Constructing a Dual-Index Regulation for the Design of Envelope Performance of Hybrid Ventilated School Building

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ABSTRACT

Responding to the hot humid climate, the Taiwan government expects to broadly install air-conditioning in classrooms to provide a comfort study environment for school buildings and prevent the risk of overheating; therefore, corresponding to the installation of air-conditioning, it is important to draw up the energy-saving strategy while considering the thermal comfort. This study firstly discussd the insufficiency of the regulations in Taiwan, and then suggested a dual-index which take building envelope performance and thermal comfort into consideration simultaneously through regression analysis. Based on the simulation results, a school building envelope design criteria for mixed-mode thermal management which simultaneously considered the cooling load and natural ventilation potential is proposed in this study. it is expected to analyze and provide accurate information for energy-saving potential and thermal comfort efficacy at the initial design stage through this criteria.

INTRODUCTION

Responding to the hot humid climate, the Taiwan government expects to broadly install air-conditioning in classrooms to provide a comfort study environment for school buildings and prevent the risk of overheating. The design of school buildings can be considered with the hybrid ventilation systems including air-conditioning (AC) and natural ventilation (NV) to reduce energy consumption while maintaining an acceptable level of thermal comfort [1]. From the perspective of building envelope design, it is an important role for the heat transferred from outer walls and the area of openings, which related to energy consumption and indoor thermal comfort [2][3]. There are two ways of energy-saving regulations for school buildings in Taiwan [4]: Firstly, Conforming the average window solar gain(ASWG) through translucent windows; Secondly, as shown in Table 1, regulating the ratio through different window-wall ratio (WWR) and restrictions on the average U-value of outer walls (U_w), the average U-value of windows (or fenestration, U_f), and the average shade coefficient of windows (SF). However, the two regulations are designed to reduce the cooling load of air-conditioning, whereas without considering the aspect of ensuring the thermal comfort through NV. Concerning the issue of overheating in classrooms, the purpose of this study is to suggest a novel index for school buildings to ensure the thermal comfort and simultaneously minimize the energy consumption through examining the energy performance and investigating the thermal comfort. Furthermore, the insufficiency of ASWG is improved and the appropriate ventilation performance is formulated.

Table 1 The design and technique directions for energy-saving of school building in Taiwan[4]

	WWR >0.5	0.5≧WWR >0.4	0.4≧WWR >0.3	0.3≧WWR >0.2
The Upper value of Uw	2.0	2.0	2.0	2.0
The Upper value of Uf	2.7	3.0	3.5	4.7
The Upper value of SFs	0.2	0.3	0.4	0.5

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METHODOLOGY

A typical Taiwanese classroom with the dimensions of 9 m × 8 m × 3.6 m (width × depth × height) is set as the model. EnergyPlus and the Typical Meteorological Year 3 (TMY3) data are used for conducting the simulations of classrooms located in northern Taiwan (Taipei),. Regarding the parameters and input variables, there are six design parameters, which are the classroom azimuth, WWR, thermal insulation thickness of external wall, glass type, shading depth ratio, and window opening ratio. In terms of the ranges of parameters, the classroom azimuth is 0~360°, WWR is 0.3~0.7, the U value of external wall is 0.542~2.632W/ m2K, the U value of glass is 2.848~5.778W/ m2K, the SHGC is 0.287~0.819, the shading depth ratio is 0.0~2.0, and the window opening ratio is 0.2~1.0. Monte Carlo Analysis is used for sampling of the sixparameters to randomly generate 360 classroom cases.

