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Research Article

Courtyard orientation and geometry impact on energy consumption and behavior of light in Traditional desert architecture of Iran (Case study: Toon city)

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Introduction

Energy consumption in the building sector has become a critical issue, as indoor spaces account for a substantial portion of total global energy use and are expected to grow further in the near future (Rajan & Sinclair, 2017). Worldwide, increasing attention is being given to energy-efficient design, demand reduction, and passive strategies. Central courtyards, as a passive architectural feature, have historically contributed to thermal comfort and reduced energy consumption in hot–arid climates (Muhaisen & Gadi, 2005; Bagheri Sabzevar et al., 2017). They enhance daylight availability, provide shade, and mitigate excess heat through vegetation and water elements (Muhaisen, 2006; Zamani et al., 2012).Research indicates that courtyard geometry and proportions can reduce cooling energy demand by up to 18% while improving occupant comfort (Diz-Mellado et al., 2023), and passive strategies overall may decrease energy use by as much as 50% in hot climates (Hu et al., 2023). Despite their historical effectiveness, courtyards remain underutilized in contemporary architectural practice. Previous studies have underscored their impact on thermal comfort, daylighting, and shading performance, highlighting the importance of factors such as orientation, dimensions, and width-to-height ratio (Soflaei et al., 2016; Al-Hafith et al., 2017).Traditional Iranian houses embody climate-responsive design principles through courtyard integration and strategic building orientation—such as northeast–southwest (Rone Rasteh), northwest–southeast (Rone Esfahani), and east-west (Rone Kermani) (Salavatian, 2022; Hamze Nejad et al., 2020). Optimizing courtyard configurations can enhance thermal performance by up to 30% and lower indoor temperatures by approximately 3°C, leading to significant energy savings and improved occupant comfort (Gunasekaran & Priya, 2025; Khan et al., 2023). However, few studies have examined the combined effects of courtyard proportions and orientation on both energy consumption and visual comfort. This study aims to address this gap for residential buildings in semi–arid Iranian climates and offer insights for contemporary housing design.

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Materials and Methods

This study examines ten historical houses from the Safavid and Qajar periods located in Toon, a representative semi–arid city in South Khorasan, Iran (34.01°N, 58.10°E, 1146 m a.s.l., BSk climate). All selected houses are single-story structures featuring central courtyards, with variations in orientation (from 14° NE to 28° NW) and courtyard proportions (1:1, 1:1.2, 1:1.3, and 1:1.4).Energy performance was evaluated using Energy Use Intensity (EUI), calculated as the annual heating, cooling, and lighting loads per unit floor area (kWh/m²·y). Daylight performance was assessed using spatial Daylight Autonomy (sDA), which represents the percentage of occupied hours receiving at least 300 lux. Direct solar exposure was quantified using the Annual Sunlight Exposure (ASE) index, indicating the likelihood of glare and overheating. Visual comfort was further evaluated through spatial Glare Autonomy (sGA), which measures the percentage of time interior spaces remain free from unacceptable glare.Comprehensive simulations were conducted to investigate the combined influence of courtyard geometry and orientation on both energy consumption and visual comfort.

Discussion and Conclusion

The simulation results show that courtyard geometry and building orientation significantly affect energy consumption, daylight adequacy, and visual comfort. Houses with square courtyards (1:1) and the northeast–southwest orientation (NE–SW) recorded the lowest heating, cooling, and overall energy use. In contrast, elongated courtyards (1:1.4) enhanced daylight performance—achieving more than 92% sDA—yet contributed to higher glare levels.ASE and sGA analyses further indicate that square courtyards reduce direct sunlight exposure and improve visual comfort, whereas elongated courtyards increase the likelihood of discomfort. Orientation also plays a critical role: northeast–southwest houses generally demonstrate better energy efficiency than northwest–southeast houses, although some visual comfort metrics were slightly higher in the latter.Overall, combining optimal courtyard proportions with favorable orientation can substantially reduce energy demand, improve natural lighting, and enhance occupant comfort in hot–arid residential buildings. These findings underscore the value of incorporating traditional courtyard principles into contemporary architectural design to achieve sustainable and comfortable living environments.

