Numerical Investigation of key design parameter impact on building loads for public space organization of courtyard hotel in South China*

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Abstract. The courtyard type hotels are commonly seen in hot summer and cold winter region as well as hot summer and warm winter region of China. With its grown size and more complex functions, its energy consumption gets dramatically increased accordingly. Up to now, research of the design parameter impact on energy consumption for space organization in courtyard hotel is quite limited. Through numerical simulation, this study validated the influence on building loads of key design parameters including the orientation, relative position, window-to-wall ratio of the public space, and the position of the traffic core space in courtyard hotels. According to the results, for both the hot summer cold winter region and hot summer winter warm region, the lower total building load was seen when the large space is on the northern side in parallel or on northwest and southeast in diagonal layout. With the traffic space splitted and placed at the corners of the building, the lighting load increases, and leads to unsatisfactory total energy performance. For the comparative suitable plan layout, higher window-to-wall ratio of public spaces (larger than 0.3) can significantly raise the total load per unit area. The findings in this research can provide valuable references for the energy-saving design of space organization in urban courtyard-type hotel buildings.

1. Introduction
Due to the architectural attributes of urban hotel buildings, the cooling, heating and ventilation facilities of specific functional spaces like the guest rooms need to be operated around the clock. Unlike, occupying a large building area and with the space form and organization relatively flexible, the public spaces such as banquet halls, lobbies etc, as a non-specific function spaces, are normally utilized intermittently. These spaces commonly meet a height higher than 5m[1], and an area larger than 10,000 m² in medium and large sized hotels. With large space volume and high total amount of energy consumption, these public spaces account as the key to reduce the high energy consumption of courtyard hotel buildings. Most public spaces of the hotel often use large-area glass curtain walls as the outer skin, easily resulting in high heating load in winter and high cooling load in summer. It is therefore necessary to understand how the window-to-wall ratio can influence the energy consumption of suitable plan layout.

Multistorey courtyard-type hotel are commonly built in urban resort. Public space with inattentive spatial organization and essential accessibility but pursuing rich functions normally rely on large volume
spaces, resulting at huge energy waste for space comfort regulations. However, research over the relationship between spatial organization design parameters and energy saving is quite limited.

Most of existing research on energy-saving design of hotel buildings highlight technologies such as improving the thermal insulation performance of envelope\(^2\), shading, natural ventilation and evaporative cooling in summer\(^3\). The study of the space design normally refers to design parameters such as the shape coefficient, functional space layout, key space scales and so on. Three main factors play the major role in affecting the heating and air conditioning load: the external disturbance, internal disturbance and building envelope\(^4\). When designing an tempered and conditioned space organization, it is needed to consider the temperature distribution inside the building due to unbalanced solar radiation and heat transfer\(^5\), therefore, a good spatial organization design can effectively reduce various building loads. Xu Shen et al. have demonstrated in the study of Solar-energy Building Design that deep buildings need to effectively organize the planes and sections to optimize the sunlight and ventilation effect; staggered rooms can help getting more sunlight, so that the rooms without enough sunlight in the north can better exchange heat through convection heat transfer with south-facing rooms with more sunshine. When the building must be arranged in a north-south direction, it should be arranged stepwise through the section, to gradually achieve the improvement of indoor thermal comfort\(^6\). Therefore, the relationship between building load and key design parameters such as functional space plan layout, spatial interrelationship and orientations of large spaces needs to be further investigated for courtyard-type hotel buildings. In this study, we established multiple sets of building models with different spaces organizations, especially based on different configurations of key spaces for comparative studies. The impacts of the examined key design parameters over energy consumption in typical courtyard hotel typologies have been numerically investigated. The research outcomes can provide valuable information for energy-saving design of public space in courtyard-type hotel buildings.

2. Research Methodology
The preliminary case studies summarized the main archetypes of courtyard-type hotels, considering both the building layout of plan and cross-section. Afterwards, based on previous research\(^7\), the numerical simulations have been carried out with the modelling configurations including the climate conditions, envelope properties, HVAC setting and operational schedule etc reasonably set up. The effect of spatial organization variation on the total building load of the courtyard-style hotel was studied over several key aspects through simulation works: relative position of large space, orientation of large space, traffic core position and window-to-wall ratio impacts.

