



## Preliminary Study on the Wind Flow Simulation Over a Biophilic City

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### ARTICLE INFO

#### Article history:

Received 9 May 2020

Received in revised form 10 September 2020

Accepted 15 September 2020

Available online 6 October 2020

#### Keywords:

Biophilic; vegetation; wind flow; urban; simulation

### ABSTRACT

Biophilic city refers to the affiliation of the cities to conserve the natural environment and strive to achieve high connections with the green surroundings. As cities face swift urbanization, the green lungs of vegetation and forestry are sacrificed to accommodate buildings and infrastructures needed by the increasing population. Via biophilic design approach, countries like Singapore and New Zealand have proven that they are able to reclaim the nature and green environment for better quality of lives. This preliminary study is therefore aimed to develop the biophilic climate-conscious design for an area by focusing on the biophilic way of sustaining natural wind condition. This is due to the fact that the disturbance on natural wind condition might lead to bad ventilation or other significant modified wind flow such as gust, where in worst case scenario, may cause disaster cause by abnormal wind. As a result, this paper is expected to discover an appropriate wind flow simulation for wind flow map of a chosen potential area which is useful in guiding the local authorities towards future development of naturally environment.

## 1. Introduction

By 2050, the urbanization and population growth are projected to add 2.5 billion people to the cities [1]. As a result, various countries including Malaysia face challenges in meeting the needs of urban population and expansion. Undeniable, the urbanization also leads to the deforestation [2]. In contrast, biophilic city term is still alien to Malaysians although city like Langkawi, Kedah is aggressively endeavoured towards becoming Naturally Langkawi [3]. A biophilic city refers to the integration of the cities to conserve the natural environment and strive to achieve high connections

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<https://doi.org/10.37934/arfmts.77.1.172179>

with the green surroundings [4]. Many elements involved in managing the biophilic city. One of the important measurements is the use of natural ventilation and airflow [5].

Primarily, biophilic defines as the innately emotional affiliation of human beings to other living organisms [6]. The concept of biophilic that near to human needs and close to nature makes biophilic dramatically popular in urban planning stage. Moreover, biophilic cities known as abundant nature in close proximity to urbanities that value residents' innate connection and access to nature through opportunities to be outside and to enjoy the multisensory aspects of nature by protecting and promoting nature within the city [7]. Hence, it is suggested by this paper that biophilic cities are cities that generate natural systems in term of natural ventilation and airflow, thus create an ecosystem for biodiversity outcomes. However, the "green cities" are a special case of "sustainable development" for cities [8] that have common green-blue infrastructure, such as city forests, river systems and lakes, parks and gardens, roof and wall greening [9]. Besides that, green cities as a multifunctional space that benefit humans, wildlife and the larger environment [10] which suggested that green cities promote energy efficiency, renewable energy and green solutions [1] with the intention of maximising social and economic benefits [11,12].

There are efforts to reinforce and integrate the green, sustainable and preserve nature in ensuring sustainable development in Malaysia. The most recent is the Eleventh Malaysia Plan 2016-2020 in addition addresses the strategic thrust of pursuing green growth for sustainability and resilience. In line with this, the Malaysian government focuses on strengthening the enabling environment, promoting sustainable consumption and production, conserving natural resources, and strengthening against climate change and natural disaster [13].

Internationally, one of the selected cities acknowledged as a biophilic city is Wellington, New Zealand. In total, 30 unique characteristics were discovered through the validity test by using Geographic Information System (GIS) mapping in order to claim Wellington as of biophilic city. The airflow variability that falls under the elements of nature of spaces and places is an important parameter in ensuring the buildings are able to be linked to its surrounding [14]. Another country which is located nearby the Malaysia's southern boundary, Singapore also recognized as a biophilic city. As instance, a small district in Singapore known as Punggol Northshore integrated its urban ecosystems into town planning. Clusters of trees and shrubs that are effective in air purification are strategically planted along the footpaths in order to direct and enhance the wind flow in ensuring the surrounding air quality. This study was priory done through Computational Fluid Dynamic (CFD) [15].

The quantitative effect of different urban vegetation conditions on the outdoor thermal comfort of pedestrian was also measured using a scaled model site [16]. It is shown that the wind speed of the pedestrian space mitigated with increasing vegetation by 0.83 to 0.51 reduction ratios for mostly vegetated canopy. Not only that, there is also significant effect normal to the predominant wind direction by varying the number of trees planted in the sidewalk. The wind speeds above an urban park slowed down three times with the presence of vegetations. Yet, a crucial assessment on the aerodynamic parameterisation for accurate wind-speed estimation still needed with the support from the on-site measurement and wind tunnel experiments with various arrays of buildings and vegetations [17].

