Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 44 (2020) 84–91

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

1st International Conference on Optimization-Driven Architectural Design (OPTARCH 2019)

Shaping the microclimate: CFD-assisted design optimization to enhance the outdoor comfort of a recreational complex in the UAE

Vittorino Belpoliti[a]*, Hasim Altan[b], Hashem Alsebai[a], Omar Melahfci[a]

[a]*Department of Architectural Engineering, University of Sharjah, University City, 27272, Sharjah, UAE*

[b]*Faculty of Architecture & Fine Arts, Final International University, Kyrenia, 99370, Cyprus*

Abstract

The United Arab Emirates (UAE) federal government has recently endorsed new regulations aimed at ensuring a sustainable development path for the country. More specifically, the UAE Vision 2021 national agenda focuses on improving the quality of air, preserving energy resources, and minimizing the energy consumption caused by the built environment by implementing green-building practices. As a matter of fact, the built environment is among the reasons for climate change, as a direct impact and modification to the natural green fields. Buildings influence their surrounding microclimate, most of the time in an uncontrolled manner, eventually causing Urban Heat Island and Urban Air Canopy effect, and artificially modifying wind patterns. This is furthermore true for the UAE where uncontrolled construction activities of the last decades have modified the natural environment. The paper presents a design study assisted by Computational Fluid Dynamic (CFD) software simulation to optimize the design and shape of an outdoor recreational/retail complex in Sharjah, UAE, in order to achieve better environmental conditions and comfort, and to extend its usage annually. The preliminary findings of the study show that the optimized design could increase the typical usage of the outdoor complex from around 40% to 58%, with substantial social, energy, and financial benefits. The design focused on the reinterpretation of traditional environmental strategies, such as cross-ventilation, wind tower, and chimney effect, merging them with innovative technologies, as well as energy simulation software, assisting the design optimization.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Optimization-Driven Architectural Design

Keywords: Sustainability; Passive Design; CFD; Outdoor Environments, UAE

* Corresponding author. Tel.: 971-563920305
E-mail address: vbelpoliti@sharjah.ac.ae

Peer-review under responsibility of the scientific committee of the 1st International Conference on Optimization-Driven Architectural Design
10.1016/j.promfg.2020.02.208

1. Introduction

Passive design consists of design approaches that utilize natural ventilation and the use of renewables such as solar energy through architectural solutions (e.g. designs of site, plan, section, detail and node), eventually cutting down the building energy consumption and improving the built environment [2, 3]. In other words, responding to the natural context while also confined by the geographic environments, thus evidently local- and climatic-adaptive [4]. Compared to active design that features straight-forward metering method and obvious cost-driven effect, passive design has its weaknesses in terms of evaluation and performance quantification. On the other hand, when architects lack the knowledge and the potential of passive design, they can still bring on strategies that could accommodate climate characteristics and project features during the early stage of design in building projects. Instead, the architect would suppose complicated and expensive technology, and instruments, placing passive design on the wrong track [5]. Wind environment affects human physical wellbeing. Computational Fluid Dynamic (CFD) simulation technology not only brings convenience to architects but also opens up a new area in design where CFD wind environment simulation and architectural design strategies are combined. With the CFD wind environment simulation technology, enhancing projects by describing the wind environment in a design scheme, and conducting analysis based on simulation results, providing a basis for evaluation and performance quantification of wind environment design [6, 7].

The United Arab Emirates (UAE) is building a future in sustainability for the enhancement of the environment in different sectors of life according to the UAE Vision 2021. Furthermore, air quality plays a major role in this challenge, and unfortunately this had a negative effect on physical comfort in public areas, which is why during the hot season people tend to shelter themselves in cooled areas; avoiding the hot climate, increasing the power consumption of cooling, especially in outdoor facilities, while dropping the overall air index and quality of physical comfort. In fact, outdoor recreational/retail complexes in the UAE are only used during winter time, approximately from November to March, when the weather is mild (about 40% of the year). Considering that these complexes make revenues for about half a year, it could be asserted that their construction cost is twice the cost of a building that is fully operational the entire year round (similar to conventional closed shopping malls). The building shape has been modelled according to an iterative process assisted by CFD analysis using Autodesk Flow Design [8], step by step the building shape has been modified in order to increase ventilation in premises, with the aim to reduce temperature and humidity with particular regard to mid-seasons of the year (end of fall and beginning of spring).

