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An exhaustive parametric study on major passive design strategies of a typical high-rise residential building in Hong Kong

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Abstract

This paper presents a comprehensive sensitivity analysis (SA) of the typical High-rise residential building in Hong Kong. A generic building model is constructed with proposed natural ventilation strategies subject to the examination of thermal comfort criteria. The numerical modelling exhaustively investigate the thermal and energy responses based on the variation of different passive design parameters. The parametric studies with respect to multiple output indices are able to prove that the window solar heat gain coefficient is the most influential architectural design factor. Different thermal comfort models including the Adaptive Comfort Standard (ACS) and Predicted Mean Vote (PMV) are compared in estimating the indoor environmental quality (IEQ) for the generic building. It is believed that sensitivity analysis benefit the identification of important inputs to facilitate further optimization of the building performance in initial plan stages.

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Keywords: Mixed-mode ventilation, Thermal comfort, Passive design, Sensitivity analysis

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Nomenclature

Abbreviation

ACS	Adaptive Comfort Standard
AFN	Airflow Network
LHS	Latin Hypercube Sampling
MCA	Monte Carlo Analysis
MM	Mixed-mode
PMV	Predicted Mean Vote
PRH	Public Rental Housing
SA	Sensitivity Analysis
SRC	Standardized Regression Coefficient
SRRC	Standardized Rank Regression Coefficient
SHGC	Solar Heat Gain Coefficient
WGR	Window to Ground Ratio

Symbols

R^2	Coefficient of determination
T_a	Average air temperature (°C)
T_o	Operative temperature (°C)
$\overline{T}_r$	Mean radiant temperature (°C)
$T_{o,up80}$	Upper limit of acceptable operative temperature (°C)
$T_{o,low80}$	Lower limit of acceptable operative temperature (°C)
β_j	Regression coefficient
x	Input variables
y	Output variable

Subscript

i	ith row in the input matrix
j	jth column in the input matrix
k	Number of input factors
N	Sample size

1. Introduction

Building sectors in Hong Kong accounts for about 92.7% of total electricity consumption [1], in which high-rise public rental housing (PRH) with typical designs accommodates around 30% of the local population [2]. Passive design (i.e. energy efficient strategies fixed by architectural structures such as building layout, envelop thermophysics, building geometry and infiltration & air-tightness) has been adopted in PRH and proved to be effective energy saving measures by many researchers [3-6]. Extensive studies and analyses of multiples building design factors are made possible by exploiting building simulation technologies. Among existing studies, validating the relative importance of passive design parameters which requires a large amount of work is collectively called parametric studies or sensitivity analyses (SA).

SA has been applied to investigate multiple inputs in various types of buildings [7]. Office buildings in Hong Kong are examined by basic principles of sensitivity methods to study their energy performance with DOE-2 [8]. Sensitivity studies were also carried out on residential buildings in different meteorological zones. Yildiz and Arsan adopted Monte Carlo method with Latin hypercube sampling technique to estimate the sensitivity of building parameters for apartment buildings in the early design stage [9]. Investigations focusing on a single design feature were also carried out to validate the potential in reducing heating or cooling loads [10].

According to the brief literature review, it can be clearly seen that there are few detailed sensitivity studies on the passively designed high-rise residential buildings under natural ventilation conditions. Such studies should involve demonstration and verification with controlled modelling scenarios and appropriate SA methods, which could be applicable to a further optimization process. This paper will mainly focus on a proposed SA procedure and miscellaneous influences over its outputs.

2. Methodology

2.1. Building modelling description

PRH buildings in Hong Kong are generally high-rise buildings surrounded by dense neighborhoods. The main habitable area is located on typical floors with similar space configurations. The ground and top floors are service areas whose energy consumption is negligible in contrast with the 30 to 40 domestic floors in the middle.

The base case model carries a significant weight in sensitivity analyses because all subsequent comparative calculations use it as the reference in a local sensitivity study. The baseline model is established in compliance with the local construction practice and green building standard. Building physical parameters, space loads and operating schedules which combine space functions of the living room and bedroom are summarized in Table 1.

