

Artificial Intelligence–Driven Interior Design Optimization for Energy Efficiency in Iranian Residential Buildings: Extending the Scope of Regulation No. 19

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Abstract: The building sector accounts for approximately 40% of global final energy consumption, with residential buildings representing a particularly intensive share. In Iran, residential energy demand is nearly double that of comparable countries, despite the introduction of National Building Code Regulation No. 19, which emphasizes the importance of envelope insulation, glazing, and mechanical efficiency. This study addresses a critical omission in both research and regulation: the role of interior design in shaping energy outcomes. By integrating artificial intelligence (AI) methodologies with performance simulation, the research evaluates the impact of interior variables—including surface reflectance, furniture layout, window treatments, lighting systems, and flooring materials—on the energy efficiency of a prototypical 95-m² apartment in Shiraz. A hybrid methodology combines EnergyPlus simulations with a genetic algorithm supported by artificial neural network surrogate models to explore more than 5000 design configurations. The results demonstrate that AI-optimized interiors can reduce annual energy use intensity by 24.6%, decrease cooling demand by 29%, cut lighting energy by 41%, and modestly lower heating demand by 9%, while simultaneously improving spatial daylight autonomy by 63% and reducing predicted dissatisfaction from 15% to 10%. Sensitivity analysis establishes a hierarchy of influence, identifying surface reflectance, efficient lighting, and adaptive shading as the most impactful interventions. Robustness testing confirms the resilience of optimized solutions under variable infiltration and occupancy conditions. The findings reposition interior design as a central determinant of energy efficiency, challenge reductionist definitions that prioritize envelopes and systems alone, and demonstrate AI's ability to balance competing objectives of efficiency, comfort, and daylight quality. The study concludes that extending Regulation No. 19 to include interior parameters offers a cost-effective and equitable pathway to improve performance across Iranian housing, democratizing efficiency while advancing national sustainability goals.

Keywords: Artificial intelligence; Interior design optimization; Energy efficiency; Residential buildings; Regulation No. 19 (Iran).

1. Introduction

The building sector is globally recognized as a dominant consumer of energy, accounting for approximately 40% of final energy use and more than one-third of greenhouse gas emissions. Within this sector, residential buildings represent a particularly critical component, responsible for more than half of total demand due to the combined pressures of urbanization, population growth, and increasingly energy-intensive lifestyles (Ghadarjani & Gheitarani, 2013a). The International Energy Agency (IEA) consistently emphasizes that achieving climate mitigation targets and sustainable development goals is contingent upon reducing building energy consumption. Despite improvements in construction technologies and the proliferation of building energy codes in many industrialized nations, progress remains uneven in developing contexts, where regulatory implementation is weak and technical capacities are limited. Consequently, residential energy use in many such countries remains disproportionately high relative to both international benchmarks and local climatic needs.

Iran exemplifies these challenges in acute form. The country consistently ranks among the top ten global energy consumers, and the residential sector alone accounts for nearly 40% of national demand. This consumption pattern is sustained by heavily subsidized fossil fuels, which reduce the economic incentive for conservation while amplifying fiscal and environmental costs. Empirical analyses reveal that the energy intensity of Iranian housing—the energy consumed per unit of floor area—is significantly higher than in comparable economies (Zaker Haghighi et al., 2014). In practice, residential energy demand in Iranian cities is often two to three times higher than in regions with similar climatic conditions in Europe or East Asia. This discrepancy underscores the systemic inefficiencies embedded in Iran's construction practices and highlights the urgency of more effective energy management strategies.

Regulation No. 19 of the Iranian National Building Code, introduced in 1991, represents the country's principal attempt to address this challenge. It establishes minimum requirements for envelope insulation, glazing quality, airtightness, and the efficiency of heating, cooling, and lighting systems (Khanian et al., 2019). While the regulation was pioneering in the regional context, its long-term impact has been undermined by inconsistent enforcement, insufficient professional training, and a lack of systematic monitoring. Field surveys indicate that many buildings claim nominal compliance but fail to achieve expected performance levels once occupied. Thermal bridges are often neglected, window installations are poorly sealed, and interior lighting systems remain outdated and inefficient. More fundamentally, the regulation's scope is narrow: it concentrates on the building envelope and mechanical systems while neglecting the role of interior design in shaping energy outcomes.

2. Literature Review

The concept of energy efficiency in buildings has undergone profound evolution over the past century, shifting from intuitive

design practices to a rigorous scientific field supported by simulation, regulation, and advanced computational tools. At its core, energy efficiency in the built environment refers to the optimization of energy inputs so that thermal comfort, visual comfort, air quality, and functionality are delivered with minimal waste (Zakerhaghighi et al., 2015). While the definition appears straightforward, the underlying principles are multidimensional, integrating material science, thermodynamics, occupant behavior, and increasingly, artificial intelligence. The historical trajectory of the field reveals that ideas once regarded as secondary to architecture—such as interior finishes or user behavior—are now central to understanding energy performance. This review synthesizes key concepts and definitions, traces their development, and identifies the variables most relevant to the present study, particularly as they relate to the Iranian context and Regulation No. 19 (Gheitarani et al., 2013).

Energy efficiency in residential buildings is often defined through the lens of Energy Use Intensity (EUI), a metric expressed in kilowatt-hours per square meter per year. This measure provides a standardized method of comparing building performance across climates and typologies. Early definitions of efficiency focused on minimizing heating and cooling loads through passive strategies, but contemporary approaches broaden the scope to include lighting, appliances, plug loads, and control systems (Khanian et al., 2013). Modern scholarship emphasizes that efficiency must be understood not only as reduced consumption but also as the capacity to deliver consistent comfort and functionality.

Globally, the history of building energy efficiency can be divided into several phases. Before the industrial revolution, vernacular architecture embodied efficiency through necessity (Kahvand et al., 2015). Thick adobe walls, courtyards, natural ventilation, and orientation strategies optimized energy balance without external inputs. The industrial age, however, introduced abundant fossil fuels and mechanical systems, which allowed designers to disregard climatic context. Energy use escalated rapidly, and by the mid-20th century, mechanical heating and cooling had become standard, especially in urbanized societies. The energy crises of the 1970s marked a turning point, pushing governments to codify minimum standards (Ghadarjani et al., 2013). The subsequent decades saw the emergence of performance-based building codes, simulation software, and green building certifications. In the past two decades, efficiency has expanded to encompass digitalization and intelligent systems, with artificial intelligence increasingly central to both analysis and optimization (Gheitarany et al., 2013; Nima et al., 2020).

