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Research Article

Energy Consumption Analysis For Courtyard Design Office Buildings In Composite Climate

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ABSTRACT

Passive design is widely acknowledged as a cost-effective and efficient approach to sustainable building practices. However, there is still a lack of comprehensive scientific testing methods and conclusive results regarding the validation of passive design strategies. By comparing the energy usage of office buildings with and without courtyards and focusing on analysing their influence on building energy performance, this study tries to close this gap.

To validate and optimize the influence of passive spaces on sustainable buildings, a rectangular courtyard approach is employed in this research. The research considers elements like occupant happiness and the quality of the built environment, and it recognises inner courtyards as efficient climate modifiers that allow for the assessment of comfort perception in the surrounding environment. In order to maximize daylighting and energy savings within building interiors, the proposed systems replace the eaves of roofs over the courtyard with glazed devices.

Two scenarios are used to apply the research methodology: a case study that takes the courtyard impact into account in terms of air temperature, humidity, bulb temperature, and heating and cooling settings, and a reference scenario that does not. According to the findings, a courtyard lowers the need for cooling in nearby spaces. Additionally, the floor, roof, and wall levels of the structure have an impact on the energy demand, with lower floors in the courtyard building having a higher energy demand. 126 (without courtyard) and 130 (with courtyard) are discovered to be the effective coefficient ratios for energy consumption.

These findings offer valuable insights for architects, providing a deeper understanding of the energy consumption associated with different courtyard configurations. This knowledge can facilitate the creation of more energy-efficient designs. It is important to note that in office buildings without a courtyard design, the use of fully passive heating and cooling systems and good daylighting functionality can result in energy savings of up to 3%.

Keywords: Courtyard Building, Energy Consumption, Energy Saving, Composite Climate, Office Building, Thermal Behaviour.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) emphasizes the urgent need for substantial and continuous reductions in greenhouse gas emissions to mitigate climate change risks [1]. Construction activities contribute significantly to climate change, as well as to landfills and various forms of pollution, including air, water, and noise pollution [2]. Buildings and structures account for an average of 41% of global energy consumption. Moreover, they generate hazardous emissions that pollute the air, while the construction industry produces over 170 tons of waste annually [3]. Consequently, there is a growing demand for environmentally friendly buildings. In this context, passive design plays a crucial role in achieving architectural and environmental sustainability goals [4]. An effective passive design ensures thermal comfort, lower heating and cooling costs, and reduced greenhouse gas emissions throughout the lifespan of a building [5]. Courtyards, as enclosed outdoor spaces that are open to the elements at the top, are designed to optimize thermal performance, shading, and natural ventilation [6].

In order to achieve energy-efficient designs, it is crucial to integrate climate-responsive principles into the functionality of a building [7]. Particularly in dry and hot climates, the shape of a courtyard plays a significant role in casting shadows on the building envelope, thereby affecting solar radiation exposure and the cooling and heating loads of the structure [8]. The thermal performance of courtyards is primarily influenced by the penetration of solar radiation onto the internal surfaces, which is determined by the courtyard's geometry and the position of the sun [9].

Aerial courtyards, designed for super high-rise buildings, serve as shared spaces that incorporate transportation organization, recreation, sightseeing, natural scenery, and other elements. These courtyards provide quality interaction areas for upper floors, which are far removed from the ground level. They enhance the environment, promote physical and mental relaxation, and are crucial considerations in the construction of vertical cities [10][11]. Semi-enclosed courtyards, on the other hand, can improve the thermal conditions of surrounding spaces by reducing air temperature by 2°C to 3°C through the control of wind speed and direction.

The primary goal of courtyard design is to minimize solar heat gain during the summer months while maximizing the ingress of daylight and sunlight during colder seasons [12]. With an emphasis on the thermal, daylighting, shading and airflow elements of low-rise buildings in various climates, many studies have investigated the effect of courtyard design on energy usage [13]. Comprehensive studies on the impact of design choices on energy use in high-rise structures located in tropical regions are still lacking, albeit [14]. Consequently, this study aims to bridge this gap by presenting appropriate design strategies that effectively reduce energy consumption in composite climates. The analysis draws upon case studies of energy-efficient buildings, comparing those with and without courtyard designs. Building envelope characteristics, orientation, shape, materials, space organisation, and other pertinent elements are all thoroughly taken into account in an integrated way [15].

