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Cuimei Xu
Yuriy Biks

SUSTAINABLE LCA-OPTIMISED ENVELOPES FOR SUBURBAN BUILDINGS

Vinnytsia National Technical University

Abstract

This paper introduces a multi-objective optimisation approach based on MATLAB, focusing on the design of sustainable building envelopes through multi-objective optimisation. The study addresses three key objectives: thermal performance (represented by K-value and D-value), carbon emissions, and construction cost.

Keywords: Sustainable building; Multi-objective optimization; Thermal performance; Carbon emissions; Construction cost

Introduction

In the field of architectural engineering, China has issued the *Green Building Evaluation Standard* GB/T 50378 [1], which mandates that building projects comply with relevant green building regulations. The Shenzhen municipal government has further required that all newly constructed public buildings in Shenzhen must meet green building standards [2]. Building energy efficiency is one of the key indicators in the design review process for new construction projects in China. However, architects often overlook the carbon emissions and construction costs associated with building envelope systems when pursuing energy efficiency targets. Therefore, it is of great significance to develop a method that enables designers to achieve minimal carbon emissions and lower construction costs while meeting energy conservation goals. This study examines the XA project in suburban Shenzhen as a case study, a near-zero carbon demonstration project located in the suburbs. By optimising the commonly used material thickness combinations in the envelope design of the XA project, this research successfully minimises both carbon emissions and construction costs while fulfilling thermal performance requirements.

Research Methodology for Envelope Materials

This study employs a multi-objective optimisation method based on MATLAB, combined with Optimal Control algorithms (such as NSGA-II [3]) for solving. When calculating carbon emissions, the database of carbon emission factors for building materials [7] was referenced, and the principles of ISO 14040 Life Cycle Assessment [5] were followed. The calculation of thermal performance is based on the methods outlined in "Thermal Performance and Energy-saving Design of Building Envelopes" [6].

In this study, the thickness of different materials is taken as the variable. By combining these materials and calculating their heat transfer coefficient (K-value), thermal inertia index (D-value), carbon emissions, and cost, different combinations are compared to determine the optimal solution. The specific calculation formulas are as follows:

Heat transfer coefficient (K-value): The K-value is the reciprocal of the total thermal resistance, calculated as:

$$K = 1 / R \tag{1}$$

Where R - total thermal resistance consists of internal surface thermal resistance (R_i, typically taken as 0.11 m^2K/W), thermal resistance of each material layer (R_n), and external surface thermal resistance (R_e, typically taken as 0.04 m^2K/W), i.e., $Rwall = R_i + \Sigma Rn + R_e$.

Thermal resistance of a material layer (Rn) is the ratio of the material's thickness (d) to its thermal conductivity (k), i.e., $Rn = d / k$.

Thermal inertia index (D-value): The D-value is calculated using the heat storage coefficient (Si) and thermal resistance (R_i) of each material layer, given by the formula:

$$D = E(S_i \times R_i) \tag{2}$$

Where S_i is measured in $W/(m^2K)$, and Ri is measured in m^2K/W.

Carbon emissions (CO_2): The carbon emissions from the envelope structure are the sum of the carbon emissions from each constituent material, expressed as:

$$CO_2 = \Sigma(\text{Envelope area} \times \text{Carbon emission factor of each constituent material}) \tag{3}$$

Cost (Cost): The total cost of the envelope structure is the sum of the costs of each constituent material, calculated as:

$$\text{Cost} = \Sigma(\text{Envelope area} \times \text{Unit price of each constituent material}) \tag{4}$$

Research Results

After performing the optimisation calculations using MATLAB, the optimised thickness values of each material in the building envelope structure, along with the corresponding K-value, D-value, carbon emissions (CO2), and construction cost, were obtained. These optimised results are compared with the original design values, as shown in Table 1. The comparison charts between the MATLAB-optimised results and the design values are presented in Figures 1 to 5.

