The Influence of the Courtyard Geometry on the Passive Lighting Energy Savings

Jie TAN¹,* Xin GUO² and Ming-ping ZHANG¹

¹Department of Architecture, College of Hubei Engineering, Xiaogan, China
²Chongqing Planning Research Institution, Chongqing, China

*Corresponding author

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Abstract. Although there have been multiple studies on energy performance and thermal comfort of courtyard buildings, the effect of courtyard geometry factors have been studied much less. To gain new insight into this relationship, this study evaluated the role of geometry factors - the atrium shape and the ratio of length to width - on building lighting energy performance in courtyard building. First, more than ten ancient dwelling house in JiuFangGou village in Hubei Province were measured and modeled. Second, a series of lighting illuminance in 50 halls beside the courtyards were measured. Third, Five Typical Daylighting factor curve on 5 typical geometry factors were draw. Results show that courtyard which height to width ratio less than 1 have better lighting illuminance. No advantage was observed for height to width ratio more than 5. Result indicate that comprehensive consideration, height to width ratio between 3 and 5 and inverted V-shape courtyard profile form was suitable to the local area.

Introduction

For the past half century, new building construction has greatly increased in China. Building energy consumption, especially the artificial lighting load which about 15% to 45% [1] is considered a major problem in commercial and official building. Atrium design will bring natural lighting into the interior spaces of the building and therefore minimize depending on artificial lighting load.

The influence of various design parameters on courtyard lighting environment is not fully understood. There are numerous parameters for efficient design and reduced energy consumption in building by atrium. These parameters include size, form, location of the atrium in building, height, reflectivity of materials.

In principle, we could never study affectivity of courtyard for energy saving just by one parameter independently. But we are able to investigate or analyze how effective these parameters could be in separate studies. The problem is that lighting energy saving is not the primary focus of atrium design consideration. The courtyard allows daylight to penetrate into the core of a building that contributes not only social interactions and architectural matters but also the potential to resolve many environmental issues. The architects face a more difficult challenge due to the lack of adequate and comprehensive design guidelines that use less energy without compromising occupant comfort. Despite numerous studies demonstrating strategy [24] to achieve visual comfort and remarkable artificial lighting savings, the geometry factor, such as atrium profile shape, size and dimension, are much less considered.

Dwelling House Description

This paper investigates dwelling houses were JiuFangGou village in Hubei Province where in the middle and lower of the Yangtze River region. The village is a composed of many independent building more courtyard buildings, including Ming Hall, Qinlong Tai, YanShi old curtilage, YanShi ancestral temple, etc. YanShi old curtilage, which have 31 courtyard, 165 rooms, with the brick structure, are better overall preservation, with building area of about 10000 ㎡.
The dwelling houses in this village, which have been used for 5000 years, are the in-between architectural spaces where the indoor and outdoor climates is moderated without mechanical control system \[2-4\]. These space not only increases socialization but also passively reduced energy consumption in building. Courtyards were generally not fully enclosed and where important to indoor thermal environment. It provided daylight, passive solar gains and was part of the natural ventilation system as it acted as an air channel to enhance convective airflow through and around the adjacent buildings \[6\].

Methodology

A large number of traditional local-style dwelling houses in this village are surveyed and mapped. Though spatial analysis, summarizes the common features of scale and spatial form, analyze the effect of indoor light environment luminance distribution and glare, discusses its application in public building atriums. The analysis aims to investigate how different courtyards forms and geometries respond to various conditions.

The analysis in this paper includes two parts: (i) measured Indoor light environment illuminance distribution of the room adjacent to the courtyard of ancient dwelling. And (ii) modelled according to surveying and mapping to the ancient JiuFangGou dwellings and analyze the suitable height to width factor and the shape of courtyard.

The Courtyard Dwellings

The courtyard dwellings are architecture creation adapt to nature to improve the indoor environment by Chinese people a long time ago. A lot of design technology used in the dwellings are worth using in modern architecture from the perspective of passive energy saving. From the survey of the dwelling in JiuFangGou village, we found courtyard is the most common lighting form, as shown in Figure 3, the courtyard arc combination of four eave of roof and wall, the bottom floor area is greater than the mouth of the well. There are other architectural function collect rainwater, lighting, ventilation, and firefighting. If the courtyard for manual workshop and other places of work, use the lighting tile strengthen daylighting effect. As shown in Figure 4, the rain will not affect work.

