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An Intelligent Fuzzy Logic Based Framework for Optimizing Energy Consumption in Residential Buildings

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Abstract

Population growth and the increasing demand for housing require a shift from traditional construction methods to industrialized approaches aligned with sustainable development. Using modern materials and technologies can lower costs, shorten construction time, and improve quality.This study reviewed literature and consulted experts to identify factors influencing the adoption of industrialized construction methods. A researcher-designed questionnaire was completed by 92 construction professionals, and factors were grouped into four main indicators. The Analytical Hierarchy Process (AHP) was applied to prioritize them.Findings showed that the urban management index, with a weight of 0.454, was the most influential factor. This index highlights environmental responsibilities and managerial commitments within the urban system. Its proper implementation can significantly reduce energy consumption and promote sustainable practices. Within this index, strict legislation, effective monitoring, and proper resource allocation (weight 0.15) were identified as critical sub-factors.The results stress the importance of urban governance in facilitating sustainable construction. By focusing on management and policy, decision-makers and construction firms can better integrate innovative technologies into housing projects. This study provides practical guidance for aligning industrialized construction with sustainability goals, improving efficiency, and reducing environmental impacts while meeting growing housing needs.

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INTRODUCTION

The 21st century has witnessed an unprecedented focus on energy management within the built environment. As buildings constitute a substantial portion of global energy demand, their efficient operation is paramount to addressing broader economic and environmental challenges, including resource depletion and climate change (Ukil, 2016). Inefficient energy use, particularly in regions with rapidly growing economies and urban populations, poses significant threats to energy security and environmental sustainability. In Iran, the residential sector is a predominant energy consumer, with statistics from the 2019 energy balance sheet indicating that buildings account for nearly one-third of the country's total energy use (Akbari & Hosseini Nejad, 2019). This high consumption is often attributed to a lack of strategic energy management and the absence of intelligent control systems that can adapt to both occupant needs and external conditions.

The core challenge lies in reconciling the dual objectives of energy conservation and occupant comfort. Simply reducing energy use at the expense of thermal or visual comfort is neither practical nor acceptable (Keshtkar & Arzanpour, 2017). Therefore, the development of smart, adaptive systems that can make intelligent decisions based on a multitude of parameters is essential. Fuzzy logic, a computational intelligence technique pioneered by Lotfi Zadeh (Zadeh, 1965), provides an ideal framework for this task. Unlike conventional binary logic, fuzzy logic handles the concepts of partial truth, allowing it to model human-like reasoning and manage the inherent uncertainties and nonlinearities present in building environments (Fayek, 2020).

This paper presents a comprehensive study on the design and implementation of a fuzzy logic-based management system for residential buildings. The primary objective is to create autonomous subsystems for lighting and heating that require no direct user intervention, thereby optimizing energy consumption while maintaining a high level of occupant comfort. The research is structured in two main phases: first, an analysis of the solar energy potential in the city of Shiraz to capitalize on passive energy sources, and second, the development and simulation of the fuzzy logic control systems in MATLAB. By integrating climatic data with socio-personal user inputs, this research moves beyond conventional static set-points towards a truly responsive and personalized building management system.

Literature Review

The Role of Solar Energy and Building Design

The strategic use of solar radiation is a cornerstone of energy-efficient building design. The orientation, window placement, and material selection of a building directly influence its heating, cooling, and lighting loads (Farahzadeh, Abbasi, 2012). Studies in Shiraz have shown that buildings with climatic orientations towards the southeast and northwest exhibit more favorable energy reception and consumption profiles (Borzgar, Heidari, 2013). Furthermore, the integration of daylighting not only reduces the demand for artificial lighting but also has proven benefits for occupant health and psychological well-being (Javaheri *et al*., 2013). Research by Jacobs and Brown (Brown & Jacobs, 2011) has established a direct correlation between inadequate lighting in living spaces and increased risks of depression and falls among occupants.

