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The impact of the urban pattern on solar radiations

Case study : *City of Jeddah (Saudi Arabia)*

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Abstract— The sustainable development in Saudi Arabia and especially the city of Jeddah, our study case, goes through the analysis of the latest developments and the vernacular architecture. The climate is really hot and humid and the West orientation is the most difficult to prevent the sun energy from penetrating inside the buildings and to irradiate the streets.
Our study case is focused on four zones in Jeddah: two from the old city of Jeddah and two from new districts. These four zones are representatives of the entire city by their typology. They have been simulated with two recognized software: Autodesk Ecotect and Autodesk Vasari. Also, a reference site with no solar mask has been simulated. The results are compared with a satisfaction survey of 537 inhabitants of Jeddah. The purpose of the simulations is to find a direct link and quantify it between the existing urban forms in Jeddah and the solar energy received by the façades and the streets and then find out what are the best solutions to reduce the solar radiations inside the urban fabric to design a more sustainable cities for the future constructions and in hot and humid climates in general. We have deduced from the results compared to the reference, a solar energy reduction coefficient by the urban form that shows that the impact of the urban form on the solar energy is considerable.
This study shows that the solar energy reduction coefficient is directly linked with the indoor environmental quality: thermal and natural lighting. There is a remarkable difference between the old city and the modern city of Jeddah due to the urban configuration and not in favor of the new districts, this study will show why there is such a contrast.

Keywords—Jeddah; Saudi Arabia; Solar radiations; sustainable; housing; urban; pattern

I. INTRODUCTION (*Heading 1*)

This paper is an important part of a thesis concerning the sustainable habitat in Jeddah, Saudi Arabia. This thesis studies the climatic comfort and the sociocultural role of architecture and its elements in order to find a direct link between the urban and the architectural form, the energetic performances and inhabitants' satisfaction level. The housing is something really important for a human being; we do search instinctively for a pleasant home to live in[1].
Solar radiations, especially in hot climates as the one in Jeddah, can be a real source of inconvenience because of the possible glare and mostly because of the overheating inside the buildings[2]. In Jeddah there are different types of buildings and urban patterns. We can classify the different patterns into two types: the old city and the modern city. Each type has its own characteristics and we will see how and why these can influence the amount of solar energy reaching the ground and the façades.
The amount of solar energy that enters the building is set by the shading element on the façade, the orientation and the amount of solar radiations that reach the façade. This value depends on the orientation of the façade, the geographic position and the urban pattern that could cause shadow and thus set a microclimate in the streets. [3]
In current thesis, the results of our study have been compared with a satisfaction survey done in 2012 on internet. 385 inhabitants of Jeddah answered all 58 questions. The aim of this survey is to find a link between the climatic comfort and the sociocultural aspect of the satisfaction of the inhabitants.

II. URBAN CONTEXT

A. *Selecting a Template (Heading 2)*

Jeddah is located on the coastline of the Red Sea in Saudi Arabia. 2500 years ago, it was a fishing port and a famous sailor and trade place. The city was already a historical port in the spice trade in 1249 when the caliph Othman bin Affan proclaimed it as an official port for the Muslim pilgrims traveling to the Mecca and Medina.