Table 1. Comparison of Design Values and Optimised Values for the Envelope Structure

Component	Material	Design					Optimised				
		Thickness (mm)	K W/(m^2K)	D	CO_2 (Kg)	Cost (RMB)	Thickness (mm)	K W/(m^2K)	D	CO_2 (Kg)	Cost (RMB)
Wall	M20 Cement Mortar	25	0.476	6.324	103141.5	719150.0	25	0.592	5.061	83913.5	695400.0
	Aerated Concrete Block	250					200				
	Perlite Insulation Mortar	30					20				
	M20 Plastering Mortar	35					30				
Roof	M20 Cement Mortar	20	0.272	4.364	36806.8	1722746.0	20	0.336	3.512	29526.4	1641730.8
	C25 Fine Aggregate Concrete	50					40				
	Waterproof Mortar	5					5				
	C20 Fine Aggregate Concrete	30					30				
	Extruded Polystyrene Board	100					80				
	Reinforced Concrete	200					150				

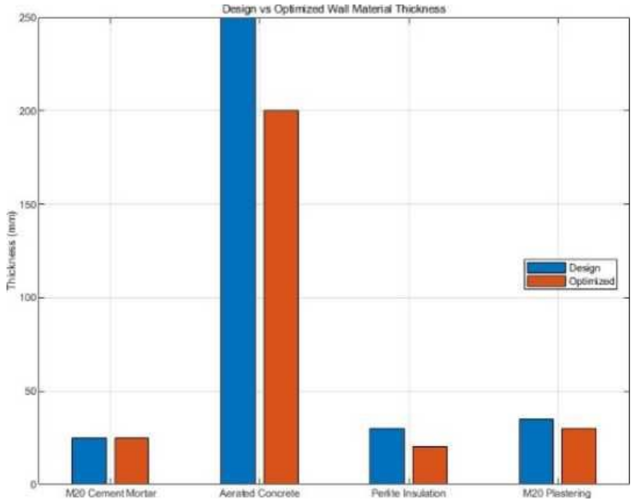

Figure 1. Design vs Optimised Wall Material Thickness

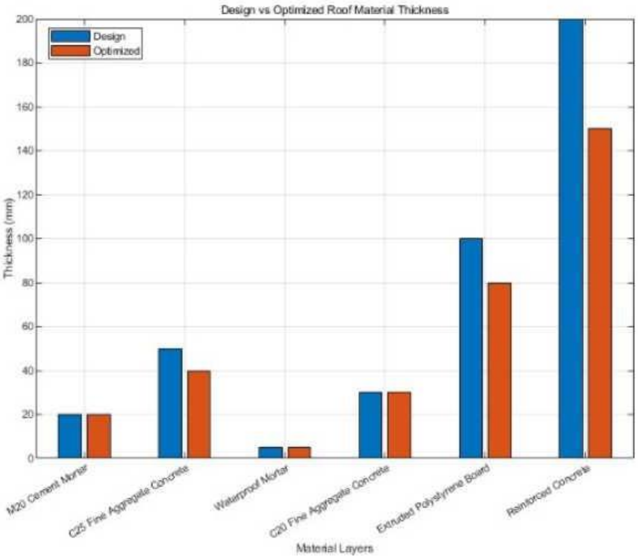

Figure 2. Design vs Optimised Roof Material Thickness

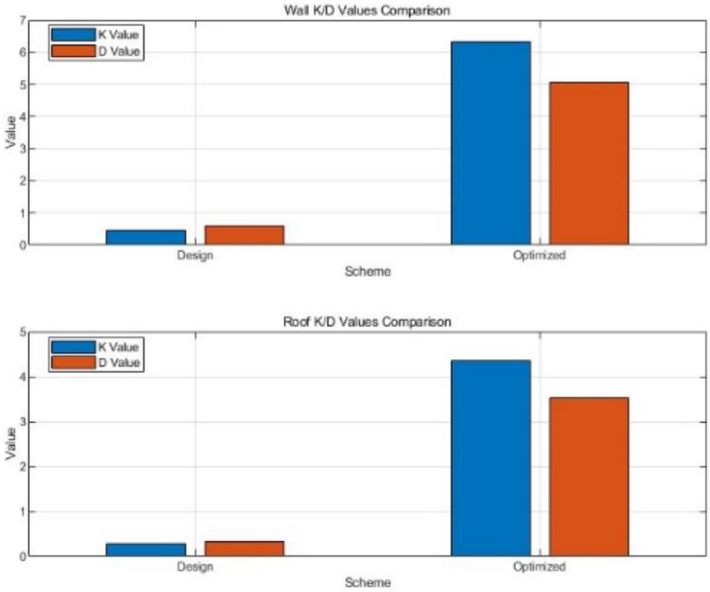

Figure 3. Wall K/D Values ˆ Roof K/D Values Comparison

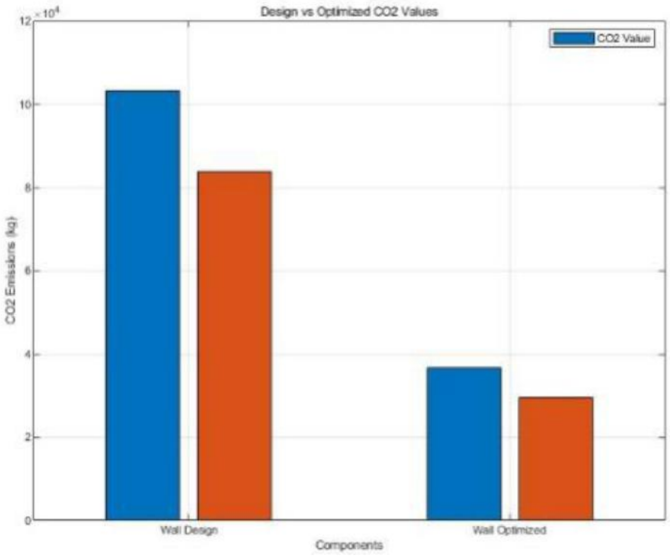

Figure 4. Design vs Optimised CO2 Values

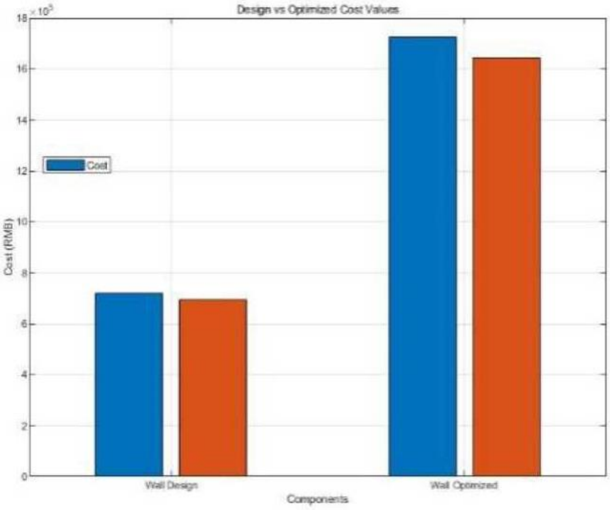

Figure 5. Design vs Optimised Cost Values

Conclusion

This study conducted a multi-objective optimisation design for the envelope structure of the XA near-zero energy public building project in suburban Shenzhen, reaching the following conclusions:

Thermal Performance Optimisation Results

The optimised heat transfer coefficient (K-value) of the exterior wall increased from 0.476 W/(m^2-K) to 0.592 W/(m^2-K), while the thermal inertia index (D-value) decreased from 6.324 to 5.061.