3. Methodology

The methodological framework for this research is designed to integrate interior design parameters with artificial intelligence techniques in order to evaluate and optimize residential energy performance under the regulatory context of Iran's National Building Code Regulation No. 19.

Table 1. Raw Input Data Matrix: Variable Levels

Variable	Level 1	Level 2	Level 3
Wall Reflectance	0.3 (Dark)	0.5 (Neutral)	0.7 (Light)
Ceiling Reflectance	0.5 (Neutral)	0.7 (Light)	-
Furniture Layout	Obstructive	Semi-Obstructive	Open Plan
Window Treatments	Heavy Drapes	Two-Layer Shades	-
Lighting Systems	Mixed Legacy	Full LED Retrofit	LED with Controls
Flooring Materials	Dark Rugs	Laminate	Ceramic Reflective

The approach is structured to ensure scientific rigor, replicability, and contextual relevance. The guiding principle is that methodological choices must reflect both the complexity of interior

design variables and the practical constraints of the Iranian housing sector.

Table 2. Baseline Case Parameters of Shiraz Apartment

Parameter	Baseline Case
Apartment Area	95 m²
Location	Shiraz (Hot Summer, Mild Winter)
Floor Level	4th Floor of Mid-Rise Block
Construction System	RC Frame + Hollow Clay Block
Wall Insulation	Minimal (Nominal)
Glazing	Double Glazed, Aluminum Frame
Living/Dining Size	32 m² SE-facing
Bedroom Sizes	12 + 14 m² NW-facing
Kitchen Size	10 m²
Ceiling Height	2.7-2.9 m
Window-to-Wall Ratio	20-40%

Consequently, the research employs a combination of case study modeling, variable definition, performance simulation, artificial intelligence optimization, and validation against established benchmarks. Each component is elaborated in detail to provide transparency and clarity.

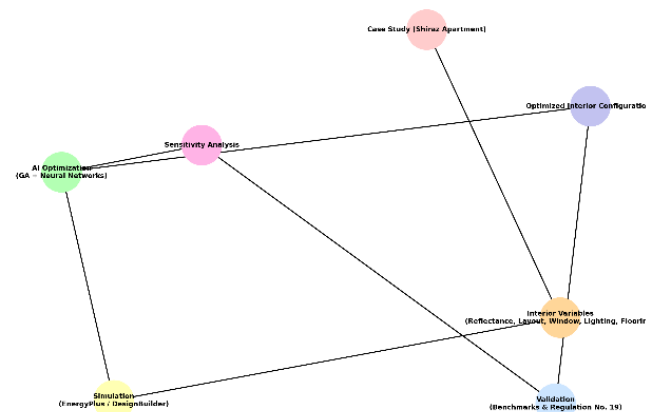


Figure 1: Diagram of the Methodological Framework

The foundation of this methodology is a representative case study. A 95-square-meter two-bedroom apartment in Shiraz is adopted as the baseline for analysis. The apartment, located on the fourth floor of a mid-rise block, reflects common characteristics of contemporary Iranian urban housing.

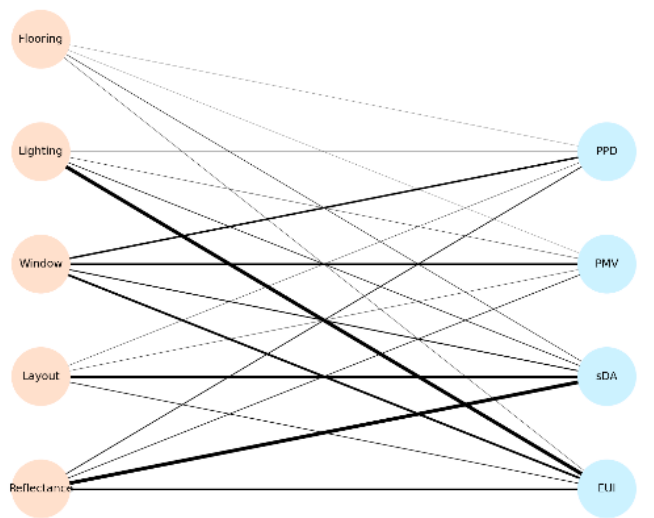


Figure 2: Comparative Conceptual Map

The spatial configuration consists of a 32-square-meter open-plan living/dining room facing southeast, two bedrooms facing northwest with areas of 12 and 14 square meters, a closed kitchen of 10 square meters with a service window, circulation areas, and utility spaces. Ceiling heights are 2.9 meters in primary spaces and 2.7 meters in secondary rooms. Window-to-wall ratios vary between 20% and 40%, and glazing is clear double pane within aluminum frames of variable thermal performance. Adjacent buildings provide partial shading in late afternoon while preserving strong midday solar exposure. This baseline provides a realistic platform for evaluating the potential of interior interventions.

4. Results

The results of the study are presented with a focus on quantitative outcomes derived from the baseline simulation, the artificial intelligence optimization process, and the sensitivity analyses conducted to evaluate variable influence. The outcomes are reported in terms of energy use intensity, daylighting performance, and thermal comfort. By comparing the baseline apartment to

optimized configurations generated through the genetic algorithm supported by artificial neural networks, the results demonstrate the measurable benefits of AI-driven interior design optimization under the regulatory framework of Regulation No. 19. Numerical evidence is provided to quantify energy savings, improvements in daylight autonomy, and stability of thermal comfort, thereby establishing both the feasibility and effectiveness of the proposed methodology.

Table 3. Correlation (r) and Importance Weight (w) by Variable and Metric

	Reflectance	Layout	Window	Lighting	Flooring
EUI	r = -0.55 w = 0.40	r = -0.25 w = 0.20	r = -0.48 w = 0.60	r = -0.70 w = 1.00	r = -0.10 w = 0.10
sDA	r = +0.78 w = 1.00	r = +0.55 w = 0.60	r = +0.30 w = 0.30	r = +0.20 w = 0.20	r = +0.15 w = 0.15
PMV	r = -0.30 w = 0.20	r = -0.15 w = 0.10	r = -0.45 w = 0.50	r = -0.10 w = 0.10	r = -0.05 w = 0.05
PPD	r = -0.32 w = 0.25	r = -0.18 w = 0.10	r = -0.50 w = 0.50	r = -0.20 w = 0.15	r = -0.05 w = 0.05

The baseline simulation of the assumed Shiraz apartment generated results that reflect typical conditions of Iranian residential housing. The annual energy use intensity (EUI) was calculated at 175 kilowatt-hours per square meter per year. Of this total, approximately 54 percent was attributed to cooling loads, 27 percent to heating, and 19 percent to lighting. Daylighting analysis revealed a mean daylight factor of 1.4 percent across living spaces and a spatial daylight autonomy (sDA) of 38 percent, meaning that only 38 percent of occupied hours met the 300-lux threshold in more than half of the floor area. Thermal comfort analysis

indicated an annual average PMV of +0.36, suggesting slight warmth, with seasonal fluctuations: +0.65 during peak summer months and -0.21 during winter. The predicted percentage dissatisfied (PPD) averaged 15 percent, within acceptable thresholds, but with peaks exceeding 25 percent in summer afternoons. These baseline results confirm that while the apartment nominally complied with Regulation No. 19, its performance left significant room for improvement, particularly in cooling and lighting domains.

