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IMPACTS OF COURTYARD ENVELOPE DESIGN AS AN IMPORTANT ARCHITECTURAL PARAMETER FOR ENERGY SAVINGS

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ABSTRACT

When designing facilities with lower energy consumption, the most crucial parameter is the correct choice of location. The terrain configuration has a distinct influence on the organization of the urban plan and the building design. It largely determines the microclimate, especially the temperature level, direction, and wind speed. The subject of this paper is the analysis of courtyard configuration as a dominant parameter in architectural design and energy savings. The courtyard is an open area that is tied to a specific building. It is usually surrounded by walls, other buildings, or a fence. The courtyard's dimensions significantly affect the project's development and the location's microclimatic characteristics. The courtyard's proportions and configuration directly affect the building's shape, so it is essential to consider the advantages and disadvantages of different influential parameters adequately. The influence of solar radiation on heat gains is evident, while it also increases the energy demand of buildings with different shapes and proportions of yards. Through an overview of various architectural aspects, the paper provides guidelines that can be useful to designers and spatial planners to form and select adequate courtyards for the buildings.

Keywords: courtyard configuration, architectural design, energy savings, urban planning;

1. INTRODUCTION

Increased urbanization in larger cities has influenced the design of buildings with an increased need for mechanical ventilation. Along with ensuring higher air quality and thermal comfort for the tenants, there was an increasing energy consumption. Global warming and climate change consequently lead to significantly higher energy consumption to provide thermal comfort in buildings, directly affecting the environment.

As a result, there has been a general movement toward finding effective design strategies to reduce buildings' energy demands and encourage further awareness of energy-conscious design. Designing a passive solar

building can reduce additional heating costs in buildings without compromising user comfort. Besides the impacts on the energy performance of integrating passive energy strategies [1], such as Trombe wall [2], double skin facade [3], green roof [4], and chimney effect [5]), the implementation of the courtyard and atriums can contribute to energy savings in buildings. In addition to climatic features [6–8], orientation [9–12], shape [13–16], and the ratio between the surface of the outer envelope of the building and its volume, the inner courtyard or atrium could also affect the final energy consumption in buildings [17]. They are integrated into the construction so that they could be considered a unique space, the so-called "atrium room". The geometry of the courtyard can play a significant role in the final energy consumption of the building [18].

By improving the urban landscape architects aim to solve global challenges. Some ways to achieve these goals are reflected in preserving heritage-inspired planning and design. At the same time, we should strive to develop cities of the future following modern approaches to urbanization patterns, architecture and design. This paper points out the benefits of designing buildings with an internal courtyard and the impact of good courtyard design. The paper concludes that adequate application of the courtyard could contribute to sustainable energy-efficient development of future cities.

2. COURTYARD AND ATRIUMS THROUGHOUT HISTORY

The original courtyards originated around the great Indus River region from 6500-6000 BC and evolved in response to the climatic and cultural conditions of the context. During the medieval period, the courtyards acted as an open space within the fortress to enjoy nature but remained protected from enemy forces. Although they varied in size, the houses of the time had a typical plan with a square courtyard in the center and rooms surrounding it. The smaller dwellings consisted of one courtyard along the northern wall, while the larger ones had several courtyards. The courtyard size is determined proportionally to the surrounding walls per the local climatic conditions.

The courtyard is an open area connected to a particular structure, often bounded by walls, other buildings, or a fence. The history of the courtyard can be traced back to 3000 BC in the archaeological remains of a courtyard house in Ur, Mesopotamia (Figure 1). In the Roman Empire, courtyards had basins to catch rainwater. Early medieval Christian churches often used atriums or courtyards as covered, open spaces at the front of the building. The courtyard served not only to achieve natural ventilation but also as a space for the socialization of the building's residents. Its purpose was different during the historical development: socializing, walking, cooking, looking after animals, etc. Although in ancient times, the primary idea was to ensure better social connection within the central premises, in the nineteenth century, the application of metal and glass enabled the further development of these systems so that from the middle of the twentieth century, the concept of the atrium experienced a revival and significantly improved the economy and the environment.

