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Simplification and adjustment of the energy consumption indices of office building envelopes in response to climate change

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HIGHLIGHTS

- Taiwanese building energy conservation index (ENVLOAD) was converted to OTTV.
- New models for energy efficient envelope were proposed as an adaption to the changing climate.
- Coefficients of the OTTV model should be changed to reflect climate change.
- Thermal insulation is gaining more concern while climate change proceeds.
- Altering method of OTTV and setting new criteria in response to future climate was proposed.

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ABSTRACT

Changes in the climate system affect a building's energy consumption. Many countries have implemented building energy consumption indices to regulate the newly built buildings from excessive energy use. However, those indices were developed based on previous climate datasets and were incapable of responding to the changing climate. To stabilize the energy uses of future buildings as those under today's climate, regular updates of the evaluation index are mandatory to take climatic variations into consideration. This study firstly discussed the limitations in responding to future climate of current practicing building envelope energy conservation index in Taiwan. Secondly, we proposed a new index, the overall thermal transfer value (OTTV), based on the simulation results and tried to convert existing baseline criteria for the new OTTV. An approach on how to alter the OTTV index in response to the climate change was proposed. We found that because of the warming climate, the coefficient of the OTTV equation has to be changed over times to accurately respond to the changing climate. The approach presented in this paper provides a method on how to formulate a climate responsive index in pursuit of a better energy efficient building in the future.

1. Introduction

Given the growing awareness on the balance between the use of natural resources and the protection of the environment, the importance of building envelope design, as it relates to a building's energy performance, is increasing gradually. Many countries had adopted certain building envelope indices to regulate the building envelope design to prevent excessive energy use. The evaluation equation and the baseline value of a building's envelope thermal performance are often determined based on past climatic conditions, which are insufficient in response to the fast-changing climate in recent decades. Furthermore, none of these indices had adopted a certain mechanism on how to adapt to the changing climate, which we believe may be inappropriate in perspective of future climate responses. Due to the fact that the criteria and the assessing equations of these indices remain unchanged, it would result in the criterion complied buildings nowadays or in the future may consume more energy than those in the previous days, which is considered ineffective in perspective of controlling the building cooling energy usage. An effective index should be capable of regulating the building cooling energy use under a specific amount regardless of the changing climate at all times.

If the climate maintains the same conditions as in the past and does not change, then it will not be a problem to continue using the existing evaluation equation and baseline. However, the climate has been

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Nomenclature

A_w	areas of the external walls for air-conditioned zones, m^2
A'_w	areas of the external walls for non-air-conditioned zones, m^2
A_f	areas of fenestrations for air-conditioned zones, m^2
A'_f	areas of fenestrations for non-air-conditioned zones, m^2
A_p	total floor area of the air-conditioned perimeter zone, m^2
A_o	total area of the overall elevated building facade, m^2
CF	the correction factor of the orientation
DH	annual cooling degree-hours based on 23 °C, °C h
G	annual internal cooling load, Wh/m^2 yr
IH_i	annual total solar insolation hours of *i* orientation, Wh/m^2
L	heat loss coefficient of building envelope, W/m^2 K
M_i	solar insolation heat gain coefficient of *i* orientation of the building envelope, dimensionless
U_w	thermal transmittances of external walls, W/m^2 K
U_f	thermal transmittances of external windows, W/m^2 K
K_i	external sunshade shading coefficient of *i* orientation
S	the heat storage capacity of walls
SC	the shading coefficient of fenestrations, dimensionless
SC_1	the glass shading coefficient, dimensionless
SC_2	the external sunshade shading coefficient, dimensionless
SF	the annual average solar radiation factor for the specific reference orientation, W/m^2
Tu	the average room temperature increment, °C
TD	the average temperature difference between the indoor and outdoor air, °C
TD_{eq}	the average equivalent temperature difference of external walls during the cooling seasons, °C
a_0, a_1, a_2	constant coefficients of the ENVLOAD
b_0, b_1	constant coefficients of the simplified ENVLOAD
c_1, c_2, c_3	constant coefficients of the OTTV

Subscript letters

i	*i* orientation of the building envelope
w	walls
f	fenestrations
p	parameter zones
o	overall area
eq	equivalent temperature

Greek letters

η	solar heat gain coefficient (SHGC)
δ_1	thickness of the insulation material in wall, cm
δ_2	thickness of the heat storage material in wall, cm
θ	azimuth angle

Acronyms

ENVLOAD	annual building envelope sensible cooling load, kWh/m^2 yr
$ENVLOAD_{simple}$	simplified calculation equation of ENVLOAD, kWh/m^2 yr
IA	index of agreement
MB	mean bias
OTTV	the overall thermal transfer value
RMSE	root mean square error
SCL	annual sensible cooling load
SHGC	solar heat gain coefficient of the glazing
SRC	standardized regression coefficient
WWR	window to wall ratio

changing under accelerating speeds in recent decades and will be in a state of continuous change. Therefore, facing the challenges of future climate change, a conceptual leap in building thermal performance design will be necessary; particularly, the present evaluation method and the baseline value of a building's thermal performance should be constantly updated over times by a new model, taking consideration of the differences in the present and future climatic states. In other words, it is an important issue that also must be further studied in depth by using existing future climate data and by carefully amending the provisions on the thermal performance of building envelopes, to guide the new direction of building energy conservation design in facing with the changing climate.

1.1. The Taiwanese thermal performance evaluation index (ENVLOAD)

During the 80s of last century, Taiwan promulgated the Building Energy Conservation Design Standard. The standard provides a performance-based approach to guide the energy conservation design of building envelopes. The performance-based approach comprehensively considers the three main parts of energy consumption of a building envelope: conduction heat through opaque external walls, conduction and solar radiation heat through window fenestrations. The standard also allows trade-offs in between them, providing innovation and flexibility in building design for architectural designers. The focal point of the performance-based approach is expected to reduce building energy consumption through good envelope design; it focuses on the long-term or annual total energy consumption of the building's envelope. The thermal performance evaluation index of the office building, according to the standard, is called the ENVLOAD. The ENVLOAD represents the annual sensible cooling load in an air-conditioned building perimeter zone of a unit square meter floor area during the cooling season. The perimeter zone refers to the indoor space within a distance of 5 m from the external wall, where it is susceptible to heat flow through the building envelope. The calculation of ENVLOAD [1] is as follows:

$$ENVLOAD = -20370 + 2.010G + 0.033L\cdot DH + 1.079\sum_i (M_i\cdot IH_i) \quad (1)$$

$$G = 13.5(a_0 + a_1 T_u + a_2 T_u^2) \quad (2)$$

$$T_u = \frac{13.5}{L} \quad (3)$$

$$L = \frac{\sum_i (U_{w,i}A_{w,i}) + 0.5\sum_i (U_{w,i}A'_{w,i})}{A_p} + \frac{\sum_i (U_{f,i}A_{f,i}) + 0.5\sum_i (U_{f,i}A'_{f,i})}{A_p} + 1.011 \quad (4)$$

$$M = \frac{\sum_i (K_i\eta_i A_{f,i}) + 0.5\sum_i (K_i\eta_i A'_{f,i})}{A_p} + \frac{0.035[\sum_i (U_{w,i}A_{w,i}) + 0.5\sum_i (U_{w,i}A'_{w,i})]}{A_p} \quad (5)$$

Since there are many variables contained in Eqs. (1)–(5) and there are many combination types of various variables, the calculation process and the lookup of tables tend to be overly complicated and cumbersome. In view of this, Wang and Lin [2] proposed a simplified calculation equation (hereinafter referred to as $ENVLOAD_{simple}$), as shown in Eq. (6):