2. LITERATURE SURVEY

Sahnoune et al. [16] conducted a study on the winter thermal comfort within a courtyard that exhibited a typical geometry suitable for hot summer conditions in a semi-arid environment. Their research indicated a significant relationship between the Predicted Mean Vote (PMV) and interior orientation of the courtyard, particularly concerning cold stress. They recommended an optimal height-to-width (H/W) ratio of less than 0.8 and emphasized the benefits of north-east and south-east orientations to enhance winter climatic conditions in semi-arid regions.

Peng et al. [17] focused on the microclimatic differences between courtyards, particularly in moderating seasonal and diurnal thermal extremes and enhancing ground level thermal textures. Their research aided in the improvement of spatial and landscaping plans for creating and modifying courtyard microclimates.

Fang et al. [18] introduced the COMFA courtyard model, which integrates Comfa, Pet, and Set to establish a robust and scientifically validated outdoor thermal comfort index specifically tailored for courtyards located in hot and humid areas. This model presents a distinctive approach that greatly aids in designing outdoor environments that are adaptable to prevailing climate conditions and ensure thermal comfort for individuals, especially in light of climate change challenges. By employing the COMFA courtyard model, designers and planners can effectively develop outdoor spaces that prioritize thermal comfort and promote overall well-being.

Zhang et al.'s study [19] examined the efficacy of optimisation solutions for both traditional suburban villages and traditional villages located in metropolitan historic districts. They discovered that for conventional urban structures, a width to length ratio of 0.6, a window-to-wall (WWR) ratio of 0.6, and an eave depth of less than 1.0 m were essential for getting the best performance. These findings provide valuable insights for enhancing the design and functionality of traditional village structures in both urban and suburban settings.

Saleh et al. [20] identified energy-efficient features of vernacular architecture that affect indoor thermal comfort conditions, which can be adapted in modern architecture to suit present-day lifestyles. They recommended more investigation into traditional homes' thermal comfort as well as strengthening and extending the use of earth as a construction material.

Comprehensive courtyard design structure and wind environment performance optimisation was carried out by Fang et al. [21]. The findings of their study indicated that the Computational Fluid Dynamics (CFD) simulations exhibited a level of accuracy similar to that of other simulations. The simulations achieved R2 values above 0.8 and Root Mean Squared Error (RMSE) values below 0.3 m/s for the building array case. In the case of the row of trees, the simulations yielded RMSE values below 0.2 m/s. These results highlight the reliability and effectiveness of CFD simulations in accurately predicting airflow and wind speed in different scenarios.

A comprehensive review and meta-analysis were done by Zeng et al. [22] to determine if passive cooling methods (PCSs) for residential buildings are beneficial. The review indicated that employing various PCSs can lead to an average decrease of 2.2°C in indoor temperature, a 31% reduction in cooling load, and energy savings of 29%.

In their research, Kamyab et al. [23] created an optimized model of the Iwan, a traditional architectural element, with the aim of promoting sustainable development and seamlessly integrating it into modern housing designs in the hot and dry climate of Yazd. They conducted simulations using Design Builder software, considering samples from north-facing and south-facing rooms within a central courtyard model. The simulations explored different proportions of the Iwan and various window sizes to determine their impact on the overall performance of the design. By utilizing these simulations, the researchers were able to assess and refine the design of the Iwan, ensuring its effectiveness in contemporary sustainable housing designs in Yazd.

In their study, Agarwal et al. [24] examined the thermal performance of n-Eicosane and OM35, which were integrated into clay bricks—a commonly utilized construction material. The research findings indicated that incorporating OM35 in the East orientation led to a significant 31.1% reduction in cooling load for the month of May, resulting in an annual cost saving of USD 1.05 per square meter. On the other hand, the North orientation with n-Eicosane demonstrated the lowest cost saving of USD 0.023 per square meter. These results highlight the potential benefits of incorporating phase change materials like OM35 into clay bricks, particularly in specific orientations, to achieve substantial energy savings and cost reductions in cooling operations.

In their research, Sun et al. [25] aimed to identify the optimal design parameters for courtyards in modern Low-Storey High-Rise (LSH) buildings to enhance thermal comfort. To accomplish this, the researchers employed multiple strategies, such as the Mahoney table, field investigation, and Computational Fluid Dynamics (CFD) simulation, to assess the thermal performance of the courtyards. The study proposed innovative design approaches and recommendations based on the findings, aiming to create more comfortable and thermally efficient environments in LSH buildings.