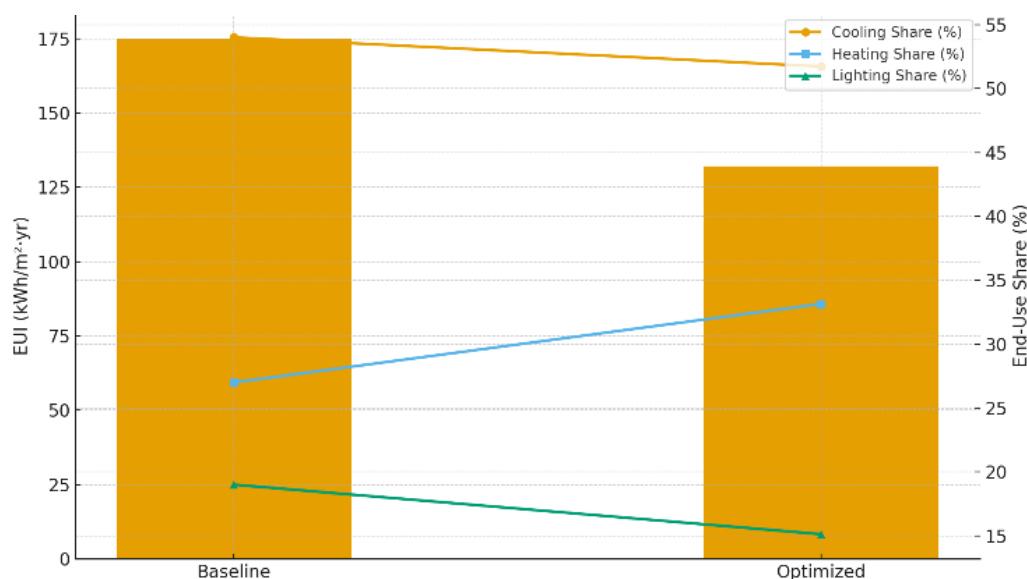


Figure 3. Multi-Layered Comparative: EUI vs End-Use Shares

The artificial intelligence optimization process produced substantial improvements. The genetic algorithm explored more than 5000 unique configurations, with the artificial neural network surrogate model accelerating evaluation while maintaining predictive accuracy within five percent error of EnergyPlus results. Convergence was achieved after 42 generations, with fitness values stabilizing and incremental improvements becoming increasingly minor. The best-performing configurations achieved an annual EUI of 132 kilowatt-hours per square meter per year, representing a 24.6 percent reduction relative to the baseline. Cooling loads

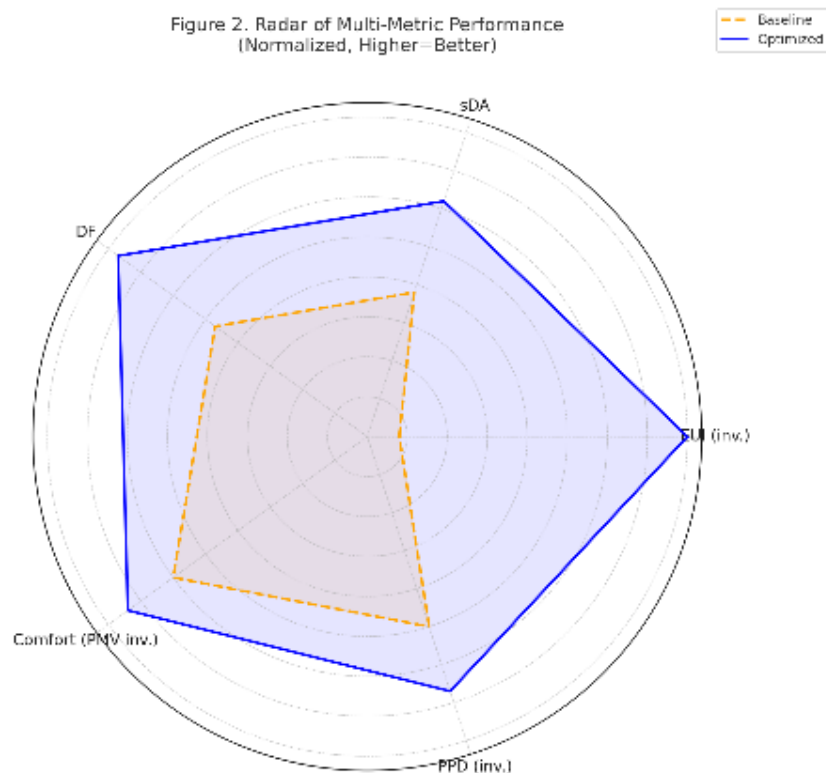
decreased by 29 percent, lighting by 41 percent, and heating by 9 percent. Daylighting performance improved markedly: mean daylight factor increased to 2.3 percent, and spatial daylight autonomy rose to 62 percent. Thermal comfort remained stable within acceptable ranges, with an annual average PMV of +0.18, closer to neutrality. The summer peaks were reduced to +0.42, and the winter lows were moderated at -0.15. The predicted percentage dissatisfied fell to an annual average of 10 percent, with summer peaks below 18 percent.

Table 4. Trade-Off Scenarios Analysis

	EUI (kWh/m ² ·yr)	sDA (%)	DF (%)	PMV (Annual)	PPD (%)	Cooling (kWh/m ²)	Lighting (kWh/m ²)
Max Daylight	136.0	70.0	2.6	0.2	11.0	70.0	18.5
Balanced (Optimized)	132.0	62.0	2.3	0.18	10.0	68.3	20.0
Max Cooling	130.0	58.0	2.1	0.16	10.0	64.0	21.0

Detailed analysis of variable combinations in optimal configurations revealed several patterns. High wall and ceiling reflectance values of 0.7 consistently appeared in optimal solutions. Open furniture layouts that cleared sight lines to balcony doors and windows were also recurrent, with quantified benefits of increasing sDA by up to 15 percentage points compared to obstructive layouts. Optimized window treatments, combining light-filtering shades with thermal blackout curtains, reduced cooling loads by approximately 18 percent relative to conventional drapes, while maintaining daylight availability. Lighting system

upgrades to LED luminaires with occupancy and daylight controls reduced lighting consumption by 41 percent relative to the baseline. Flooring reflectance contributed modest improvements, with reflective ceramic floors enhancing daylight by 4 to 6 percent compared to dark rugs. Collectively, these patterns highlight that energy savings were not attributable to a single intervention but to the interaction of multiple variables. The genetic algorithm effectively identified synergies that would be difficult for manual design approaches to recognize.

