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Effects of non-uniform and orthogonal breezeway networks on pedestrian ventilation in Singapore's high-density urban environments

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A B S T R A C T

Urban breezeways need effective arrangements in order to benefit the natural airflow and mitigate the Urban Heat Island effect. This paper uses CFD simulations to study various non-uniform and orthogonal breezeway networks in urban environments referring to the CBD in Singapore. Firstly, it assessed effects of the patterns of roads and walkways with breezeway densities of 0.034 to 0.021 $m \cdot m^{-2}$ and varying morphological components; and arrangements of open-spaces inside plots with breezeway area ratio of 50 to 80% on pedestrian ventilation. Secondly, a linear regression analysis was conducted to explore whether newly-proposed breezeway-related indices are effective complements to building-related indices when predicting the pedestrian wind velocities. The results show that, for roads and walkways, coarse networks with varying morphological components benefit the airflow in most cases. For open-spaces inside plots, natural ventilation is improved when they are oriented to the prevailing wind direction. Furthermore, the pedestrian ventilation is less affected by the adjustments of roads than open-spaces inside plots. Finally, the regression results prove that more effective predictions are obtained toward pedestrian wind velocities by using both building-related and breezeway-related indices. Qualitative and quantitative recommendations are provided for integrally arranging road networks and plot typologies, which complement the existing knowledge of urban planning.

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Nomenclature

Urban morphological features

A	total site area (m^2)
BCR	building coverage ratio
BD	breezeway density ($m \cdot m^{-2}$)
BD_{par}	component of breezeway density parallel to the wind direction ($m \cdot m^{-2}$)
BD_{perp}	component of breezeway density perpendicular to the wind direction ($m \cdot m^{-2}$)
BAR	breezeway area ratio
BAR_{par}	component of breezeway area ratio parallel to the wind direction
BAR_{perp}	component of breezeway area ratio perpendicular to the wind direction
FAD	frontal area density
GPR	gross plot ratio
H_{max}	maximum building height (m)
H_{min}	minimum building height (m)
H_{max}/H_{min}	varying building height
H/W	aspect ratio of breezeway/street canyon height to width
L/W	aspect ratio of breezeway/street canyon length to width
L_i	length of the centerline of linear breezeway segment i (m)
W_i	width of the breezeway canyon along linear breezeway segment i (m)
θ	wind direction (°)
α_i	angle between the direction of the wind and breezeway segment i (°)

Breezeway network patterns

GZ	Guangzhou's coarse breezeway network
HK	Hong Kong's fine breezeway network
SG	Singapore's medium breezeway network
U	Unvarying morphological components
V_b	varying breezeway widths (unequal alternated breezeway widths)
V_f	varying building façade widths (unequal alternated building facade widths)
V_j	varying breezeway junctions (not only X-shaped but also T-shaped junctions)

Wind evaluations

κ	Karman constant
$U_{overall}$	spatially-averaged wind velocity at the overall outdoor area (ms^{-1})
$U_{walkable}$	spatially-averaged wind velocity at the walkable outdoor area (ms^{-1})
U^*_{ABL}	atmospheric boundary layer friction velocity (ms^{-1})
U_{ref}	reference wind velocity (ms^{-1})
VR_W	spatially-averaged wind velocity ratio for the overall outdoor area
VR'_W	spatially-averaged wind velocity ratio for the walkable outdoor area
z_0	roughness length (m)
z	wind evaluation height (m)
z_{ref}	reference height (m)

1. Introduction

In Singapore, effective arrangements of urban morphologies for optimizing outdoor ventilation is increasingly essential in the urban planning and design process. There are three reasons. Firstly, temperature in the tropical region remains high during the year. Secondly, high-density urban constructions without careful

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