Results

The simulations of ten historical houses in Toon demonstrate that courtyard geometry and building orientation significantly influence energy use and visual comfort. Houses featuring square courtyards (1:1) with northeast–southwest orientation achieve the lowest heating, cooling, and overall Energy Use Intensity (EUI). In contrast, elongated courtyards (1:1.4) offer greater daylight adequacy (sDA) but also increase direct solar exposure (ASE).Visual comfort is highest in square courtyards, which exhibit lower glare levels and higher sGA values. Overall, orientation primarily affects energy performance, whereas courtyard proportions have a stronger impact on natural lighting. These findings highlight the combined importance of courtyard geometry and orientation in optimizing sustainable residential design in semi–arid climates.

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Keywords: Central courtyard, Thermal comfort, Energy consumption, Visual comfort, Semi-arid climate.

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مقاله پژوهشی

تأثیر جهت‌گیری و هندسه حیاط مرکزی بر مصرف انرژی و رفتار نور در معماری سنتی کویری ایران (مطالعه موردی: شهر تون)

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چکیده

حیاط‌های مرکزی از عناصر کلیدی معماری سنتی کویری به شمار می‌روند و نقش مهمی در بهبود خرداقلیم و ارتقای آسایش حرارتی و بصری ایفا می‌کنند. اگرچه مطالعات فراوانی پیرامون نقش حیاط‌های مرکزی در بهبود آسایش حرارتی یا روشنایی انجام شده است، اما پژوهش‌ها غالباً یکی از این دو بعد را بررسی کرده و به تحلیل هم‌زمان هر دو بعد کمتر پرداخته‌اند. با این زمینه، این پژوهش بررسی می‌کند که چگونه هندسه و جهت‌گیری حیاط مرکزی بر مصرف انرژی و آسایش بصری در ساختمان‌های مسکونی در اقلیم نیمه خشک و کویری اثر می‌گذارد. برای این منظور، شبیه‌سازی ده خانه تاریخی مربوط به دوران صفوی و قاجار در شهر تون انجام شد و دو جهت‌گیری شمال‌شرقی- جنوب‌غربی و شمال‌غربی- جنوب‌شرقی به همراه نسبت‌های مختلف حیاط (۱:۱، ۱:۱.۲، ۱:۱.۳ و ۱:۱.۴) مورد ارزیابی قرار گرفت. نتایج نشان می‌دهد خانه‌هایی با تناسب مربع (۱:۱) و جهت‌گیری شمال‌شرقی- جنوب‌غربی کمترین میزان مصرف انرژی را دارند. در زمینه روشنایی روز، حیاط‌های کشیده‌تر (۱:۱.۴) تا ۹۲ درصد کفایت روشنایی سالانه در سطح ۳۰۰ لوکس را فراهم می‌کنند اما براساس شاخص‌های تابش مستقیم خورشید و خودکفایی کنترل خیرگی، باعث افزایش خیرگی می‌شوند. در مجموع، جهت‌گیری تأثیر بیشتری بر مصرف انرژی دارد تا عملکرد روشنایی، به‌گونه‌ای که خانه‌های با جهت‌گیری شمال‌شرقی- جنوب‌غربی عملکرد بهتری نسبت به جهت‌گیری شمال‌غربی- جنوب‌شرقی نشان می‌دهند. این یافته‌ها بر اهمیت بهینه‌سازی تناسبات و جهت‌گیری حیاط مرکزی برای ارتقای بهره‌وری انرژی و آسایش بصری در طراحی مسکن معاصر کویری تأکید می‌کند.

واژه‌های کلیدی: حیاط مرکزی، آسایش حرارتی، مصرف انرژی، آسایش بصری، اقلیم نیمه خشک.

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