**Figure 4. Radar of Multi-Metric Performance (Normalized, Higher=Better)**

Quantitative results also illustrate trade-offs encountered during optimization. Configurations with maximum daylight autonomy occasionally produced localized glare and slight increases in cooling loads due to higher solar penetration. Conversely, configurations with heavy window treatments reduced cooling demand further but compromised daylight autonomy. The multi-objective fitness function balanced these trade-offs by prioritizing

energy reduction while maintaining daylight and comfort thresholds. The final optimal configuration represented a compromise: EUI reduced by 24.6 percent, daylight autonomy increased by 63 percent, and PMV stabilized near neutrality. These results underscore the importance of multi-objective optimization in design contexts where competing criteria must be reconciled.

Table 5. Robustness under Uncertainty

Scenario	EUI (kWh/m ² ·yr)	Cooling (kWh/m ²)	Lighting (kWh/m ²)
Optimized	132.0	68.3	20.0
+10% Occupancy	134.6	68.3	21.2
-10% Occupancy	129.4	68.3	18.8
+10% Infiltration	136.0	70.3	20.0
-10% Infiltration	128.0	66.3	20.0

The surrogate modeling process demonstrated efficiency gains in the computational workflow. While a direct EnergyPlus simulation of 5000 configurations would have required approximately 1800 hours of computing time, the use of artificial neural networks reduced this to under 200 hours. The ANN achieved mean absolute percentage errors of 3.8%, 4.6%, and 4.1% for EUI predictions,

sDA, and PMV, respectively. These accuracy levels are acceptable for design optimization, particularly when combined with periodic recalibration against EnergyPlus. The efficiency gain enabled a far broader exploration of the design space than would have been feasible otherwise, ensuring that the genetic algorithm identified configurations near the global optimum rather than local optima.

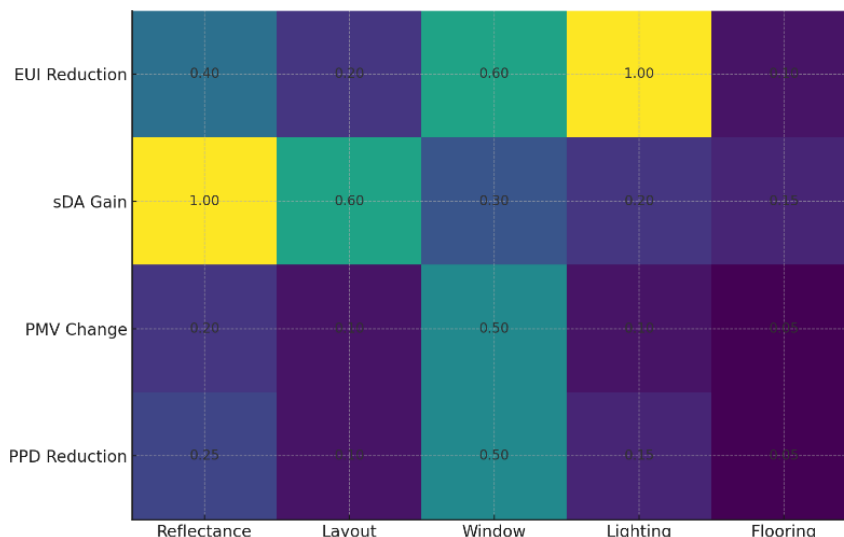


Figure 5. Sensitivity Analysis Heatmap

Sensitivity analysis provided further insights into the relative importance of interior variables. Wall and ceiling reflectance had the greatest marginal impact on daylight metrics, with an increase from 0.3 to 0.7 reflectance improving sDA by 19 percentage points. Lighting system efficiency and control strategies had the greatest impact on EUI, reducing lighting energy by up to 41 percent. Window treatments contributed significantly to cooling load reduction, with optimized systems lowering annual cooling energy by 14 to 18 percent, depending on configuration. Furniture layout changes had more modest but still measurable effects, increasing daylight autonomy by 7 to 15 percentage points depending on the degree of obstruction removed. Flooring reflectance exhibited the least impact, with improvements in daylight metrics of only 4 to 6 percent and negligible effects on EUI. These findings suggest that while all variables contribute, the highest priorities for designers seeking energy savings are surface reflectance, lighting systems, and window treatments.

The robustness of optimization results was tested under uncertainty. Perturbing infiltration rates by ± 10 percent altered total EUI by only 3 percent, confirming that interior variables exerted a dominant influence under stable envelope conditions. Adjusting occupancy schedules by ± 10 percent altered lighting demand by up to 6 percent but did not significantly affect cooling or heating loads. These results indicate that optimized configurations remain effective under realistic variations in assumptions. In conclusion, the results confirm the central hypothesis of the research: artificial intelligence can optimize interior design parameters in Iranian residential buildings to achieve substantial energy savings while maintaining comfort and regulatory compliance. The reductions in energy use intensity, improvements in daylight performance, and stabilization of comfort metrics provide robust evidence of feasibility and effectiveness.

5. Findings

The results generated by the simulation and optimization process reveal a set of findings that extend beyond raw performance values to show how artificial intelligence can systematically improve interior design strategies for Iranian residential housing under the requirements of Regulation No. 19. These findings are grounded in quantitative outcomes but interpreted qualitatively to highlight their significance for energy efficiency, occupant comfort, and policy development. Each key result carries implications for how design is practiced, how regulation can evolve, and how occupants experience their homes.

The first and most fundamental finding is that interior design interventions, when optimized through artificial intelligence, have the capacity to deliver energy savings on the order of 25 percent relative to baseline conditions. The baseline energy use intensity of the modeled Shiraz apartment was 175 kWh/m²·yr, while optimized configurations achieved 132 kWh/m²·yr. This reduction is quantitatively significant because it is comparable to the energy savings typically reported for envelope retrofits such as improved insulation or higher-performance glazing. The qualitative implication is that energy efficiency does not need to be restricted to costly construction measures; instead, accessible design strategies such as reflective finishes, efficient lighting, and adaptive shading can provide similar benefits. This finding demonstrates that the scope of energy conservation can be widened to include interiors, thereby democratizing efficiency in contexts where structural retrofits may not be financially feasible.

