additional cost and one step back into the main target of having a sustainable city.

In this paper, we describe how we can analyze one alternative strategy in hot and arid urban environments (like Abu Dhabi) with the help of Urban Modeling Interface (UMI), EnergyPlus (EP), and Ecotect. The energy simulations are divided in two groups. The first group includes the current energy consumption of the different typologies of buildings placed in an urban district and the results are taking into consideration the surrounding environment. The second group of energy simulation analyses the same districts taking into consideration smart shading devices spread into the different districts according to the shading butterfly provided from Ecotect. By proposing this intervention of the necessary shading in the different districts, there is a possibility to moderate the temperatures inside the buildings and as a result the energy consumption by improving in the same time the outdoor quality.

The innovation stands in the application of this smart shading structures in this type of city and the measurement tools used for such proposal. Part of the work for the energy simulation is the preparation of different templates for the selected building categories, the weather data for the hot arid climate, the use of the shoebox model and experimenting Part as a new tool that makes this kind of simulation possible. The simulation results will be then compared with the field observation data for the different building typologies taken into consideration. This comparison helps keeping the results near to the real energy consumption conditions.

1. Introduction

UHI strategy

The Middle Eastern Cities have had a high speed development in terms of construction with few possibilities to make the necessary tests before applying. Like other cities in other parts of the world, they are experiencing an unprecedented wave of urbanization. For the next 10 years is expected that the number of citizens will reach over 40 million.

The speed of growth brings out a great challenge for all those involved in the design, planning, construction, and the case study taken into consideration will make a difference into this critical analysis. The Main Island of Abu Dhabi has had a growth that didn't take into consideration many aspects contributing the increase of the UHI levels. In hot and arid climates, interventions like cool roof, innovative pavements, vegetation and shading devices are often employed to make a city more sustainable. There must be interventions in order to make the city more sustainable, such as: cool roof, innovative pavement materials, shading trees and urban shading fixtures. New software like ENVI Met and UMI enable us to monitor these interventions in an easy way. Technically, analyzing such proposals takes a long time, but thru new software's it can be possible to monitor the suggested intervention. From the economical point of view there should be an analysis if such suggested intervention is sustainable cost wise.

Environmental impact of the integration we are talking about in this research is crucial as the energy efficiency is a sensitive topic in the today building environment. The results of the research will show if the planned project of this suggested and the applied one are correlative.

The real challenge of this development is controlling the sustainability in all the aspects. The challenges are also so diverse that sustaining cities will not be possible without external multidisciplinary interventions. The complex process of city transformation has to take into consideration problematic topics connected to a better life quality for the citizens, green solutions for the reduction of the CO2 levels and in this research also strategies of mitigating heat island as a way of contributing in a direct and indirect way to a higher life quality.
The building cooling in Abu Dhabi can be reduced by referring in different points such as, introduce to the community energy saving benefits, replacing non efficient energy management systems with innovative ones etc, and indirectly by proposing strategies to mitigate the heat island.
Different papers and studies have proven that by painting in white the roofs of the buildings, changing the old materials used for the pavements and the asphalts even by making minimal interventions in them, by increasing the trees quantity the temperatures can be decreased. This approach is quite wide. In a city like Abu Dhabi with hot arid climate an interesting point is to look back into the history of the emirates and other countries of the region. The old generation approach in the urban planning point of view gives practical lessons in cooling the cities. Narrow streets, the use of the solar chimney, the mashrabiya, the ventilation system. Some of this strategies can be used by being modified and redesigned as a strategy in mitigating the UHI. The focus in this case is in the urban shading devices.

