DESIGN IN THE DESERT. A BIOCLIMATIC PROJECT WITH URBAN ENERGY MODELLING

Silvia Coccolo, Jerome Kaempf, Jean- Louis Scartezzini
EPFL Solar Energy and Building Physics Laboratory, Lausanne, Switzerland

ABSTRACT

The increase of the world's population leads to an urgent need of radical measures to diminish the energy footprint of humanity. This study considers the realisation of an optimal Masterplan in energy terms for the new EPFL Research Centre in Ras Al Khaimah, United Arab Emirates (UAE). The methodology makes use of an Urban Energy Modelling tool to define the best urban form considering solar irradiation and buildings' energy needs for cooling. The paper contains the simulation methodology, the simulation results and gives some insights about how to improve sustainability for this specific climate at the concept stage.

Keywords: Urban energy modelling, optimal urban form, subtropical-arid climate

INTRODUCTION

The world population is projected to increase by 47 % from 2000 to 2050 (United Nations, 2004). The growth of the urban population will vary in different sites, and in 2050 will reach 96 % in the United Arab Emirates. In this perspective it is essential to reduce the energy foot print of cities, knowing that they are responsible for 2/3 of the world's energy use (IEA, 2008). The climate in UAE is hot and dry, and the Rub Al Khali Desert covers the main part of the confederation. In this climate, buildings are responsible for the high request of energy to provide the cooling needs. The studies aimed by Givoni (Givoni, 1968, 1989, 1998) define theoretical guidelines to improve the comfort - in indoor and outdoor spaces- in hot dry climates. The study of the city of Kashan (Taleghani and al., 2010) in Iran defines the bioclimatic principles of the ancient Medina, from the urban to the architectonical scale. The measures in the city of Fez, in Marocco (Johansson, 2006), underline how the ancient Medina can assure a better comfortable outdoor climate, compared with the new European city.

The water scarcity is a problem for the federation: in UAE the most exploited source is the groundwater – with a total use of 880 Mm³/y – and the desalinated water – with a total use of 694 Mm³/y (Murad and al., 2007). These two sources are not renewable: the rate of recharge of ground water is inferior to the use, and the use of desalinated water is destroying seas flora and fauna.

In this climate, to reach sustainability, it is essential to reduce the energy consumption for building's cooling needs, and study less invasive water resource.

Nowadays, most of the buildings energy simulations neglect the influence of the urban context, missing the relationship between buildings which influence solar irradiation and related energy efficiency.

The aim of this study is to define a bioclimatic approach at the urban scale for the new EPFL (Ecole Polytechnique Federale de Lausanne) Research Centre in Ras Al Khaimah, using advanced urban simulation methods. The application of the Minergie standards for tropical climate (Fouad and al., 2011), and the optimisation of the urban form aims at reducing the energy needs for cooling on the site.

METHODOLOGY

To achieve the proposed project for the new EPFL Research Centre in Ras Al Khaimah, we define a methodology divided in three steps. The first one is the analysis the site, with the evaluation of the climatic data, such as external temperature, relative humidity, wind direction and frequency. Moreover, the traditional Arab architecture from the urban to the architectonical scale is studied. The second part concerns the reduction of the solar irradiation, studying the buildings geometry. The third part addresses the evaluation of the energy demand for cooling, applying the Minergie standards for tropical area.

Hot dry climatic analysis

The first approach to the project is the analysis of climatic data, obtained with the software Meteonorm (Meteonorm, 2012). The temperature reaches 47 °C during June -as the maximal value- and the minimal temperature during the winter is 7 °C. The relative humidity is high, and precipitations are around 110 mm per year. Two predominant winds affect the site: the sea breeze - from North- West, with an average speed of 2.39 m/s- and the sand storm wind, from South, that whips the area during August. The site is located in the desert loess area, with characteristics transversal dunes facing the winds.

The traditional Arab architecture as the bioclimatic archetype is considered for the project. The medina and the courtyard house are studied to define the bioclimatic strategies that will be applied on the project, reinterpreted with actual technologies.

Self-shading analysis

In this climate, it is essential to reduce the solar gains during the hottest months, and to ensure a correct daylight provision during the winter months. The buildings geometry and orientation has a great influence in the solar irradiation: choosing them wisely reduces the cooling needs during the summer.

Evaluation of cooling energy demand

The last part of the study concerns the simulation of energy demand for cooling. On the market, there are different software that can simulate the energy demands for cooling, but they analyse single building: they don't take into account the relationship between buildings, such as shadows and interreflections. For that reason we decided to use the software CitySim (Robinson, 2011), an urban energy software developed at LESO- PB/ EPFL. In order to be confidence on the simulation results, two existing buildings in Ras Al Khaimah and their transformation to achieve Minergie standards (Fouad and al., 2011) were simulated with CitySim. The results were compared with two previous studies made with EnergyPlus (Fouad and al., 2011). The difference between the two models is negligible in the existing building – around 1 % on the yearly cooling demand- but is higher – around 19 % - in the Minergie building, because of the complex blinds system studied with EnergyPlus.