3. RESEARCH PROBLEM DEFINITION AND MOTIVATION

The excessive carbon emissions brought on by construction fuel use are a significant factor in climate change. Reducing energy consumption and promoting sustainable practices can enhance both Iran's economic and energy security. Sustainable architecture principles necessitate designers to consider climate conditions, environmental preservation, and energy reduction when identifying architectural requirements for projects. The performance of building structures in terms of thermal efficiency and lighting can be influenced by natural energy sources like the sun, and renewable energy can help meet energy demands. Integrating climate-responsive design with building functionality is crucial for the development of energy-conscious designs. However, there is a lack of comprehensive research on the influence of design strategies on energy consumption in high-rise buildings located in tropical climates. While previous studies have explored the impact of design strategies on energy consumption in high-rise office buildings in specific climate zones in China, there remains a research gap in understanding these strategies within composite climates.

To address this gap, this study aims to investigate design strategies that effectively reduce energy consumption in high-rise office buildings situated in composite climates. The research will employ simulation software, specifically Design Builder, as a foundational tool for conducting energy calculations. Design Builder is a commercially available software package that provides a three-dimensional interface for dynamic and comprehensive energy simulations in buildings. It will be utilized to analyse various aspects such as shading efficiency and overall energy usage, aiding in the assessment and development of energy-efficient design strategies for high-rise office buildings in composite climates.

4. PROPOSED RESEARCH METHODOLOGY

The utilization of courtyard buildings in hot climate regions, whether as regulators of inter-building microclimates or as climatic regulators at the urban scale, is a characteristic feature of such regions. However, it is crucial to apply courtyard buildings in a manner that aligns with the specific climatic features of the region. There is a research gap in understanding the optimal courtyard form and its impact on comfort conditions, considering the climatic and meteorological differences across various climatic regions. Therefore, this study aims to develop a model that determines the optimal courtyard form and achieves comfortable conditions by optimizing its design according to the specific requirements of each climatic region.

The primary objective of this investigation is to assess the energy efficiency of rectangular buildings, comparing those with and without courtyards. The courtyards serve as composite climatic regulators, impacting the building's thermal performance during both the summer and winter seasons.

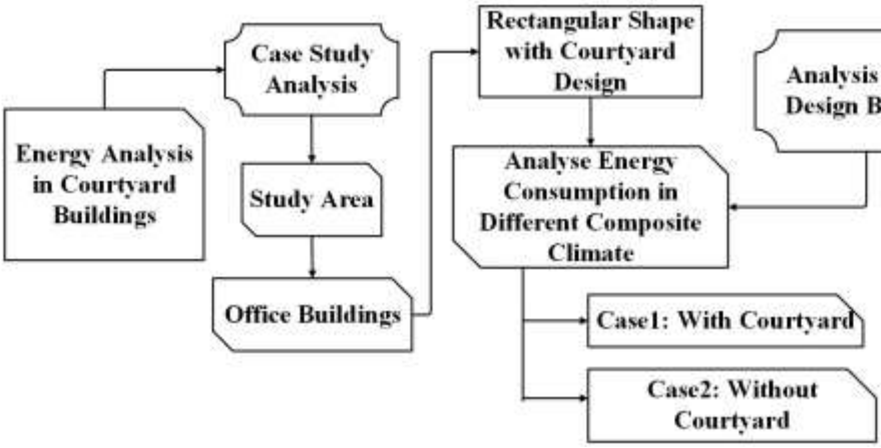


Figure 1: Block Diagram of the Proposed Work

The proposed work's flow diagram is depicted in Figure 1. It aims to determine the comfort levels within the buildings and courtyards, as well as accurately estimate their thermal behaviours under different design and climatic conditions using computer energy simulation. This comprehensive analysis will be conducted for both courtyard office buildings and buildings without courtyards. The findings of this study will provide valuable insights to designers regarding the optimal courtyard form based on specific climate characteristics and data for various climatic regions.

This study focuses on suitable design approaches that successfully lower energy usage in tall office buildings situated in composite climates, a subset of tropical climates. The research will detail these design principles and examine the energy consumption statistics for the chosen buildings in the composite climate via case studies of energy-efficient office buildings. Except for a few months of the year, composite climatic zones have persistently high temperatures and heavy radiation. In order to minimise heat gains and maximise lighting in building interiors, design solutions emphasised in this study attempt to lower office buildings' overall energy usage.

4.1 Case Distribution Analysis

In today's context, creating a sustainable environment that promotes human presence in open spaces is crucial for enhancing the quality of these spaces and ensuring human thermal comfort. Courtyards, as open spaces, play a significant role in absorbing solar radiation and providing thermal comfort. In this study, the adopted methodology involves a comprehensive analysis of energy consumption aspects in buildings with and without courtyards. Two case studies are conducted, one with a courtyard design and the other without a courtyard design, enabling a detailed comparison of their energy performance (see Table 1).