2. The case study: A Typical Urban District in Abu Dhabi

The case study we took into consideration for our research due to more available data measured on site is in the main island of Abu Dhabi, surrounded from the streets of: Zayed the First Street, Sultan Bin Zayed the First Street, Fatima Bint Mubarak Street and 5th Street. This a representative district among others with similar properties, characterized of high rise residential, hotels and office buildings on the borders of the area and low rise residential buildings inside the area. We visited the site, took measures met the residents in order to understand the internal life. Based on the information we had from the Abu Dhabi Municipality and from the site verifications we elaborated the table below that was a base for the templates that were created later on in the UMI program for the energy evaluations.
The district is surrounded by high residential and office buildings creating a barrier to the external conditions. This influenced the temperature values on ENVI-met. Will see below that the change of the temperature is visible because also of this influence. The internal part of the district has Medium Rise residential buildings. From the material we had and the façade architecture the different building edge is easy to be recognized. In the older buildings build round the 1990 the windows are smaller and inserted inside the façade wall. In the buildings post 2000 the buildings have full glazed façade. In the perimeter 2 of the older buildings were demolished and new Office/Residential building will take place. The same process is happening also in other similar districts.
The inhabitants of the buildings in this district are mostly non UAE citizens. Since Abu Dhabi is a developing city, the biggest part of the inhabitants work in the construction sector and recently service sector. This influences again the templates in terms of occupancy. We took this fact based also on a previous survey done in the area.
The highest range of the cooling load is in the evening time due to the occupancy of the buildings.
Also part of the building is an elementary school and a mosque. The district is characterized of open parking lots along to the buildings line. The biggest ones are oriented in the south and north part of the district.
In the south part the building line creates shading over the parking lots. This can be defined better with Ecotect as mentioned below. The pavement used in the district is a standard one and the asphalt also doesn't have special characteristics in mitigating the UHI.

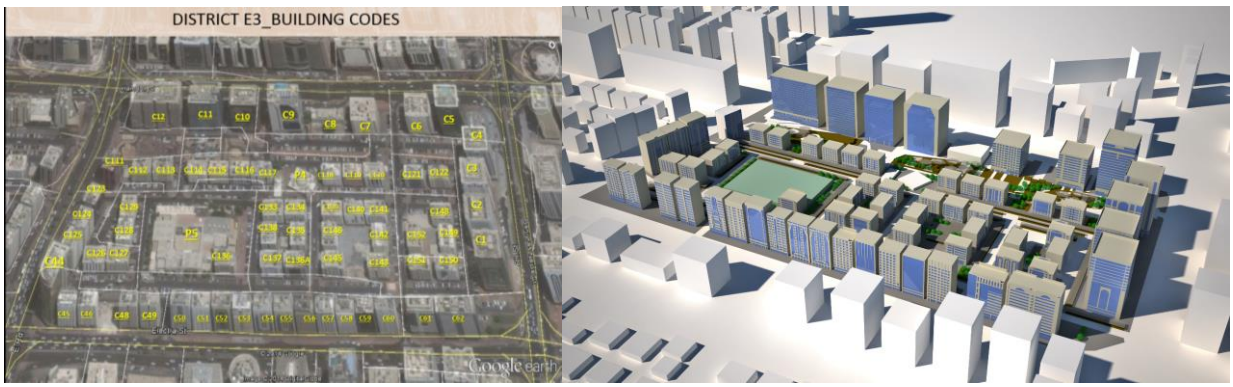

Fig. 1. Arial view with the building codes.

In the above 2 images are shown the codes on each building matching the one defined from the Municipality Survey. By making this categorization it was easier to define the rest of the information. The 3D view elaborated from 3D max helped understand the intervention scale. Other 3D will be done to give a better view to stakeholders of the importance of such intervention. The last fig. shows a façade evaluation when studying the façade glazing.

3. Data collection

The data we used to calibrate our models was partially from internal reports and partially from the information we received from the ADM. Specific values such as U-values for the walls and windows, glazing ratio, year of construction were crucial for or templates.

4. The shading devices

As shown in the two images below the district before the proposed intervention is characterized by opened parking lots. No shading is applied anywhere and there is only one underground parking in the north-west side of the district. There are few trees placed near the elementary school. The residents don't have a park inserted into the district or a play area for the children. The aim of this proposal is to prove that by having a minimal intervention on the urban shading devices over the parking lots and in the internal parks can bring cost saving in terms of energy consumption of the buildings. And this is one of the results of such proposal. The outdoor comfort and the walkability have a considerable improvement, but this part will not be included in this research.
In the proposed intervention there are different typologies of shading. A detailed description will take place below. There is created an internal park with shading devices integrated with trees that are typical of the Middle Eastern countries. This will help saving irrigation water and maintenance costs but on the mean time will provide shading. The area where the park is located covers all the parking places that are thought to be placed in a second underground parking.
All this landscape and shading, despite being used as UHI mitigation strategy which means decreasing the air temperatures will also bring a better life quality, outdoor comfort that the inhabitants can take advantage of in the free time of the long working days. The idea of having such intervention in each district can improve the city scale sustainability. This area is characterized of straight line streets, as the main island of Abu Dhabi, this helps the design to be standardized that means also to reduce the costs of the intervention. The ark takes place in the north side as this area has more access to the sun and a modification in this part will have a bigger feedback. Also there already an existing underground parking there that can simplify possible construction of a new underground parking.