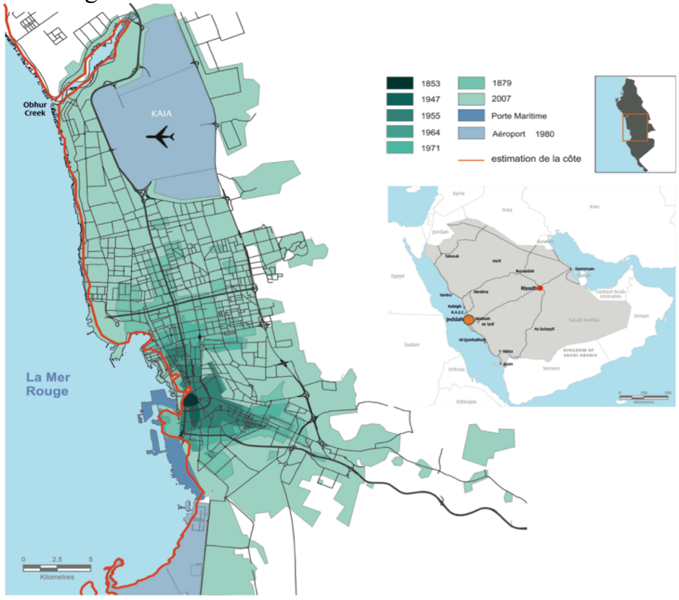


Fig. 1. Historical expansion of Jeddah. *(Jeddah's strategic plan, 2007)*

The history of Jeddah as a place of pilgrimage contributed to model its urban pattern.
The rapid growth in population (natural and migratory) in the last four decades coincided with the Kingdom's enormous increase in wealth. This resulted in Jeddah city expanding physically at an unprecedented rate.
This expansion was in part due to the limited success of spatial planning and regulatory frameworks that attempted to constrain development to certain areas of the city.
Without effective regulation and a coordinated, strategic approach, the urban area of Jeddah grew beyond the capacity of its infrastructure, leading to structural problems in the provision of water, sewage and roads. This growth also left the city with a number of structural challenges, including large quantities of vacant land and a dependency on the private car.
Insensitive development, pollution, high energy consumption and lack of awareness damaged Jeddah's marine environment, while the relics of Jeddah's remarkable heritage, in particular Al Balad (la Medina), fell into decline. [4]
Jeddah has a hot climate; the temperatures vary around 18°C and 39°C and rarely go below 16°C and above 41°C. There is almost only clear skies that vary around 2% of cloud cover to 18% and then the relative humidity vary around 30% to 89%, the air is mostly humid. [5].
People in the city have always found a way to bring comfort in their houses by using shading elements on their facades like moucharabies and mawshans (a type of moucharaby) [6]. The urban pattern has its own role to play, bringing shadow and a microclimate. For example if the Rawshan let go through 20% of the solar energy received on the façade, if the urban pattern filters 50% of the normal amount of solar radiations (without masks), then only 10% of the energy goes indoors.

III. METHODOLOGY

The study of the solar radiations on the façades and on the ground was made possible with computer simulations. Three main types of software were used:

- Autodesk Revit : cubic modeling
- Autodesk Vasari : solar simulations
- Autodesk Ecotect : obtaining more accurate solar simulations

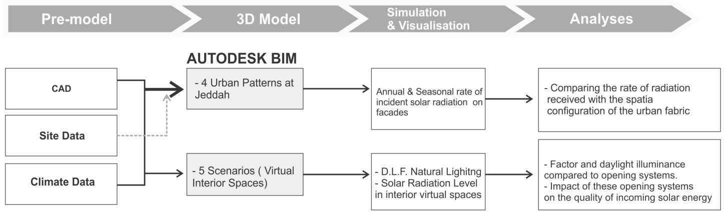


Fig. 2. The methodology. *(by the author)*

Four zones of the city were modeled, two of the ancient city and two of the modern one. The old city is located at the South part of Jeddah, while the "modern" one is located at the Northern part. [7]These areas were modeled in accordance with the actual topography and urban structure of Jeddah. They represent typical urban patterns of the city. Solar radiation simulations were run on these models; a building with no solar masks on any of the four façades (South, North, East and West) was modeled as a reference - a blank sample.

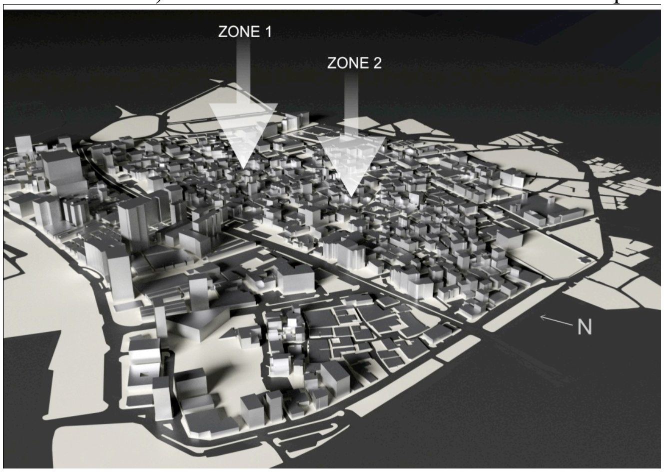


Fig. 3. The two zones of the old city on Revit. *(by the author)*

The four zones have different characteristics in terms of built surface, the surface of the streets and its rate in relation to the total area which is the same for all zones : 10 000 m² for a 100m wide square. The following table shows all the differences between the four zones.