Intelligent Control Systems in Buildings

The advent of smart grids and Building Management Systems (BMS) has revolutionized energy conservation. These systems allow for the automated control of various building services. However, many conventional control methods, such as Proportional-Integral-Derivative (PID) controllers, struggle with the complex, non-linear dynamics of building environments (Singhala *et al*., 2014). In recent years, fuzzy logic has emerged as a powerful alternative. Its ability to incorporate expert knowledge through linguistic rules makes it exceptionally suitable for systems where precise mathematical models are difficult to obtain (Sobur & Taheri, 2014). For instance, Tavoosi and Valizadeh (2021) demonstrated that a fuzzy logic controller could achieve higher efficiency and lower energy consumption compared to a conventional PID controller in a building HVAC system.

Fuzzy Logic in Energy Management

Fuzzy logic has been successfully applied in various building management contexts, from lighting control (Panjaitan & Hartoyo, 2011) to HVAC optimization (Algarin *et al.*, 2017). The strength of fuzzy systems lies in their flexibility and robustness. They can integrate diverse inputs—from environmental sensors to user profiles—to make nuanced control decisions. Studies have shown that systems using fuzzy logic can lead to significant energy savings, with Zanganeh *et al.* (2022) reporting up to 60% reduction in grid electricity use for lighting through a fuzzy-based system that incorporated daylight and presence sensors. Furthermore, hybrid approaches that combine fuzzy logic with other optimization techniques like genetic algorithms or neural networks are being explored to create even more powerful and adaptive systems (Shah Rahmani & Zarifi Kermani, 2020).

Research Methodology

Climatic Analysis and Solar Potential of Shiraz

The city of Shiraz, with geographical coordinates of 29°36'N and 52°32'E, is located in a semi-arid, subtropical climatic zone (BSK according to the Köppen classification). This region is characterized by high solar radiation levels, with approximately 200 sunny days per year (Jafarpour & Yaghoubi, 1989). To quantify this potential, a computational model based on the equations of Kashkooli (2003) was implemented in MATLAB to calculate key solar parameters.

Calculation of Solar Angles: The solar altitude angle (α) and azimuth angle (β) were computed using astronomical relationships, which consider the latitude, day of the year, and time of day. The equations are as follows:

$$\sin\alpha = \sin L * \sin\delta + \cos L * \cos\delta * \cos\omega \quad (1)$$

(where L = latitude, δ = solar declination, ω = hour angle)

Determination of Radiation Intensity: The intensity of solar radiation on a vertical surface (I_S) was then calculated, considering the atmospheric extinction coefficient and the Angstrom turbidity coefficient (Fig. 1).

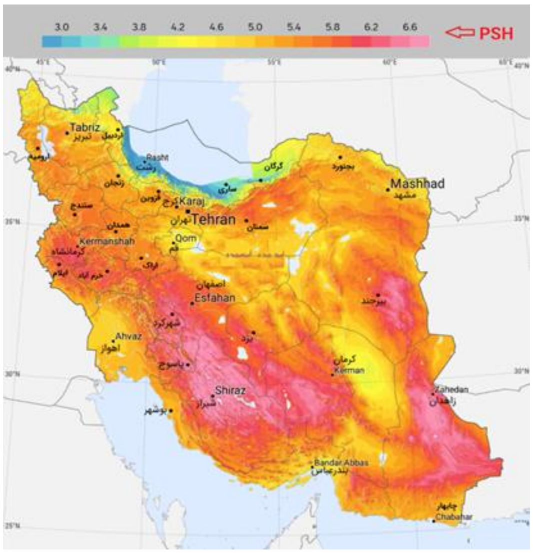

Fig 1. Solar radiation potential map of Iran, indicating high potential in the Shiraz region

Daylighting Simulation with RELUX

To translate solar potential into practical building design, the RELUX lighting simulation software was employed. A residential building plan of 137 m² with a northwest-southeast orientation was modeled (Fig. 2). The model was populated with architectural elements like windows, doors, and furniture. RELUX was then used to perform a daylight analysis, calculating illuminance levels (in lux) across the floor plan throughout the year. This simulation provided a clear visual and quantitative understanding of how natural light penetrates the building, identifying areas with sufficient daylight and those requiring supplemental artificial lighting.

