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AI-Driven Multi-City Optimization of Glazing and Shading Systems for Building Energy Use and Operational Carbon Reduction Across Global Climate Zones

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INTRODUCTION & AIM

1. PURPOSE

This study develops an AI-assisted, simulation-based optimization framework to evaluate glazing and shading strategies across multiple climate zones. The aim is to identify climate-responsive façade configurations that reduce energy use and operational carbon while maintaining thermal comfort.

2. OBJECTIVES

This study aims to evaluate the performance of façade design strategies across contrasting climate zones using an AI-assisted, simulation-based optimization framework. It seeks to identify optimal combinations of glazing and shading variables that minimize energy use and operational carbon emissions while maintaining acceptable thermal comfort conditions. In addition, the study aims to translate optimization outcomes into interpretable, climate-specific design rules that can support early-stage architectural decision-making.

3. RESEARCH QUESTIONS

(**a**) How do optimal glazing and shading configurations vary across different climate zones?
(**b**) To what extent can AI-assisted optimization reduce energy use and operational carbon while maintaining thermal comfort?
(**c**) Which façade design variables (WWR, shading, glazing type, orientation) have the greatest impact on performance in each climate?
(**d**) Can optimization results be translated into consistent, climate-specific design rules for practical application?

METHOD

A standardized five-story residential prototype (20 zones) was simulated in DesignBuilder (EnergyPlus) with fixed non-façade parameters across all climates. Façade variables: WWR, orientation, shading depth, and glazing type, were optimized using an NSGA-II–based computational approach to minimize EUI and operational CO_2.

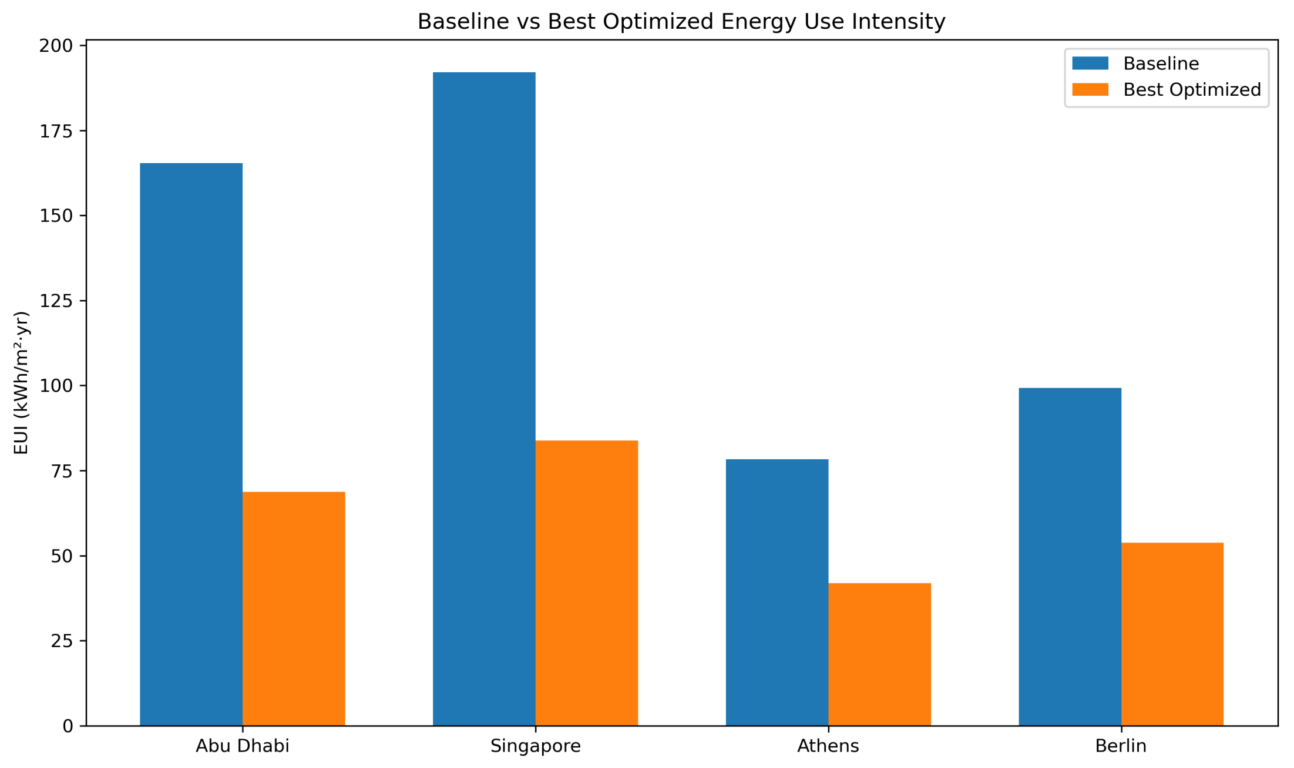
Thermal comfort was constrained using ASHRAE 55 discomfort hours, and ~100 iterations per city were analyzed to identify optimal solutions. Pareto-optimal solutions were analyzed to extract interpretable, climate-specific façade design rules. (**Table 1**) summarizes the climatic characteristics of the selected case study cities.

