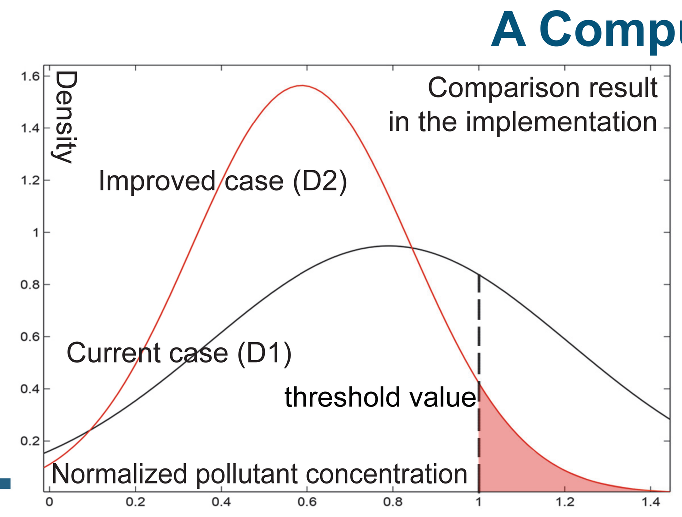
Improving Air Quality in High-density Cities by Understanding Air Pollutant Dispersion and Urban Morphologies

CHAO YUAN, Massachusetts Insitute of Technology, Cambridge, US
Singapore University of Technology and Design, Singapore
EDWARD NG, The Chinese University of Hong Kong, Hong Kong, China
LESLIE NORFORD, Massachusetts Insitute of Technology, Cambridge, US
香港中文大學 The Chinese University of Hong Kong

