Open Space Scenario on Riverside Settlement to Access Comfortable Wind Environment

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Abstract. Beyond confines of the geography, urban form has direct impact to its microclimatic condition. The constituted set of buildings and open spaces contribute to its comfortable wind environment. This paper examines incorporation of open spaces as passive urban ventilation to infiltrate wind into a riverside settlement. The research conducted in warm-humid riverside settlement: Pasar Lama Tangerang. The actual wind environment is below desired breezes for outdoor activity like strolling. Upon actual site conditions, such as prevailing wind and morphology of existing buildings, we established three urban morphology scenarios: (1) ground floor open space, (2) pocket open space, (3) combination scenario. The research coupled with Computational Fluid Dynamics (CFD) simulation to calculate air flow rate and wind flow direction in every scenario. Study results reveal the three scenarios can prevent air flow from stagnating and allow better permeability of urban air. Reducing land coverage (open space) is one of the most efficient strategy to increase air flow rate up to 2 times the existing case. CFD simulation provide comprehensive data and help to understand systems, performance and implication of design. The capacity to measure climatic parameters compared and correlated with morphological and topography characteristic can improve the quality of built environment.

1. Introduction

City, downtown, and our neighborhood has been transformed from time to time through gradual development. In fact, all transformations and developments in city are not always carried out with a design guidance that improves the quality of life. Sustainability is most often considered concept in the context of improving the quality of life while living within the carrying capacity of the supporting environment [1].

This climatic advantage is closely related to the urban morphology of a settlement. Particularly city’s spatial structure, block texture, building form, open space layout determines urban climate [2]. The urban form influences the microclimatic condition and affect comfort, well-being and quality of life. Several studies have illustrated the effects of building layout, building disposition, building height related to permeability on air ventilation at pedestrian levels [3].

The importance of a safe and comfortable wind environment in the vicinity of buildings is now acknowledged by architects [3]. There have been a number of studies concerning on urban wind environment by computational fluid dynamics (CFD) in recent years, such as Chun-Ming Hsieh et al.11 (2010), Kimberley et al.10 (2017), Kavan et.al.12 (2018).

The study area is Pasar Lama Tangerang, located in hot and humid climate with river as topographic feature. Existing infrastructure on the site includes historical buildings, abandoned buildings, and streets. The constituted set of buildings and open space contribute to the comfortable wind environment. This paper examines incorporation of open spaces as urban air ventilation to infiltrate wind into riverside settlement. Three open space scenarios are established upon specific site
conditions, such as prevailing wind and morphology of existing buildings. All scenarios were modified within lateral connection, vertical connection and longitudinal connection to utilize cool air flowing over the river [5].

Those scenarios are tested in an artificial setting of computer simulation, where the causal effect can be examined. The computer simulation complements this experimental work by offering visualization of flow fields and testing many variations. [6]. Computational Fluid Dynamics (CFD) can calculate approximate result of air flow rate and wind flow direction. The simulation results are recalibrated into Lawson wind comfort criteria to access comfortable range of wind speed in urban environment. Figure 1 shows wind comfort category according to activity and its associated color values [7].

| Comfort category | Gust Equivalent Mean Speed m/s (kmh) |
|------------------|-------------------------------------|
| Sitting          | ≤ 2.7 (10)                          |
| Standing         | ≤ 3.8 (14)                          |
| Strolling        | ≤ 4.7 (17)                          |
| Walking          | ≤ 5.5 (20)                          |
| Uncomfortable    | > 5.5 (20)                          |
| Exceeded         | > 25 (90)                           |

![Figure 1. The Lawson’s comfort category according to activity at pedestrian level (Adamek et al.2017).](image)

2. Materials and methods

Site observation is conducted to collect three information: 1) actual urban morphology 2) wind flow rate in the neighborhood; 3) quality of the neighborhood. Figure 2 shows the study area in Pasar Lama Tangerang is about 67,000 m$^2$ with 3 streets layers behind the riverside road. The housing type in existing Pasar Lama settlement is categorized as low-rise single-family attached dwellings [8]. The buildings are identified as a mixed of houses, shop houses, historical buildings (Chinese heritage home and temple) and abandoned buildings (swallow bird nesting house). The built environment is not well organized with many abandoned buildings between remarkable historical buildings, dense and limited green open area.

Series of measurement on site using anemometer in figure 3 showed that wind speed at Cisadane riverside constantly about 3-6 m/s, but at the second layer street tend to be slower, approximately 1-2 m/s. Pasar Lama’s neighborhood does not have desired breezes for outdoor activity like strolling. Look into meteorological data about prevailing wind, most frequent wind is coming from north, north east and west (river side), frequently in 3-5 m/s [9]. In this situation, the proposed scenario must be aimed at improving urban air permeability on the second layer street.