For the roof, the optimised heat transfer coefficient increased from 0.272 W/(m2-K) to 0.336 W/(m2-K), and the thermal inertia index dropped from 4.364 to 3.512.

Carbon Emissions Optimisation Results

The carbon emissions of the exterior wall were significantly reduced, decreasing from 103,141.5 kg in the original design to 83,913.5 kilograms, representing a reduction of approximately 18.6%.

Carbon emissions for the roof also saw a substantial decrease, dropping from 36,806.8 kg in the original design to 29,526.4 kg, indicating a reduction of about 19.7%.

Construction Cost Optimisation Results

The cost of the exterior wall was reduced from 719,150.0 RMB in the original design to 695,400.0 RMB, marking a decrease of approximately 3.3%.

The cost of the roof significantly decreased from 1,722,746.0 RMB in the original design to 1,641,730.8 RMB, representing a reduction of approximately 4.7%.

The optimisation method employed in this study demonstrated excellent performance in balancing multiple objectives, consistent with the findings of existing research [4]. Future work can extend the scope of investigation by incorporating algorithms recommended in the official MATLAB documentation [8] and by validating the feasibility and reliability of the optimisation approach using on-site measurement data. This would further promote the development of sustainable buildings.

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Xu Cuimei – Master’s student, Vinnytsia National Technical University, Vinnytsia, email: 93520200@qq.com

Biks Yuriy **–** PhD, Associate Professor, Department of Construction, Urban Economy and Architecture, Vinnytsia National Technical University, Vinnytsia.