The regression analysis was used to develop two index for solving heat performance issue in classrooms with hybrid ventilation. Firstly, thermal performance index for building envelope, OTTV[5] (Eq.(1)), is used to restrict the cooling load derived from the building envelope during air-conditioning season (May to October) because of the OTTV can specify the cooling load of the classroom better than the regulation in Taiwan (ASWG), and the OTTV formula suitable for taipei is proposed through the regression analysis. Secondly, overheating assessment criteria proposed in CIBSE TM52 [6] are applied to evaluate overheating risk (Table 2) in the NV season (November to April). Through analyzing the ventilation rate ($\overline{V_{NV}}$), the azimuth correction factor (CF_1) and area ratio correction factor (CF_2) are suggested to obtain the equivalent ventilation area (A_{eq}, Eq.(2)). Eventually, by coupling analysis of OTTV and A_{eq}, the relationship between OTTV, A_{eq}, and overheating risk can be confirmed.

$$OTTV = c_1(1 - WWR) \times U_w + c_2 \times WWR \times U_f + c_3 \times WWR \times SC \times CF \quad (1)$$

$$\overline{V_{NV}} = CF_1 CF_2 A_{min} (\overline{C_v U})_{ref} = A_{eq} (\overline{C_v U})_{ref} \quad (2)$$

$$A_{eq} = CF_1 CF_2 A_{min} \quad (3)$$

Where WWR is the window to wall ratio of a classroom; U_w is the thermal transmittances of external walls W/m^{2}K; U_f is the thermal transmittances of external windows W/m^{2}K; SC is shading coefficient of fenestration; CF is the correction factor of the orientation; V_{NV} is the natural ventilationrate, A_{min} is the smaller one of opening area; $(\overline{C_v v})_{ref}$ is a fixed value for the same area; A_{eq} is the equivalent ventilation area.

Table 2 Overheating risk assessment criteria of CIBSE TM52

Criteria	Definition	Limit
He	Hours of exceedance	< 3% of occupied hours
We	Daily weighted exceedance	≤ 6 K/hour in a single day
Tupp	Upper limit temperature	ΔT < 4K

RESULTS AND DISCUSSIONS

3.1 Developing the OTTV formula of Taipei

According to the results of EnergyPlus simulations, the final form of OTTV is obtained, and the information including the coefficient of multiple determination(R^2), coefficients c1~c3, t-statistics and standardized regression coefficient(SRC), is summarized in Table 3. From the calculated results of t-statistics, it is known that solar radiation make the greatest influence on OTTV, followed by equivalent temperature difference of external walls, and outdoor temperature difference, while all of these factors reach the significant statistical testing (P<<0.01).

Table 3 Results of the OTTV regression model

	Coefficient	t-statistics	p-value	SRC
R^2	0.942		0.00	
$(1 - WWR)U_w$	4.477	54.2	0.00	0.27
$WWR \times U_f$	2.233	20.4	0.00	0.26
$WWR \times \text{SC} \times CF$	67.77	16.4	0.00	0.86

3.2 The equivalent ventilation area

Regarding the calculation of equivalent ventilation area (A_{eq}), the related orientation correction factor(CF_1) and area ratio correction factor(CF_2) can be obtained by regression analysis. Specifically, CF_1 is calculated by simulating the classrooms with the same window area on both sides of the classrooms, changing by 7 types of window openings (2.1m^2~14.7m^2), as shown in Figure 4(a); The results of CF_2 is shown in Figure 4(b), where z is the area ratio of the windows on the opposite sides in the classrooms. Consequently, the A_{eq} of the classroom can be calculated by Eq.(3).

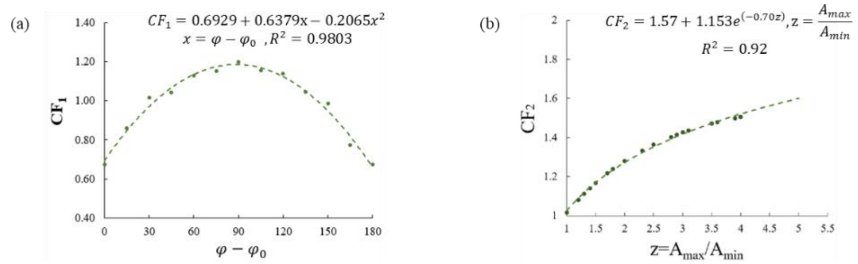

Figure 4 (a) The orientation correction factor(CF_1) and (b) the area ratio correction factor(CF_2)