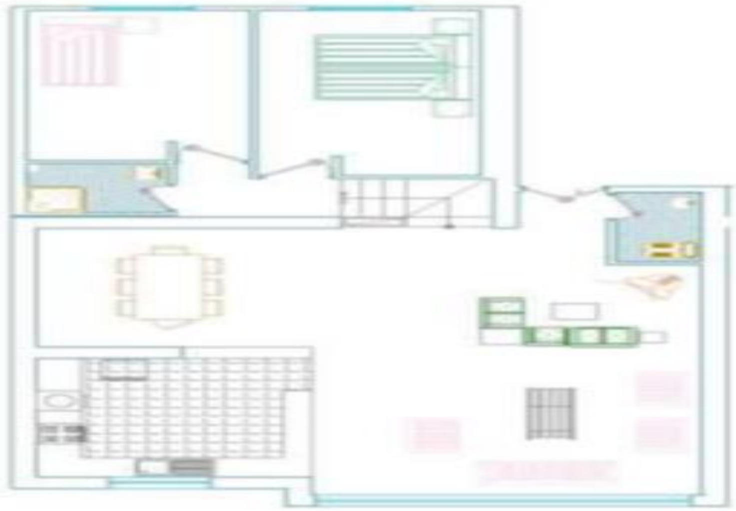

Fig 2. The building plan used for daylighting calculations in RELUX

Fuzzy Logic System Design

Two independent Fuzzy Inference Systems (FIS) were developed using the Mamdani method in MATLAB's Fuzzy Logic Toolbox.

Lighting Subsystem:

Input Variables (8): The system takes eight inputs; each defined with linguistic variables and membership functions (typically triangular or trapezoidal).

Age: {Babies, Children, Young Adults, Adults, Middle-age Adults, Old Adults}

Education: {Low, High}

Occupation: {Unprofessional, Semiprofessional, Professional, Retired}

Economic Situation: {Bad, Well} (a qualitative scale from 0 to 1)

Lifestyle: {Traditional, Modern}

Marital Status: {Single, Married}

Geographical Condition: {Sunny, Partly Cloudy, Cloudy}

Activity Level: {Low, High}

Output Variable (1): LightingNeed {Low, High}. The output membership functions were Gaussian for smoother results.

Fuzzy Rules: A total of 629 "IF-THEN" rules were defined. For example: "If (geographical condition is cloudy) and (activity level is high) then (LightingNeed is high)". The rule base was optimized by merging rules that produced identical outcomes.

System Structure: Fig. 3 shows the overall structure of the lighting FIS in MATLAB.

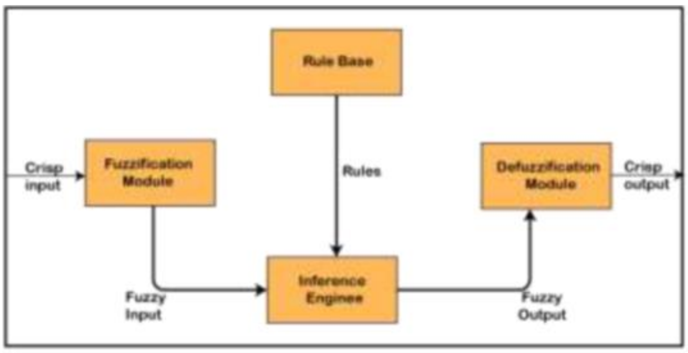

Fig 3. Overall structure of the defined fuzzy subsystem for detecting required lighting

A. Heating Subsystem:

Input Variables (6):
Age: (Same as lighting subsystem)
Climate Condition: {Cold, Warm} (based on ambient temperature in °C)
Activity Level: {Low, Much}
Lifestyle: {Traditional, Modern}
BMI: {Thin, Ideal, Overweight} (Calculated from weight and height)
Gender: {Female, Male}
Output Variable (1): HeatingNeed {Low, High}. Output membership functions were triangular to simplify computations.
Fuzzy Rules: A set of 74 rules was developed. An example rule is: "If (climate_condition is warm) and (activity_level is high) then (HeatingNeed is low)".
Defuzzification: The Centroid (Center of Gravity) method was used for both systems to convert the fuzzy output sets into crisp, actionable values.