2.2. Sensitivity analysis approach

The sensitivity analysis (SA) is adopted to determine how much variance in the specified output of the generic model is attributed to each identified architectural parameters. SRC or SRRC explains the relative importance of different inputs, while the sign of these indices indicates the relative changing direction of the output to the input. The linear multidimensional regression model is expressed by Eq. (1):

$$\hat{y} = \beta_0 + \sum_{j=1}^{k} \beta_j x_j \tag{1}$$

where βj is the regression coefficient determined by minimizing Eq. (2):

$$\sum_{i=1}^{N}(y_i - \hat{y}_i)^2 = \sum_{i=1}^{N}\left[y_i - \left(\beta_0 + \sum_{j=1}^{k}\beta_j x_{ij} \right) \right]^2 \quad (2)$$

R^2 value (coefficient of determination) in Eq. (3) is used to assess the correlation between the input and output. A R^2 value higher than 0.7 means the obtained regression model can explain most of the variation in the output variable.

$$R^2 = \frac{\sum_{i=1}^{N}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{N}(y_i - \bar{y})^2} \quad (3)$$

SRC can be calculated by the below equation:

$$SRC_j = \frac{\beta_j \sigma_x}{\sigma_y} \quad (4)$$

Table 1 Baseline building physical and space load parameters

Parameter		Unit	Value
1. Building Physics			
Building Layout	Floor Area	m^2	23.2
	Height	m	2.7
	Orientation	-	West
Obstruction/Shading	Obstruction Angle	°	0
	Overhang Projection fraction	-	0
External Wall	Thermal Resistance	m^2 K/W	0.09
	Specific Heat	J/kg K	840
	Solar Absorptance	-	0.60
Fenestration/Window	U-Value	W/m^2 K	5.69
	SHGC	-	0.57
	WGR	-	0.40
2. Space Load			
Lighting Load		W/m^2	15
Occupant Load		W/person	100
Misc. Equipment Load		W	142

3. Results and discussions

3.1. Sensitivity on the cooling energy

Fig. 1 shows obtained SRRCs based on the multiple regression analysis of 1000 outputs against specified building design parameters. All the input parameters except the building orientation are determined to make important contributions to the variation of lighting energy.

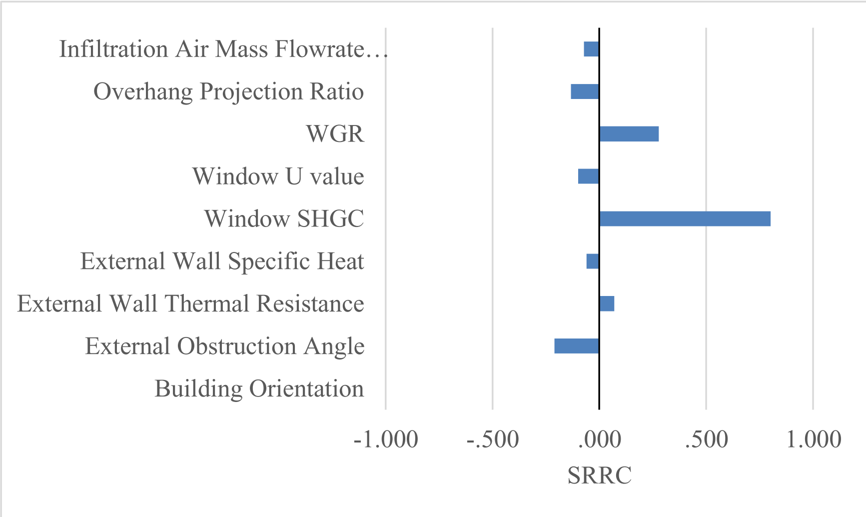

Fig.1 Sensitivity indices of selected design parameters for the cooling energy

3.2. Sensitivity on the operative temperature

Different from using cooling energy as the output index, sensitivity analysis based on the yearly average operative temperature is presented in Fig.2. The Window SHGC, WGR, external obstruction angle and overhang projection ratio were still four of the most important input factors as summarized form the previous section. However, the building orientation which was formerly considered to have insignificant impact on the cooling energy became a critical input ranking in the fourth place instead of the overhang projection ratio. The variation in the importance of the input factors can lead to the conclusion that the choice of output indices can also tremendously influence the SA results.