2.1. Design archetypes modelling
Public spaces of hotel mainly include large spaces such as lobbies, cafeterias, banquet halls, large meeting rooms, as well as common scale spaces like logistic offices, small meeting rooms, and auxiliary spaces. The lobby and banquet halls are thermocline large spaces, the cafeteria, and large meeting rooms are single-story large spaces, and office spaces, meetings, guest rooms are small single-story small spaces. According to the case survey over around 200 medium-sized multistorey hotels, the building area was determined to be 24,000 m\(^2\), and the floor height to be 4.8 m for the archetype model scale. In order to simplify the model, the length and width dimension of the courtyard are configured as in square shape, and two core courtyards are placed as in adjacent array. The final standard archetype model was therefore determined as follows: the building is in 86.4m length and 70.8m width, with fifth floors above the ground. The total height of the building is 24m. In the first floor, the lobby, dining room, large space, kitchen, office and other functions are arranged. In the second floor, the cafeteria and conference functions are planned. The large spaces are arranged side by side in four different directions or diagonally in the four corners. The traffic space is set to be either concentrated or dispersed. And finally with a chosen most suitable plan layout, the window to wall ratio impact was examined with its value set to be from 0.1 to 0.9.

Of course, the actual building space organization is often not strictly corresponding to the pre-set archetype models, but can be reflected as an integrated results of them. As a study, we can understand
the effect of the examined key design parameters on building loads through the archetype simulations, and then to predict the results for comprehensive design use.

Table 1. Classification of horizontal layout of multistorey hotel and model size

| Types              | Model                                  | Surface area(m²) | Volume (m³) | Shape factor | Layer number | Total height(m) | Storey height (m) | Area (m²) | Case |
|--------------------|----------------------------------------|------------------|-------------|--------------|--------------|-----------------|-------------------|-----------|------|
| Multi-storey courtyard hotel | | 17401 | 117404 | 0.15 | 5 | 24 | 4.8 | 24459 |

2.2 Simulation tools and calculation configurations

Table 2 Material selection

| Name       | Material                                                                 |
|------------|--------------------------------------------------------------------------|
| Façade     | Concrete, cast-foamed (300.00mm) + Extruded polystyrene (XPS) (60.00mm) + Concrete block (240.00mm) |
| Roofing    | Cement mortar (20.00mm) + Waterproof layer (10mm) + polystyrene (EPS) (150.00mm) + Reinforced concrete slab (100.00mm) + whitewashing (20.00mm) |
| Exterior window | Generic PYR B CLEAR 3mm colourless + Air 13mm + Generic CLEAR 3mm; Window wall ratio 0.3 |

This work selected the simulation software Design Builder to conduct energy consumption simulations. The selection of the material of the enclosure wall, roof, window typologies and window to wall ratio, have been set according to the design standard for energy conservation of public buildings (GB50189-2015)[8] and "Building Daylighting Design Standard" (GB 50033-2013)[9]. "Civil Building Green Performance Calculation Standard"(JGJ/T 449-2018)[10] has been referred to set the operational conditions of hotel buildings, including the occupant density, ventilation, lighting and other equipment configurations such as general power, air-conditioning temperature and operational schedule of indoor functional rooms.

3. Results and discussion

3.1 Large space relative position and orientation

The lobby space and banquet space were set as large space with a floor height of 9.6m. Its positions were set to be on the southern, northern, eastern and western side, as well as in both the southwest, northeast, northwest and southeast corner respectively. Table 4 lists the comparative archetype models and their detailed characteristics of six different spatial organizations. In order to simplify the model, the function and streamline of public space has been simplified as much as possible. The rooms in the upper part of the courtyard have a depth of 9.9m, a width of 4.5m and an inner corridor of 3m width. In order to better show the organization of public space, the model diagram in the table shows only the public area, and the modeling details are as shown in table 3.

3.1.1 Archetype modelling scheme.

The functional space type and area, envelope material properties and other parameters of the model remain unchanged, with only the relative position and orientation of the large space varying.
Table 3. Simulation scheme of the relationship between Spatial orientation and Building load of public space organization

| Type  | Plan | Model | Type characteristics |
|-------|------|-------|-----------------------|
| planA | ![Diagram](image) | ![Diagram](image) | The large space is completely separated in the southwest and northeast corners. |
| planB | ![Diagram](image) | ![Diagram](image) | The large space is completely separated in the southeast and northwest corners. |
| planC | ![Diagram](image) | ![Diagram](image) | Large spaces are arranged on different sides of the courtyard, and are all on the west side. |
| planD | ![Diagram](image) | ![Diagram](image) | Large spaces are arranged on the different sides of the courtyard, and are all on the east side. |
| planE | ![Diagram](image) | ![Diagram](image) | Large spaces are arranged on the same side of the courtyard, and are all on the south side. |
| planF | ![Diagram](image) | ![Diagram](image) | Large spaces are arranged on the same side of the courtyard, and are all on the north side. |