TABLE I. THE FOUR ZONES AND THEIR DIFFERENCES

	Urban fabric - old city of Jeddah – average density	Urban fabric - old city of Jeddah – high density	Urban fabric – new area - apartments	Urban fabric – new area - villas (attached and detached)
Surface area (m²)	10000	10000	10000	10000
Built surface (m²)	5846,00	5534,00	5861,00	4973,00
Built surface (%)	58%	55%	59%	50%
Common area surface (streets and pavement) (m²)	4154,00	4466,00	4139,00	5027,00
Common area surface (streets and pavement) (%)	42%	45%	41%	50%
Façade surface area (m²)	11324	12546	13572	8160
Number of floors	R+3	R+2, R+3	R+4	R+2

Diffuse solar radiation is disseminated by clouds and the atmosphere ((i_d) the diffusion by the sky and the ground reflection(i_r)). This is always measured on a horizontal surface. The equation behind the software values is[8]:

$$Ib\ fshading\ \cos\theta + (id\ fsky) + ir \qquad (1)$$

IV. SIMULATIONS AND RESULTS

We have simulated the four areas : 1,2,A and B.

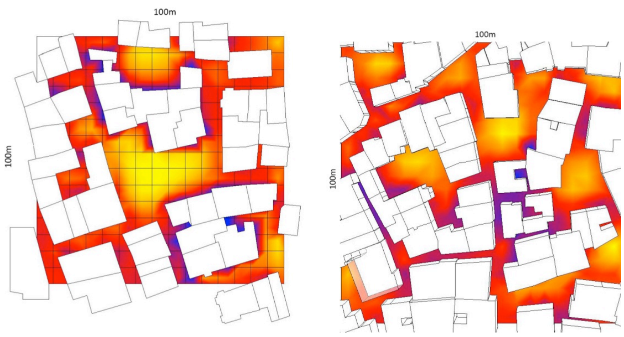


Fig. 4. The simulation of the two zones (1 & 2) of the old city. *(by the author)*

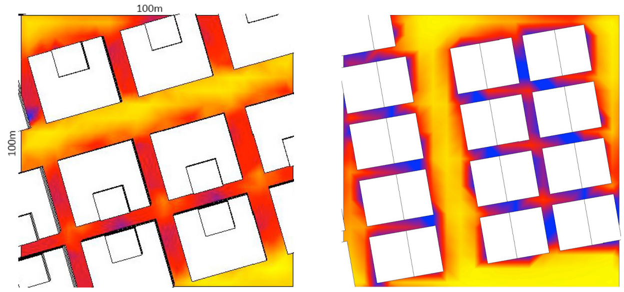
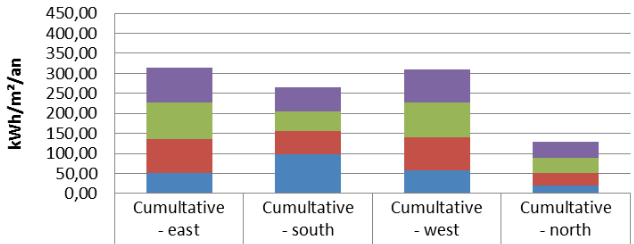


Fig. 5. The simulation of zones A and B of the modern city. *(by the author)*

The results were entered in Microsoft Excel in order to compare the differences between the 4 zones, for the 4 facades' orientations.

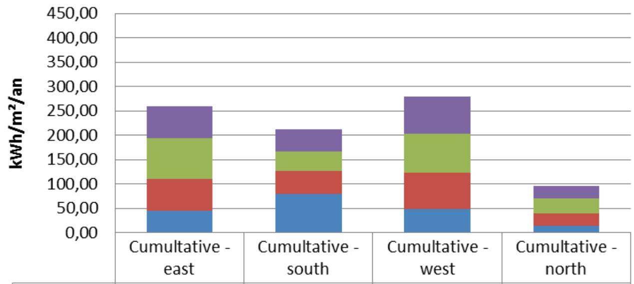
Solar simulations show the different values for each orientation and the ground on each zone.