Climate Context of Case Study Cities

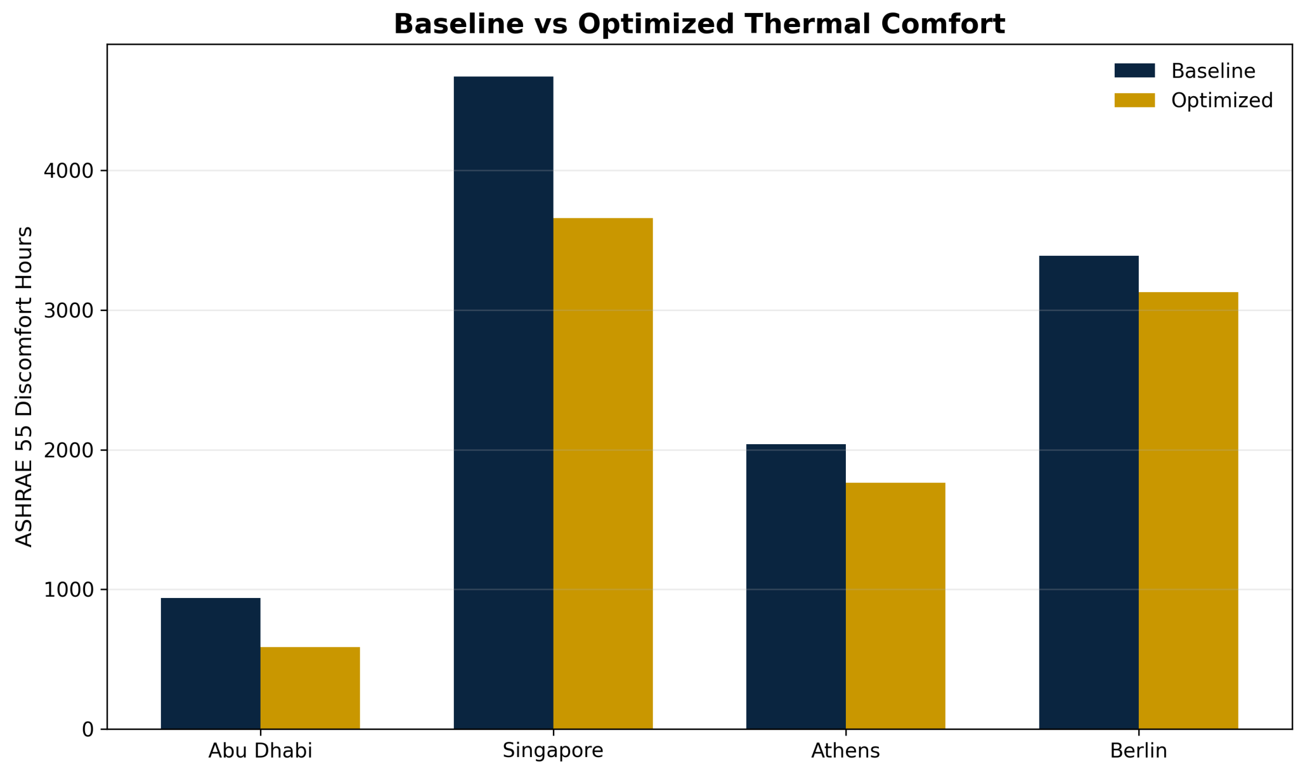
City	Climate	ASHRAE Zone	Peak Temp (°C)
Abu Dhabi	Hot-arid	1B	46.2
Singapore	Hot-humid	1A	34.1
Athens	Mixed	3A	35.6
Berlin	Temperate	5C	29.3