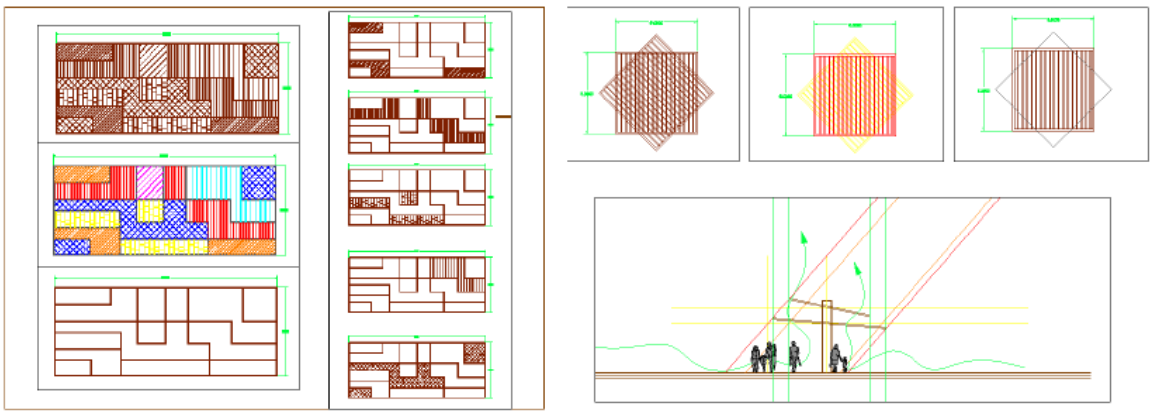

Fig.2. Shading devices 1.

Since Abu Dhabi is still working on the sustainable transportation the car is the main tool to access to the work from the inhabitants. Of course the aim of the Abu Dhabi development plan of the 2030 is to minimize the use of the car but still there will be this need of parking lots with at least one car per apartment.
In additional to all the shading and green areas there are also several fountains. In any case in the below research is was not considered as the focus is in the effect of the shading devices.
Even though we detailed different typologies of shading, in reality during the ENVI met simulation the representation that the tool allows us to use is a block with a height of 30 cm in wood material. This is the schematic representation closer to a shading device. The detailed shading will be part of the optimization study.

5. The energy evaluation

After all the evaluations in terms of urban scale intervention and shading analysis the main aim of this research as mentioned is to measure this intervention in terms of energy. The whole process is divided in 3 steps:

1- The base files,
2- The link,
3- The simulations.

The aim of all this part is to prove that by comparing the different files before and after the intervention there is a reduction of the energy consumption on the cooling load of the buildings in the district taken into the study.

The base files are elaborated by ENVI met then the weather results coming from it were processed under Matlab with 2 different scripts, as described below and then in the end brought to UMI. The biggest difficulty in this process was the weather file link. Since the simulations at the first step are daily ones, and the ones in the last step are yearly ones the weather file had to be created for a full year based on the 4 existing days.
Since the beginning in the full research have been used several programs to achieve the desired results. Among this programs such as Ecotect, AutoCAD, 3D Max, ENVI met, Matlab and UMI, ENVI met and UMI are the ones to work on the energy simulations. The first at an urban scale by focusing on the external environment taking into consideration the UHI effect and the second one again at an urban scale but related to buildings energy consumption. Practically UMI simulations run 2 times with a different weather file, before and after the interventions.
Each program had its own difficulties, advantages and disadvantages but the result was the expected one. There are going to be further improvement in other tests on the other districts that will be studied but this first results have brought our attention in some main points such as the boundary conditions in the ENVI met files, the precision of the script in Matlab and the occupancy of the templates as well as the shapes in UMI.
Even though this district had the biggest area among the 5 that are subject of a future research it was possible with this development of this programs to analyze altogether the full area. For example in the first step the previous version couldn't simulate such area, in the second step there was a new script and in the third one, this is a new version of UMI used taking into consideration the shading of the buildings.
There were difficulties met on the way that will be better described at conclusions but this study pointed out the important steps and defects in each step that will have place for improvement. This can make it possible for different stakeholders such as urban planners, architect, engineers, real estate developers, and government entities to analyze and use the results in each intervention in order to contribute in mitigating the UHI but also to increase the life quality of the citizens of Abu Dhabi.