TABLE II. THE AMOUNT OF ENERGY IN KWH/M²/Y ACCORDING TO THE ORIENTATION FOR THE ZONE 1



	Cumultative - east	Cumultative - south	Cumultative - west	Cumultative - north
Automne	86,45	58,93	81,82	41,48
Eté	91,46	48,66	87,56	36,42
Printemps	84,34	58,45	81,65	32,37
Hiver	52,31	98,52	58,75	19,41

TABLE III. THE AMOUNT OF ENERGY IN KWH/M²/Y ACCORDING TO THE ORIENTATION FOR THE ZONE 2

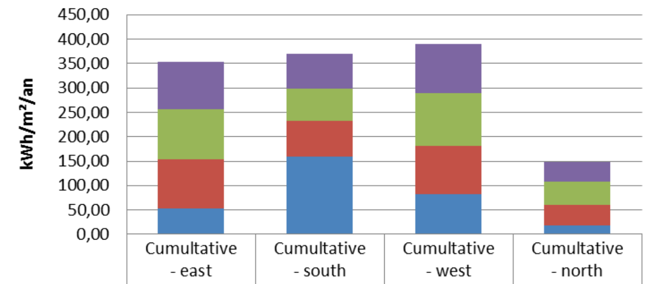


	Cumultative - east	Cumultative - south	Cumultative - west	Cumultative - north
Automne	65,67	46,76	76,49	25,56
Eté	83,13	39,90	79,39	30,51
Printemps	65,05	46,50	75,34	25,34
Hiver	45,46	79,57	47,90	13,36

As far as the zone 2 of the old city is concerned, we notice that its façades generally receive less solar radiation (apart from the southern side). Nonetheless, table 1 proves that zone 1 has a higher density of dwellings and its buildings are almost of the same height. This is mainly the result of the street configuration: streets are curved and have numerous cusps, thus hindering direct sunlight penetration. Zone 1 also has a large central square, which allows more sunlight radiation both on the ground and on the façades.

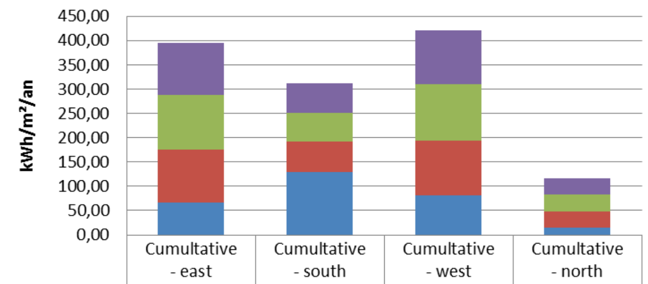
We are now going to present the results concerning the areas in the modern city.

TABLE IV. THE AMOUNT OF ENERGY IN KWH/M²/Y ACCORDING TO THE ORIENTATION FOR THE ZONE A



	Cumultative - east	Cumultative - south	Cumultative - west	Cumultative - north
Automne	97,66	71,40	100,40	40,90
Eté	103,20	66,17	107,54	48,07
Printemps	99,56	72,47	98,65	41,59
Hiver	53,65	159,25	82,47	18,34

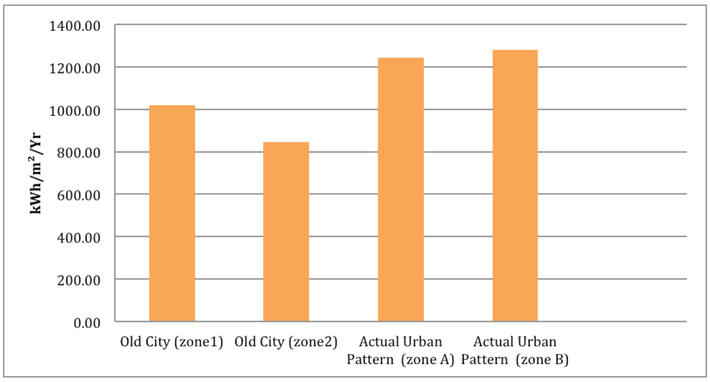
TABLE V. THE AMOUNT OF ENERGY IN KWH/M²/Y ACCORDING TO THE ORIENTATION FOR THE ZONE B