Table 1: Case Distribution Analysis of Office Buildings

Case	Building Description	Occupancy		Metabolic Factor	Clothing Value		DHW
		Density (m^2/people)	Schedule (hrs.)		Winter Clothing	Summer Clothing	
Case 1	Rectangular Shape with Courtyard	10	9:00-17:00	1	1	0.04	Off
Case 2	Rectangular Shape without Courtyard	10	9:00-17:00	1	1	0.04	Off

The office building in this study features a rectangular central courtyard, which is enclosed on three sides. The courtyard has a total area of 4495 m2, with a floor height of 3.5 m. The building's walls cover an area of 2951 m2, while the windows occupy an area of 1033 m2. The courtyard is designed to meet the requirements for lighting and ventilation. The analysed building consists of three floors and basements, and it is typically used during daytime hours from 9 am to 5 pm on weekdays (five working days per week). The selection of the case studies is based on the following parameters:

- Case 1: Rectangular shape with a courtyard
- Case 2: Rectangular shape without a courtyard

The study is conducted in two phases: the first phase analyses the rectangular shape with a courtyard, while the second phase examines the rectangular shape without a courtyard. The aim of this research is to quantitatively assess the physical environment of passive spaces and their surroundings to enhance overall comfort and reduce energy consumption in buildings. The study considers factors such as occupancy density, schedule, clothing value, and DHW (domestic hot water) in relation to building characteristics and the built environment, aiming to improve energy performance and space efficiency. Therefore, this research underscores the importance of monitoring the physical environment of buildings to optimize passive strategies and enhance energy efficiency from an architectural design perspective.

4.1.1 Data Collection: Building Type

In this study, various office building typologies were examined, specifically focusing on rectangular-shaped buildings. The building area considered for analysis is 4495 m2, and the building consists of three floors and a basement. The floor height of the building is 3.5 m, with a wall area of 2951 m2 and a window area of 1033 m2. The analysis is conducted during the daytime usage of the office building, which is from 9 am to 5 pm. The Window-To-Wall Ratio (WWR) of the building is 35%. Detailed data regarding the building sections, including floors, windows, and walls, are provided in Table 2.

Table 2: Data Collection in Building Sector

Building Section	**Area**
Area of building	4495 m^2
Floor	3 Floor and Basement
Daytime Usage	9 am to 5 pm
Floor height	3.5m
Wall area	2951 m^2
Window area	1033 m^2

This analysis highlights the fact that previous studies predominantly focused on experimental models for investigating daylighting and energy aspects, with a particular emphasis on residential typologies for thermal comfort. However, there exists a gap in the research regarding the study of daylighting in courtyards specifically within the context of residential typologies.

4.2 Analysis of Socio-Environmental Characteristics of Selected Courtyard Building

The courtyard, being a crucial passive architectural element in traditional buildings, is purposefully designed to cater to the socio-cultural requirements of its occupants. As a result, it can manifest various variations depending on factors such as geographical location, climate, and society, while still sharing common characteristics. Courtyards embody the concept of sustainable design, which integrates social, environmental, and economic sustainability. This study's investigation of a particular office courtyard design was chosen because of its significant contributions to socio-cultural and environmental issues.

4.2.1 Analysis of Socio-Cultural Parameters

Courtyards, serving as central open-to-sky spaces, play a vital role in accommodating a variety of activities throughout their existence. Aspects including urban shape, entry and circulation, architectural character, symmetry and formality, community and privacy, as well as activities and rituals, have all been taken into consideration while analysing them. Table 3 presents the rectangular courtyard design's building profile analysis and highlights its salient features.

Table 3: Building Working Profile for Analysis

Building Section	**Area (m^2)**	**Working profile (No. of Day in the Week)**
Rectangular	4495	5

In this study, the thermal performance of the building during a typical five-day working week is examined. Two distinct boundary configurations were identified, which resulted in the minimum and maximum modifications of indoor air temperature and corresponding airflow rates. The climate conditions considered in the analysis represent the dry season, while winter periods experience heavy rainfall. The case study building discussed in this study incorporates passive design strategies to mitigate thermal discomfort caused by overheating and cooling conditions in the composite climate. The results of the investigation are presented and analysed in the following sections.