BASELINE VS OPTIMIZED PERFORMANCE

Optimization reduced Energy Use Intensity (EUI) across all climates, with the strongest improvements in hot-arid and hot-humid conditions (**Figure 1**). These gains are mainly driven by adjustments in glazing ratio and shading, which directly affect solar heat gains and cooling demand. In mixed and temperate climates, improvements were more moderate due to the balance between heating and cooling needs.

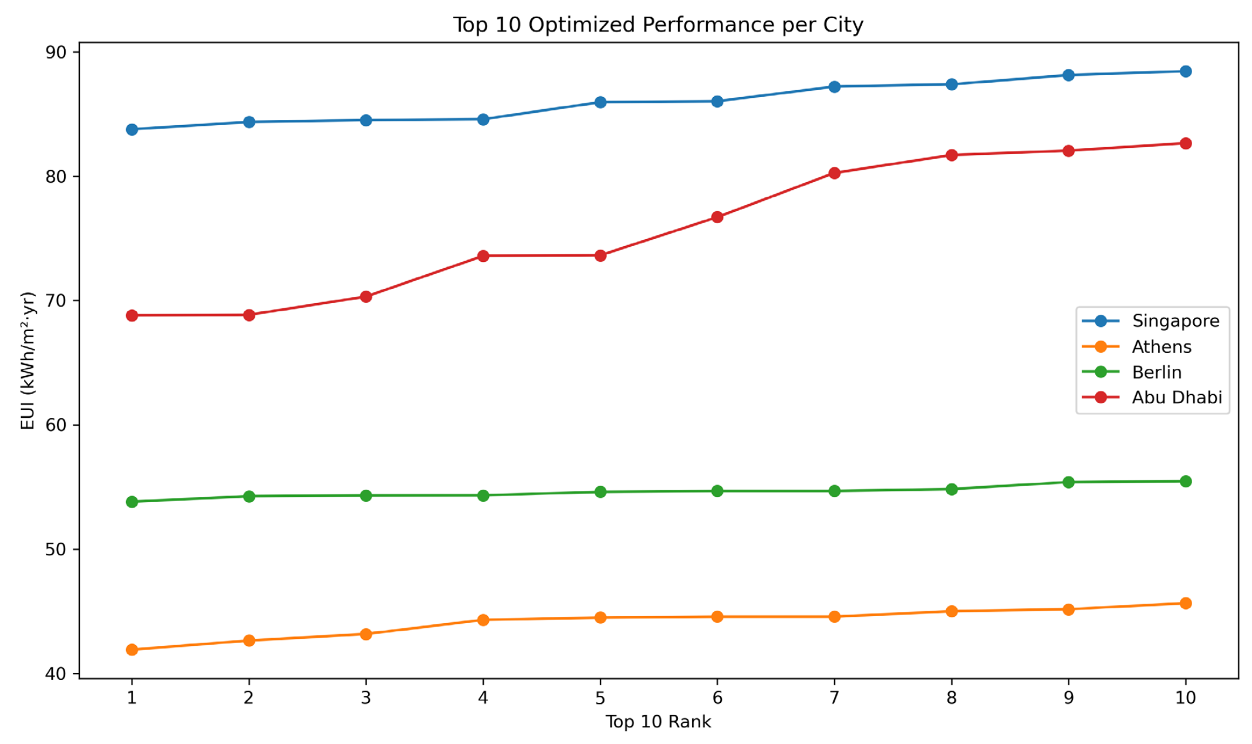


Thermal comfort was maintained or improved in all cases (**Figure 2**), confirming the effectiveness of applying ASHRAE 55 discomfort hours as a constraint. This shows that energy reductions were achieved without compromising indoor conditions, demonstrating the reliability of the optimization approach across different climates.