A Computational Parametric Study for Air Quality

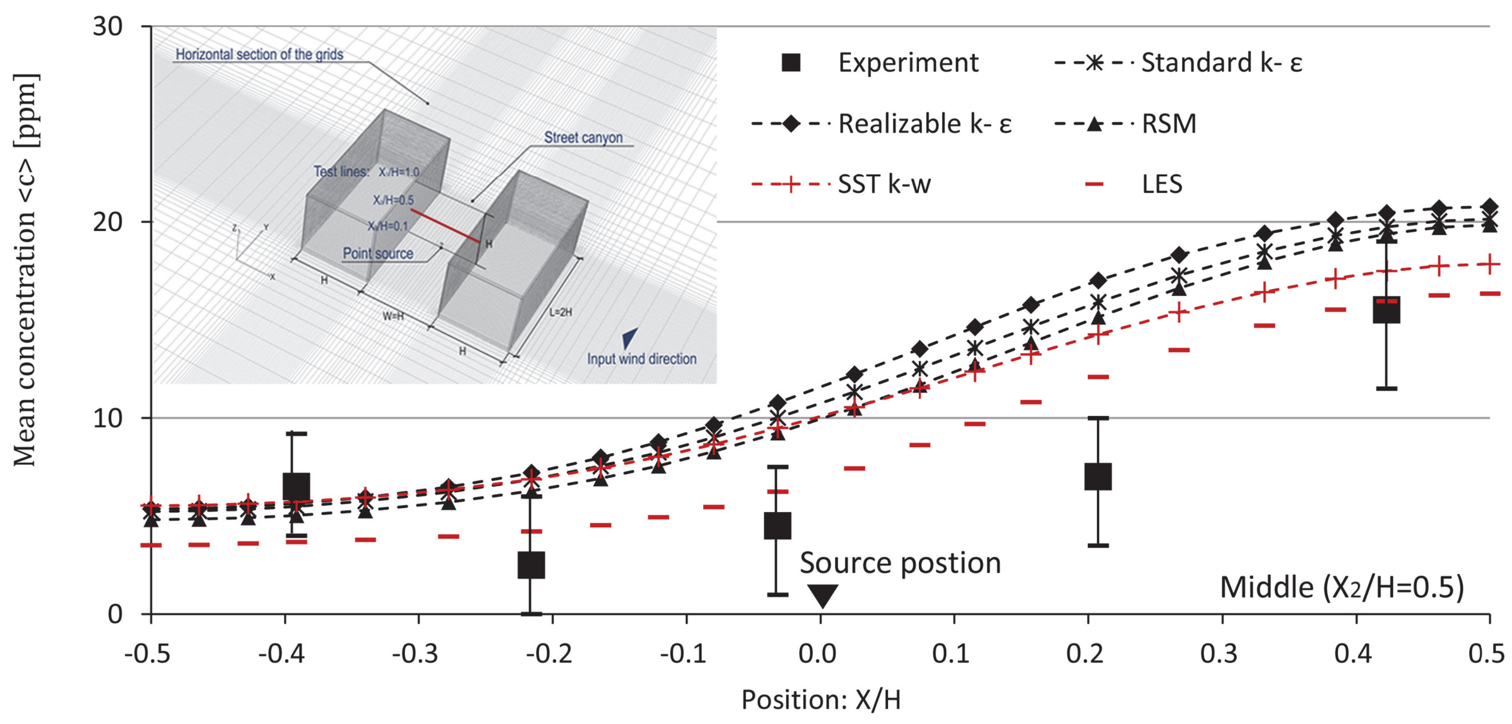


INTRODUCTION

Emissions from motor vehicles contribute to air pollution in urban areas, particularly at the street canyon level. The European Environment Agency (EEA) (2012) has reported seven types of pollutants that are primarily or secondarily related to road traffic emission. The risks associated with exposure to air pollution are relatively low for individuals but are a significant public health concern (Kunzli et al., 2000). Understanding the problem in densely populated cities is therefore paramount.

