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The Influence of Community Planning on Urban Thermal Environment

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Abstract. The purpose of this study is to examine the possible application of urban design in the aspects of building envelope and arrangement in order to improve wind and thermal conditions in high-rise building areas in urban community scale in hot-humid climate regions. This study compares different urban design options for a site in Thanh Hoa city, Viet Nam, and their potential effects on the wind field and air temperature at ground level. A Computational Fluid Dynamics (CFD) commercial code CFD-ACE simulation is used to investigate the wind and thermal conditions in community with those design options. Simulation results shows that a well-designed urban community could improve wind and thermal conditions by taking advantages of wind channelling and the Venturi effect, as well as adjusting the building orientation in order to reduce air stagnation.

Keywords: urban thermal condition, heat island, channeling effect, Venturi effect.

1. Introduction

Both theoretical and applied studies have been conducted to study wind and thermal conditions between buildings in order to provide input for knowledge-based expert and model systems. Many factors, such as surface albedo, sky view factor, and height to total floor area ratio, have been established beside wind velocity and solar radiation in order to understand urban climate, especially in the relationship with the urban heat island (UHI) phenomenon, and aim to address them at the concept design stage [1]. However, further study of the above factors is required on community scale in order to develop the design suggestions required by urban planning and design profession.

The purpose of this paper is to develop potential improvements to wind field and thermal conditions by adapting the envelope and arrangement of buildings in the planning phase. By means of computational fluid dynamics (CFD) simulation method, this research focuses on critical evaluation in order to find out solutions for designing a community in hot-humid condition.

2. Method

2.1. Numerical model

The mathematic model applied for the computational fluid dynamic (CFD) simulation is based on governing equations (known as the Navier-Stokes equations), formed by two laws:

- The mass of a fluid is conserved.
- The time rate of momentum change equals the sum of the forces on the fluid (Newton's second law).

A computational fluid dynamics commercial code CFD-ACE is applied to predict wind field and thermal condition in studied residential community.

2.2. Design option

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Position of the studied site belongs to a proposed New Urban Park in the east of Thanh Hoa city, Viet Nam. The selected 6.5 hectares of land is intended to be a residential area for about 2000 to 2500 average income families. The buildings are 12 to 15 stories high; occupy about 30% of the total site area.

The site is located in a hot-humid climate region with summer mean air temperature from 25^0C to 33^0C, the prevailing wind direction is from south-east, average wind speed is around $3.0m\ s^{-1}$ at 10m above open land. Mean relative humidity in this region for an average year is recorded about 85%.

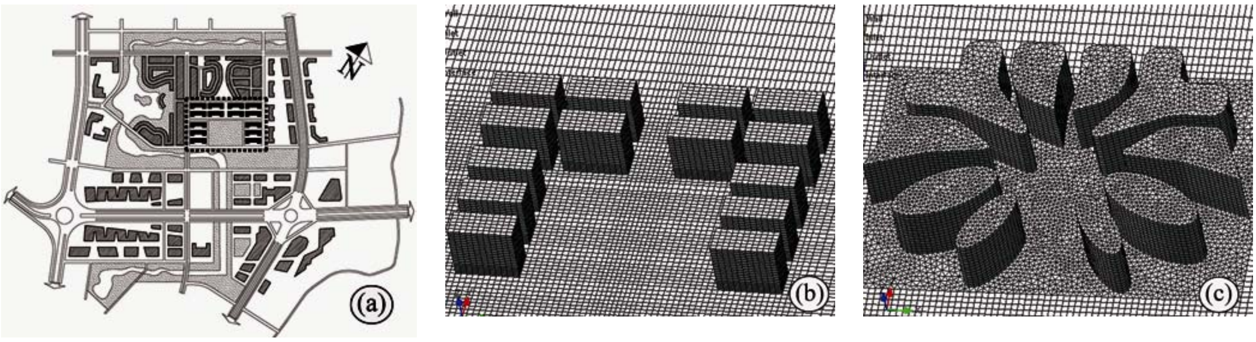

Fig.1. (a) Studied site in Thanh Hoa, Viet Nam; (b) Initial design; (c) Proposed design

The computational grids of two design options are built by 3D-CAD program, with the distances between grid points ranging from 3m to 5m, as shown in Fig.1

Original model: the community is designed to 14 rectangular building blocks (Fig.1b). Each block is 24m wide x 60m long x 50m high, and has 15 floors.