For each building, we assigned the Minergie Standards for tropical area: the U value for roof and walls is 0.2 W/m²·K. The walls are composed of 2 cm of external plaster, 15 cm of insulation, 12 cm of brick, and 1 cm of internal plaster. The infiltration rate is 0.05 ACH. The U value of windows is 1 W/m²·K, and the g value is 0.05, taking into account the activation of blinds when the solar irradiation exceeds 150 W/m². The short wave reflectance of walls is 0.2; this value is the product of the wall and windows reflectivity, and their geometrical dimension. The colour chosen for the wall is pink, RAL (Reichsausschuss für Lieferbedingungen) 3015. This pigment assures a perfect compromise between the reduction of energy absorption and albedo: in the climate of Ras Al Khaimah, the solar irradiation is elevated, and buildings with white external surfaces can create important visual problems to pedestrian. In addition, RAL 3015 evokes the tone of the local loess sand. The maximal internal temperature of buildings is set to 26 °C, knowing the mean metabolic rate for the sedentary activity – 1.2 met – and the use of summer clothes, 0.5 clo. No heating system is applied, as in the UAE the temperature are comfortable during the winter months.

The cooling energy system is a heat pump air/ air, with a maximum power source of 372 kW, an EER of 4, and a ηtech of 0.25. The EER is defined as (Kaempf, 2009):

$$\text{EER} = \eta_c \cdot \eta_{tech} \qquad (1)$$

Where η_c is the Carnot efficiency and η_{tech} is the technical efficiency.

The electrical demand for cooling needs is rather high, and the annual solar irradiation is 2015 kWh on the site of Ras Al Khaimah. For these reasons, we decided to apply solar panel on the roof of the campus, optimising the total surface covered by panels, and comparing with the electrical needs.

DISCUSSION AND RESULT ANALYSIS

The new masterplan for the EPFL Middle East is defined as a courtyard house in a continuous urban texture. The total area of the project is 90,650 m², with an expected population of 435 people, including students and staff. The new campus will host five EPFL laboratories, the classrooms, the social area - library, auditorium- and the residence.

Results of the climatic analysis

The climatic analysis aimed at different solutions, transforming the problems of the site in opportunities to achieve a sustainable project.

The urban form is designed to implement the natural ventilation, optimizing the exposition to the breeze from North- West: the buildings are oriented perpendicular to the wind, and the atriums improve the natural circulation of the air in edifice. Wind towers are designed in the internal courtyard, ensuring natural ventilation in the court.

The lack of drinking water is solved using a machine that creates potable water from humidity. We analysed the water needs of the campus, taking into account the occupants (435) and the recommended litres per day (SIA, 2026:2006), as shown in Table 1.

Table 1 Water. Recommended litres per day

Purpose	Recommended (litres per person per day)	Total (litres per day)
Drinking water	17	7,395
Sanitation	21	9,135
Bathing	32	13,920
Toilets	47	20,445
Washing machine	31	13,485
Others	4	1,740
Total	162	70,470

The water need of the projected population is 70,470 litres per day, and 28,721,550 litres per year. The machine that transform the humidity in drinking water can cover the 69 % of water needs. the purification of waste water can cover the 18 %, and collection of rain water from the roof can insure the 13 % (Figure 1).

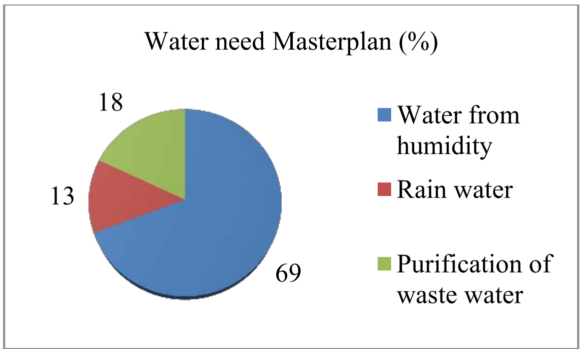

Figure 1 Water needs %

The vegetation has an important role to play in the protection from dust and wind, but also in the creation of a comfortable outdoor space. Knowing the problems due to the lack of water, we decided to plant local trees - which store the water in succulent leaves, or absorb water from the humid air- as Ghaf Trees (Prosopis Cineraria), Acacias (Acacia Albida) and different palms trees. Small gardens are provided with Desert ephemerals, Hyacinths and Thumbs, which flourish mainly during the winter and spring season.

The Medina and the courtyard house, as defined in the scientific literature, are studied, for their bioclimatic features.