This study, therefore, focuses on optimized design solutions for outdoor environments in the UAE with substantial social, energy, and financial benefits. The design focused on the reinterpretation of traditional environmental strategies, such as cross-ventilation, wind tower, and chimney effect, merging them with innovative technologies.

2. Approach and Methodology

The study presents the result of an integrated design approach that aims to enhance the overall microclimate and air quality of public spaces. The design approach involved a preliminary CFD analysis, using Autodesk Flow Design, to assist the modelling of a public commercial/recreational building in Sharjah, UAE.

The study moves within the national framework of sustainability policies (including the UAE federal government's socio-economic development plans; the UAE Centennial 2071 project, a happy and cohesive society; the UAE National Innovation Strategy; and the UAE Vision 2021, improving the air quality index, improving the share of clean energy), which target stimulating innovation in seven sectors, among which renewable energy, technology, and water, have been targeted in this study to achieve the following:

- Impact the overall microclimate;
- Extend the duration of visiting public spaces during the year;
- Improve the overall air quality.

Achieving a system of design interpretation would enhance and maintain the environment of the UAE in all its aspects. In order to do this, and as part of the study, CFD analysis has been carried out, which is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows

[1]. CFD was introduced in the architectural field in the 1990s, and the number of CFD-related studies has been constantly growing since 1997. The growth implies that researchers recognized the potential of CFD, and thus, an interest in CFD-related topics permeated the architectural field, allowing continuous development throughout multiple simulations effecting the massing of the building projects [9]. However, flow takes shapes from a variety of objects, and with the speed and simplicity of flow, it is not a full-fledged CFD code. It handles only wind tunnels by also making a lot of assumptions. While air speed can be adjusted, an arbitrary speed is assigned initially. The lack of knowledge concerning the principles of fluid mechanics has been one of the barriers as well. Using CFD requires knowledge of the underlying principles that can be translated into effective procedures. Nonetheless, concepts in fluid mechanics can be difficult for architectural designers, who are often visually oriented professionals.

As part of the design development stage, the project was proposed parallel to a main road, providing fairly a Southwest and Northeast direction by tilting the building, although, it was not possible at the same time to tilt the building to the best solar orientation, which would have increased its impact on the ground, hence requiring more land. Below are the more specific techniques applied as part of the study to achieve an optimized design.

Additionally, working on a single case study and addressing its problems on a specific location does not necessarily cover all of the UAE's typological areas, however, after conducting a survey with the residents of Sharjah and Dubai, the study focused on the most selected typological areas, which were the coastal areas.

2.1. Site analysis and project requirements

The site is located in the UAE, in the Emirate of Sharjah where currently a lot of development is happening by the main developer, Sharjah Investment and Development Authority (Shurooq). One of the sites was located on the sea front near the Emirate of Ajman (Figure 1) along the coastline at the Northern part of Sharjah.

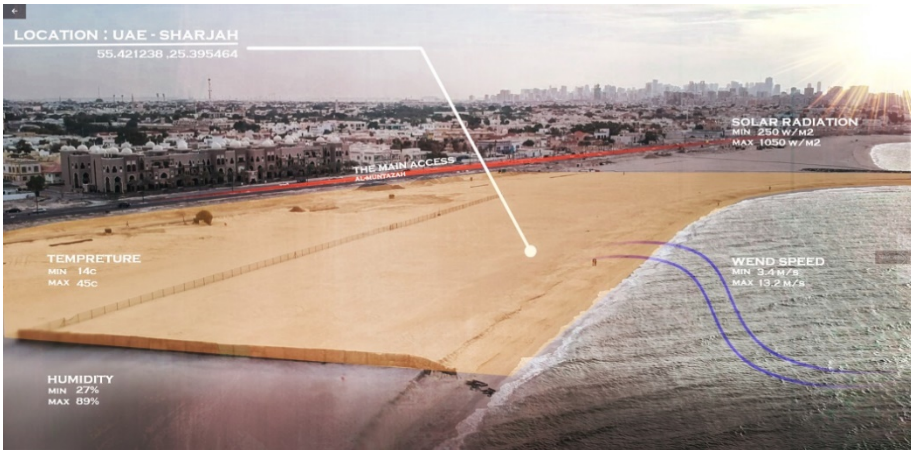


Fig. 1. A complete site analysis.