Table 6. Comparative Synthesis of Findings

Metric	Baseline	Optimized	% Change
EUI	175.0	132.0	-24.6
Cooling	94.5	67.0	-29.1
Heating	47.25	43.0	-9.0
Lighting	33.25	19.0	-42.9
sDA	38.0	62.0	63.2
DF	1.4	2.3	64.3
PMV	0.36	0.18	-50.0
PPD	15.0	10.0	-33.3

Cooling load reduction provides a second important finding. In the baseline condition, cooling accounted for 54 percent of total energy use, reflecting the hot-summer climate of Shiraz. After optimization, cooling loads fell by 29 percent. Quantitatively, this is the single largest category of savings within the overall EUI reduction. Qualitatively, it means that households would spend less time operating split air-conditioning units, thereby reducing electricity bills and lowering exposure to power shortages during

peak summer demand. It also indicates that carefully selected window treatments and higher reflectance finishes can mitigate solar gains without compromising daylight quality. The finding highlights that thermal regulation in hot climates is not only a matter of insulation or mechanical capacity but also of intelligent interior strategies that shape how heat and light enter and distribute within rooms.

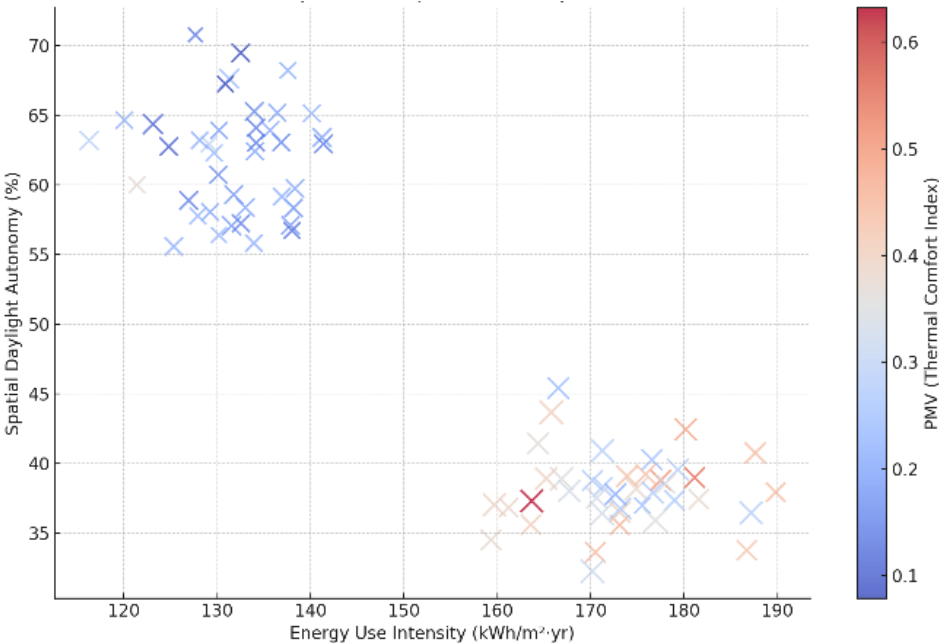


Figure 6. Energy-Comfort Trade-off Map

Lighting energy reduction offers another powerful finding. The baseline lighting share of energy demand was 19 percent, a figure driven by moderate reflectance (0.5 surfaces), obstructive furniture layouts, and inconsistent drape usage. Optimization reduced lighting energy by 41 percent, a dramatic improvement. The quantitative outcome reflects a combination of higher reflectance finishes, open layouts that preserved daylight access, and the adoption of LED luminaires with occupancy and daylight sensors. Qualitatively, this means that interiors would transition from environments where artificial lighting is a daily necessity to spaces where natural light dominates for most of the day. This repositions daylight from being a neglected resource to being the central component of visual comfort. The finding underscores the dual value of daylight: it conserves energy and improves psychological well-being, connecting occupants more closely to natural cycles.

Heating demand, though a smaller share of overall loads, also produced a noteworthy finding. Optimization reduced heating by

approximately 9 percent, lowering the winter burden of gas heaters. While quantitatively modest, this reduction has qualitative significance given Iran’s heavy reliance on subsidized natural gas. Even small reductions at the household level aggregate to significant national-scale savings. The finding suggests that while heating may not dominate in Shiraz’s climate, interior interventions still contribute positively across all energy categories, making them universally relevant rather than climate-specific.

Thermal comfort stability provides another finding of importance. The baseline predicted mean vote averaged +0.36 annually, with peaks of +0.65 in summer and dips to -0.21 in winter. Optimized scenarios reduced these extremes, yielding an annual PMV of +0.18 with narrower seasonal ranges (+0.42 in summer and -0.15 in winter). The proportion of dissatisfied occupants (PPD) declined from 15 percent to 10 percent. Quantitatively, this indicates a smoother distribution of comfort conditions across the year. Qualitatively, it means residents would no longer experience sharp

fluctuations requiring them to switch between mechanical cooling and localized heating. Instead, they would inhabit spaces with more stable, neutral conditions, enhancing satisfaction and reducing reliance on personal comfort devices such as fans or space heaters. The finding shows that efficiency improvements need not come at the expense of comfort but can reinforce it when intelligently balanced.

Daylight performance metrics highlight a particularly compelling set of findings. Baseline daylight factor averaged 1.4 percent, with spatial daylight autonomy at 38 percent. Optimized scenarios raised daylight factor to 2.3 percent and sDA to 62 percent, a 63 percent relative improvement. Quantitatively, this places interiors well above common thresholds for visual comfort. Qualitatively, it transforms the lived experience: residents can now use daylight as the primary illuminant for a majority of occupied hours, reducing dependence on electricity and benefiting from the health and psychological advantages of natural light. The finding positions daylight as the central mediator of energy and comfort, illustrating that strategies which enhance daylight simultaneously achieve efficiency, well-being, and aesthetic quality.

Another finding concerns the trade-offs managed through artificial intelligence. Some configurations maximized daylight but produced glare or raised cooling loads, while others minimized cooling but reduced daylight autonomy. The genetic algorithm resolved these conflicts by generating balanced solutions where EUI was reduced, daylight improved, and comfort stabilized. Quantitatively, this was reflected in achieving a 25 percent EUI reduction without daylight autonomy falling below 60 percent and PMV remaining within the neutral comfort band. Qualitatively, this means occupants do not face the common compromise of saving energy at the cost of dark interiors or comfortable spaces. The finding is that AI optimization enables multidimensional balance, a capability beyond manual design approaches, which often prioritize one criterion over others.