## **2. Proposed Methodology**

### *2.1 Process Flow Chart*

This study is still at the initial stage of formulation the statements of the problem. Throughout this paper, brief literature review done in parallel of the aim and objectives of the study in order to

figure out the suitable method to be applied. Figure 1 shows the flow chart of this study in guiding towards achieving the desired outcome.

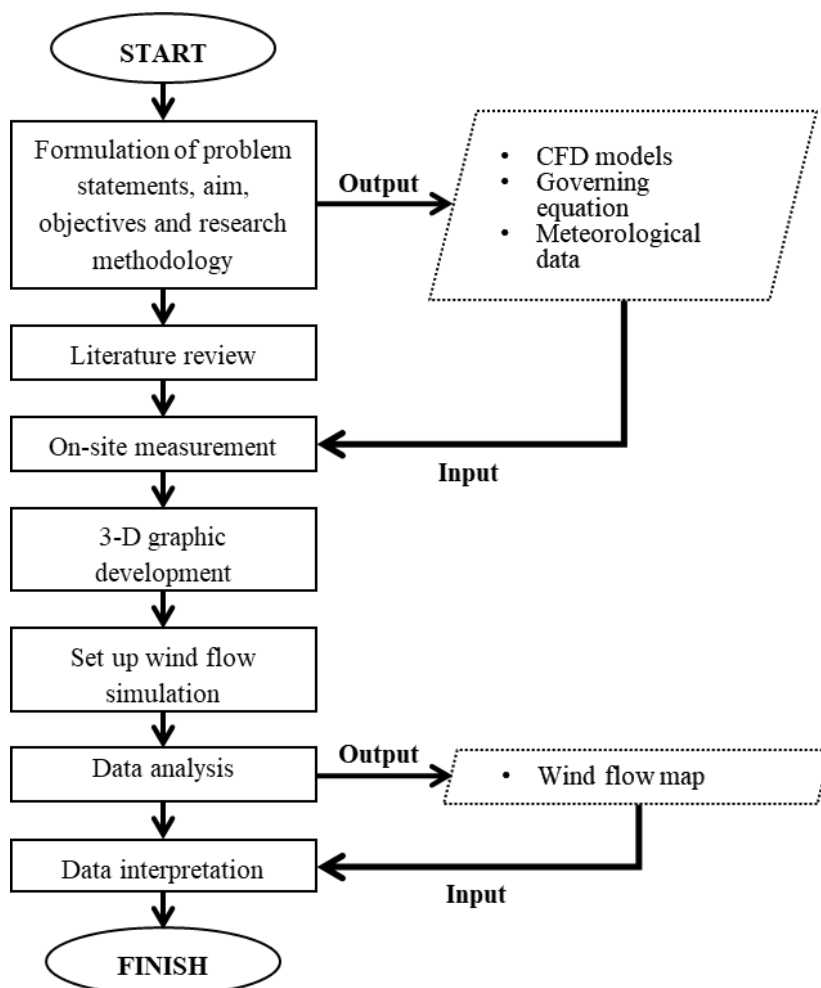


Fig. 1. Process flow chart

## 2.2 Simulation Setup

This study will consider a suitable wind flow simulation over a build-up area with the presence of vegetation. An optimum normalized value of vegetation to buildings and the porosity of vegetation will be taken into account. A modified morphometric method with meticulous aerodynamic parameterizations on the roughness element of both buildings and vegetation will be applied [17]. Besides that, large-eddy simulation (LES) with the lattice Boltzmann method is proposed to counter the wind flow in the build-up area that induced turbulent flow [18]. This simulation will be executed using the OpenFOAM software [19].