The local weather data has been obtained from the local Meteorological office as shown below (Figure 2). With the aim of exploring the possibility of implementing passive design strategies, a specific analysis showed the following useful aspects:

- The prevailing wind blows from the shore (Northwest) throughout the year (with a peak in November). Although it is mostly hot and highly humid during summer, in November the humidity is lower and the temperature is much cooler. It blows mostly during daytime (18 hours, from 12:00 pm to 4:00 am);
- A minor, but relevant, wind blows from the desert (South or Southeast). It is warm but dry, and is perceived mostly if far from the shore (desert locations). It mostly blows at night (8 hours, form 4:00 am to 12:00 pm).

General Information	Latitude	25°16'12"N)												
	Longitude	55°19'48"E)												
	Altitude	~6 m												
	Time zone	'C + 4 hours												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature	Record high [°C]	31.8	37.5	41.3	43.5	47.0	48.5	52.1	51.3	45.1	42.4	41	35	52.1
	Daily mean [°C]	21.1	20.6	24.8	30.1	33.4	35.8	38.7	38.5	35.2	32.6	25.4	23.4	29.97
	Record low [°C]	6.1	6.9	9.0	13.4	15.1	18.2	20.4	23.1	16.5	15.0	11.8	8.2	6.1
Humidity	Average relative humidity [%]	65	65	63	55	53	58	56	57	60	60	61	64	59.8
Precipitation	Average precipitation [mm]	18.8	25.0	22.1	7.2	0.4	0.0	0	0.0	0.0	1.1	2.7	16.2	93.5
	Average precipitation [days]	2	4.7	4	2.6	0.3	0.0	0	0.5	0.1	0.2	1.3	3.8	19.5
Wind	Wind direction	N-W	V / W	N-W	N-W	N-W / W	N-W	N-W	N-W	N-W	N-W	N-W	N-W	N-W
	Wind probability [%]	22	31	34	35	44	40	41	42	35	29	24	20	33
	Wind speed [Km/h]	17.75	20.41	19.62	19.76	21.96	21.28	20.05	19.19	18.61	17.24	15.55	17.60	19.08
	Wind speed [m/s]	4.93	5.67	5.45	5.49	6.10	5.91	5.57	5.33	5.17	4.79	4.32	4.89	5.30
	Mean Air Temperature [°C]	22	23	26	31	35	37	39	39	36	33	28	24	31

Fig. 2. Weather conditions in the UAE [10].

2.2. Design scheme of a sea front development project in Sharjah

After multiple meetings with the client Shurooq, the proposed site was established with three main functions; parking, activity area, shops and cafes (Table 1).

Table 1. Code and details of the project functions

Colour	Function	Max. height	Area
(red)	Parking	10 m	1600 m^2
(green)	Activity Area	8 m	800 m^2
(purple)	Shops & Cafes	5 m	400 m^2

As a first step, starting with an initial massing as shown in Figure 3. The site is located on the coast of Sharjah, near Ajman, receiving hot humid wind from the sea. The main purpose of the proposal was to maximize the usage with the design during winter seasons as well as keeping the area functional during hot seasons and fulfilling the desired functions assigned by Shurooq (Table 1).