At the urban scale, the medina can ensure:

- The minimisation of the urban temperature, thanks to the reduced sky view factor.
- The minimisation of glare in street and open spaces.
- The protection from dust storm, thanks to the high external walls.

At the architectonical scale the courtyard house can ensure:

- A compact layout, minimising the external surfaces, and maximising the internal volume.
- An external sheltered space -the court- where there is a pool and planted palms, ensuring ventilation and comfortable humidity.

In additions some guidelines can be applied:

- The building's orientation North- South.
- The reduction of air infiltration during the day, and the natural ventilation during the night.
- The design of small windows, in equal area in the windward and leeward side of the building.
- The use of integrated blind systems on the façade.
- The use of material with a high thermal inertia, such as brick.
- The implementation of natural ventilation, thanks to Malqaf (wind scoop) and Bagdir (wind tower).

Results of self- shading analysis

The buildings geometry and orientation influence the solar irradiation, reducing the cooling needs during the summer. We have studied seven buildings with the same typologies of wall, roof, floor, and the same glazing ratio per oriented surface. The basic plan is 25 m per 12 m (Figure 2, C and D). The simulation of the energy consumption shows that buildings with three floors consume 8 % less than buildings with two floors.

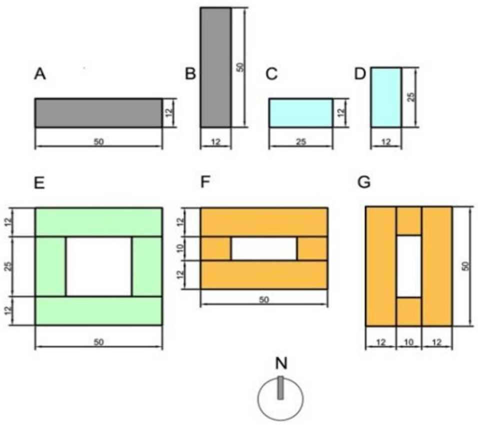

Figure 2 Building geometry

The courtyard house ensure a lower solar irradiation to the building: solar gains are reduced during summer, and the illumination is comfortable during winter (Figures 3 and 4). The detailed study of the solar irradiation on each floor of the building demonstrates that the difference in solar irradiation from the ground floor to the third one, on the court, can reach 41 % on the South- West side, and the difference from the internal and external surface can reach the 68 % on the North- East side.

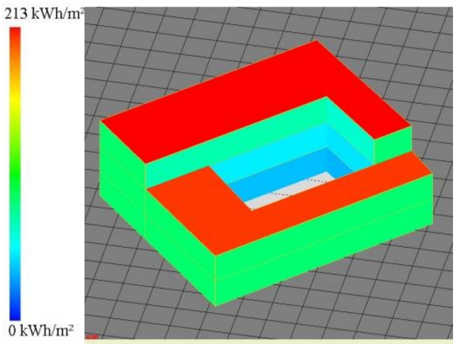

Figure 3 Solar irradiation analyse of the courtyard house for the month of June.

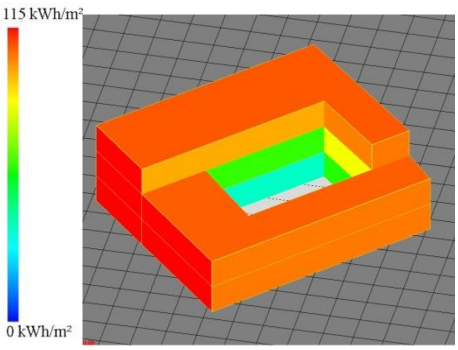

Figure 4 Solar irradiation analyse of the courtyard house for the month of December.

CitySim simulates the occupant's behaviour, such as the opening and closing of the blinds or the windows. The program assumes the closing of the blinds when irradiation exceeds 150 W/m²; in addition, a deterministic window opening strategy is applied and the windows are assumed open if the temperature:

$$Ta\text{- } Text > 1°C \qquad (2)$$

Where *Ta* is the internal air temperature (°C), and *Text* is the outside air temperature (°C).

With this strategy, we can ensure night internal ventilation, which is one of the most important elements for ensuring thermal comfort in the building.

The urban form ensure a comfortable illumination during the winter, and reduces the solar gains during the hottest months. The solar irradiation is defined during the summer and winter solstice, the 21st of June, and the 21st of December. During the summer months, the solar irradiation is reduced, thanks to the courtyard buildings form. However, during the winter, when temperatures are lower, the solar irradiation can enter in buildings, assuring a correct internal daylight. The difference in solar irradiation - during the summer solstice - between wall exposed to East and wall in internal courtyard, can reach 40 % (Figures 5 and 6).

