The Adaptability of Passive Design Strategies for Public Buildings in Shenzhen

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Abstract. In recent years, with increasing demands of improving public indoor environment for living in a more comfortable manner, a large number of mechanical equipment are applied to public buildings, making public buildings be major energy consumers in civil buildings. Passive technology is an effective way to design buildings of energy saving strategies. Therefore, this paper summarizes the overall energy consumption of public buildings in Shenzhen by collecting and analyzing statistical data through Shenzhen Statistical Yearbook over the years. Besides, using Ecotect's sub-software “Weather tool” to analyze the local meteorological environment. Through the analysis of the psychrometric chart to get the different energy-saving potential used the specific six passive design strategies, the results have shown that the best combination of passive design strategies suitable for climate conditions are natural ventilation, passive solar heating, and thermal heating. Finally, these three passive design strategies are further analyzed and discussed to obtain the feasible schemes, which could provide constructive suggestions for passive energy-saving design of public buildings in Shenzhen.

1. Introduction

With the dramatic increase of public buildings and people's increasing demands on office environment and comfort in recent years, a large number of machinery and equipments are used, which directly lead to a large amount of energy consumption. According to relevant researches, more than 75% of the existing public buildings are high energy consumption in Shenzhen, making it a major energy-consuming category in civil buildings[1]. At present, many architects are no longer only considering traditional factors such as architectural shape, function and aesthetics, but taking passive design adapted to local climatic conditions as the first guideline for architectural design. Architecture saves energy through its own structural layout, and achieves the requirement of reducing energy consumption, making the building an "ecological building" [2]. For example, Wang, Y.G et al proposed the calculation and correction methods of energy consumption after the comprehensive renovation of office buildings in the hot summer and warm winter areas [3]. Cai, Q used PHPP which is a energy simulation software to simulate the changes after the passive design transformation in the local space of existing public buildings [4]. Jing, F et al proposed an evaluation algorithm for the natural ventilation potential of office buildings, and conducted empirical researches on several major cities in China [5]. Zheng, Z proposed an evaluation method for the contribution rate of passive solar energy utilization in low-energy green buildings [6]. Jiang, F et al studied the heat storage performance of passive building envelopes by establishing a thermal storage material particle model [7]. Based on their researches, the most suitable passive strategy combination for Shenzhen will be
analyzed by WeatherTool.

2. Overview of Energy Consumption in Public Buildings

According to the definition of “Shenzhen Architectural Design Rules 2019”, urban buildings are divided into industrial buildings and civil buildings. Civil buildings are divided into public buildings and residential buildings, public buildings include office buildings, commercial buildings and other public service buildings[8]. The energy consumption in the statistical yearbook of Shenzhen is not classified according to building types but different industries. So this paper classifies it into three categories: civil buildings, residential buildings and public buildings. Through statistics, the energy consumption data of civil buildings in Shenzhen from 2005 to 2014 are obtained, as shown in Table 1. The following conclusions can be drawn:

1) Since 2005, the total energy consumption of buildings in Shenzhen has increased from 29.36 million tons to 52.44 million tons in 2014 at an average annual growth rate of 8.8%, nearly doubling.

2) Civil buildings accounted for 1/5 of the total energy consumption of buildings in the whole society, with an average annual growth rate of 6.6%, which is not significantly different from the trend of the total energy consumption of buildings in the whole society.

3) The energy consumption of public buildings accounts for a large proportion in civil buildings. From 2005 to 2014, the energy consumption of public buildings has been stable at about 60%.

Table 1. Energy consumption from 2005 to 2014[1][9]

| Year | Total Buildings | Civil Buildings | Public Building | Residential Building |
|------|-----------------|----------------|-----------------|---------------------|
|      | EC/ Million tons | EC/ Million tons | EC/ Million tons | RATIO% | EC/ Million tons | RATIO% |
| 2005 | 29.36           | 5.82           | 3.64           | 62.54 | 2.18           | 37.46 |
| 2006 | 33.25           | 6.17           | 3.80           | 61.59 | 2.37           | 38.41 |
| 2007 | 37.46           | 7.13           | 4.22           | 60.19 | 2.91           | 39.81 |
| 2008 | 40.43           | 7.25           | 4.40           | 60.69 | 2.85           | 39.31 |
| 2009 | 43.49           | 8.51           | 5.30           | 62.28 | 3.21           | 37.72 |
| 2010 | 47.26           | 8.24           | 5.13           | 62.26 | 3.11           | 37.74 |
| 2011 | 45.10           | 9.22           | 5.59           | 60.63 | 3.63           | 39.37 |
| 2012 | 46.91           | 9.98           | 5.74           | 57.52 | 4.24           | 42.48 |
| 2013 | 46.52           | 9.92           | 5.70           | 57.46 | 4.22           | 42.54 |
| 2014 | 52.44           | 10.44          | 5.55           | 53.16 | 4.89           | 46.84 |

Fig 1. Proportion of annual completions of buildings[9]

In addition, the proportion of completed buildings (Figure 1) shows that the public buildings, mainly office and commercial buildings, has increased year by year since 2000. The rapid increase from 20% in 2000 to about 40% in 2014 shows that the vigorous development of tertiary industry
3. Analysis of Passive Design Strategy Based on WeatherTool