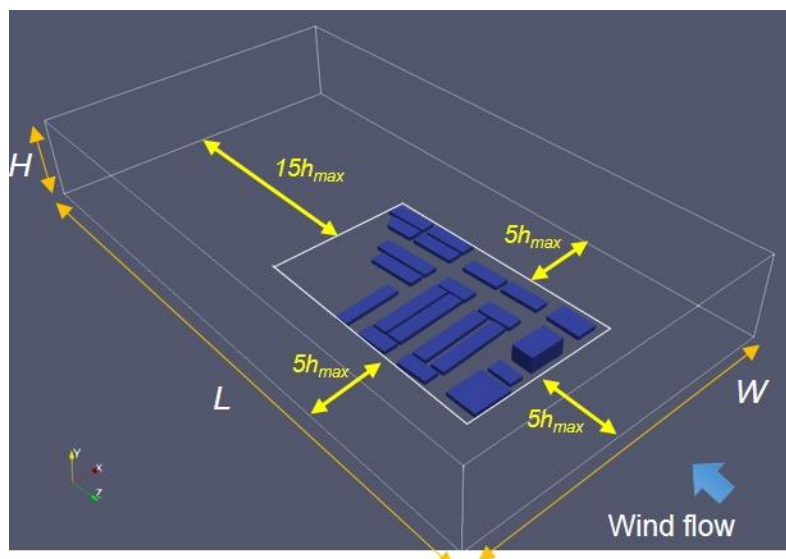
There are many parameters need to be carefully examined prior to the execution of the wind flow simulation over a vegetated build-up area. The simulation domain setup will consider the 3D graphic development that includes the chosen urban landscape and vegetations with the details on its aerodynamic parameters and porosity respectively. As the input to the simulation, the prevailing wind in terms of its magnitude and direction need to be determined. In considering the limitation of this complex simulation and the capacity of the available facilities, homogeneous mesh for the building, vegetation and wind (instead of a real wind profile) will be used in this preliminary study.

As shown in Figure 2, the domain size is about 400 m in streamwise (x), 300 m in spanwise (y) and 10 m in vertical direction (z). This domain is reproduced using a grid resolution of 1 m containing ground surface data i.e. building height while the topography is set to be flat. The maximum building height,  $h_{max}$  is 28.0 m.



**Fig. 2.** Map showing location of Jalan Pandak Mayah and the simulation domain within the dotted boundary. Google Earth, [earth.google.com/web/](http://earth.google.com/web/)

Figure 3 shows the idealized three-dimensional (3D) model of the urban blocks at Jalan Pandak Mayah. The geometry of the computational domain is based on the guidelines set by the Architectural Institute of Japan (AIJ) for performing a CFD simulation. The upstream and lateral lengths are approximately  $5h_{max}$  while the downstream length is  $15h_{max}$ . The height,  $H$  and width,  $W$  of the computational domain are 140 m (i.e.  $5h_{max}$ ) and 544 m, respectively. The entire length of the domain,  $L$  is 992 m.



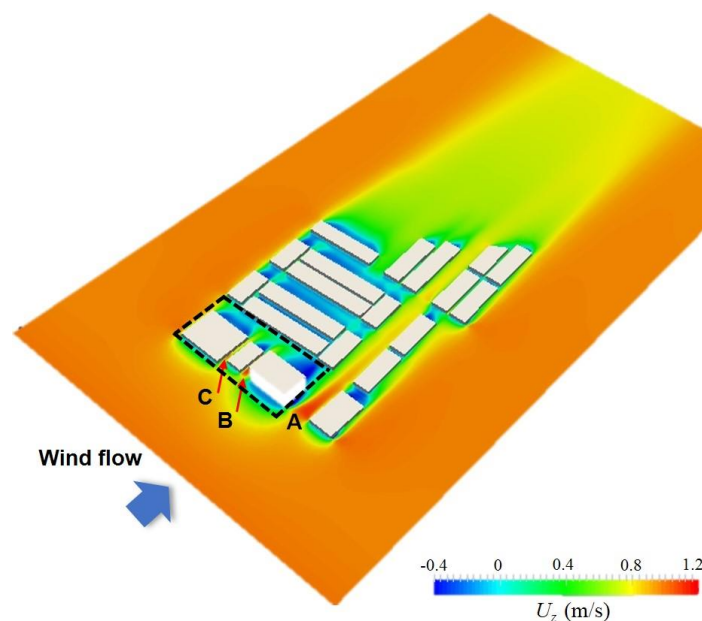
**Fig. 3.** Geometric idealization of the built-up area at Jalan Pandak Mayah shown in the isometric view where the domain's geometry is based on the AIJ Guidelines

### 3. Preliminary Result

This preliminary study is expected to discover a suitable method of wind flow simulation to be applied over a vegetated built-up area. The output data will be analysed in order to illustrate horizontal distribution of the wind flow at an average pedestrian level i.e. 1 m height of the studied area. The wind flow behaviours with and without vegetation effect within the simulation boundary will be compared. The wind map will be interpreted in understanding the biophilic climate-conscious design of the selected area by focusing on the biophilic way of sustaining natural wind condition.