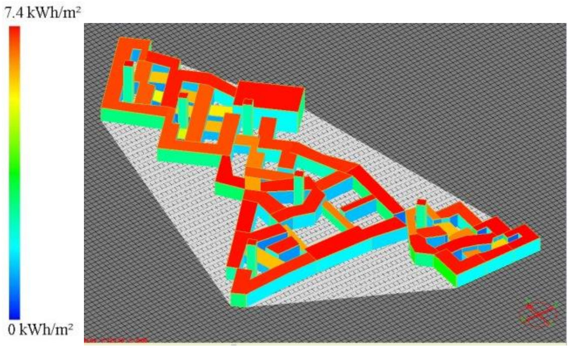

Figure 5 Solar irradiation analyse. 21st June.

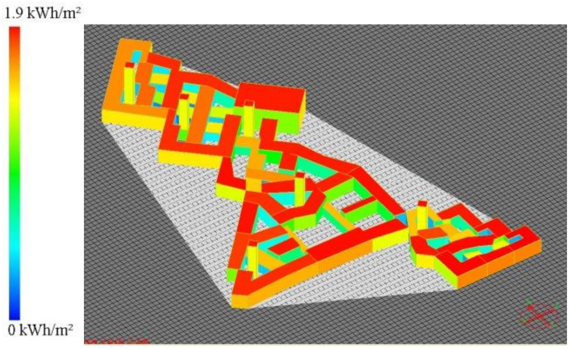

Figure 6 Solar irradiation analyse. 21st December.

Results of the energy needs for cooling

The impact of the urban texture is essential in the reduction of the energy needs: a stand-alone building needs 5 % more energy for cooling needs, compared to the same edifice in an urban texture. The position of the windows is substantial: reducing the opening in the facades exposed to the desert - 20 % of the wall - and increasing the openings in the internal courtyard – 40 % of the wall - allows the selective control of the natural light and solar gains, and reduces the energy needs for cooling.

The first simulation analyses the buildings without occupants, and the total energy consumption for cooling needs is 2,500 MWh/y. The second simulation defines the impact of people presence in the site: we created an occupation profile for each building, taking into account the people presence and the machine power of electrical appliances for each function (SIA, 2024:2006). Now the total energy needs for cooling is 5,700 MWh/y. The results show the impact of the occupants: the total energy needs in the Masterplan with occupants is 44 % higher than in the simulation without occupants. Looking into detail the sport area, we can see that in the sports centre the energy needs rise up to 80 %, with the highest energy needs of 28 kWh/m³y (Figure 7).

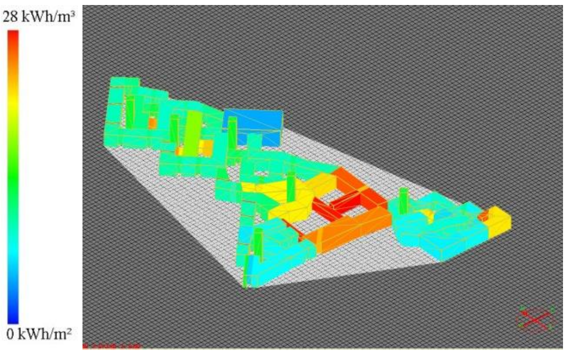

Figure 7 Energy needs for cooling, yearly results with occupants.

The solar energy can be used to ensure a sustainable electrical production. As an example solar panels BP SX 120 S are applied on the external roofs. We simulated different percentage of solar panel on the roofs, from 50 % - circa 10,000 m²- to 10 %. The object of the simulation was to define the percentage of electric consumption covered by solar panels, in the case of empty buildings. In Table 2 we can see that above 20 % of roof covered by solar panels, the production is higher than consumption.

Table 2 Solar panel production

PV surface per percentage of the roof	Energy consumption covered (%)
50	230
30	137
20	92
10	46
0	0

CONCLUSION

The object of the research was to develop a new approach in the urban energy modelling, analysing how the urban form can influence the energy consumption.

The bioclimatic elements applied to design the desert campus of the EPFL are:

- The building form is a courtyard house in a continuous urban texture.
- The external buildings are higher than the internal, creating solar and wind protection.
- Buildings cover the streets: creating shadows, and a comfortable outdoor space.
- The windows are mostly in the facades facing the court, assuring reduced solar gains during the hottest months, but the correct illumination during the winter.
- The chosen vegetation is local and is planted around the campus – to protect the campus form the dust storms- and in the court, ensuring shadows and increasing the natural ventilation.
- The wind towers and atriums ensure natural ventilation in court and buildings.

The study presented in this paper summarizes the bioclimatic approach at the urban scale for the design of the new EPFL Research Centre in Ras Al Khaimah. This study gives guidelines, and can be apply to other sites in hot and dry climate.

Future work could study the impact of the urban form in pedestrian comfort and optimize the vegetation.

NOMENCLATURE

η_c = Carnot efficiency
η_{tech} = technical efficiency
Ta = internal air temperature (°C)
$Text$ = outsider air temperature (°C)

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