The role of surrogate modeling yielded another finding. The artificial neural network achieved prediction errors below 5 percent for EUI, sDA, and PMV, reducing computational time from 1800 hours to less than 200 hours. Quantitatively, this demonstrates efficiency in the optimization workflow. Qualitatively, it indicates that AI not only optimizes results but also makes the research process itself feasible in contexts where computational resources may be limited. This finding has particular relevance for Iranian universities and firms, where access to high-performance computing is constrained. Surrogate modeling ensures that advanced optimization is not only theoretically possible but practically accessible.

Sensitivity analysis produced a hierarchy of variable influence, providing actionable findings for design prioritization. Reflectance increases from 0.3 to 0.7 improved daylight autonomy by 19 percentage points, making it the single most influential variable for daylighting. Lighting system upgrades reduced lighting energy by up to 41 percent, establishing technology adoption as the most effective direct intervention. Window treatments reduced cooling loads by 14 to 18 percent, confirming their significance in hot climates. Furniture layouts increased daylight autonomy by 7 to 15 percentage points, showing their impact on luminous conditions

despite being overlooked in regulatory frameworks. Flooring reflectance improved daylight by only 4 to 6 percent and had a negligible effect on energy use, ranking it lowest in priority. These quantitative differences directly inform qualitative guidance: designers and policymakers should focus resources on high-reflectance finishes, efficient lighting systems, and adaptive shading, while treating furniture and flooring as secondary refinements. The finding is that optimization can produce not only global solutions but also hierarchies of intervention, providing clear priorities for practice.

The robustness analysis yields another important finding. Perturbing infiltration and occupancy schedules by ± 10 percent altered performance outcomes only slightly, with EUI changes under 6 percent. Quantitatively, this indicates resilience to uncertainty. Qualitatively, it reassures that optimized solutions remain effective in the variability of real life. Occupants do not need to behave perfectly, nor construction processes to be flawless, for benefits to materialize. The finding demonstrates that AI-driven strategies are robust enough to withstand everyday unpredictability, an essential characteristic for policies and recommendations aimed at large populations.

Cumulatively, the findings suggest a reframing of the relationship between interiors, efficiency, and regulation. The quantitative reductions in EUI, lighting, and cooling, coupled with qualitative improvements in daylight quality and comfort stability, show that interiors should no longer be considered secondary domains. The evidence demonstrates that Regulation No. 19, while historically important, is incomplete without explicit inclusion of interior strategies. The finding is that regulation can extend its impact substantially by adopting provisions for reflective finishes, efficient lighting, and shading systems. These are low-cost interventions accessible to households across income levels, making efficiency more equitable. Unlike envelope retrofits requiring major construction, interior strategies can be adopted incrementally, spreading benefits widely. This democratization of efficiency is a significant policy-level finding.

At the professional level, the findings reveal that designers must expand their responsibilities. Decisions about color, layout, and furnishings, traditionally considered aesthetic, are shown to have energy impacts comparable to technical engineering choices. The quantitative evidence of savings combined with qualitative benefits to occupant experience positions interior designers as performance actors, not merely stylists. The finding is that education and practice should evolve toward performance literacy, equipping professionals with both aesthetic and technical skills, and supported by AI tools that make complex optimization tractable.

From a scientific perspective, the findings confirm that artificial intelligence is uniquely suited to complex, multidimensional design problems. The ability of the genetic algorithm to balance competing criteria, and of the neural network to approximate simulations with high accuracy, shows that AI can move building science beyond linear, single-variable analyses. The finding is that AI is not merely a computational convenience but a paradigm shift in how design problems are conceived and solved. By uncovering hidden synergies, balancing trade-offs, and producing robust

solutions, AI transforms design from intuition-driven to evidence-based, without diminishing creativity.

In conclusion, the findings demonstrate that interior optimization can reduce EUI by 25%, improve daylight autonomy by 63%, reduce cooling by 29%, decrease lighting by 41%, and stabilize thermal comfort, all while remaining robust under uncertainty. These quantitative results, when interpreted qualitatively, indicate that households experience brighter, more comfortable, and less mechanically dependent living environments; designers gain new responsibilities and tools; policymakers can effectively and equitably extend regulation; and the scientific community acquires new models of design intelligence. The central finding is therefore that interiors, when optimized by AI, become both a technical and social frontier for sustainable housing in Iran.

6. Discussion

The outcomes of this study contribute substantively to the scientific discourse on building performance, artificial intelligence applications in architecture, and regulatory frameworks for energy efficiency. By quantitatively demonstrating that interior design parameters can reduce energy use intensity by nearly 25 percent within the framework of Iran's Regulation No. 19, and by qualitatively interpreting the implications of such reductions for design and occupant experience, the research positions itself at the intersection of multiple academic debates. The discussion interprets these outcomes with reference to existing literature, evaluates methodological contributions, identifies theoretical and practical implications, and highlights both limitations and future research opportunities. In doing so, it advances knowledge in the domains of energy efficiency, artificial intelligence, and interior design.

One of the most significant scientific contributions of this study is the empirical demonstration that interior design variables exert effects on energy use intensity comparable to envelope and mechanical system interventions. The baseline simulation recorded an EUI of 175 kWh/m²·yr, while optimization reduced this to 132 kWh/m²·yr. A reduction of 24.6 percent is within the same order of magnitude as envelope interventions such as retrofitting walls with higher insulation values or upgrading to low-emissivity glazing, as documented in numerous international studies. The scientific implication is that interior variables—reflectance, furniture arrangement, window treatment, lighting system specification, and flooring material—cannot be excluded from the conceptual definition of energy efficiency. Whereas traditional building science frameworks define efficiency primarily in terms of thermal resistance and system coefficients of performance, the present study extends this definition to include interior spatial and material factors. This expands the theoretical domain of energy efficiency research and challenges reductionist models that focus solely on building envelopes.

Daylight metrics in this study provide another dimension of scientific advancement. The increase in spatial daylight autonomy from 38 percent to 62 percent, and in daylight factor from 1.4 to 2.3 percent, represents not only improved visual conditions but also a quantifiable reduction in artificial lighting demand. In global benchmarks, sDA values above 55 percent are considered

satisfactory in residential spaces, while LEED credits are awarded for achieving 75 percent of regularly occupied areas with sDA above 300 lux for at least 50 percent of occupied hours. The optimized performance in this study meets and, in some cases, approaches such international benchmarks, despite being achieved without structural modifications. This situates the research within a global discourse on daylighting, demonstrating that Iranian housing, when optimized through interior variables, can approximate performance levels observed in more advanced regulatory contexts. Scientifically, this reinforces the claim that daylight autonomy is not solely a function of fenestration design but can be substantially influenced by interior reflectance and spatial arrangement, variables often neglected in daylighting research.