Research findings

The MATLAB calculations confirmed that Shiraz has a high capacity for receiving solar energy. The graphs of solar altitude and azimuth angles throughout the day (e.g., for July 5th) provide a precise model of the sun's path, which is essential for optimal building orientation and shading design. The RELUX simulations demonstrated that with proper orientation and window design, the sample building could utilize daylight effectively, significantly reducing the need for artificial lighting during daytime hours and contributing to passive solar heating in winter.

Performance of the Fuzzy Systems

The systems were tested by varying one input parameter across different scenarios while keeping others constant.

Lighting Subsystem Results

Age: While the elderly required slightly lighter due to age-related vision changes, the difference was not drastic enough to warrant completely different lighting standards across age groups.
Economic Situation: This was a highly influential factor. Individuals with a stronger economic profile consistently preferred higher lighting levels, whereas those with a weaker economic status showed a tendency to conserve, accepting lower light levels.
Geographical Condition: As expected, cloudy weather directly and significantly increased the required artificial lighting output.
Activity Level: The level of light-dependent activities (e.g., reading, crafting) had a direct and substantial impact. Higher activity levels demanded higher illumination.
Other Factors: Education, occupation, lifestyle, and marital status showed minimal to negligible impact on the lighting needs within the defined home environment context.
Heating Subsystem Results:
Activity Level: This was the most significant factor. Individuals with higher physical activity levels preferred lower ambient temperatures due to increased metabolic heat production.
BMI: Overweight individuals consistently preferred lower temperatures. The additional body fat acts as insulation, leading to greater heat retention and a preference for cooler environments.
Lifestyle: A modern lifestyle, often associated with interior designs featuring neutral and cool colors, correlated with a preference for slightly higher temperatures. This is hypothesized to be a psychological response to the "cool" visual perception created by such color schemes.
Climate Condition: Individuals accustomed to warmer external climates preferred lower indoor comfort temperatures.
Age and Gender: Contrary to some expectations, these factors did not show a statistically significant influence on the thermal comfort temperature under the tested scenarios.

Results

This research successfully designed, implemented, and tested an intelligent framework for managing energy consumption in residential buildings. The key conclusions are:
The climatic potential of Shiraz for solar energy utilization is significant and can be effectively harnessed through appropriate architectural design and building orientation.
Fuzzy logic provides a highly effective and intuitive methodology for developing building control systems that can handle multiple, complex, and often subjective input parameters.
The lighting control system is highly responsive to environmental conditions (weather, daylight) and user activity, while also being sensitive to economic factors.
The heating control system's performance is dominantly influenced by physiological factors

(activity level, BMI) and psychological/perceptual factors (lifestyle-linked interior design).

The systems demonstrate that it is feasible to achieve substantial energy savings without sacrificing occupant comfort by moving from static control set-points to dynamic, adaptive, and personalized management.

Recommendations for Future Work

Hybrid AI Models: Future work should explore the integration of fuzzy logic with other computational intelligence techniques like neural networks or reinforcement learning to create systems that can learn and adapt over time.

Real-World Validation: The proposed systems should be deployed in a physical testbed or real building to collect empirical data and validate the simulation results against actual energy savings and occupant satisfaction.

Expanded Scope: The research can be extended to other building types (e.g., commercial offices, educational institutions) and other energy systems (e.g., cooling, ventilation, plug loads).

User Interaction: Incorporating a feedback mechanism where occupants can fine-tune the system's decisions could further enhance comfort and acceptance.

Integration with IoT: The framework can be developed into a full-scale IoT solution, with sensors continuously providing real-time data to the fuzzy controllers for even more precise and responsive management.

Ethical considerations

Following the principles of research ethics: In the present study, informed consent forms were completed by all subjects.