3.1.2 Simulation results and discussion.

The simulation results as shown in figure 1 & 2 illustrate that both in Hot summer and cold winter region as well as in Hot summer and warm winter region, when the lobby and banquet hall are arranged diagonally in the northwest and southeast, the lighting load and cooling load can be reduced with the heating load increasing resulting in a reduction of total load of the building, comparing to the southwest and northeast reference. When the large space is located in the northwest and southeast corner, the total load also tends to be comparatively even lower. In case of large spaces being arranged side by side, when the lobby and banquet hall are located in the northern side of the building, the lighting and cooling loads are relatively reduced, and the total building load per unit area exhibits as the lowest. This may be due to the fact that, the northern side placed large space can provide climate buffer for the small space in summer, and also can ensure the sunshine and daylighting of the small space in winter. Although the large space will also increase the heating load on the north side In winter, in general the north side placed
large space can reduce the total building load.

![Figure 1](image1.png)  
**Figure 1.** Building load of various large space relative position and orientation in Hot summer and cold winter regions.

![Figure 2](image2.png)  
**Figure 2.** Building load of various large space relative position and orientation in Hot summer and warm winter regions.

### 3.2 Traffic Core Location

#### 3.2.1 Archetype modelling scheme.

The functional space type and area, envelope material properties and other parameters of the model remain unchanged, with only the relative position and orientation of the traffic core varying, from being located the center of the building to the four corners of the building, to explore the resulted building load change.
Table 4. Simulation scheme of the relationship between Spatial orientation and Building load of public space organization

| Type | Plan | Type characteristics |
|------|------|----------------------|
| planE | ![Plan Image] | Service spaces are arranged on both sides of the courtyard. |
| planG | ![Plan Image] | Service spaces are scattered in the four corners of the building. |

3.2.2 Simulation results and discussion.

The simulation results as shown in figure 3 illustrate that in Hot summer and cold winter region compared with the middle location, when the traffic core is placed in the four corners of the building, the lighting load gets increased, the heating load gets a bit decreased but not much, and the heating load of the building get slightly increased. The situation in Hot summer and warm winter region is quite similar but with both heating and cooling load slightly increase as well instead (Fig. 4). As a result, the total loads per unit area for both region tend to be comparatively higher when the traffic core is placed in the four corners. This may be due to the fact that, when the traffic space is located at the four corners, the traffic space can act as a buffer space[11] to form a thermal insulation layer, to reduce the heat invasion and resulted indoor temperature increase, thereby reducing the cooling load in summer. However, the traffic space located at the four corners occupies better lighting areas for the functional spaces, so also increases the lighting energy consumption substantially. Therefore when the traffic space is set at four corners, more cavity space such as atrium, side court, gray space, etc are appreciated, to increase the building internal lighting as well as maintaining heat buffer, so as to achieve the energy consumption reduction.

Figure 3. Building load with changing traffic nuclear location in hot summer and cold winter regions.
3.3 Public space window to wall ratio

As shown in the above analysis, plan E always exhibits as the most suitable function organization solution for both Hot summer and cold winter region as well as Hot summer and warm winter region, or in general, the South China area. It is therefore selected as the basic archetype for the window to wall ratio research accordingly. Based on the Plan E in Table 3, the window-to-wall ratio is set to be 0.1, 0.3, 0.6, and 0.9 respectively.

As shown in Figures 5 and 6, in both hot summer and cold winter regions as well as hot summer and warm winter regions, the growth rate of the total load per unit area is relatively small when the window-to-wall ratio is less than 0.3. But with the window-to-wall ratio higher than 0.3, the cooling load and the total load per unit area get more rapidly increasing. Therefore, controlling the window-to-wall ratio also demonstrates as the key point of energy-saving design for courtyard hotels in the southern China areas, especially considering summer loads control.

4. Conclusion

In this study, the impacts of key design parameters for typical courtyard-type medium-sized hotel buildings have been investigated in hot summer cold winter areas and hot summer warm winter areas. It has been found that, with diagonal plan layout, large volume space are preferred to be arranged in the northwest and southeast rather than in the southwest and northeast. With parallel plan layout of large volume space, the northern side are mostly appreciated. Both can mainly be attributed to better illumination and cooling shield effect. Meanwhile, the traffic spaces are preferred to be placed in side central position rather than the corners, so as to benefic more from the daylighting for other functional
spaces. And finally, the external window to wall ratio are suggested to be restricted, to maintain enough cooling shield effect in summer.

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