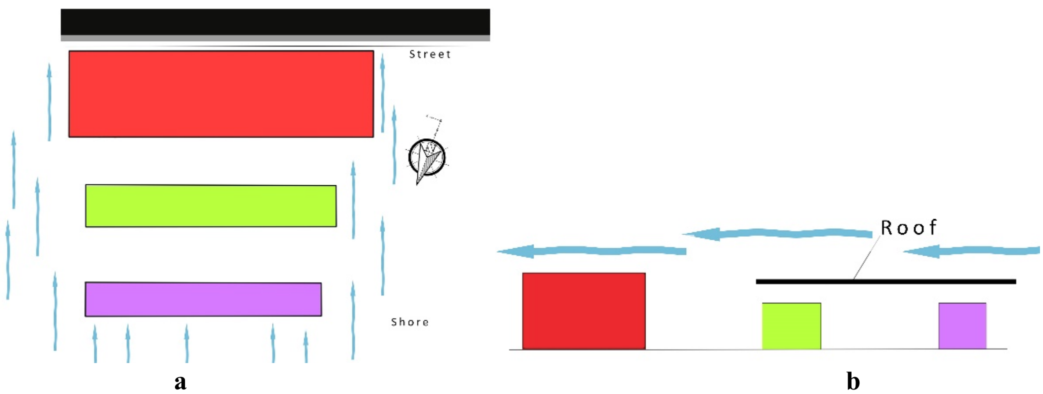
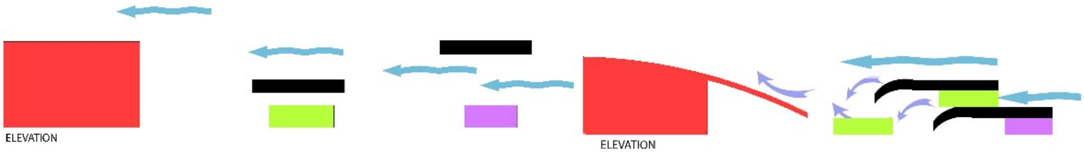


Fig. 3. The initial massing of the project; (a) Plan view and (b) Section.

2.3. Design stages

The project was dealing with a very humid area due to its presence being a sea front location, thus as all types of building in the UAE, it was going to be an indoor/closed space. However, when the requirements from Shurooq were received, there was a chance to implement this as part of a research work, and to further investigate passive design strategies in one of the typological areas existing in the UAE, with the aim to increase the usage period of the particular area while getting the most out of the research experience. Initially, a roof covering the whole area was considered, but by splitting the roof into parts, the design provided flexibility in its features (Figures 4-6). Using the roof as route controlling the channel of the wind would allow air distribution to focus on the core element of the project, which is the main path of the area, achieving human physical comfort.



a b

Fig. 4. (a) Splitting the roof; (b) Curving the roof.

By curving the roof, the wind was allowed to flow into the core element of the project, and the main path leading to different types of functions, using it as gate route that the air flows into, hence making the air spread out evenly with sufficient and efficient amounts (Figure 4). Finally, achieving the last form on the section plane and running it through a CFD analysis (Figure 5). The air coming from the upper opening is being directed into the lower level, increasing ventilation and human comfort levels.