Courtyard Scale and Daylight Factor Analysis

The main index of daylighting effect is daylight factor. Measure based on more than 50 patio, with
different scales, corresponding to the hall and room lighting situation, found the courtyard height to width ratio \((h/w)\) minimum of 0.8, and the largest 4.4, where beside the kitchen is strip shape. Because the hall part is most important in receive a visitor area of the building, in the biggest and brightest of all the space, so choose hall measuring intensity of illumination. For comparison, five typical height to width ratio patio corresponding hall are measured. Measure in the cloudy day, with partition board in the hall be opened entirely. Measure illumination with illuminance meter on 6 points which on the hall central axis, apart 0.8 meters, shown in Figure 5. And the illumination on the horizontal plane outdoor. Through calculation, height to width ratio were 0.8, 1, 1.9, 3.1, 4.4, the daylighting curve of the hall was shown in Figure 6. The height to width ratio below 1 hall lighting factors are more than 2%. Conform to the requirements of sitting room lighting factor standard 2%, only 9 out of 50 meet the requirements of the modern building daylighting factor of the sitting room.

![Figure 5. Point of measurement.](image5)

![Figure 6. Daylighting factor curve.](image6)

The illumination on courtyard with lighting tile roof was also measured and calculate the factor of daylighting. Daylighting curve as shown in Figure 7, the daylighting coefficients in more than 3%, meet the requirements of working space lighting factor standard 3%.

![Figure 7. Daylighting curve.](image7)

The Form of Courtyard and Lighting Efficiency

Although illuminance of the measured hall beside the courtyard modern can’t meet the lighting factor values, but as you know, in the Ming and Qing dynasties especially in the Ming dynasty hierarchy was very strict. And at that time land resources scarce, with various restricting factors limit, it’s hard for the ancient builders used proper form of courtyard to improved lighting efficiency. As shown in Figure 8, courtyard eaves, eaves gallery on the second floor and the bottom open hall formed an inverted v-shape space. JiuFangGou village is in the fourth kind of light climate zones, cloudy day is more. The courtyard space which in accordance with the distribution characteristics of diffuse light are not too dark in the rainy or cloudy days. Modern buildings designed large volume to get enough space for use, so that a lot of black room which don't had access to natural lighting and ventilation. If modern building designed reference to the practice of the ancients, with an inverted V-shape courtyard or atrium of natural lighting and ventilation, will gain more high quality environment. As show in Figure 9, Matsushita Electric Industrial Information dissemination center had an inverted V-shape atrium which could meet the ventilation indoor even when there was no wind.
Glare Analysis
In winter, because the angle of the sun was low, the depths of the hall get more direct sunlight. There didn’t cause dazzling glare, and the light was downy, mainly due to ground material of hall was stone bricks with diffuse surface, won't produce strong reflection. In summer, the angle of the sun was high, while the light is strong. Only part of courtyard ground get the direct sunshine because the big overhangs roof keep most sunshine out. The sunshine diffuse into the indoor with reflect on the stone brick on the courtyard and avoid the glare. And if shut down the partition door in the hall also could avoid glare because the diffuse light from the wood carving on partition door reduce brightness contrast.

Ecological Analysis
Ecological regulation effect of courtyard was respond to its scale and morphological characteristics. Most measured height to width ratio was about 4, which space like a deep well couldn’t get more direct sunlight, and the store brick of courtyard diffuse light reflection to indoor, while the downy daylighting weakened the sun radiate to heat up. And between the courtyards often has a small pool or water vat or some young trees, provide a cool, strengthen the ecological regulation effect.

The courtyard spatial of small top big bottom structure was good for natural ventilation. It’s called chimney effect. The air on the top of courtyard been heated and went upwards and the air at the bottom of the courtyard also went upward because the air-press, then bring the air of hall or room beside the courtyard outlet. That was bring a cool wind, blow away the indoor hot air. On the inverted V-shape spatial structure is beneficial to form blowing effect, strengthen ventilated effect. By the measured in hot weather, as well as direct sunlight place patio inside than the outside air low 7 to 10 degrees.

Conclusion
Measurement of the scale of the local residential courtyard and morphological characteristics were undertaken. The parameters considered important in the courtyard design effect the indoor environment were recorded and analyzed. Comparing 5 hall beside the courtyard with different height to width ratio, the most suitable ratio for the local were obtained. It was found that the inverted V-shape spatial courtyard is beneficial to ventilated effect.

At the beginning of the design should be in the daylighting of the atrium of the surrounding space compensation as the main factor. The local-style dwelling houses in JiuFangGou village should be carefully preserved and studied. The morphological characteristics and the scale of the courtyard must be as important reference factors, height to width ratio between 3 and 5 and inverted V-shape atrium profile form was suitable to the local area.

Discussion
The shape and height to width ratio of courtyard could be used to modern buildings because it had important significance not only in terms of lighting, but also in energy saving design and ecological design. 5 layer in the traditional library as an example, the atrium in reading seat only 4-5 layers can use daylighting to reading, 2-3 layers of artificial lighting is needed to supplement, if make it
inverted V-shape will have greatly improved. In addition, layer upon layer of spotlighting the inverted V can also cleverly avoid the line of sight of the atrium interference, and get a new visual experience. The atrium of modern public building design could adjust the indoor environment, ultimately achieve the goal of sustainable development.

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Reference