4.3 Courtyard Configuration

Although the rectangular shape of the suburban courtyard is the subject of investigation in this study, a courtyard does not always have a predefined layout. Over the course of history, the basic courtyard plan has undergone transformations to accommodate various environmental features, such as site restrictions, topography, building orientation, and function, resulting in the emergence of new courtyard shapes, Courtyard configurations can take the form of semi-enclosed (three-sided), fully enclosed (four-sided), or, in some cases, two-sided designs. Courtyards have been implemented in office buildings, and extensive investigations have been conducted to explore their design concepts and characteristics. It is evident that the design configuration of a courtyard can act as a climate transformer, shaping the surrounding environment.

Numerous researchers have examined the impact of the typical rectangular courtyard form in temperate or hot environments and its influence on environmental performance. Key factors that significantly affect thermal comfort include ensuring sufficient coverage to protect against concentrated solar radiation and hot dusty winds, as well as promoting natural ventilation. Additionally, the proportions and geometry of the courtyard play a crucial role in determining the patterns of shading within the courtyard, which are influenced by the courtyard's geometry and the sun's position in the sky.

4.3.1 Orientation Design

Courtyard orientation is a significant design variable that can be assessed using both simulation and experimental methods to evaluate its impact on environmental performance. The height of courtyard walls has a notable effect on reducing the air temperature within the courtyard and its immediate vicinity. However, it has a lesser impact on overall air temperature but significantly influences ventilation due to the potential obstruction of airflow by enclosing walls. Proper orientation of the courtyard can enhance its thermal comfort. While building orientation is commonly determined based on various factors, the components directly influencing courtyard microclimatic behaviour, such as wind direction, shading effects, sun position, and radiant heat, are crucial considerations for courtyard orientation. It is crucial to remember that building orientation and the relationship with the courtyard are fundamental approaches to mitigate the cooling effects within the courtyard and the building as a whole. However, due to variations in geographical locations, different longitudinal and latitudinal positions may require distinct orientation requirements.

4.3.2 Wall Enclosure

The elements comprising the courtyard, including wall enclosure, windows, walls, and doors, play a significant role within the building. These courtyard elements have a crucial influence on the execution of microclimate conditions, particularly in relation to natural ventilation strategies. The proportion of walls to windows can be adjusted to positively impact the wall enclosure. The adaptation of enclosing walls is influenced by various region-specific factors such as cultural, economic, social, and environmental considerations. The location and purpose of the building determine the design specifications. When all windows are closed, limited cooling effects are observed, but the opening of doors and windows enhances natural ventilation. Building components related to the external wall and roof are depicted in Table 4. The utilization of natural elements can yield multiple eco-friendly advantages. In hot and dry areas, incorporating garden elements within the courtyard can contribute positively to its thermal performance. If the courtyard includes a water pond, it can provide abundant cooling during sunny hours, benefiting the thermal conditions of the inner courtyard envelope.

Table 4: Study Components of Office Building

Building Components	**U value (W/m^2-K)**
External wall	0.694
Roof	0.357

After taking measurements in the field, identical circumstances were reproduced using Design Builder software on the same day (week), taking into account meteorological information from both the office block with a courtyard design and the office block without a courtyard design. The meteorological information includes variables like the temperature of a dry bulb, wet bulb, humidity, solar heat gain, and other pertinent elements. These simulations allowed for a comprehensive analysis of the thermal performance and environmental conditions of both building designs.

5. EXPERIMENTATION AND RESULTS DISCUSSION

The office building's energy usage was calculated by compiling weekly electronic bills for each month. This information made it possible to determine the times of year when energy use is highest and lowest and to calculate the energy use intensity (EUI) of a building in kWh/m2/year for two scenarios: one with a courtyard and the other without, both in a composite climatic zone. To perform the energy analysis, Design Builder software was utilized. This powerful tool enables quick modeling, calculation, and simulation of the building's energy performance and daylight behaviour. Design Builder is known for its integration with EnergyPlus software, making it a reliable choice for thermal simulations. All of the models' wall, roof, and floor construction elements were based on typical building supplies found in traditional homes in hot, dry areas.

5.1 Design Builder Software

This research focused on the investigation and validation of Design Builder software. Due to the significance of the results obtained from this software, its reliability was thoroughly examined and confirmed. Design Builder is widely recognized as a highly reliable tool for studying various aspects of building performance, including energy consumption, lighting, CO_2 levels, and thermal comfort. It facilitates building energy simulations, allowing designers to gain a comprehensive understanding of a building's energy behaviour and explore different strategies to optimize its performance.