3.3 Coupling analysis of OTTV, Aeq, and overheating risk

To meet the overall requirements including energy-saving in AC season and ensuring thermal comfort in NV season, the impacts of natural ventilation performance (i.e., Aeq), envelope thermal performance (i.e., OTTV) on overheating risk are clarified through coupling analysis. Regarding the results, the cases are classified into two groups of with/without overheating risk and displays their relationship to A_{eq} and OTTV in a scatter diagram (Figure 6). Furthermore, the Aeq and OTTV values of cases with overheating risk are processed by Pareto ranking method, and the solutions of 10 sets of Pareto front are obtained, which represented by red dots in Figure 6. Eventually, the optimal prediction of the frontier is confirmed through Eq.(4). The variation of A_{eq} and OTTV variables suggest that the issue of hybrid ventilation classroom design should be addressed with the objectives of energy savings and thermal comfort in different seasons through dual-index regulation.

$$A_{eq} = 0.184e^{0.239 \cdot OTTV}, \quad R^2 = 0.987 \tag{4}$$

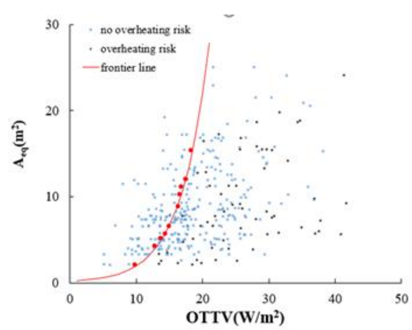

Figure 6 Relationship between A_{eq}, OTTV and overheating risk

CONCLUSION

In order to formulate the proper evaluation index, a massive amount of classroom model is generated by Latin hypercube sampling method. Based on the simulation results and regression analysis, this study discusses the relationship between the sensible cooling load, equivalent ventilation area, and overheating risk of the classroom; besides, the regulation strategy is further investigated. Specifically, the OTTV formula suitable for Taipei, the orientation correction factor(CF_1), and area ratio correction factor(CF_2) related to A_{eq} are proposed. In addition, the optimal prediction of the A_{eq} frontier for preventing overheating risk is suggested through the coupling analysis results of natural ventilation performance and envelope thermal performance. Through this dual-index regulation for building envelope, it is expected to analyze and provide accurate information for energy-saving potential and thermal comfort efficacy at the initial design stage. Ultimately, achieve the goal of building energy-conservation and improve the indoor thermal comfort by superior building envelope design.

REFERENCES

[1] M Gil-Baez, Á Barrios-Padura, M Molina-Huelva. Natural ventilation systems in 21st century for near zero energy school buildings, Energy(2017) 137:1186-1200

[2] KT Huang, RL Hwang, Parametric study on energy and thermal performance of school buildings with natural ventilation, hybrid ventilation and air conditioning Indoor and Built Environment(2016), Vol. 25(7) 1148 – 1162

[3] R Duarte, M da Glória Gomes, AM Rodrigues. Classroom ventilation with manual opening of windows: findings from a two-year-long experimental study of a Portuguese secondary school. Building and Environment (2017)124.

[4] Construction and Planning Agency. Technical codes for energy conservation design of educational buildings. Ministry of the Interior, Taiwan(2005).

[5] Huang, J., &Deringer, J. Status of Energy Efficient Building Codes in Asia (China, Hong Kong, Taiwan, Japan, Korea, Malaysia, Philippines, Singapore, Thailand, India). 1–65. (2007)

[6] CIBSE. The limits of thermal comfort: avoiding overheating in European Buildings. CIBSE Technical Memorandum No. 52. London: Charted Institution of Building Services Engineers(2013)