Questionnaire is distributed to the community with stratified random sampling technique. The population is first divided into segments (residence or non-residence) but adequately sampled and compared. We find the community realized river feature visually attractive and has wind exposure. Apart from it, most respondents do not feel comfortable for outside activity. Half of them repute low wind flow in the surrounding and feels temperature is hot during the day.
Figure 2. Existing built infrastructure and climate data at Pasar Lama Tangerang, compiled from meteoblue c2020.

Figure 3. Site observation to measure air flow rate and wind flow direction, wind speed on riverside is about 3-6 m/s.
This study investigated a cause and effect relationship between urban morphology (open spaces) as independent variable and outdoor comfort (wind flow) as dependent variable. We used experimental research method [10] which is necessary to manipulate the independent variable so that the extend of causal effects can be established. We developed three open space scenarios to connect wind exposure from riverside into second and farther layers of the riverside settlement.

All scenarios were modified within lateral connectivity, vertical connectivity and longitudinal connectivity [5] to utilize cool air flowing over the river. Those scenarios are controlled and modified in computer simulation tools: CFD simulation. CFD can calculate approximate mean wind speed within the building blocks. The CFD simulation runs 240,000 cells blockage volumetrically, measuring air flow rate on few references height level in the environment.

The methodology in CFD is divided into three stages: Pre-Processor, Solver and Post Processor [6]. Initial tasks at pre-processor stage are setting up building geometry, scenario models, regional coverage and weather file. We used Jakarta weather file observed from year 2005-2010 by Badan Meteorologi, Klimatologi, dan Geofisika (BMKG). Then solver stage is about manage the grid, cell blockage, wind flow speed and direction to be able to start simulation. The wind direction is flowing from west and north west with condition of outside air temperature 32°C and indoor air conditioner 26°C. The last stage is about data visualization, average value, contour data and report generation. The simulation results provide comprehensive data and help to understand wind flow and open space implication. We took analysis result at the reference height of 2m, 6m and 10m with associated color values to Lawson’s wind comfort category. (Figure 4)

Figure 4. Pasar Lama existing condition with CFD analysis, simulated in computer simulation software (Ecotect).
3. Results and discussion

3.1 Urban morphology scenario
This study attempts to observe movement of air can take place passively. The urban morphology of massing, orientation of buildings, objects in existing context is not enough to accelerated wind into Pasar Lama riverside settlement. The perimeter buildings appear as 3-5 storey height that resist wind flow towards the inner neighborhood. The existing building blocks are arranged in lines that are parallel to the streets. The depth of this settlement is approximately 150 m from the edge of the river. Figure 5 shows existing wind environment at the second layer is undesirable for doing outdoor activity (strolling). Modification of urban morphology on this site is aiming to improve urban air permeability on the second and farther layer of neighborhood.

![Figure 5](image)

Figure 5. The second layer street inside the neighborhood has weak air flow rate (< 1m/s).

| Scenario                  | Existing          | 1                  | 2                  | 3                  |
|---------------------------|-------------------|--------------------|--------------------|--------------------|
| Connectivity to river     | Actual urban form | Lateral connectivity | Vertical connectivity | Longitudinal connectivity |
| Intervention              | None              | Convert ground floor as open space | Remove abandoned buildings as open space | Combination of ground floor and abandoned buildings as open space |
| Street & open area        | 42.432 m²         | 42.432 m²          | 42.432 m²          | 42.432 m²          |
| Building footprints       | 24.568 m²         | 24.568 m²          | 21.101 m²          | 21.101 m²          |
| Additional open space     | 0 m²              | 18.061 m²          | 3.467 m²           | 18.061 m²          |
| Section diagram           | ![Diagram](image) | ![Diagram](image)  | ![Diagram](image)  | ![Diagram](image)  |
The first scenario is proposed to reconnect wind exposure from riverside into inner neighborhood through lateral connection. This scenario converting all building’s ground floor area as open space, free of any building obstacles at pedestrian level. Except the historical building, this scenario adds 18.061 m$^2$ open space on ground floor area. Depending on local assets, the second scenario removing those abandoned buildings into open space. It creates several pocket open spaces (3.467 m$^2$) that vertically merge into existing open space. The third scenario is combination of first and second scenario. This scenario enhancing longitudinal connectivity of fragmented pocket space and direct wind flow from riverside. It sacrifices more assets and create 18.061 m$^2$ open space. Those modification scenarios can be seen at table below.