Proposed model: the community is organized in a flexible way (Fig.1c). The building envelopes are in free shapes with the same height as those in the original model. They are arranged in a way that the buildings form pathways which channel the wind to desired areas. Besides, the alleys are larger at their windward entrance and narrower at their leeward entrance, creating "Venturi shape" streets.

2.3. CFD simulation boundary conditions

Flow velocity at the inlet is derived from climate data, and is set to value v = $3m\ s^{-1}$ in the simulation. Inlets and outlets turbulence are calculated by Standard k-ε Model.

For simplification, the following assumptions are adopted to develop the heat balance model of ground and building surfaces: There is no concavity in the building surfaces, and all walls have the same thermal character (the heat transfer through the doors and windows is supposed to be very little, therefore the doors and windows are neglected in the model); The inside of the buildings have thermally insulated walls; the ground cover is concrete asphalt base and thermally insulated; The time at which thermal conditions are considered is 5pm.

The surfaces are set to a heat flux, $Q_s = -K_{conductivity}\frac{(T_{suface} - T_{wall})}{d_{wall}}$

For concrete wall, $K_{conductivity}$=0.6 $Wm^{-1}K^{-1}$; d_{wall}= 300mm; $\nabla T = 5^0C$;

For asphalt ground, $K_{conductivity}$= 0.8 $Wm^{-1}K^{-1}$; d_{ground}= 150mm; $\nabla T = 10^0C$. Then heat flux of walls is Q_w= 10 (W m^{-2}), heat flux of ground Q_g= 120 (W m^{-2})

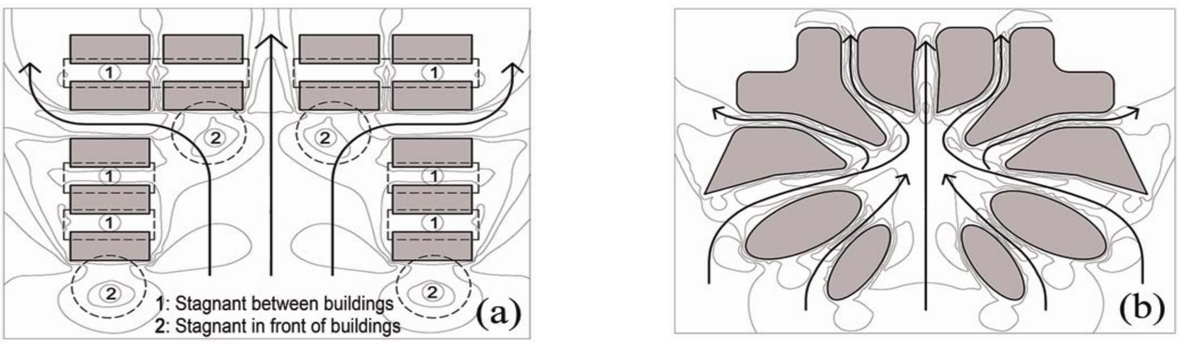

Fig.2: Wind field analysis at 2m height. (a) In initial model; (b) In proposed model

3. Result

3.1. Air pathways

Only 3 main air pathways are seen in initial model (Fig.2a) allow wind to penetrate through, while other areas are impenetrable. The wind distributes better in the proposed model with air paths in almost every street (Fig.2b). The mean wind velocity within the pathways at 2m height range from 1.05 $m\ s^{-1}$ to 1.21$m\ s^{-1}$ (0.8U_0 to 1.0U_0, as U_0=1.22 $m\ s^{-1}$ is the wind at 2m height in empty land in simulation).

3.2. Wind velocity within alleys

In initial model: Wind is weak in alleys i1, i2, and i4; the mean velocities along the axis of those alleys are 0.14 $m\ s^{-1}$, 0.62$m\ s^{-1}$, and 0.2$m\ s^{-1}$. Strongest wind appears in alley i3, mean velocity1.22 $m\ s^{-1}$, higher at the windward alley entrance, decreasing slightly further into the alley (Fig.3c)

