On the development of exponential regression analysis concerning occupant density and space form to predict energy consumption of outpatient department in hospital

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Abstract. In outpatient area of medical buildings, the distribution of people and energy consumption are significantly different when the space form scale changes. To obtain the simulation results of energy consumption under different occupant densities and different space forms, then establish a predictive regression model which can quantify the influence on building energy when space form scale and occupant density change, the Design Builder software is used to simulate the energy consumption. On the basis of the above simulations, this paper explores the characteristics and rules of energy-saving form of outpatient area which could provide references for the low-energy medical building design. The results show that when the total area of the outpatient department is constant, the energy consumption decreases when the occupant density increases; when the width of the peripheral zone increases, the energy consumption increases accordingly. The specific value of energy consumption can be predicted by regression model.

1. Introduction
In recent years, with the rapid development of China's construction industry, the building energy consumption also shows a steady growth. According to the data of 2015, the total building operation energy consumption has reached 20% of the total energy consumption of the country [1]. Therefore, the research on building energy conservation is urgent. Study on the influence mechanism of building energy consumption and tapping the potential of building energy conservation can help improve building energy conservation work and respond to the national strategy of energy conservation and emission reduction.

The research on building energy conservation at home and abroad is mainly divided into two categories. The first category mainly studies the influence of building envelope and construction on energy consumption [2-4], and the second category studies the correlation between building layout, space form and energy consumption. The research on the former has attracted the attention of the academic circle earlier and has gradually improved. In recent years, the latter has attracted more and more scholars' attention, and some scholars have made some new explorations.

At present, the research on the influence of building layout and space form on energy consumption mainly focuses on the plan function layout and architectural form design.
The space close to the building facade can obtain good natural lighting and ventilation, so Carlo Ratti and Nick Baker put forward the concept of passive area, and take the ratio of passive area and inner area as a index to predict energy consumption. The higher the ratio is, the higher the potential of building using natural environment resources will be, and the lower the energy consumption will be [5].

Amaia studies the layout of European office buildings, and draws the conclusion that the energy consumption of the layout which arranges the single offices in the center of the building is lower. Because under the climate conditions of Europe, when single office is located in the center, energy dissipation such as cold air infiltration can be avoided, and the indoor heating load can be reduced because of the heat production generated by people activity and use of equipments [6].

He Cheng et al. studied the correlation between the functional layout and energy conservation of the typical multi-storey buildings in Wuhan, adopting the method of randomly sampling the possible layouts, simulating the energy consumption of the samples, then analyzed the simulation results. It was concluded that the layout of air-conditioned rooms such as offices and meeting rooms in the north side was more energy-saving than that in the south side. When the number of non air-conditioned rooms in the south side increase, the total energy consumption of the building would be reduced. The energy consumption is smaller when toilets, storage rooms and staircases are in the south side, compared to in the north side, especially when they are in the the westernmost side of the building[7].

Tian Yixin et al. studied the relationship between the layout of office buildings and energy consumption in cold areas, and found that the energy consumption of west auxiliary space is lowest, and that of center is the highest. The energy consumption of single small space is more energy-saving when it is located in the peripheral zone(compared to in the center), and the energy consumption of single space used as private office is lower than that as conference room, that is, the lower the occupant density is , the lower the energy consumption will be [8].

Liu Ligang, et al. summarized 8 cases of typical high-rise office building layout in 6 categories, respectively simulated their energy consumption in Beijing, Changsha and Guangzhou, and proposed that the energy consumption per functional area can better reflect the layout efficiency and energy consumption level compared with total floor area. The depth of the functional area has a higher correlation with energy consumption, which is positively related to the lighting energy consumption and negatively related to HVAC energy consumption. Different climate regions have different sensitivity to the energy consumption of these 8 cases. The energy consumption differences between these 8 cases in Guangzhou and Changsha are greater than that in Beijing. The reason is that plan layout has a greater impact on lighting energy consumption, while Beijing has a large proportion of heating energy consumption and is not sensitive to lighting energy consumption [9].

Mei Hongyuan et al. studied the optimization mode of energy-saving oriented architecture form in cold area, and concluded that the design of buffer areas such as lobby and atrium should be strengthened. For example, according to the design of Yichun Academy of calligraphy and painting, two large spaces, academic lecture hall and dining hall, are arranged at the most peripheral part of the building to form a thermal buffer space around the building [10].

All of the above studies are oriented to low energy consumption, and analyze the influence trend of various plan layout factors on energy consumption. However, there is still a lack of accurate quantitative research on the correlation between space form, occupants density and building energy consumption. This paper takes one typical medical building in Xi’an as an example to study this problem, and obtain the regression model. When given any reasonable width of the peripheral zone and the number of total energy users in the outpatient area, the regression model can be used to predict the energy consumption.