5.2 Parameter Analysis

For a structure to achieve thermal comfort and internal temperature stability, weather data is essential. In energy simulations, it is also essential for precisely determining comfort levels. Building occupancy is another key factor that significantly impacts energy performance. For this study, appropriate simulation settings were selected within the Design Builder software to account for these factors. Additionally, air infiltration is a significant contributor to energy consumption and thermal behaviour in a building. The building's location has a direct influence on the wind speed experienced around it. Therefore, precise location information and accurate weather data are essential to ensure reliable simulation results. The interior heat dynamics of a building are significantly influenced by the opening and shutting of windows. The simulation technique is improved in traditional homes when entrances facing the courtyard are not often used for vehicular traffic.

Table 5: Parametric Analysis of Courtyard Buildings in Timely Manner

Time	Temperature [°C]	Absolute Humidity [g.kg]	Enthalpy [kJ.kg]	Relative Humidity [%]
9:00	30.1	7.3	50.3	32.3
9:30	30.9	7.3	51.1	30.8
10:00	31.7	7.3	52.9	29.4
10:30	32.5	7.3	53.7	28.1
11:00	33.6	7.3	54.8	26.4
11:30	33.7	7.3	56.9	26.3
12:00	33.9	7.3	56.1	26
12:30	34.3	7.3	56.5	25.4
13:00	34.6	7.3	56.9	25
13:30	35.1	7.3	57.4	24.3
14:00	35.4	7.3	57.7	23.9
14.30	36.1	7.3	57.8	22.6
15.00	36.3	7.3	58.3	21.3

The collected data was used to compare the solar gain obtained from experimental measurements with the simulated conditions. The results of this simulation are presented in Table 5. While the numbers do not exhibit a consistent pattern throughout the graph, they generally align within acceptable conditions with only slight differences.

5.2.1 Thermal Behaviour Analysis

The thermal analysis conducted in this study was accompanied by energy consumption data. A dynamic simulation was conducted since the office building's uncontrolled thermal behaviour made direct comparisons of energy usage between situations difficult. For this, Energy Plus, version 6.0, was used as the programme. To help with a better comprehension of the trends seen, the data gathered from measurements made every 15 minutes were averaged on an hourly basis.

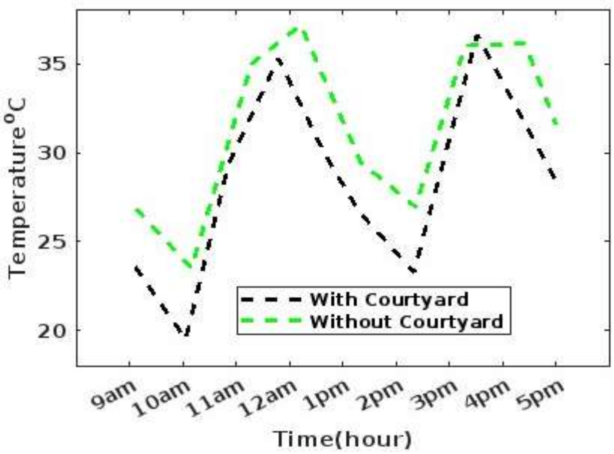


Figure 2: Thermal Behaviour of Office Building

The temperature graphs for the two cases, the building with courtyard design and the building without courtyard design, reveal similarities in terms of the highest and lowest temperatures. The exact moment that the maximum temperatures are attained varies, though. The design of the structure, the technology used in its construction, and internal heat gains, which are present in both spaces, all have an impact on the maximum and minimum temperatures. Through graphical analysis, it is possible to observe stable performance in the office during the summer period, despite variations in exterior temperatures. The maximum exterior temperatures ranged from 30°C to 35°C, while the minimum temperatures ranged from 19°C to 25°C. This phenomenon can be due to the inner spaces' high heat inertia, as illustrated in Figure 2.

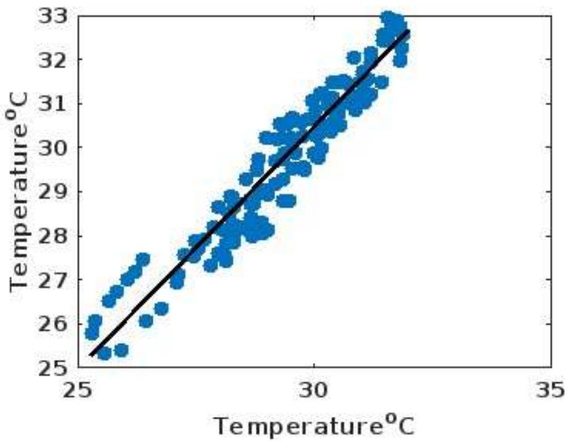


Figure 3: Temperature correlation between actual and simulated values

Figure 3 depicts the correlation analysis between the simulated and measured temperatures. The R2 value of 0.92 indicates a strong correlation between the two sets of data. These temperatures serve as the control variables for validating energy consumption. Furthermore, this methodology enables the exploration of various case study scenarios, facilitating a comparative assessment of energy consumption in relation to different courtyard designs, including variations in geometry and solar protection.