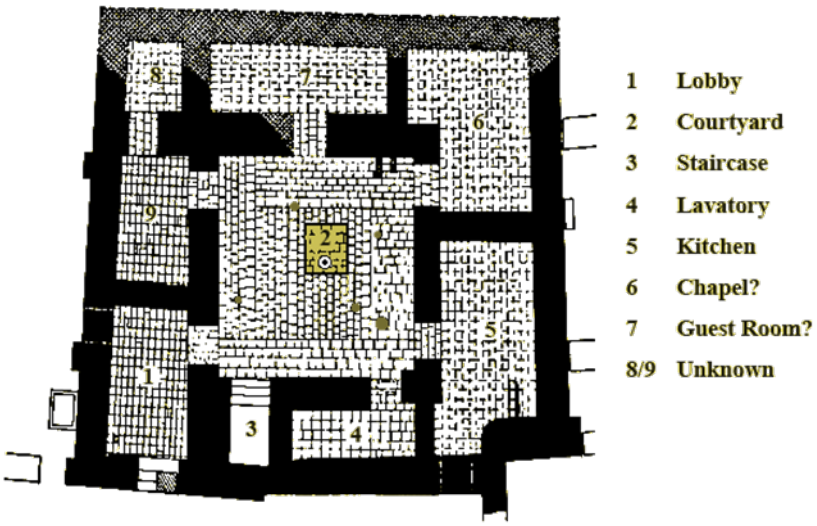

FIGURE 1: House in Ur, Mesopotamia [19]

The incorporation of the courtyard into building design in the modern era began during the Industrial Revolution with the availability of plate glass and slender structural elements of iron and steel. However, modern atriums appeared in the late 1950s and early 1960s. The new atrium originates from the temperate

climates of high latitude regions, providing an environmentally controlled room, natural sunlight, and warmth during winter. The ecological benefits of the atrium and courtyard design were reconsidered in response to the energy crisis. However, when designing these types of constructions, special attention should be paid to analyzing climatic conditions. Nowadays, many hotels, houses, country houses, and public spaces carefully recreate courtyards [20]. Land costs are increasing with the current urbanization rate and residential architecture development, so implementing internal courtyards in buildings is becoming very expensive [21].

2.1. Basic forms of the atrium

Despite its various advantages, the approach to courtyard housing typology is often neglected. Houses with a courtyard belong to particular types of individual family buildings. Unlike atriums which are enclosed spaces or spaces for "public use", courtyards are not covered with a roof, and these spaces may or may not be enclosed. Courtyards can be designed in several ways, but their configurations should always be a reasonable response to climate goals and a pleasant living environment. Typical configurations of this architectural element can be surrounded by walls or partially enclosed. The design is mainly based on climatic conditions and architectural experiments to ensure the expected level of thermal comfort in the building. There are four different forms of the atrium, and each has a unique environmental advantage chosen according to its ambient condition, expected ventilation, and daylighting. In moderate climatic conditions, it is recommended to design the atrium next to the building as a glazed facade, enabling more significant solar gains in winter. For hot and humid climates, centralized and linear atriums minimize temperature fluctuations during warm and temperate seasons (Figure 2).

a) central b) semi-closed c) glued d) linear

FIGURE 2: Forms of the atrium (From left to right: central; semi-closed; attached; linear)

3. OVERVIEW OF THE MAIN INFLUENCING FACTORS WHEN DESIGNING BUILDINGS WITH AN INTERNAL COURTYARD

3.1. Climatic characteristics and orientation of buildings

Climatic conditions have a dominant influence on the design of buildings with courtyards. Thermal characteristics of a building with a square courtyard, which is surrounded by buildings on all four sides, in different climatic conditions, differ depending on the climate, and have a different impact on cooling, heating, and total annual energy consumption. Generally, buildings with an open interior courtyard show better energy performance in hot-dry and hot-humid areas.[7]. In warm, humid climates, it is desirable to orient the longer axis of the courtyard along the northeast-southwest direction to achieve good performance. Furthermore, buildings with internal courtyards are best oriented along the north-south axis in moderately cold climates. In a warm, dry climate, buildings are best oriented between the northeast-southwest and north-south directions to ensure efficient performance in both seasons [6]. Using the modeling method, Muhaisen [6] performed an analysis of the influence of the geometric shape of the courtyard, as well as the effects produced on the inside of the analyzed rectangular shape for four different locations as characteristic representatives of regions with warm, humid, warm dry, moderate and cold climates. The study indicates the influence of climatic conditions on the proposed geometric characteristics and height of the yard to achieve a justified annual performance of the investigated locations. The results showed that the shading conditions of the inner side of the courtyard depend significantly on the proportions of the shape, geographical location, and available climatic conditions. Almhafdy, Ibrahim, Ahmad, and Yahyaocene [8] performed an analysis of the microclimate characteristics of a U-shaped courtyard in a General Hospital in Malaysia. It was confirmed that the change in the yard's configuration and its orientation affect the microclimate inside the yard.