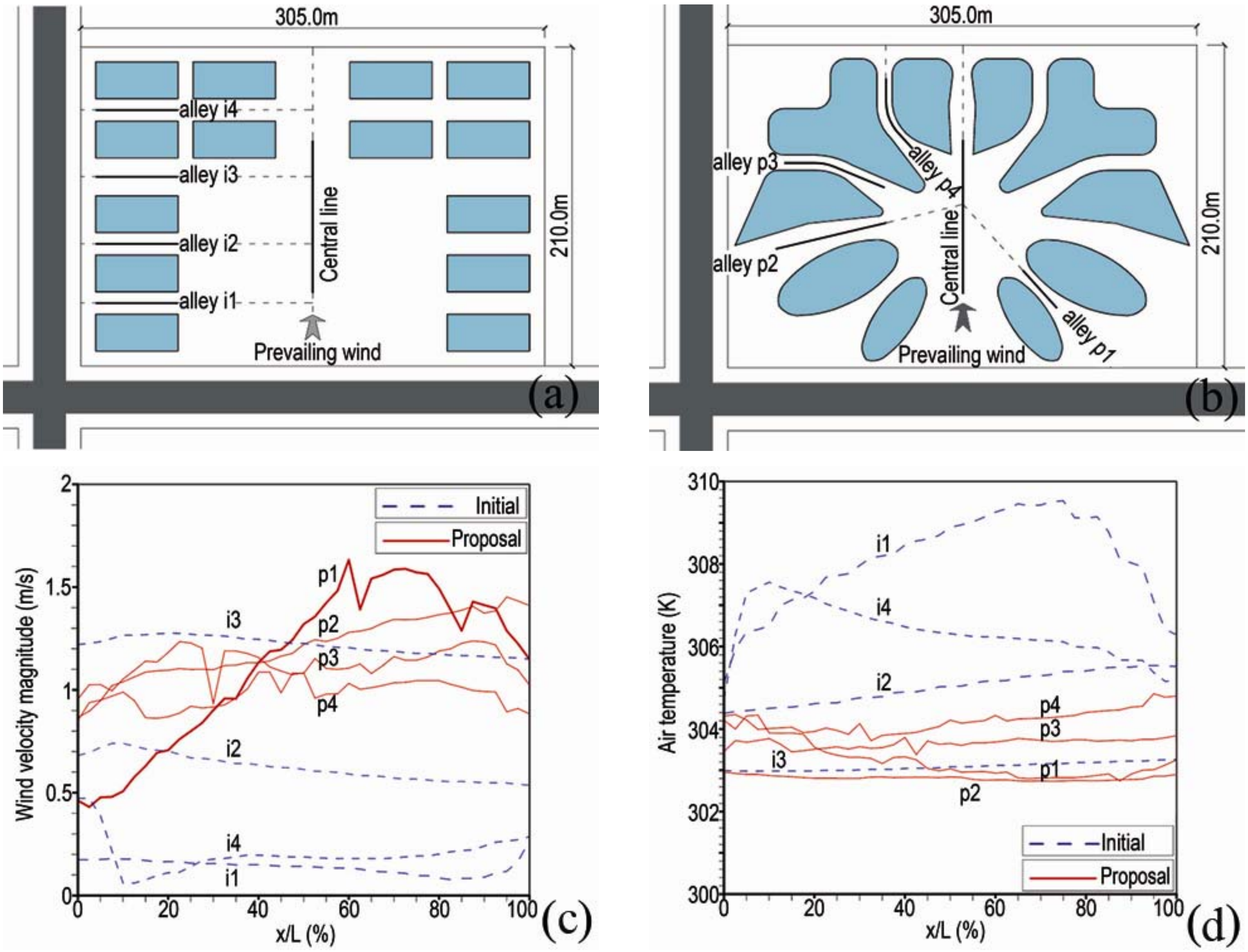

Fig.3. (a) Alleys position in initial model; (b) Alleys position in proposed model (c) Wind velocity at 2m height in alleys of initial model (i1 to i4) and proposed model (p1 to p4); (d) Air temperature at 2m height in alleys of initial model (i1 to i4) and proposed model (p1 to p4)

In proposed model: Mean wind velocity at 2m height along the axis of alleys p2, p3, and p4 are: 1.2 $m\ s^{-1}$, 1.05 $m\ s^{-1}$, and 1.05 $m\ s^{-1}$, respectively. The wind velocity tends to remain higher comparing to in innitial model along the length of the alleys (see Fig.3c).