Sponsor

Conflict of interest: According to the authors, this article was free of any conflict of interest.

References

Akbari, J., & Hosseini Nejad, F. (2019). Building orientation angles for benefiting from solar radiant energy; A case study of Tehran city. *Geographical Research Quarterly*, 426–435. (In Persian)

Algarin, C. R., Cabarcas, J. C., & Llanos, A. P. (2017). Low-cost fuzzy logic control for greenhouse environments with web monitoring. *Electronics*, 6(4).

Baniyounes, A. M., Ghadi, Y. Y., Zahia, M. M. A., Adwan, E., & Oliemat, K. (2021). Energy, economic and environmental analysis of fuzzy logic controllers used in smart buildings. *International Journal of Power Electronics and Drive System (IJPEDS)*, 12(2), 1283–1292.

Borzgar, Z., & Heidari, Sh. (2013). Investigation of received solar radiation on building envelopes and household energy consumption; A case study of south-west and south-east orientation in Shiraz. *Journal of Fine Arts, Architecture and Urban Development*, 56–65. (In Persian)

Brown, M. J., & Jacobs, D. E. (2011). Residential light and risk for depression and falls: Results from the LARES study of eight European cities. *National Center for Healthy Housing*, 126(1), 131–140.

Farahzadeh, M., & Abbasi, M. (2012). Optimization of building orientation in the city of Qir in relation to sun radiation using the cosine relationship method. *Geographical Space Quarterly*, 9(35), 43–59. (In Persian)

Fayek, A. R. (2020). Fuzzy logic and fuzzy hybrid techniques for construction engineering and management. *Journal of Construction Engineering and Management*, 146(7).

Jafarpour, K., & Yaghoubi, M. A. (1989). Solar radiation for Shiraz, Iran. *Solar & Wind Technology*, 6(2), 177–179.

Javaheri, Z., Madani, R., & Hejrat, A. (2013). Daylight as a stimulus for happiness and mental health of residents of residential complexes: Case study of complexes 7, 8, 12, and 14 in Isfahan. *Armanshahr Architecture & Urbanization Journal*, 55–65. (In Persian)

Kashkooli, M. (2003). *Climate and Architecture*. Isfahan: Khak Publications. (In Persian)

Keshtkar, A., & Arzanpour, S. (2017). An adaptive fuzzy logic system for residential energy management in smart grid environments. *Applied Energy*, 186(1), 68–81.

Lah, M. T., Zupancic, B., Peternelj, J., & Krainer, A. (2006). Daylight illuminance control with fuzzy logic. *Solar Energy*, 80(3), 307–321.

Panjaitan, S. D., & Hartoyo, A. (2011). A lighting control system in buildings based on fuzzy logic. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 9(3), 423–432.

Shah Rahmani, M., & Zarifi Keramani, F. (2020). Optimization of energy consumption and intelligent control of building management system using evolutionary algorithms and fuzzy logic. *3rd Conference on Mechanics, Electrical and Computer Engineering*. (In Persian)

Singhala, P., Shah, D., & Patel, B. (2014). Temperature control using fuzzy logic. *International Journal of Instrumentation and Control Systems (IJICS)*, 4(1).

Sobur, J., & Taheri, M. (2014). Optimization of energy consumption in smart buildings with fuzzy logic. *4th International Conference on New Approaches in Energy Conservation*. (In Persian)

Tavoosi, J., & Valizadeh, M. (2021). Designing a new intelligent building air conditioning control system to reduce energy waste. *Journal of Environmental Science and Technology*, 23(6), 245–259. (In Persian)

Ukil, A. (2016). *Design of fuzzy logic based controller for energy efficient operation in building*. 42nd Annual Conference of the IEEE Industrial Electronics Society.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353.

Zanganeh, M., Aghajani, L., & Foruzanfar, M. (2022). Implementation of an intelligent method based on fuzzy logic for managing energy resources of a home power system including solar energy and storage source using Arduino boards. *Journal of Intelligent Methods in Electrical Industry*, 16–18. (In Persian)