	Cumultative - east	Cumultative - south	Cumultative - west	Cumultative - north
Automne	107,79	60,80	110,59	32,60
Eté	112,28	58,04	117,47	35,89
Printemps	109,27	62,02	111,36	33,45
Hiver	65,89	130,19	81,66	14,67

After analyzing figures 4 and 5 we notice that streets are larger and more rectilinear in the modern city. Nevertheless, table 1 shows that zone A of the modern city has a higher density in terms of urban fabric with 59% of built surface. The street configuration allows us to understand why radiation values are higher in the modern city than in the old one. Average radiation levels reach 400kWh/m²/year for the western façade in zone A compared to 300kWh/m²/year in zone 2. The table VI confirms this study, who describes also the projected solar radiation on the ground for each scenario. Thus the energy reaching the façades is augmented by roughly 14.2%, which proportionally causes increased discomfort and energy consumption in terms of air conditioning.

TABLE VI. COMPARISON BETWEEN THE AMOUNT OF SOLAR RADIATIONS THAT FALL ON THE GROUND



V. INTERPRETATION AND CONCLUSIONS

The small variations that were registered after analyzing the two urban areas are mostly determined by the particularities of each neighborhood and each building. We notice nonetheless that there is a clear correlation between the urban structure and the amount of solar energy registered on ground level. Results have shown that the values of solar energy tend to be higher in the modern urban fabric than in the old one because of the significant differences between these two areas.

These results show that modern districts with straight streets and large avenues receive more energy than the old city with its curved and narrower streets.

The wider the street is, the easier it is for the sunlight to penetrate it. The fact that the modern city has almost only straight streets and avenues allows the solar radiations to penetrate in; on the other hand, the old city has narrower and more curved streets that cast enough shadow to considerably reduce direct sunlight.

This paper has shown the effects of two major types of urban patterns in Jeddah, which brings us to the following relation: Coefficient of energy reduction (*Cer*)= Incident energy on the urban pattern (*If*) / Original incident energy without masks (*Io*)

$$Cer = If / Io \qquad (2)$$

This relation helps us approach more efficiently the effects of the urban structure, and by extension the amount of solar energy that penetrates inside buildings according to the type of protection and its porosity.

In all scenarios, the Northern façade received less solar energy than the others. After a frequency analysis, this façade is the

favorite one chosen by people that answered the survey at more than 62%. That can be explained by the fact that the solar radiations have a physical impact on the energetic performance of a building but also on the satisfaction and comfort of the users (less overheating, more daylight, less solar protections). However, this is not the only factor for the satisfaction of the inhabitants, the second preferred orientation according to the survey is the West one while this is the most irradiated façade. We can conclude that solar radiations are a key factor for the comfort and the satisfaction of the inhabitants and for the energetic performance of a building but this is not the only one to take into account to build a sustainable housing in Saudi Arabia.
Our research shows the effects that the urban structure has on the degree of comfort and of energy performance registered in the buildings [9] of Jeddah. This allows us to see to what extent it is essential to study vernacular architecture and the old city structure in order to understand its functioning and to apply some of its concepts on new buildings in order to come closer to the creation of sustainable cities.

References

[1]- How buildings work, Allen, 2005

[2]- Traité d'architecture et d'urbanisme bioclimatique, Alain Liébard and André de Herde, p123a and 123b, 2005

[3]- Plea2004 - The 21th Conference on Passive and Low Energy Architecture., Eindhoven, The Netherlands, 19 – 22,September 2004 - Non-Uniformity in Incident Solar Radiation over the Facades of High Rise Buildings Dr Andrew Marsh.

[4]- Jeddah's strategic plan, by Jeddah Municipality. 3 Books, (2007).

[5]- ASHRAE; https://www.ashrae.org/ 2013

[6]- Ragette, Traditional domestic architecture of the Arab region, (2006)

[7]- Robert Mathew; Study of historical City of Jeddah, Consultants : Robert Mathew, Johnson et Marshal by The Ministry of Municipal and Rural Affairs, Saudi Arbaia (1981).

[8]- Autodesk website : http://www.autodesk.com/

[9]- IUG Journal of Natural and Engineering Studies 2013