The wind velocity within alley p1 demonstrates much more change. At the windward ally entry, the flow rate of p1 is lower than that of other alleys, but wind velocity increase quickly when going inside the ally p1, the maximum value U_{p1max} gained at the narrowest section is about 1.65 $m\ s^{-1}$ (1.35U_0).

3.3. Street ventilation

Simulation shows two types of windless area in initial model: The first is a sheltered stagnant street between buildings, which can be seen in alleys i1, i2, and i4, formed when the buildings are arranged perpendicular to the prevailing wind; the second is a standing vortex stagnant street in front of buildings. These stagnations cause the accumulation of heat within the alleys. Increasing in sensible heat raises the air temperature within alleys leading to higher temperature in initial model than in proposed model as shown in Fig.3d and Fig.4.

4. Discussion

4.1. Wind channelling effect

Wind blowing through the spaces between buildings is driven by a pressuring "channel" created by the building surfaces. This produces the so-called wind channelling effect, which can change the wind direction as well as accelerate wind velocity at certain positions.

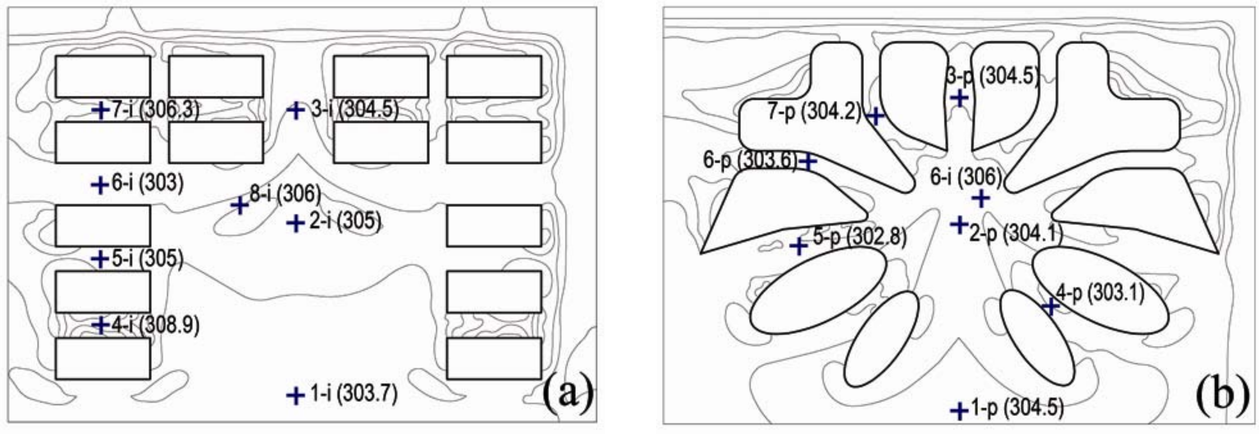

Fig.4. Air temperature distribution at 2m height. (a) In initial model; (b) In proposed model

Channeling effect creates more air paths: The high-rise nature of the community requires air paths between buildings as the most effective way to move air into areas, since above-roof wind cannot access the pedestrian level [2]. The flexibility of building shape and building arrangement in proposal model give the channels to direct wind flows to sheltered alleys. Both alley i4 (initial model) and p4 (proposal model) are obstructed by buildings from the prevailing wind, however, a wind flow, which changes direction when blowing through alleys p1 and p2, is "channeled" into alley p4 when meeting the pressure of the central air path. The stagnation observed in alley i4 in the initial model is destroyed, also means having better ventilation bring more cool air to alley replace the hotted air, thus the temperature in alley p4 are about 2 degrees lower that of alley i4.

Channeling effect speed up wind flow in designed places: Changing in building shape and arrangement could increase wind speed in certain places by directing wind flows. For instance, the central area of the community is supposed that desires wind most. The results shows that wind flows from alley p1 and alley p2 are channeled to near centra area, and the pressure from those flows strengthens the wind force in the central area, thus increasing speed of the air movement through the area. Wind velocity at pedestrian level in the central area of the proposed model is higher than that of the initial model; this leads to a drop in air temperature of about 1 degree.