This study aims to provide insights on the effect of building geometries on air pollutant dispersion for the design practice. We built up this study based on our previous parametric study (Yuan & Ng, 2012) to extend the understandings in outdoor natural ventilation to the air pollutant dispersion. These insights are helpful to avoid the mistakes at the beginning stage of the design process, which cannot be easily corrected later. The result of this study could change architecture design from experience-based to scientific and evidence-based.

METHOD AND VALIDATION



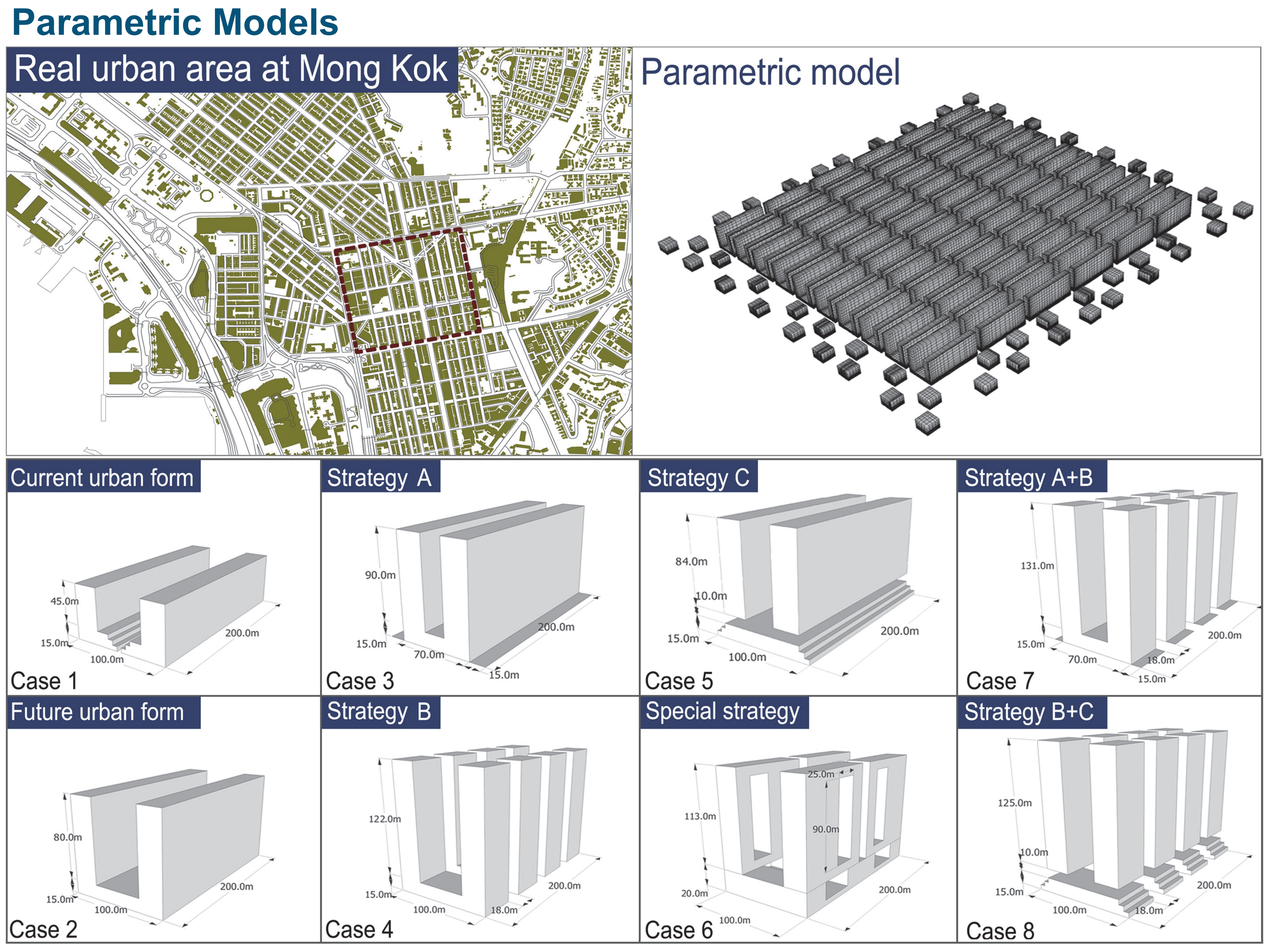
Cross-comparisons of time-averaged concentrations <c> between the wind tunnel experiment and different turbulent models