The simulation was run with the uniform inlet velocity of 1 m/s. Figure 4 shows the distribution of the streamwise velocity,  $U_z$  at the height of 1 m which represent the approximate pedestrian height. The region bounded by dashed lines refers to the main area for the preliminary investigation. The figure shows that the maximum streamwise velocity, of approximately 1.2 m/s, is observed at several upwind locations marked as A, B, and C. This is due to flow channeling effect that results in the sharp peak of velocity near the buildings' walls [20]. The effect is more visible at A due to a larger gap of the street between the two adjacent buildings. In other regions where the wind flow is not obstructed, the streamwise velocity is relatively higher, i.e. between 0.8 and 1.2 m/s. This is mostly observed in the lateral and downstream regions of the domain. In the leeward region of the main investigation area, the lower streamwise velocity which ranges from -0.4 m/s to 0.4 m/s is observed where the negative velocity indicates a reverse flow.

The velocity distribution shows that the leeward region has a low potential for wind-induced natural ventilation which is necessary for improving pedestrian thermal comfort and reducing the urban heat island effect [21,22]. As an alternative, street tree planting would be ideal to create a shading and cooling effect in the leeward region [21]. On the contrary, at the locations particularly B and C where flow channeling is observed, tree planting would not be suitable as it would disrupt the path of wind flow into the leeward region. If the paths are obstructed, the streamwise velocity into the leeward region will be further reduced, leading to decreased ventilation potential in the leeward region.



**Fig. 4.** Streamwise velocity distribution at a 1-metre height from ground

Figure 5 shows the distribution of wind pressure,  $p$  at the height of 1 m from ground. The figure shows that the maximum pressure, which occurs where the fluid flow is brought to rest, is observed at and near the windward façades of buildings in the main investigation area (bounded by dashed lines). This subsequently induces a lower and negative wind pressure in the leeward region. The difference in the windward and leeward pressures is a driving force for wind-induced natural ventilation [19]. Since the leeward region is shielded by the upwind buildings, it has a low ventilation potential. This is an unfavourable condition for pedestrian thermal comfort [22] in the leeward region.

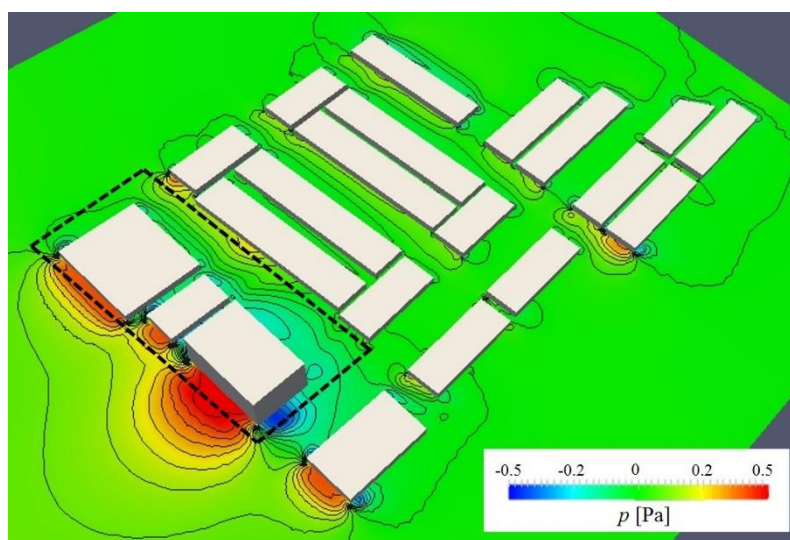


Fig. 5. Pressure contour at a 1-metre height from ground

#### 4. Conclusion

To conclude, this preliminary study on the wind flow simulation over a biophilic city is capable to give a better understanding and a clear view on the effect of vegetation within a built-up area. The preliminary findings of the streamwise velocity and wind pressure distributions at pedestrian level suggest the suitability of tree planting to improve pedestrian thermal comfort, particularly in the leeward region. The wind flow and ventilation at the pedestrian space is expected to suit the comfort scale with increasing vegetation. The potential in integrating a city development that connected to biophilic concept can be a systematic tool in strengthening the model of affiliating the nature and built-up environment for better quality of lives.

#### Acknowledgement

Authors would like to thank the Transdisciplinary Research Grant (Vote 06G99) of Universiti Teknologi Malaysia, Razak Faculty of Technology and Informatics, and Langkawi Development Authority (LADA) in supporting this research.

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