The orientation of the building significantly affects its relationship to the natural environment, sun, wind, weather, thermal inertia, thermal insulation, topography, landscape, and views. Decisions made during spatial planning have an impact on the energy characteristics of the building throughout its life cycle [9]. The optimal

orientation of the building is one of the essential factors that create the conditions for the rational use of energy in the urban planning stage[10]. Regardless of the orientation, smaller houses and houses of higher quality performance are more efficient and better than those whose square footage exceeds 250m^2 or houses designed for the basic level of energy efficiency compliance[10]. The best position for symmetrical houses is when they are exposed to all directions.

In contrast, for houses with an elongated base, the longitudinal side of the house should be oriented towards the south [11]. The analysis of sunlit surfaces facilitates the determination of temperatures inside the building. Graphically determining the sunlit area is helpful for visualization and precise measurement [12]. East and west orientation are favorable in summer, while winter is much less sunny. The building should be opened to the south to have as much heat gains as possible through the windows - a direct solar energy gain. A south-facing free wall can have large glazed areas that provide solar gains. Living areas should be oriented toward the south, and bedrooms and utility rooms should be oriented toward the north. Rooms often used should have the most significant solar energy gains, made possible by large glass surfaces. On the contrary, less used rooms (cold, unheated rooms) with little need for daylight can be oriented on the opposite side.

3.2. The influence of the shape of the building and courtyard on energy consumption

The influence of the shape of the building on the total energy consumption in buildings primarily depends on three factors: relative compactness, window-to-wall ratio, and solar heat gain coefficient of the glazing.[14–16]. Optimizing the geometry of office buildings and glazing can reduce energy consumption and achieve savings regardless of the climate zone in which the building is located [22]. An object whose shape creates less airflow resistance and friction will cool or heat less. Florides and others [11] indicate that annual heating needs an increase in the elongated shape compared to the square-shaped base. That increase ranges between 8.2 and 26.7%, depending on the type of construction. In thermally insulated buildings that have a different form factor, the rates of thermal energy savings range between 1% to 7%, while in the case where buildings have the same form factor, the rate of thermal energy savings is from 34% to 36% compared to buildings without thermal insulation. Considering that these measures relate to the saving of thermal energy, it is pretty evident that they can significantly affect the financial picture of the entire facility [23].

The energy characteristics of buildings with a yard depend on many variables. The type of building with a courtyard has proven to be relevant in all climates. The energy performance of buildings with a courtyard compared to buildings with an atrium showed that buildings with a courtyard are a more energy-efficient option as part of low-rise buildings, while buildings with an atrium record better results in buildings with a higher height, i.e., in multi-story buildings [24]. In general, shallow rooms have the best energy performance for all window orientations and sizes in warm and temperate climates, while deep rooms perform best in cold climates. Regarding the shape of the base, in warm and temperate climates, the best energy performance is recorded for shallow rooms with medium-sized windows, deep rooms with large windows for north-facing rooms with large windows, and all rooms with small windows oriented to the south. In cold climates, the best performance occurs in shallow rooms with small windows and deep rooms with medium-sized windows for south-facing rooms with large windows.[22].

Internal courtyards act as microclimate modifiers that improve the perception of environmental comfort. Using courtyards in buildings can reduce the need for adjacent cooling spaces by more than 10%[25]. Due to the significant exposure of the external walls, houses with a courtyard are more suitable for warmer climates. These buildings are primarily single-story buildings, although it is possible to design multi-story solutions in some cases. Energy-efficient solutions for such buildings imply the orientation of the living rooms towards the south, while the sleeping rooms are designed towards the east side. This construction system represents one of the most energy-efficient construction methods. With two-story courtyards, the walls of the second floor receive more radiation than the walls of a single-story courtyard of the same size would receive.