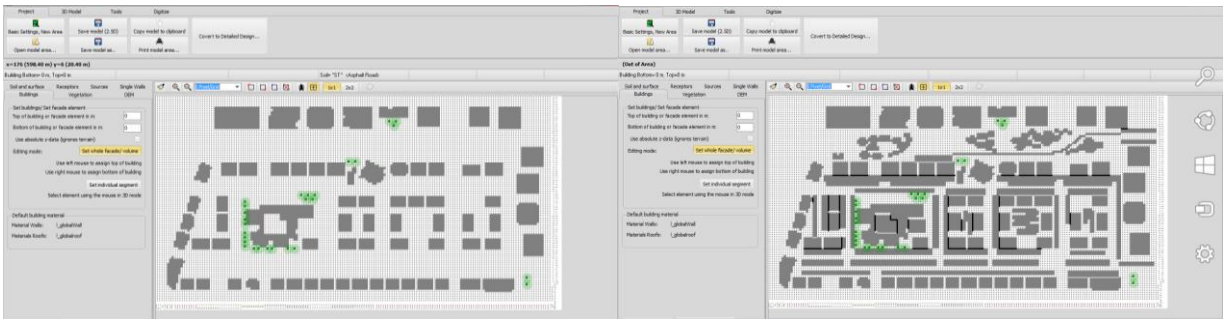

Fig. 3 Base file in ENVI met.

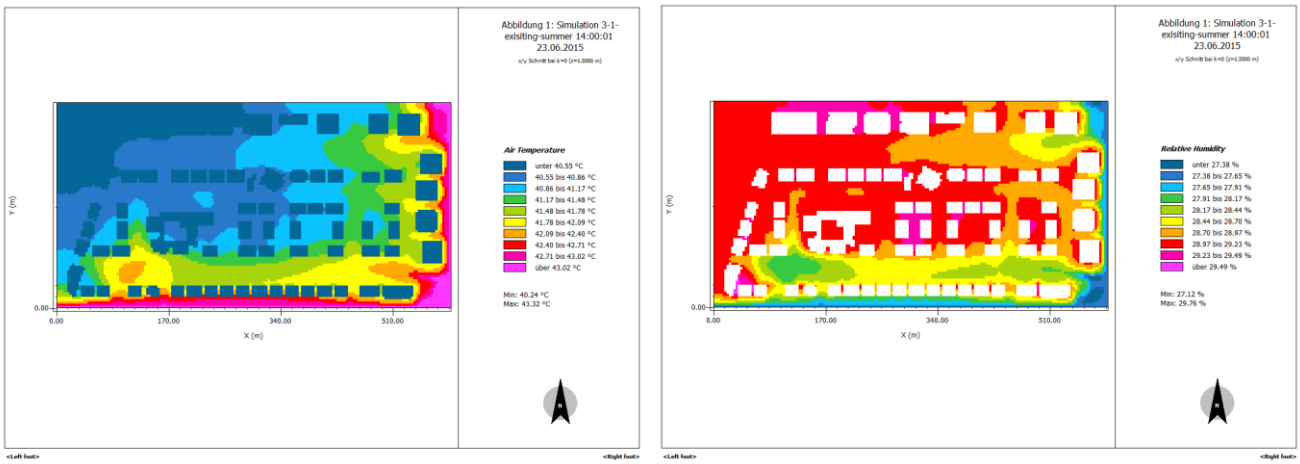

Fig. 4 Summer results for the baseline file.