5.2.2 Energy Consumption Analysis

The percentage increases in yearly total heating-cooling load for alternative building shapes were computed by examining the total heating-cooling load figures of the reference building. The structure's shape and its centre courtyard as part of its plan type was determined to have the best performance in terms of lowering the heating and cooling load.

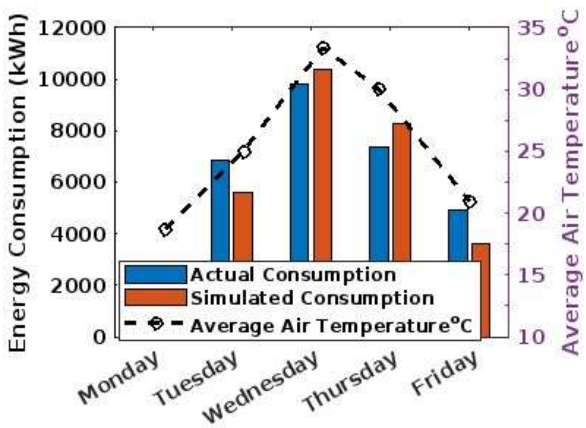
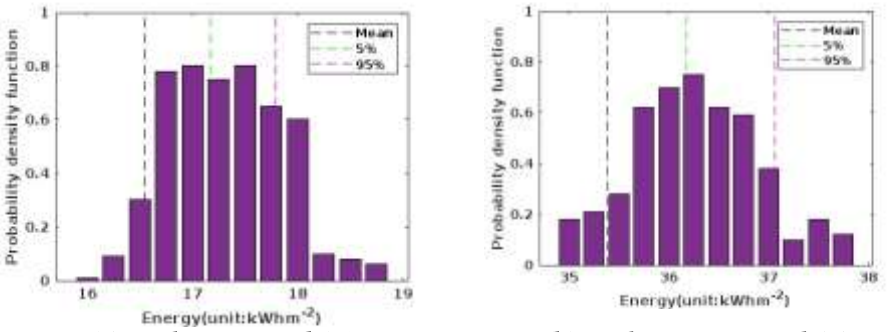


Figure 4: Timely Energy Consumption of the Simulated Case

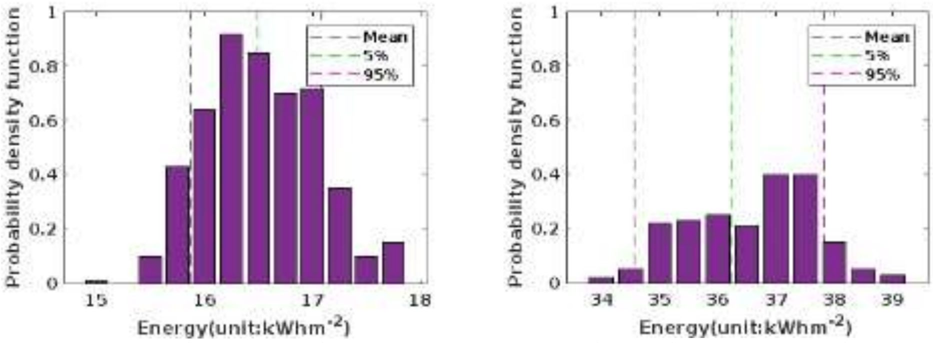
Figure 4 depicts, the monthly energy consumption pattern of the building based on the weekly predictions. The energy consumption rate of a building is heavily influenced by the environmental and climatic conditions of the city, as demonstrated by the peak consumption observed during the summer months. From September to January, there is a significant increase in energy consumption, nearly doubling during this period. This highlights the impact of various factors such as the building's architectural details, occupant activities, equipment power density, set point temperatures, and operating schedules of HVAC and lighting systems on overall energy usage. The graph shows a 5-day sequence that was chosen at random from the whole summer.



(a) With Courtyard (A) (b) Without Courtyard (B)

Figure 5: Distribution of Cooling Energy in Two Courtyard Building Layouts

Figure 5 demonstrates, the dispersal of cooling energy use in Case A, which follows a similar pattern to a normal distribution. The dispersal is slightly skewed to the left. In Case A, the mean energy consumption is 36.18 kWh/m2, whereas in Case B, it is 36.24 kWh/m2. Case B uses somewhat more energy than Case A does when compared to the 90th percentile of cooling energy use. In addition, Case B's (34.56-37.82 kWhm2) major energy consumption range is much broader than Case A's (35.38-37.06 kWhm2). These results imply that the cooling energy utilization distribution in Case A is more concentrated than Case B due to the effect of various factors.