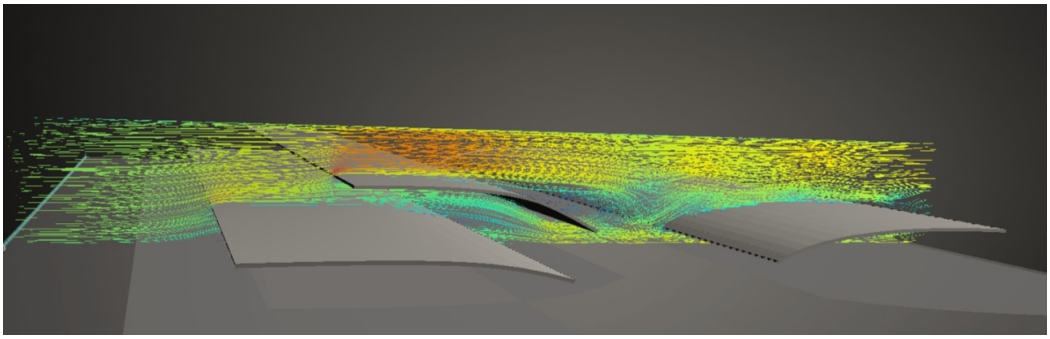
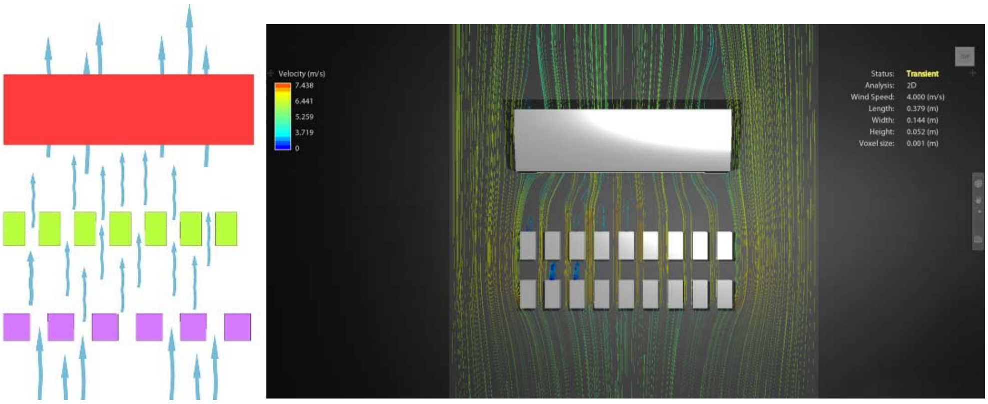


Fig. 5. Section view of the software result.

The final shape of the roof has been modified to accommodate the wind coming from the sea buffing and directing it into the main central area of the project while also providing the overall identity of the project, atheistically improving its shape and shading its area, decreasing the surface temperature as can be seen in Figure 6.

Fig. 6. Simulation final result.

Moving into the plan view was a completely different interpretation, having the wind coming mostly from the Northwest and directing it was challenging, especially in the shops area as it had to be completely open in order for the wind to circulate through it. The building shape has been modelled according to an iterative process assisted by CFD analysis; step by step the shape has been modified in order to increase the ventilation in the mass with the aim to reduce temperature and humidity with particular regard to mid seasons of the year. Through the process of defragmentation, the wind was enabled to circulate in the area between shops and cafes allowing the air to pass through smoothly (Figure 7). However, the shops were still linear in their geometry, making them an obstacle for the air.



a b

Fig. 7. (a) Masses air flow; (b) Air is spreading through the breakage of the masses.

Curving each shop allowed for a more flexible and efficient air distribution, having both these traits established a unique form design-wise that acts as buffers for the air coming from the sea. Usually CFD simulations run in 3D, but showing the result in 2D planes is much easier for interpretation (Figure 8). The first row of elements is acting as a buffer for the wind coming from the north, which increased the efficiency of the wind flowing through creating a dynamic airflow reaching the market.

a b

Fig. 8. (a) Curved masses air flow; (b) Curving the masses allowing effective air distribution.

3. Analysis and Results

Air has been effectively utilized covering up the missing natural ventilation in the area, through a series of steps where air quality has been modified to achieve human physical comfort. Reaching the final plan/shape that significantly impacted the overall air distribution as well as providing the necessary functions (Figure 9), the average air velocity has been increased from 4 m/s to 6-8 m/s, increasing the overall efficiency from 52% to 78% in terms of wind ventilation.