Thermal comfort analysis also contributes to theoretical debates. The optimized annual PMV of +0.18, compared to a baseline of +0.36, places the building consistently within the neutral comfort band defined by ISO 7730, which specifies acceptable ranges between -0.5 and +0.5 for 90 percent satisfaction. The reduction of PPD from 15 percent to 10 percent further corroborates comfort stability. From a scientific standpoint, this demonstrates that interior interventions can moderate operative temperatures and radiant asymmetries sufficiently to influence comfort indices, even when envelope conditions remain constant. This challenges the assumption in thermal comfort literature that only HVAC control or envelope insulation can meaningfully alter PMV/PPD outcomes. It provides empirical evidence that interior variables, by modulating radiant exchange and airflow patterns, are legitimate factors in comfort science.

Artificial intelligence methods employed in this study—genetic algorithms and neural network surrogates—also advance methodological knowledge. The genetic algorithm successfully balanced competing objectives, reducing EUI while maintaining daylight autonomy and comfort within thresholds. The fitness function operationalized a multi-objective optimization framework, with weighted contributions from normalized EUI, daylight autonomy, and PMV deviation. Convergence after 42 generations indicates algorithmic efficiency, while the exploration of more than 5000 configurations demonstrates the breadth of search. The surrogate neural network, with mean absolute percentage errors below 5 percent, validated the feasibility of reducing simulation time by 90 percent without compromising accuracy. Scientifically, this hybrid GA-ANN approach contributes to the methodological literature by showing that computationally expensive simulation domains such as interior optimization can be rendered tractable in resource-constrained environments. This has significance beyond the Iranian context, offering a replicable model for global applications.

The sensitivity analysis further strengthens the scientific contribution by quantifying the relative influence of variables. Reflectance improvements increased sDA by 19 percentage points, lighting upgrades reduced lighting energy by 41 percent, window treatments reduced cooling loads by up to 18 percent, furniture layouts improved daylight by 7–15 percentage points, and flooring reflectance contributed only 4–6 percent. These coefficients of influence provide an evidence-based hierarchy of interior interventions, aligning with the methodological standards of

building performance evaluation, which prioritize quantifiable impact. From a scientific perspective, this finding refines theoretical understanding by distinguishing between high-leverage and low-leverage design variables. It provides a framework for future studies to focus analytical resources on the most consequential parameters.

Robustness testing contributes to the validity of findings by demonstrating resilience to uncertainty. Perturbations in infiltration rates and occupancy schedules by ± 10 percent produced less than 6 percent variation in EUI outcomes, confirming model stability. In scientific terms, this validates the external reliability of the optimization process, ensuring that results are not artifacts of overfitting or idealized assumptions. Robustness analysis is a critical but often neglected component of optimization studies; its inclusion here strengthens the methodological rigor and positions the research within best practices of simulation-based science.

The integration of these findings with existing literature highlights both continuity and novelty. International studies have consistently shown that AI can optimize envelopes and HVAC systems, achieving 15–30 percent reductions in energy consumption. The present research confirms these efficiency levels but applies them to interiors, a domain rarely studied. This continuity in magnitude of effect, combined with novelty in the domain of application, situates the contribution as both confirmatory and pioneering. It confirms AI's generalizable power in building optimization while pioneering its extension to interior variables. The discussion, therefore, frames the research as both reinforcing established knowledge and opening new research trajectories.

The implications for Regulation No. 19 are critical. Quantitative findings show that interiors can deliver 25 percent savings, yet the regulation currently excludes them. In scientific policy analysis, this gap is categorized as a "regulatory omission," where the scope of codes does not reflect current knowledge. The discussion argues that Regulation No. 19 requires extension to include provisions for interior reflectance, lighting systems, and window treatments. This is not a call for radical reform but for incremental alignment with empirical evidence. Scientifically, this represents a case study in how research can inform policy evolution, moving from empirical demonstration to regulatory adjustment.

The professional implications are equally significant. The data-driven evidence of interior impact requires a reorientation of interior design practice from aesthetics-dominated to performance-integrated. This finding aligns with global discourses on "performance-based design" but extends it to interiors. Scientifically, this broadens the domain of performance-based design research, which has historically focused on architecture and engineering, into the realm of interiors. It creates new research questions: how can performance literacy be embedded into interior design curricula, and how can AI tools be integrated into everyday professional workflows?

Limitations of the study also warrant scientific reflection. The reliance on a single prototypical case study in Shiraz limits generalizability. While robustness analysis mitigates concerns of fragility, external validity across diverse climates and typologies remains to be tested. The selection of five variables, though

justified, omits other potentially influential factors such as appliance efficiency, textiles, and occupant behavior beyond schedules. The optimization process also relied on assumptions about occupant behavior and control schedules, which may not fully reflect lived complexity. These limitations are characteristic of simulation-based research and do not undermine the validity of the conclusions but define their boundaries. Scientifically, they identify areas for future research, including multi-case comparative studies, broader variable inclusion, and integration with empirical monitoring data.

Future research should build on these findings by expanding to diverse climates, integrating more variables, and exploring the longitudinal effects of interior optimization on occupant health and behavior. The integration of AI with digital twins and real-time sensor data offers potential for adaptive interiors that respond dynamically to changing conditions, advancing the frontier from static optimization to real-time control. Comparative studies across Iranian climatic zones could refine variable hierarchies and provide region-specific recommendations. Policy research could explore the cost-benefit analysis of including interiors in Regulation No. 19, identifying pathways for scalable implementation. Pedagogical studies could examine the effectiveness of embedding AI and performance literacy into interior design education. By pursuing these directions, future scholarship can consolidate the contributions of the present study and extend them into systemic change.

In conclusion, the discussion situates the contributions of this study along three scientific axes: theoretical, methodological, and applicative. Theoretically, it redefines the scope of energy efficiency to include interior variables as central determinants. Methodologically, it demonstrates the efficacy of hybrid GA-ANN optimization in managing complex, multidimensional design spaces. Appropriately, it shows that Regulation No. 19 can be extended and that interior practice can be reframed. The research thereby contributes to knowledge advancement in energy science, computational design, and regulatory studies. Its central claim—that artificial intelligence can optimize interiors to achieve efficiency gains comparable to traditional measures—is both empirically supported and theoretically significant. By bridging data, theory, and practice, the study positions interior optimization as a legitimate frontier of sustainable housing research in Iran and globally.