We investigated the effects of the different turbulence models, i.e. RANS and LES, on air pollutant dispersion modelling using the wind tunnel data provided by Niigata Institute of Technology (Tominaga & Stathopoulos, 2011). In RANS models, the standard and realizable κ-ε model, Reynolds stress model (RSM), shear-stress transport (SST) κ- ω model were included. The model configurations were set to match those in the wind tunnel experiment. Balancing the computational cost and accuracy, we selected the SST κ- ω model as the preferred turbulence model.

PARAMETRIC STUDY

The parametric model was at the urban scale and established based on urban geometries at Mong Kok, a high-density downtown area in Hong Kong. We designed eight cases (six strategy cases) to establish eight simulation scenarios with different building geometries and urban permeabilities. Plot ratios of Case 3 to 8, i.e. strategy cases, were set to be same to that of Case 2.

Parametric Models



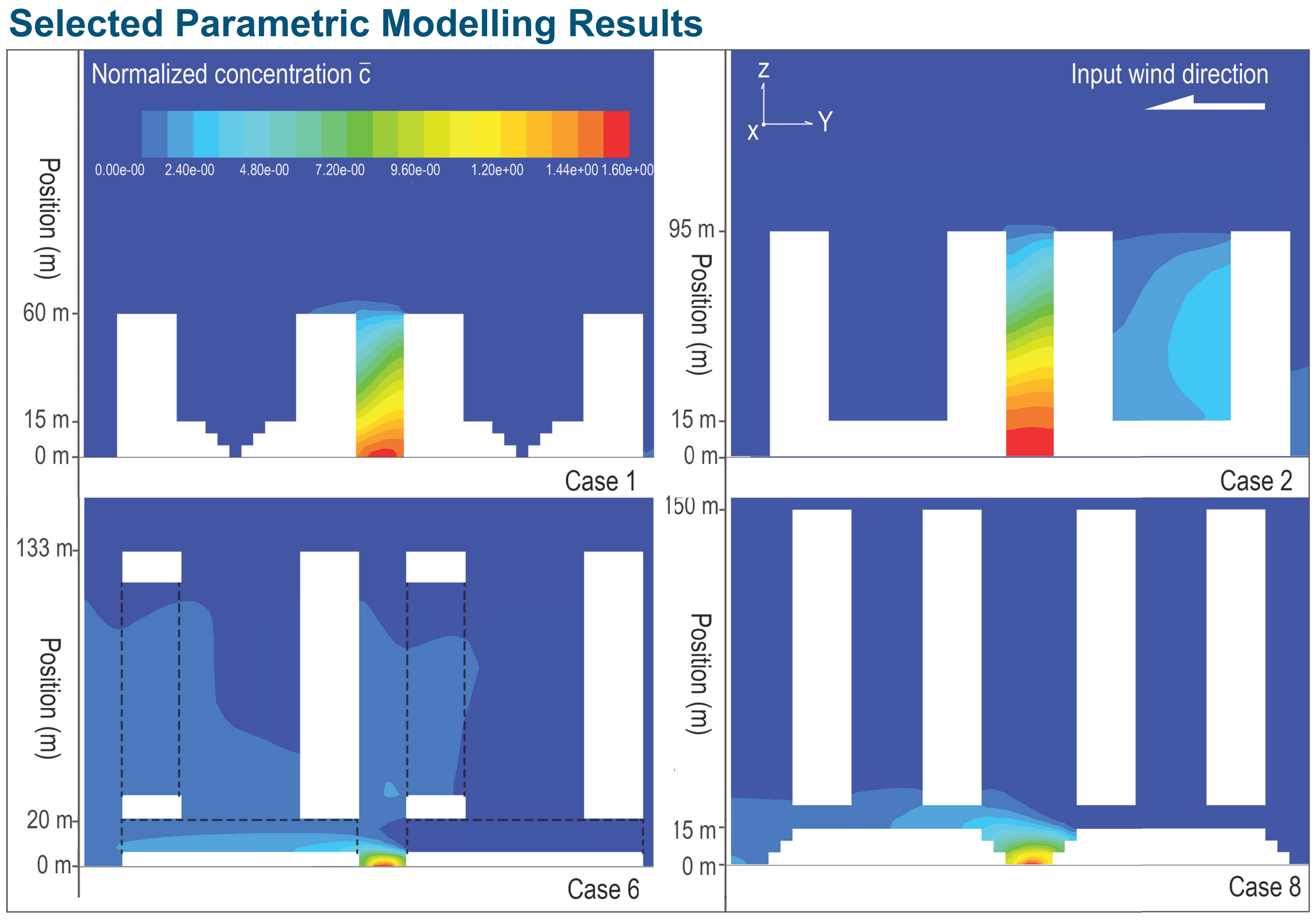
RESULT ANALYSIS

We used the normalized pollutant concentration (c) to investigate the effects of different building geometries on air pollutant dispersion as:

$$c = (\langle c \rangle)/(\langle c_0 \rangle)$$

where <c> is the time-averaged concentration of NO_2 and $\langle c_0 \rangle$ is the reference emission concentration, 1000 ppm. We set the threshold value of c as 1.0, which means that, if the value of c is less than 1.0, air pollutants disperse and do not concentrate in the street canyon.