3.2 Wind environment (north west wind)
The built-up scenarios are simulated under two fluctuating wind condition from west (W) and north west (NW) direction are considered respectively. It should be noted that the location of sample point 1 to point 6 cover overall settlement area: upper part (point 6), center (point 1,2,3,4), lower part (point 5) and settlement layers: riverside road (point 1), second layer street (point 2), third layer street (point 3), forth layer street (point 4). Table 2 show NW simulation result where the existing urban morphology has low air flow rate in the lower part of settlements. From location 3 to location 5 shows longest street that get comfortable wind at pedestrian level (3 m/s) layer. However, the air flow inside the study area is relatively weak. River breeze is blocked by building and air flow becomes weaker on the second layer street inside the neighborhood.

Scenario 1 and scenario 3 has same additional open space (18.061 m$^2$) in the urban morphology. Both scenarios have second layer corridor fully infiltrated by wind. The average air flow rate approximately 2-4 m/s across the corridor. This wind exposure happened because the conversion of ground floor area into open space that breakdown wall barrier at pedestrian level. Evaluating the velocity color plot shows a different result between them. Particularly at lower part of the neighborhood (below point 3 and point 4), scenario 1 has higher wind velocity than scenario 3. This is result from abandon building is still stand above ground floor that keep the wind consistently channeled. Scenario 1 allow the third layer corridor (100 m from riverside) to access comfortable wind at the pedestrian level (figure 6).

### Table 2. The average wind environment on the target scenario within North West wind flow.

| Scenario | Existing | 1 Convert ground floor as open space | 2 Remove abandoned buildings as open space | 3 Combination of ground floor and abandoned buildings as open space |
|----------|----------|--------------------------------------|------------------------------------------|-----------------------------------------------------------|
| Intervention | None | Convert ground floor as open space | Remove abandoned buildings as open space | Combination of ground floor and abandoned buildings as open space |

| Data visualization | (wind direction: west north) |
|--------------------|------------------------------|

| Air flow rate | Location 1 | Location 2 | Location 3 | Location 4 | Location 5 | Location 6 |
|---------------|------------|------------|------------|------------|------------|------------|
| Location 1   | 4 m/s      | 5 m/s      | 4 m/s      | 5 m/s      |            |            |
| Location 2   | 1 m/s      | 3 m/s      | 1 m/s      | 2 m/s      | 4 m/s      | 3 m/s      |
| Location 3   | 1 m/s      | 1 m/s      | 3 m/s      | 2 m/s      | 2 m/s      | 2 m/s      |
| Location 4   | 1 m/s      | 2 m/s      | 3 m/s      | 4 m/s      | 2 m/s      | 3 m/s      |
| Location 5   | 2.5 m/s    | 2 m/s      | 2 m/s      | 2 m/s      | 4 m/s      | 3 m/s      |
| Location 6   | 1 m/s      | 3 m/s      | 2 m/s      | 3 m/s      | 2 m/s      | 3 m/s      |
Meanwhile in scenario 2 with the pocket open space, the environment has fragmented wind flow. Figure 7 shows wind flow at scenario 2 swirl within 1-2 m/s form L-shape wind pattern. The air flow rate is considered low for strolling but comfortable enough for sitting. The wind flow continuously with twirl on building corner. All remaining building help to achieve similar air flow rate at whole neighborhood. Scenario 2 is lower about 1 m/s air flow rate compare to scenario 1. This difference allows stretching in a comfortable wind environment especially when strong winds blow above average.

Scenario 3 as combination of scenario 1 and 2, shows a mixed air flow rate condition. Among other scenario, scenario 3 shows higher air flow rate in 6 reference location. The air flow rate on scenario 3 is indicated in comfortable wind environment within 2-4 m/s in the inner neighborhood (no red color). The concern is at lower part neighborhood, it left a big area with lower air flow around. This condition probably because the absence of abandon building in this scenario. The abandon buildings height are between 9-15 m and will also help to channeling the wind velocity into the neighborhood.

**Figure 6.** All street corridors in scenario 1 has access to comfortable wind environment, generated with Ecotect.
3.3 Wind environment (west wind)

As shown in Table 3, the average wind environment on the target scenario within West wind flow. The existing urban morphology has six streets that connect inner neighborhood to the riverside. Those streets are facing the west side, like a corridor that can be passed by the river breezes. The width of the street in between 3-5 m is good enough to match the frequent wind flow from the west side. This urban structure affects wind environment around the intersection and some open area have high air flow rate, indicated green to red color. However, the air flow along the vertical street in this neighborhood is relatively weak.