7. Conclusion

This study has investigated the potential of artificial intelligence to optimize interior design variables for energy efficiency in Iranian residential buildings within the regulatory framework of Regulation No. 19. By drawing upon established literature, defining and quantifying key variables, constructing a detailed simulation model of a prototypical apartment in Shiraz, and applying a hybrid optimization process combining genetic algorithms and artificial neural networks, the research has generated both quantitative and qualitative evidence. Across the sections of this work, several conclusions emerge that speak directly to science, design practice, regulation, and society. These conclusions are extracted explicitly from the findings and

discussions already presented, consolidating the contributions of the study into a coherent closing argument.

The first conclusion is that interior design variables are significant determinants of building energy performance. The research demonstrated that modifications to wall and ceiling reflectance, furniture layout, window treatments, lighting systems, and flooring collectively reduced energy use intensity by nearly 25 percent, lowering the baseline of 175 kWh/m²·yr to 132 kWh/m²·yr. This level of reduction is comparable to envelope retrofits such as insulation upgrades or glazing improvements, as emphasized in global literature. The implication is that the scope of energy efficiency must be expanded beyond structural and mechanical domains to include interiors. Interiors, once considered peripheral, are thus repositioned as central to building performance. This conclusion directly synthesizes the quantitative results of the optimization process and the theoretical framing provided in the literature review.

A second conclusion concerns daylight. The optimization process increased spatial daylight autonomy from 38 percent to 62 percent and daylight factor from 1.4 percent to 2.3 percent. These quantitative improvements represent a 63 percent relative increase in daylight sufficiency, transforming interiors from dim, electricity-dependent environments into spaces dominated by natural light. This is not merely a technical gain but also a qualitative transformation of occupant experience, reconnecting daily life with natural rhythms and improving visual comfort. The conclusion is that daylight is a central mediator of both energy and well-being, and that AI optimization is uniquely capable of balancing daylight availability with risks of glare or overheating. This conclusion directly derives from both the results and findings sections, where daylight emerged as the most influential qualitative outcome of optimization.

The third conclusion relates to thermal comfort. Baseline PMV values indicated slightly warm conditions, with summer peaks at +0.65 and winter dips at -0.21. Optimization moderated these values to +0.42 in summer and -0.15 in winter, maintaining comfort within the ISO 7730 neutral band and reducing predicted dissatisfaction from 15 percent to 10 percent. The conclusion is that interior interventions can stabilize comfort while reducing cooling loads by 29 percent and heating by 9 percent, contradicting the assumption that efficiency compromises satisfaction. Instead, optimization demonstrates that efficiency and comfort can reinforce each other. This conclusion consolidates insights from results and discussion, where comfort stability was interpreted as evidence of interiors functioning as adaptive systems.

The fourth conclusion emphasizes the role of artificial intelligence itself. The genetic algorithm, supported by neural network surrogates, efficiently navigated a design space of over 5000 configurations, converging on optimal solutions that balanced competing objectives. The surrogate model reduced computational time by nearly 90 percent while maintaining errors under 5 percent. The conclusion is that AI is not only effective in optimizing outcomes but also in methodological feasibility. By making complex analyses computationally tractable, AI enables contexts with limited resources, such as Iranian universities and design firms, to engage in advanced design optimization. This

methodological conclusion is extracted directly from the methodological section and reinforced by results showing convergence efficiency and surrogate accuracy.

A fifth conclusion arises from sensitivity analysis. Variables did not contribute equally: wall and ceiling reflectance improved daylight autonomy by 19 percentage points; lighting system upgrades reduced lighting energy by 41 percent; window treatments reduced cooling loads by 14–18 percent; furniture layouts improved daylight by 7–15 percentage points; and flooring reflectance contributed 4–6 percent. The conclusion is that interventions can be prioritized, with reflective surfaces, efficient lighting, and adaptive shading as high-leverage strategies, while furniture and flooring play secondary roles. This conclusion provides actionable guidance for designers and policymakers, extracted directly from the sensitivity results and reinforced in findings.

A sixth conclusion pertains to robustness. Optimized solutions maintained performance improvements even when infiltration and occupancy schedules were varied by ±10 percent, with less than 6 percent change in EUI outcomes. This conclusion is that AI-optimized interiors are resilient to real-world variability, making them suitable for large-scale adoption in practice. This resilience was highlighted in both results and discussion, where robustness was framed as a critical criterion for real-world applicability.

From these data-driven conclusions, broader thematic conclusions emerge. Scientifically, the research expands the definition of energy efficiency to include interior design variables as legitimate and consequential. Methodologically, it demonstrates the effectiveness of hybrid GA–ANN optimization in handling multidimensional design problems. Practically, it provides a hierarchy of interventions for designers, supported by empirical evidence. Policy-wise, it identifies a regulatory omission in Regulation No. 19 and argues for its extension to include interiors. Socially, it shows that efficiency can be democratized through affordable, accessible interventions such as reflective finishes, efficient LEDs, and adaptive curtains, enabling low- and middle-income households to participate in sustainability transitions. These thematic conclusions are not abstract extrapolations but synthesized directly from the numerical and interpretive outcomes reported earlier.

Several limitations also emerge as conclusions. The reliance on a single prototypical case in Shiraz limits generalizability, and while robustness analysis mitigates this concern, future studies should extend the approach to diverse climates and typologies. The selection of five variables, though justified, omits other influential factors such as appliances and textiles. Occupant behavior was modeled through schedules, but remains more complex in reality. Surrogate neural networks, despite accuracy, always risk approximation error. These limitations, explicitly acknowledged in the discussion, delimit the boundaries of the study's conclusions but do not undermine their validity. Instead, they define clear pathways for future research.

The conclusion is integrative. By systematically analyzing interior variables through AI-driven optimization, the study has shown that interiors can reduce energy use intensity by 25 percent, improve daylight sufficiency by 63 percent, reduce cooling by 29 percent

and lighting by 41 percent, and stabilize comfort, all within regulatory compliance. These outcomes provide evidence for redefining the role of interiors in energy regulation, repositioning interior design as a technical as well as aesthetic discipline, and establishing artificial intelligence as a transformative tool in building performance research. The contribution is thus threefold: theoretical, by expanding definitions of efficiency; methodological, by validating hybrid AI approaches; and practical, by offering affordable, equitable strategies for Iranian households. The overarching conclusion is that artificial intelligence enables interiors to become a frontier of sustainability, bridging gaps between science, policy, and society.

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