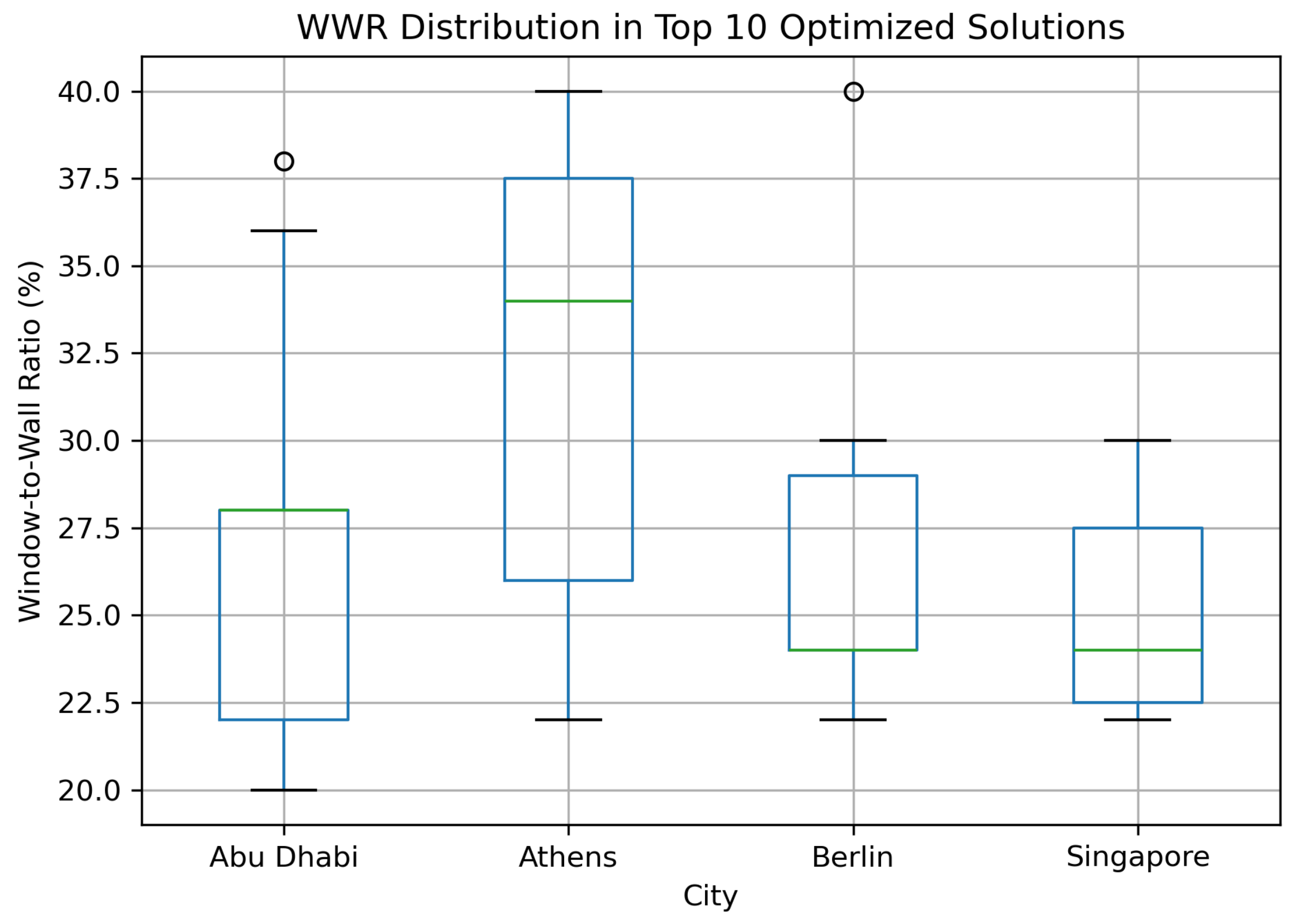


RESULTS & DISCUSSION

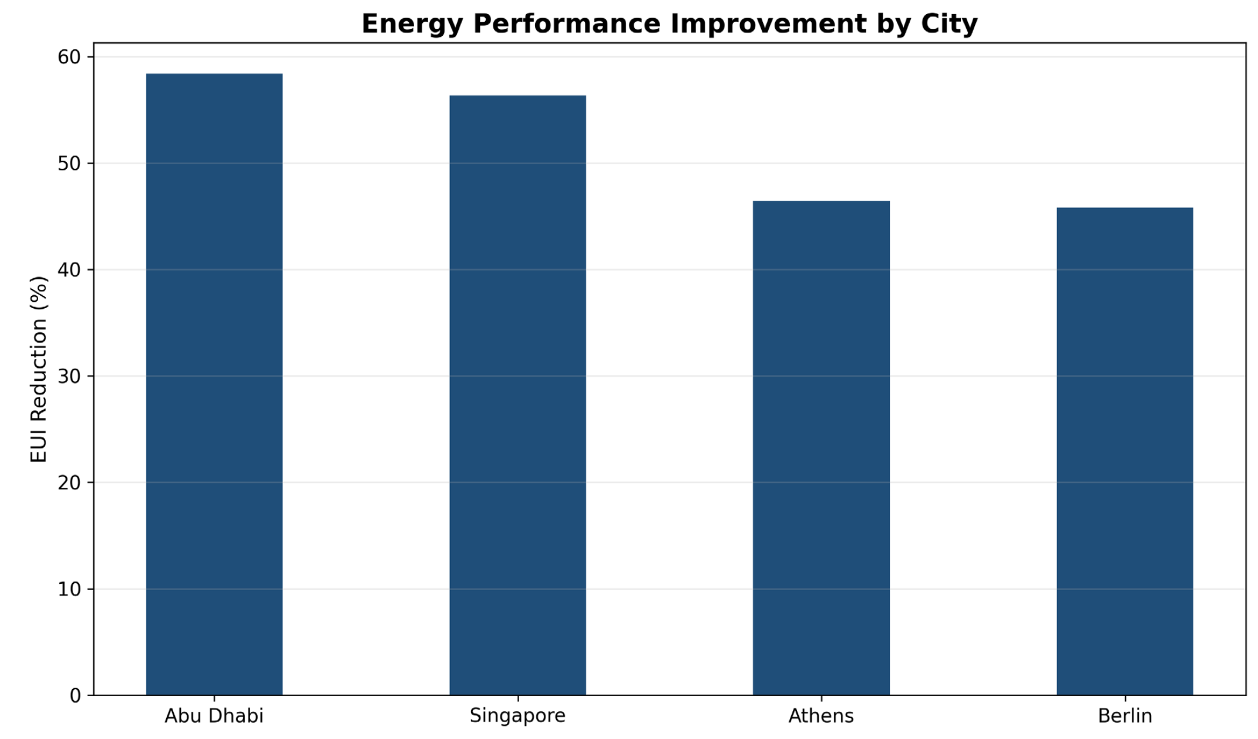
The optimization results show consistent improvements across all climates, with the fastest gains in early iterations, followed by stabilization of top solutions (**Figure 3**). This indicates that the process converges efficiently toward high-performance façade configurations under varying climatic and operational conditions. The smooth trend of top-ranked solutions suggests a clear solution space rather than random variation.



The distribution of Window-to-Wall Ratio (WWR) in top solutions shows clear climate patterns (**Figure 4**). Lower WWR values dominate in hot climates, where limiting solar gains is critical, while higher WWR values are more suitable in temperate conditions. Mixed climates show mid-range values, reflecting the need to balance heating and cooling demands effectively. This confirms WWR as a key driver of energy performance across diverse global climates.



Overall, energy improvements vary by climate (**Figure 5**), with the highest reductions in hot-arid and hot-humid environments. These results confirm that façade design must adapt to climate, as optimal solutions are not transferable across conditions. These patterns support the development of climate-specific façade design guidelines from the results.



CONCLUSION

The study demonstrates that AI-assisted, simulation-based optimization can significantly improve building energy performance across diverse climate zones. By systematically exploring façade variables such as glazing ratio, shading, orientation, and glazing type, the approach achieved substantial reductions in Energy Use Intensity while maintaining acceptable thermal comfort. The results confirm that integrating comfort constraints within the optimization process ensures that energy efficiency gains do not compromise occupant conditions.

Importantly, the findings highlight that **optimal façade strategies are strongly climate-dependent**. Lower glazing ratios and deeper shading are most effective in hot climates, while higher glazing ratios are more suitable in temperate environments. These patterns support the development of clear, climate-specific design guidelines and demonstrate the potential of AI-assisted optimization as a practical tool for early-stage architectural decision-making.

FUTURE WORK / REFERENCES

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