On the other hand, the load from solar radiation on the lower floor surfaces is far less than on the surfaces of the one-story courtyard. Forms with a minor aspect ratio of the base in the selected geometric range receive minimal radiation [26]. Total energy consumption in narrow, elongated, or rectangular atriums with a large length ratio to width is significantly higher than in square atriums[27].

4. BASIC BENEFITS OF DESIGNING BUILDINGS WITH AN INTERNAL COURTYARD

Atriums and courtyards are similar structures found in residential and commercial spaces. Despite their many differences, they have in common that they provide space for relaxation and privacy while at the same time enabling natural ventilation and daylighting. Depending on their shape and orientation and applied glazing, atriums and courtyards contribute to reduced building energy needs. Throughout history, these constructions have been most often used in landscape architecture. The benefits of using this type of construction are reflected in the excellent use of ventilation and lighting as ways in which courtyards contribute to the sustainable, energy-efficient development of buildings. These spaces contribute to aesthetics, exposing adjacent interior spaces to daylight and maximizing direct solar energy. Also, they provide air circulation, increased socialization, and interaction between building residents.

Traditionally used as a central space between apartments, there has been a paradigm shift in the approach and design of the courtyard. Serving as a focal point and a protective barrier against harsh climates, courtyards are seen as a way of life. From influencing the indoor environment to creating a peaceful corner in a busy lifestyle, yards offer many benefits to enrich our lives. The yard as a passive solar system was developed mainly in response to climatic requirements. Poor or inappropriate design can create challenges in controlling the yard's temperature, glare, and energy consumption. Energy-efficient courtyard design involves looking at the shape of the building and its associated courtyard, ventilation, and courtyard performance in terms of daylight factor to improve the building's energy efficiency performance[28].

4.1. The courtyard illuminates the surrounding rooms

The sun's position varies with latitude, which significantly impacts the created conditions [6]. External static shading should be adapted to the characteristics of the location and should be designed depending on the location, which would be controlled according to seasonal conditions [12]. The courtyard, positioned under the open sky, allows the rooms surrounding it to be exposed to more daylight. Even long, narrow houses with fewer openings can be well lit with the help of a courtyard that saves large amounts of energy and creates a pleasant atmosphere in the house. The yard's proportions and geometry significantly influence the yard's shading, which depends on the position of the sun in the sky and the geometry of the yard [18].

By introducing natural lighting to the interior, interior courtyards and atriums provide a more pleasant working environment by connecting to natural daylight and the outside environment. Protection from the sun on the south side of the building can be achieved by trees planted along the facade in the form of a horizontal shelter. Shading east and west-facing windows can be achieved with vertical barriers such as trees. Deciduous trees in the winter, when the leaves fall, allow the sun's rays to penetrate the interior of the building unhindered through the branches, and in the summer, it provides a strong shadow.

4.2. The yard provides ventilation

Natural ventilation in buildings plays a crucial role in ensuring the optimal quality of internal air circulation in the building and maintaining an acceptable level of thermal comfort without using mechanical systems such as heating, ventilation, and air conditioning. One of the most critical roles of the inner courtyard is the supply of fresh air and the removal of stale air from the building premises. By providing natural and cross ventilation, courtyards increase oxygen supply and provide the maximum cooling effect. While they draw in the fresh air and expel hot air in the summer, solar radiation protects against cold winds in the winter. In addition to helping to exchange heated air from adjacent spaces from the building, it enables connecting the space with the outside space. The courtyard can use ventilation for heating by bringing fresh air in and exhausting stale air with less air exchange ventilation. In case of intense solar radiation, in addition to the yard's design, it is necessary to install a solar chimney or a double facade in the facade of the building. The use of additional mechanical ventilation is most often used in urban areas to extract cleaner and cooler air from the upper atmosphere using an inverted solar chimney.

Atriums offer natural light, and if they are covered, they require some form of ventilation in the spring and summer because the glass retains heat. In contrast, during the fall and winter, the trapped heat enables energy savings for heating. This way, there is optimal energy consumption and summer comfort in extreme climatic conditions. An atrium with the exact geometric dimensions in different climates and glazing conditions is more energy efficient with increasing building height. At the same time, in the summer months, it is more advisable to use an open courtyard in low-height buildings.