Matlab
The tables with the results of the 4 days from ENVI met were placed in into excel and modified in the same file. This file was then imported to Matlab were a first script run and provided with the first results on a yearly file in a matlab format. A second script brought this file into epw file that can be used into UMI.
As mentioned above, the k=0 at a height of 1.5 meters is the study level of the different parameters such as the temperature, relative humidity and wind speed.

UMI
The UMI program is created at MIT with the aim of making possible the urban district energy simulation.
The version we worked on is the last version that was provided by our colleagues at MIT.

In this version it's possible to consider the shading that the buildings give on each other. There were some delays caused due some surfaces in attached buildings that were not recognized by the program. The team at MIT is working in modifying this part.

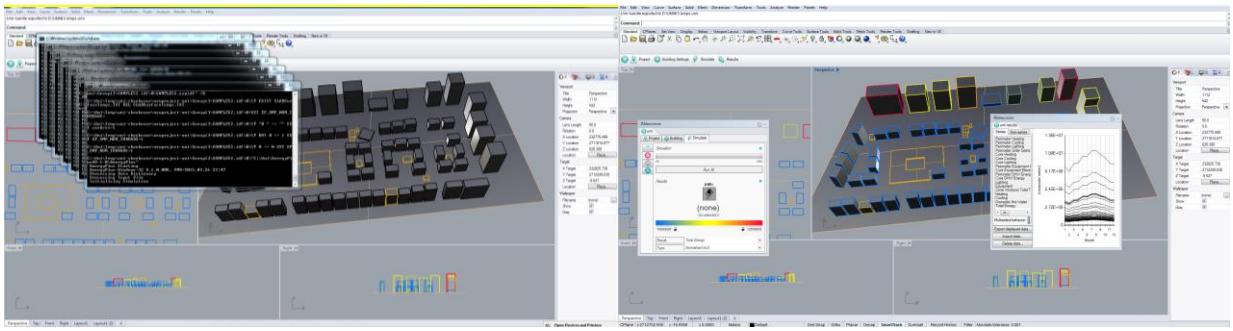

Fig. 5 UMI simulation 1.

6. Results

The city of Abu Dhabi is being transformed day by day. Despite the architectural and construction studies the urban planning analysis is crucial. In a hot arid climate city such as Abu Dhabi, the decisions made in the urban planning scale influences the building scale. Decision making must analyze many factors and one of them is the Heat Island Effect. In this case study we aimed to prove that by making such interventions at urban scale there can be a significant impact. Urban Shading Devices as UHI mitigation strategy can improve buildings energy consumption. This is a result beside others such as improving the outdoor comfort and walkability.

No	Description	Total Energy consumption (kWh)	Energy consumption (kWh/m2)
1	Baseline File	135,627,466.73	312,9
2	Shaded File	128,443,658.22	296.4
Saved Energy (%)			5.3

Table. 1 Energy consumption.

After running the simulations the final results shows a 5.3% of energy saving. This percentage is valuable to the research because this energy saving shows that this kind of intervention not only improves the outdoor comfort, walkability and life quality but also reduced the cooling load. We are not including here the energy that can be gained from the photovoltaic cells that can be used in the smart shading devices.
According to the results the baseline energy consumption is 312, 9 kWh/m2 and after the intervention 296 kWh/m2.

7. Conclusions

There is a considerable saving in energy shown using the analysis and the research there are different factors in each program that can bring models with a certain percentage of error has to be calculated, but in any case our aim was this difference which shows that our models gave the expected result.
Our future scope is to precise much more the model and create a better link between the different programs. Will use this case study analysis as a base for the other 4 districts in order to optimize the typology of shading in each district. The combination between smart and traditional shading device has to be analyzed at a closer scale. At the current stage the programs used can't see the difference at an urban scale, but they provide the input of which shading device to use in which area of the district.
A crucial point in this research is also the management. Management in terms of coordinating different programs, managing the time that each program takes to finish a certain task in order to have the desired results. Alco coordinating with different working teams in different programs helped this project to be finished in time.

Acknowledgment

This work was funded under the Cooperative Agreement between the Masdar Institute of Science and Technology, Abu Dhabi, UAE and the Massachusetts Institute of Technology, Cambridge, MA, USA, Reference Number02/MI/MIT/CP/11/07633/GEN/G/00.

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