2. Methods
The typical medical building outpatient area plan is shown in the figure 1. The outpatient area is located in the northwest corner of the hospital, mainly divided into two parts: the inner zone and the peripheral zone. As shown in figure 1, the peripheral zone refers to the area close to the facade of the building, its thermal environment is more vulnerable to the impact of the external environment, while the inner zone
is far away from the facade of the building. In this case, the inner zone includes offices, consulting rooms and corridors, while the peripheral zone is the north side corridor that bears part of the waiting function.

Figure 1. Diagram of outpatient area

In the simulation, the length and width of the outpatient area are kept unchanged, and the width of the peripheral zone changes. The width of the peripheral zone is increased from 1.3m to 8.5m, rising 0.6m per step, taking 13 different values. Considering the different occupant density in different periods when the building was used, the total number of occupants in outpatient area is from 200 to 450, rising 50 per step, taking 6 different values. Therefore, 78 simulations were executed to obtain the energy consumption values of outpatient areas under 78 different conditions.

Through regression analysis of the 78 simulated data, the regression model of the width of the peripheral zone, the occupant density in outpatient area and the energy consumption per area are obtained.

3. Building energy simulation

The length and width of the outpatient area were 51.3 meters and 37.2 meters, which remained unchanged. When the width of the peripheral zone increased from 1.3m to 8.5m, the width of the inner zone should decrease accordingly. When the total number of occupants in the outpatient area was determined, the number of occupants using energy in the peripheral zone was determined by the width of it. To evaluate the number of occupants in the peripheral zone (that is, the density of the occupant in the peripheral zone), we introduced the concept of attendance. The attendance in this case means the number of the occupied seats, that is, the number of people in peripheral zone. When the width of the peripheral zone is greater than or equal to 2.5 meters, there will start to have waiting seats, with 24 seats in a row. After that, for each increase of 0.6 meters of the width, the seats will be increased by one row, and the maximum value of the seats will be 7 rows. Once reach 7 rows, the seats will not increase. When the total number of people in the outpatient area is 200, the attendance will be 50%. After that, for every 50 newly increased people, the attendance will increase by 10%. When the number of people reaches 450, the attendance will be 100%. According to the above hypotheses, the number of occupants in the peripheral zone under different widths is shown in table 1.

| Occupants in outpatient area | 200 | 250 | 300 | 350 | 400 | 450 |
|-----------------------------|-----|-----|-----|-----|-----|-----|
| Width of peripheral zone is 1.3m | 0   | 0   | 0   | 0   | 0   | 0   |
| Width of peripheral zone is 1.9m | 0   | 0   | 0   | 0   | 0   | 0   |
Width of peripheral zone is 2.5m 12 14.4 16.8 19.2 21.6 24
Width of peripheral zone is 3.1m 24 28.8 33.6 38.4 43.2 48
Width of peripheral zone is 3.7m 36 43.2 50.4 57.6 64.8 72
Width of peripheral zone is 4.3m 48 57.6 67.2 76.8 86.4 96
Width of peripheral zone is 4.9m 60 72 84 96 108 120
Width of peripheral zone is 5.5m 72 86.4 100.8 115.2 129.6 144
Width of peripheral zone is 6.1m 84 100.8 117.6 134.4 151.2 168
Width of peripheral zone is 6.7m 84 100.8 117.6 134.4 151.2 168
Width of peripheral zone is 7.3m 84 100.8 117.6 134.4 151.2 168
Width of peripheral zone is 7.9m 84 100.8 117.6 134.4 151.2 168
Width of peripheral zone is 8.5m 84 100.8 117.6 134.4 151.2 168

The occupant density in outpatient area equals to the total occupants divided by the area of the outpatient apartment. In this study, the total outpatient area was 1908.36 m². The number of energy users in the inner zone equals to the total number of energy users minus the number of energy users in the peripheral zone, then calculating occupant density of these 2 zones for simulation setting.

Through simulation, the energy consumption under different width of peripheral zone and different number of energy users is obtained, as shown in table 2.

Table 2. Annual energy consumption per building area under different widths of peripheral zone and different number of energy users(kwh/a·m²)