Selected Parametric Modelling Results



Design Strategies and Performance

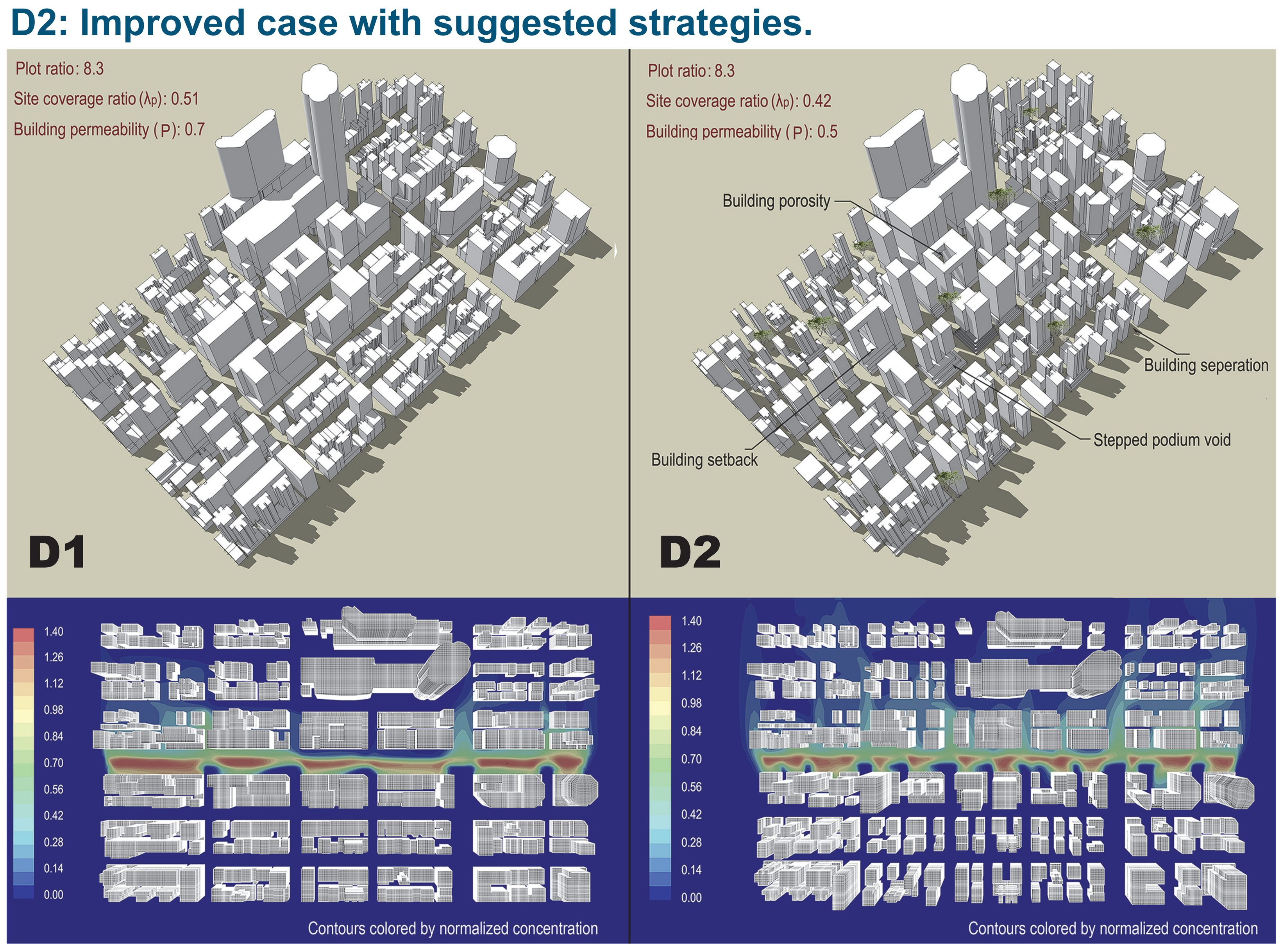
	Cases	Building geometry: Parameters	Building geometry: H (m)	Land use: Plot ratio	Urban permeability: P	Urban permeability: λ_p	Urban permeability: λ_i		Performance: Percentage of c >1.0
	1	Current urban form	60	8.9	0.9	0.7	0.9		100%
	2	Future urban form	95	14	0.9	0.8	0.9		75%
Strategies	3	Building setback	105	14	0.9	0.5	0.7	Strategy Performance	70% (Unsuitable)
	4	Building separation	137	14	0.7	0.6	0.5		29% (Good)
	5	Stepped podium void	109	14	0.8	0.6	0.7		75% (Unsuitable)
	6	Building porosity	133	14	0.7	0.8	0.7		33% (Good)
	7	Building separation & Build setback	146	14	0.7	0.4	0.3		0% (Excellent)
	8	Building separation & Stepped building void	150	14	0.6	0.4	0.4		0% (Excellent)

Note: H: building height; P: permeability of buildings (P = sum of frontal area/area of the assessment zone); λp: site coverage ratio; λi: integrated permeability.

IMPLEMENTATION

We conducted a case study to demonstrate that suggested design strategies are feasible in the real urban design practice.

D1: Current urban area of Mong Kok;
D2: Improved case with suggested strategies.



For more information of this study, please refer to:

Yuan, C., Ng, E., Norford, L.K., (2014), Improving air quality in high-density cities by understanding the relationship between air pollutant dispersion and urban morphologies, Building and Environment. 71, pp 245-258.