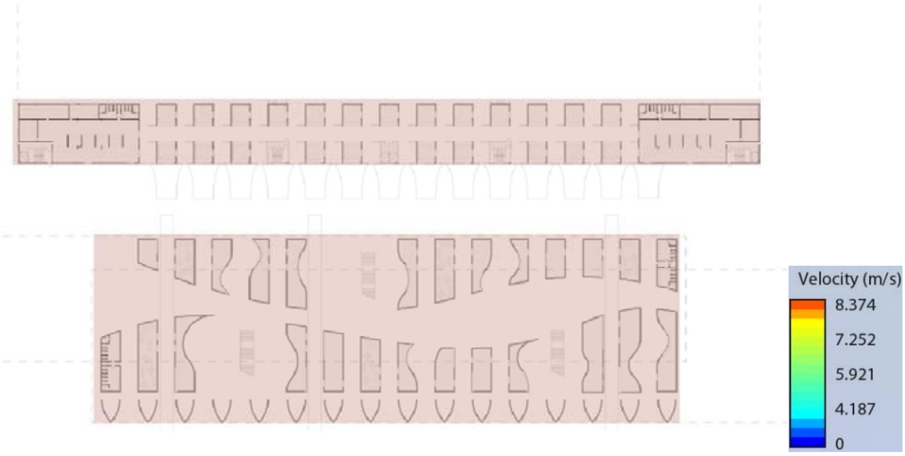


Fig. 9. The air velocity base meter for CFD simulations as well as the final shape of the plan.

Finally, CFD wind environment simulation results indicated that the air is evenly distributed throughout the site and has enabled the users to have comfortable experience inside the project, increasing the usage period of the area (Figure 10). Yet, there are still many other variables to take into consideration, looking into the differences in pressure as well as humidity levels that would prove to have a great impact on the simulation results. Accounting for the green areas is a total different section relating to the field study.

a b c

Fig. 10. The final shape of the project and views of different components; (a) Axonometric view, (b) interior render and (c) an exterior render.

4. Conclusion

With the outdoor project as an example, this paper explains in detail the methods to optimize such designs where CFD outdoor wind environment simulations have been undertaken. In basic design development, in order to make the most out of the environmental conditions, an architect needs to look at the following three aspects:

(1) After the functional requirements are met, make sure the wind distribution is spread evenly through the site.

(2) With consideration given to mass aesthetics and plane functions, create certain forms at suitable positions of a building to deflect wind and form through wind tunnels by distributing building volumes and creating open spaces, in order to provide natural ventilation.

(3) Create spatial forms that can help pressure ventilation when necessary, such as an alleyway, which would also help in the distribution of wind. With basic ventilation theories and knowledge, an architect can get a clear picture of the factors that influence natural ventilation in a project, thus improving building natural ventilation in designs of plane, elevation and section.

The CFD simulation technology enables architects to effectively and efficiently complete a quantitative analysis and an evaluation of passive design, hence it plays a key role for passive design optimization. After reaching a conclusion, it is recommended that a further investigation into the humidity percentage is carried out as this aspect would also play a huge factor in the air index of the UAE environmental conditions, having a direct impact on the outdoor spaces.

Acknowledgements

The authors would like to thank the local authority, Sharjah Investment and Development Authority (Shurooq), for their help and support throughout this design development project.

References

[1] H.H. Hu, (2012). Computational Fluid Dynamics. Fluid Mechanics, 421–472. doi: 10.1016/b978-0-12-382100-3.10010-1
[2] B. Givoni, Passive and Low Energy Cooling of Buildings, Van Nostrand Reinhold Company, New York, 1994.
[3] B. Givoni, Climate Considerations in Building and Urban Design, Van Nostrand Reinhold Company, New York, 1998.
[4] L. Yang, J.C. Lam, and J. Liu, Bioclimatic building designs for different climates in China, Architectural Science Review. 48 (2005) 187–194.
[5] G. John, D. Clements-Croome, and G. Jeronimidis, Sustainable building solutions: A review of lessons from the natural world, Building and Environment. 40 (2005) 319–328.
[6] S. Murakami, CFD and Building Environment Design, China Architecture & Building Press, Beijing, 2007.
[7] W. Guo, X. Liu, X. Yuan, A Case Study on Optimization of Building Design Based on CFD Simulation Technology of Wind Environment, Procedia Engineering, 121 (2015) 225-231.
[8] Autodesk Flow Design, https://www.autodesk.com/education/free-software/flow-design, 2019.
[9] Zhai, Zhiqiang & Chen, Qingyan. (2004). Numerical determination and treatment of convective heat transfer coefficient in the coupled building energy and CFD simulation. Building and Environment. 39. 1001-1009. 10.1016/j.buildenv.2004.01.023.
[10] Dubai Meteorological Office, https://www.windfinder.com/windstatistics/dubai, 2019.