4.3. The courtyard connects the interior and exterior and, at the same time, offers privacy and security

Although there are less pronounced differences between the modern atrium and the courtyard, their purpose is essentially the same. Both aim to improve the quality of life of those who live or work in the building or home. They offer a semi-covered or private space where one can enjoy the outdoors. The natural light entering the space provides space for growing a garden or various other plants in full sun. Courtyards are open spaces that contain indoor elements, such as places for cooking or sitting, while atriums bring a small amount of the outdoors into the indoor space. The courtyard provides physical separation of space within the house, providing residents with an open space available throughout the day. This space is private, secure, and easily accessible without the distraction of household chores. Establishing a connection with the natural environment allows residents to relax in a more private garden with fresh air and a clear mind. This way, the stress level is reduced, the immune system is strengthened, and it can be used as a meeting place for people.

4.4. Radiation control of the outer surface of the envelope

Shape parameters that affect the thermal balance of building surfaces with an internal courtyard under the influence of solar radiation are geometric (proportions, size, and orientation) and physical (reflection from the object's surfaces). The first category affects the initial radiation load on the object's surface, while the second affects the final load from solar radiation [29]. Solar heat gains through glazing represent one of the most dominant building envelope parameters that affect their energy efficiency [30]. The geometric shape of the yard has a minimal influence on the sun exposure of the inner surfaces of the yard in the winter period. In contrast, in the summer period, this influence is more significant [18]; by reducing the depth of the yard, the penetration of the sun's rays increases. The optimal height of buildings with an internal courtyard and enabling the best performance of the building in summer and winter, is a height of three floors in hot-humid areas, two floors in warm-dry and temperate areas, and one floor in cold climates [6].

The tendency is that buildings with a shallow inner courtyard are built in moderate and cold climates due to the sun's low position in the sky. By increasing the depth of the inner courtyard by adding a parapet to the top of the building walls, the load from solar radiation progressively decreases as the height of the parapet increases [26]. Deep-form patios of any geometry are generally recommended to achieve maximum internal shading in summer. On the contrary, in winter, the shallow form of the yard would allow the sun to shine on the most significant part of the yard [18]. A building with a deep courtyard significantly influences the sun exposure of the interior surfaces in the summer, which results in a low energy need for cooling. At the same time, in the winter, minimal heat loss is ensured, reducing the need for heating. Several methods can be used to improve the control of heat gains from solar radiation in the summer, such as light colors or shading devices. In this way, the absorption of solar radiation is reduced, and at the same time, the thermal characteristics of the outer envelope of buildings are improved. The courtyards shaded from the buildings contribute to a reduction in cooling needs by an average of about 4%, while in winter, the need for heating increases by an average of about 12% [31].

Controlling the thermal performance of the inner courtyard concerning solar radiation can be achieved naturally by controlling the radiation of the outer surface of the envelope. This type of solar radiation control is achieved by manipulating the geometric and physical parameters of the form [29]. Energy-saving measures such as thermal insulation, double-glazed windows, Persian blinds, and sealing strips can reduce energy needs for cooling as much as a well-designed yard. At the same time, a properly designed courtyard reduces the building's energy needs for heating [21,32].

5. CONCLUDING REMARKS OF DESIGNING BUILDINGS WITH AN INTERNAL COURTYARD

This research aimed to identify an energy-efficient, integrated use of the courtyard to improve the energy performance of buildings in terms of seasonal and climatic factors. The results of this research showed that the use of passive characteristics of the courtyard affects reduced energy consumption and improved lighting and ventilation, but also the control of the radiation of the building envelope. Architects and planners, as well as policymakers, may profit from the mentioned guidelines.

The importance of the courtyard is reflected in its practical implementation through the aesthetic aspect. In urban environments, courtyards can provide many benefits, such as security for adults and children and connecting the interior with the exterior. A contemporary approach to courtyard design requires multiple functions, adaptable recreational spaces for residents to network, and flexibility to exchange and change use

according to community requirements. Integrated use of courtyards and atriums can save energy in different climates. The integrated use of the passive features of the courtyard and atrium affects energy consumption. It is recommended to carry out further studies on the impacts on the energy performance of integrating other passive energy strategies (e.g., Trombe wall, double skin facade, green roof, chimney effect) on the buildings with the courtyard. Although the courtyard is only one of many strategies for ensuring better energy efficiency of buildings with increased thermal comfort, its adequate application contributes to sustainable energy-efficient development and could lead to the development of the cities of the future.

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