4.2. Choosing building orientation to avoid frontal stagnation

The frontal stagnation seeing in numerical simulation of initial model is also analyzed in wind tunnel studies by Tsam *et* all [3], which show windless position in front of building is caused by standing vortex appears near the ground because of the wind separation when blows perpendicularly to a building surface [4]. Based on the mechanism of that standing votex, it is clear that if the building surface is oblique to the approaching wind, then the conflict between the main flow of the standing vortex and approaching wind would be reduced.

The stagnation areas, which can be seen in the initial model with a perpendicular building surface, is absent in the proposed model with an oblique building surface. The higher wind speed in same position the proposed model comparing to wind speed at stagnant area in initial model results in a drop in air temperature of about 2 degrees in that point. The case shows improved wind movement and decreased temperature when a building surface is oblique to the prevailing wind.

4.3. Venturi effect

The Venturi effect implies the increasing of flow rate when going through a constricted section. This issue is investigated in numerical studies by Blocken *et* all [5] for passage by perpendicular buildings. The study showed an increase wind speed near ground level and decrease of horizontal wind speed in the upper part of the passage due to the wind-blocking effect.

In proposal model, the wind velocities gradually speed up along alleys which are wider at the windward entrance and narrower at the leeward entrance. Simulation result demonstrates a significant rise in wind speed at pedestrian level along the axis of alley p1 of the proposed model. Although weak and chaotic at the windward entry, wind speed and direction become more concentrated and isotropic further into the alley due to its "Venturi-shape". Wind velocity at a 2m height at the narrowest section of p1is 1.60 $m\ s^{-1}$, as 3 times of the wind velocity at the leeward entrance. This implies that the law of Venturi effect works well in the case of this alley, and could be a solution for the wind deterioration in parallel-street [6]. In addition, the air temperature at a 2m height on the axis line at the narrowest section of alley p1 is about 1.5 degrees lower temperature at windward entrance, which proves the claim that the Venturi effect, in speeding up the wind flow, carry more heat out of the alley and decreases the air temperature in the alley.

5. Conclusion

This paper details two urban design options focusing on building envelope and arrangement for a high-rise urban community in hot-humid climate, where there is a need to increase wind velocity and decrease temperature at street level. The wind channeling effect, which is dependent on building shape and arrangement, would be an efficient way to drive wind into and through all streets in the community, and to concentrate air flows in certain area to speed up the wind. The Venturi effect can be created by reducing the width of a section of a street along the street axis. Due to this effect, wind speed is increase significantly along street at pedestrian level (up to 35% compared to that of empty land).

In the above cases, the increased wind flow velocity leads to a drop in air temperature. This contributes to human comfort in a hot-humid climate by both increasing wind speed needed for perspiration, and enabling human body heat balance by reducing the temperature of the immediate environment [7].

Discussions in this study show that urban designs on a community scale with improved wind and thermal conditions could be achieved by, at the very least, the application of the channeling effect, suitable building orientation, and the use of the Venturi effect. The application of these effects in urban design and planning toward sustainable urban living places could lead to a very different urban morphology in the future, one with far more flexible building envelope and arrangement.

6. Acknowledgement

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7. Reference

[1] Giridharana R., Laua S.S.Y., Ganesana S., Givoni, B., 2007. Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. *Build Environ.* , **42**, 3669-3684.

[2] Edward, Ng., 2010: *Designing for Urban Ventilation.* Earthscan, 384 pp.

[3] Tsang C.W., Kwok K.C.S., Hitchcock P.A.. Effect of building separation and podium on pedestrian-level wind environment. *The Seventh Asia-Pacific Conference on Wind Engineering*, November 8-12, 2009, Taipei, Taiwan

[4] Song, C., 1993. Computation of Wind Flow around a Tall Building and the Large-Scale Vortex Structure. *J.Wind Eng.* Ind. *Aerodyn* , **46**, 219-228.

[5] Blocken B., Moonen P., Stathopoulos T., Carmeliet J., 2008. Numerical Study on the Existence of the Venturi Effect in Passages between Perpendicular Buildings, *Journal of Engineering Mechanics,* **134**, 1021-1028

[6] Jian Hang, Yuguo Li, Mats Sandberg, Leif Claesson, 2010. Wind conditions and ventilation in high-rise long street models. *Build Environ.***45**, 1353-1365.

[7] Tzu-Ping Lin, Richard de Dear, Ruey-Lung Hwang, 2011: Efect of thermal adaptation on seasonal outdoor thermal comfort, *Int. J. Climatol.*, **31**, 302-312.