| Occupant density in outpatient area (person/m²) | 0.1048 | 0.1310 | 0.1572 | 0.1834 | 0.2096 | 0.2358 |
|-------------------------------------------------|--------|--------|--------|--------|--------|--------|
| Width of peripheral zone is 1.3m                | 116.43 | 115.58 | 114.77 | 114.03 | 113.38 | 112.82 |
| Width of peripheral zone is 1.9m                | 117.77 | 116.95 | 116.18 | 115.5  | 114.89 | 114.37 |
| Width of peripheral zone is 2.5m                | 118.16 | 117.34 | 116.56 | 115.84 | 115.21 | 114.65 |
| Width of peripheral zone is 3.1m                | 119.12 | 118.32 | 117.66 | 116.87 | 116.24 | 115.67 |
| Width of peripheral zone is 3.7m                | 120.09 | 119.32 | 118.59 | 117.91 | 117.39 | 116.71 |
| Width of peripheral zone is 4.3m                | 121.05 | 120.31 | 119.61 | 118.95 | 118.32 | 117.76 |
| Width of peripheral zone is 4.9m                | 122.03 | 121.32 | 120.64 | 120.01 | 119.41 | 118.86 |
| Width of peripheral zone is 5.5m                | 123.00 | 122.33 | 121.69 | 121.08 | 120.51 | 119.97 |
| Width of peripheral zone is 6.1m                | 123.96 | 123.33 | 122.73 | 122.15 | 121.61 | 121.09 |
| Width of peripheral zone is 6.7m                | 124.73 | 124.10 | 123.50 | 122.92 | 122.39 | 121.88 |
| Width of peripheral zone is 7.3m                | 126.22 | 125.45 | 124.88 | 124.33 | 123.81 | 123.33 |
| Width of peripheral zone is 7.9m                | 126.32 | 125.65 | 125.11 | 124.49 | 123.95 | 123.45 |
| Width of peripheral zone is 8.5m                | 127.02 | 126.34 | 125.76 | 125.19 | 124.67 | 124.17 |

4. Regression analysis
In order to obtain the quantitative relationship, the data in table 2 are processed to obtain 13 groups of quantitative relationship between the occupant density in the outpatient area and building energy consumption. Through the curve fitting of scatter diagram, it can be seen that all of them are exponential relations, and the correlation coefficients exceed 0.99.
According to the curve fitting, the relationship between occupant density and building energy consumption in outpatient area is as follows:

\[ E = ae^{b\rho} \]  

(1)

The value of ‘a’ and ‘b’ are showed in the table 3. \( R^2 \) is correlation coefficient.

| Width of peripheral zone | a     | b     | \( R^2 \) |
|--------------------------|-------|-------|----------|
| 1.3m                     | 119.307 | -0.242 | 0.995    |
| 1.9m                     | 120.462 | -0.225 | 0.994    |
| 2.5m                     | 120.952 | -0.231 | 0.996    |
| 3.1m                     | 121.906 | -0.226 | 0.997    |
| 3.7m                     | 122.747 | -0.215 | 0.997    |
| 4.3m                     | 123.691 | -0.211 | 0.998    |
| 4.9m                     | 124.567 | -0.201 | 0.998    |
| 5.5m                     | 125.427 | -0.19  | 0.999    |
| 6.1m                     | 126.262 | -0.179 | 0.999    |
| 6.7m                     | 127.024 | -0.177 | 0.999    |
| 7.3m                     | 128.410 | -0.174 | 0.994    |
| 7.9m                     | 128.598 | -0.175 | 0.998    |
| 8.5m                     | 129.253 | -0.172 | 0.998    |
E- Energy consumption per building area;
ρ- Occupant density in outpatient area;

a, b- Coefficients determined by the width of the peripheral zone.

The relationship between a, b and the width of peripheral zone is shown in the figure 3 and figure 4, showed as linear relationship, and the correlation coefficients are both over 0.95.

The relationship between a, b and the width of peripheral zone obtained by fitting figure 3 and figure 4 is as follows:

\[ a = a_0 \cdot w + b_a \quad (2) \]
\[ b = a_b \cdot w + b_b \quad (3) \]

\[ a_0 = 1.4114, \quad b_a = 117.59, \quad a_b = 0.0104, \quad b_b = -0.2525; \]

After substituting the expressions of a and b into formula (1):

\[ E = (a_0 \cdot w + b_a) e^{(a_1 \cdot w + b_1) \cdot \rho} \quad (4) \]

Substitute the values of \( a_0, b_a, a_b, b_b \):

\[ E = (1.4114w+117.59) e^{(0.0104w-0.2525) \cdot \rho} \quad (5) \]

The above formula is the energy consumption prediction model expression of this study.

5. Conclusions

It can be concluded from table 2 that when the width of peripheral zone remains unchanged, the annual energy consumption per building area decreases when the occupant density in outpatient area increases. Within the scope of this study, when the number of energy users increases from 200 to 450, the energy consumption decreases between 2-3%. When the number of energy users is determined, the energy consumption increases following the increase of the width of peripheral zone. When the width of peripheral zone increases from 1.3m to 8.5m, the rising range of energy consumption is about 9-10%.

It is worth noting that the conclusions of this paper are only for the medical buildings in Xi’an, this paper mainly introduces the methods and ideas of quantitative research. In different regions, due to different climate conditions, external environment and building functions, the proportion of energy consumption is different, so the relationship between each influencing factor and energy consumption is not fixed, or even the opposite conclusion may be drawn, but it is correct for each specific study.

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