(a) With Courtyard (A) (b) Without Courtyard (B)

Figure 6: Distribution of Heating Energy in Two Courtyard Building Layouts

From Figure 6, it is evident that the distribution of heating energy utilization in both Case A and Case B follows a similar pattern. The center of the distributions exhibits higher values, while lower values are observed on both sides. However, considering the 90% range of energy data, Case A shows a heating energy consumption range of 15.87-17.08 kWh/m2, whereas Case B's range is 16.54-17.79 kWh/m2. This indicates that the rectangular courtyard design is more effective than the strip form design in reducing heating energy usage. Furthermore, in both cases, there is a variance of approximately 1.21 in Case A and 1.25 in Case B between the 95th percentile and the 5th percentile of energy usage. This suggests that the parameters of different courtyard buildings exert similar influences on heating energy consumption.

Table 6: Total Energy Consumption in Office Buildings

Site Description	Energy per Total Building Area (KWH/m²)
Site with Courtyard	130
Site without Courtyard	126
3% Saving on energy consumption without a courtyard	

Table 6 clearly demonstrates a notable difference in the distribution of total energy utilization between both the cases. Case B exhibits a left-skewed distribution pattern, while in contrast to Case B, Case A's distribution is more centric. The total energy consumption of Case A amounts to 130 kWh·m2, whereas Case B records 126 kWh·m2. It is noteworthy that Case B is more likely to have lower energy consumption compared to Case A. Building without a courtyard absorbs less heat from the outside climate, resulting in reduced HVAC system loads. On the other hand, a building with a courtyard absorbs more heat from the outside climate, leading to increased loads on the HVAC system. By designing a building without a courtyard, it is possible to save approximately 3% of energy per year.

The relative importance of key factors and the proportion of each energy type align closely with the ranking of parameters that impact overall energy consumption. Building orientation emerges as a crucial variable for cooling energy, while window U-value stands out as the most influential factor for heating energy. These variables have a significant impact on overall energy consumption due to the substantial shares of cooling and heating energy usage.

The heat gain coefficient of solar energy demonstrates noteworthy associations with different energy types. It exhibits a positive correlation with cooling energy while displaying a negative correlation with other energy types. Consequently, an increase in the solar heat gain coefficient leads to a reduction in heating and lighting energy consumption. However, it also leads to a gradual increase in cooling energy and overall energy consumption.

Furthermore, certain factors like lighting, heating, and cooling may not individually affect a person's energy consumption to a great extent. However, they play a vital role in determining overall energy usage.

6. RESEARCH CONCLUSION

This research paper aimed to assess the energy-saving potential of office block enclosures with and without a courtyard design. An effective strategy for reducing energy consumption is the implementation of thermal insulation techniques in external building walls. In this study, we focused on the application of thermal insulation layers to external walls, floors, and roofs in a composite climate. Specifically, we examined the impact of thermal insulation on the external roof. Additionally, we investigated the role of window glazing in reducing solar energy penetration, thereby improving the thermal efficiency of the building envelope.

The primary objective was to compare the energy consumption gains of insulated building envelopes with a courtyard-centred villa design against a base scenario. To achieve this, we utilized design builder software to simulate various scenarios. The simulation results indicated that the heat gain exhibited slight variations when comparing the simulated day with the field measurements. The differences between the simulated and observed heat gain findings were consistently below 10% in all examined steps.

To facilitate the cooling of the space, we explored the potential of evaporative cooling from water bodies due to the high density of the region's water network. In winter, the target rooms were heated using a circulation system that employed a heating mechanism similar to that of the building walls. By replacing the eaves over the patio with a glazed roof device, we improved the daylighting performance in the four target rooms, leading to reduced reliance on artificial lighting and energy savings.

The suggested systems, which can be easily integrated into courtyard structures, offer straightforward construction and require no energy for operation. By providing valuable insights into entirely passive heating and cooling systems with daylighting capabilities, this study contributes to bridging the information gap in this field of building energy conservation. Notably, our findings revealed that the elimination of courtyards from building designs could result in annual energy savings of approximately 3%. Therefore, it is advisable to conduct an analysis using simulation software before constructing a building to identify potential energy-saving opportunities.

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