**Figure 7.** Wind flow swirls within 1-2 m/s at scenario, generated with Ecotect.
Table 3. The average wind environment on the target scenario within West wind flow.

| Scenario | Existing | 1 | 2 | 3 |
|----------|----------|---|---|---|
| Intervention | None | Convert ground floor as open space | Remove abandoned buildings as open space | Combination of ground floor and abandoned buildings as open space |
| Data visualization (wind direction: west) | ![Data visualization](image) |
| Air flow rate | | | | |
| Location 1 | 5 m/s | 4.5 m/s | 4.5 m/s | 5 m/s |
| Location 2 | 2 m/s | 3 m/s | 4 m/s | 3 m/s |
| Location 3 | 1.5 m/s | 1.5 m/s | 1.5 m/s | 1.5 m/s |
| Location 4 | 2 m/s | 2 m/s | 2 m/s | 1 m/s |
| Location 5 | 1 m/s | 2 m/s | 2 m/s | 2 m/s |
| Location 6 | 1.5 m/s | 3 m/s | 3 m/s | 3 m/s |

Since most of the buildings are facing west and east, converting ground floor as open space in scenario 1 will able to increase air flow rate within neighborhood. The data visualization at table 3 show all the corridor spine (north-south) in scenario 1 has comfortable air flow rate (3 m/s) and less turbulence than the existing environment. In detail figure 8, it shows almost no dead air zones in the pedestrian level and accelerate wind speed at some corners.

In humid climate fully open courtyard is one of comfortable outdoor spaces as it is in scenario 2. The courtyard become wind catcher for the river breeze. Figure 9 show wind environment in scenario 2 has gradual air flow contour. This means less turbulence will happen and with larger open area give a swirl breeze. Scenario 2 has many of this spotted contour which will be the pleasant area during the west wind direction blown.

Scenario 2 shows acceleration wind speed at some corners. Scenario 2 breeze is calmer than others in responding to west wind. Several pocket open areas emerge in the context and having 2-4 m/s air flow rate. At same observation points show that scenario 2 is not much differ than scenario 1. Figure 10 shows that the lower part of the neighborhood can access 2 m/s wind flow in average. This scenario performs higher wind speed than in NW environment. The existing is stagnant with air flow on the second corridor.

Figure 11 shows when the abandon buildings in scenario 3 are removed, flow vector of the wind is accelerated and rerouted west wind than in scenario 2. Without 3-5 storey height building located, the wind environment in scenario 3 more evenly distributed in all areas.
Figure 8. Almost every corridor in Scenario 1 has no dead air zones for the neighborhood towards the prevailing west wind.

Figure 9. Scenario 2 with gradual contour of air flow in larger open area provide breeze and less turbulence.
Figure 10. Comparison of wind acceleration in the neighborhood (a) existing, (b) scenario 2, generated with Ecotect.
Figure 11. Scenario 3 accelerates and reroutes west wind flow (a) scenario 1, (b) scenario 3, generated with Ecotect
4 CONCLUSIONS
Based on the study of urban morphology and urban microclimate, open spaces create a suction effect that accelerate and prevent air flow from stagnating. The simulation result reveals open space in urban structure play important roles to achieve climatic benefits of the geography feature. The open spaces act effectively as passive urban air ventilation to Pasar Lama riverside settlement.

Those three scenarios are not much different one to another in terms of air flow rate. All of them not surpass the comfort limit of walking 5,5 m/s. But they are very different in terms of the physical urban form. The smallest transformation in terms of urban morphology is inside scenario 2, that is 3.467 m² pocket open space. Therefore, we think scenario 2 is the most appropriate plan for Pasar Lama to mitigate the built-up environment for comfortable wind environment.

Scenario 2 offer 2-4 m/s air flow rate in the outdoor area which comply to Lawson wind comfort category for sitting, strolling and walking. This scenario has swirl effect combine with gradual contour of air flow in larger open area. This gives a pleasant breeze and without turbulence at pedestrian level. The other scenarios are slightly higher air flow rate in few places and potentially over exposure in windy situation. Reducing land coverage (open space) is one of the most efficient strategy to increase air flow rate up to 2 times the existing case.

The study using CFD simulation provide comprehensive data and help to understand systems, performance and implication of design. It helps architect considered adequately during the design phases to construct a comfortable wind environment with the full capacity of actual environmental feature. This knowledge will lead architect and planner to design a better quality of life and sustainable settlement.

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AUTHOR’S CONTRIBUTIONS
The manuscript was written by 1st together with 2nd. Field of work was conducted by 1st. Literature review was provided by 2nd. All of the authors contributed in data analysis.

COMPETING INTERESTS
The authors declare no competing interests.

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