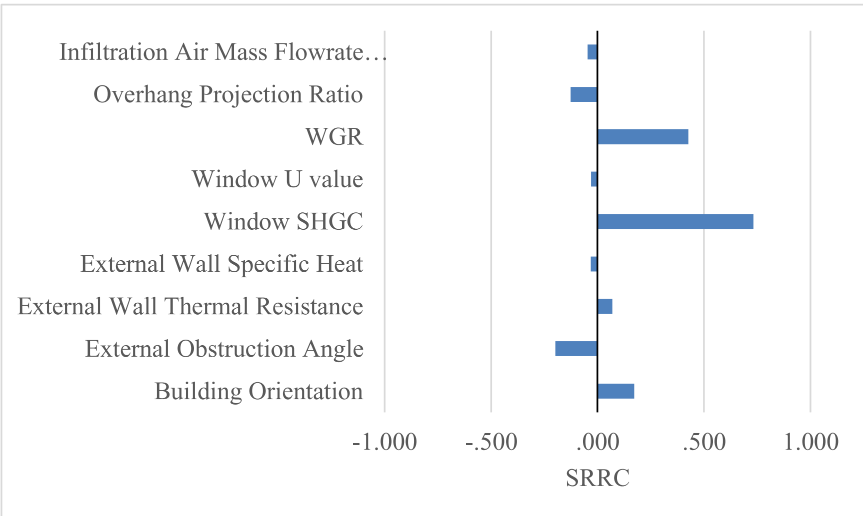

Fig. 2 Sensitivity indices of selected design parameters for the indoor operative temperature

Conclusions

Passive architectural design parameters related to the building layout, envelop thermophysics, building geometry and infiltration & air-tightness have significant influence over building energy consumption. Developers, architects and engineers should identify any energy conservation opportunities in the early design stage of a high-rise residential building. The findings from this paper can provide stakeholders more consciousness and flexibility of building designs in hot and humid climates.

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References

[1] Census and Statistics Department, Hong Kong Energy Statistics Annual Report. 2013.

[2] Census and Statistics Department, Population by type of housing. 2007.

[3] Chen X, Yang H, Lu L. A comprehensive review on passive design approaches in green building rating tools. Renewable and Sustainable Energy Reviews. 2015;50:1425-36.

[4] Song Y, Li J, Wang J, Hao S, Zhu N, Lin Z. Multi-criteria approach to passive space design in buildings: Impact of courtyard spaces on public buildings in cold climates. Building and Environment. 2015;89(0):295-307.

[5] Gong X, Akashi Y, Sumiyoshi D. Optimization of passive design measures for residential buildings in different Chinese areas. Building and Environment. 2012;58:46-57.

[6] Imessad K, Derradji L, Messaoudene NA, Mokhtari F, Chenak A, Kharchi R. Impact of passive cooling techniques on energy demand for residential buildings in a Mediterranean climate. Renewable Energy. 2014;71:589-97.

[7] Yildiz Y, Korkmaz K, Göksal Özbalta T, Durmus Arsan Z. An approach for developing sensitive design parameter guidelines to reduce the energy requirements of low-rise apartment buildings. Applied Energy. 2012;93:337-47.

[8] Lam JC, Hui SCM. Sensitivity analysis of energy performance of office buildings. Building and Environment. 1996;31(1):27-39.

[9] Yıldız Y, Arsan ZD. Identification of the building parameters that influence heating and cooling energy loads for apartment buildings in hot-humid climates. Energy. 2011;36(7):4287-96.

[10] Park B, Srubar Iii WV, Krarti M. Energy Performance Analysis of Variable Thermal Resistance Envelopes in Residential Buildings. Energy and Buildings. 2015(0).

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