3.1. Analysis of Psychrometric Chart

In the stage of building design, local meteorological data is considered as an important indicator of its passive design. Based on the meteorological data of 270 meteorological stations in China observed by China Meteorological Administration from 1971 to 2003, the monthly change of thermal comfort before and after adopting six passive strategies—Thermal Heating, Natural Ventilation, Passive Solar Heating, Night-Purge Ventilation, Direct evaporative cooling and Indirect evaporative cooling—can be obtained through the analysis of the psychrometric chart in WeatherTool, as shown in Figure 2. The yellow area indicates the percentage of thermal comfort when passive strategies is not used, and the red area indicates the percentage of thermal comfort after using the corresponding passive strategy. It can find that Natural Ventilation is better than the other five passive technologies in summer and autumn through the comparison of six passive design strategies. In spring and winter seasons, the three passive strategies of Thermal Heating, Night-Purge Ventilation and Passive Solar Heating improve the comfort. In summary, the priority of adopting passive strategy in Shenzhen should be: Natural Ventilation > Thermal Heating > Night-Purge Ventilation > Passive Solar Heating > Direct evaporative cooling > Indirect evaporative cooling.

Fig 2. Comfort percentages of six passive strategies
3.2. Analysis of Optimal Scheme

A single passive strategy will not be adopted in real life. Instead, the interrelationships and
contradictions between strategies must be considered, and do a feasibility study of passive strategy combinations. Under the premise of considering cost, technology, policy and environment, the optimal passive design strategy combination scheme is selected through the combination of different passive strategies. Firstly, the two passive design strategies of direct evaporation cooling and indirect evaporation cooling have very low improvement on indoor thermal comfort by above analyzed. Therefore, the two passive design strategies should be excluded. Then, three better combination schemes were obtained. All the passive strategies combined (maximizing indoor comfort and energy saving) are taken as benchmarks and compared with them as shown in Figure 3. Finally, relevant images and data can be obtained and the following conclusions are drawn:

1) The data show that the comfort of scheme 1 and scheme 2 are within 1% in each month, and there is no obvious difference. indicating that the passive design strategy of NPV (Night-Purge Ventilation) can not effectively improve the local indoor thermal comfort in the combined scheme, so it cannot be considered in the design.

2) The comfort of scheme 1 decreased by 2.9%, 3.3%, 1.3%, 0.6%, 0.7% and 4.5% from January to April, November and December, respectively. Scheme 2 is roughly the same as that. The maximum decrease in January, February and December indicates that the thermal comfort in winter has great potential to improve. The passive design strategy of adding winter thermal insulation to scheme 1 or 2 is proposed.

3) The scheme 3 (NV+TM+PSH) after joining Passive Solar Heating shows roughly the same data as the benchmark, with no more than 1% comfort difference per month for the whole year (a decrease of more than 1% in November alone, reaching 1.3%).

In summary, under the premise of comprehensive consideration of various practical factors, compared with the benchmark, the combination scheme of Natural Ventilation + Thermal Heating + Passive Solar Heating is the optimal combination of passive design strategies for public buildings in Shenzhen.

4. Discussion on the Specific Contents of Passive Design

4.1. Natural Ventilation
According to the analysis above, natural ventilation is the most effective passive design strategy. The ventilation period, wind direction and interior space design suitable for the passive ventilation strategy can be found out through the analysis of temperature, wind environment and interior space layout.

4.1.1 Atmospheric temperature. The “Indoor Air Quality Standard” defines that the most comfortable temperature is 19-24℃ in summer, while it is 18-22℃ in winter. When it exceeds 28℃, it will feel hot and requires refrigeration equipment [10]. As can be seen from the Figure 4, March, April and November are in comfortable temperatures, the temperatures in January, February and December are lower than 18℃. And the temperatures from June to September are higher than 28℃. It is suitable for ventilation in Shenzhen, and the ventilation time can account for more than 50% of the whole year. According to its influence on indoor thermal and humid environment, it can roughly divided into three periods: warming period (December to February), ventilation period (March to May and October to November), and refrigeration and dehumidification period (June to September).

4.1.2 Wind environment. Considering the local wind environment is an important index of natural ventilation design. the annual wind rose diagram of Shenzhen can be obtained by WeatherTool, which function is to help architects know the dominant wind direction, frequency and speed, and to provide better design ideas for natural ventilation conditions of public buildings. As shown in Figure 5, the dominant wind direction is NNE , which frequency is high. The maximum wind speed is close to 55 km/h, and it is relatively uniform in other directions, approximately in the range of 20-30 km/h.
4.1.3 Internal Space Optimization of Buildings. The public buildings of Shenzhen are generally densely distributed, large in size and deep in depth, which make the force that hinders air flow increase and affect the natural ventilation effect. Therefore, in the architectural design, the atrium that disperse the internal space and improve the natural ventilation effect can be designed[12]. Atrium design mainly includes three types: core type, through strip type and one-way contact type [13]. The core atrium design divides the building volume into multiple parts, and the public rooms of each floor open to the atrium, which is the most commonly used layout form of public buildings at home and abroad. The through strip type atrium is actually equivalent to a street atrium with a roof at the top of the building. The public space is placed on the side of the building and most of the glass windows are displayed outward. The one-way contact atrium is interconnected with the first floor of the main body of the building. It is separated from the other floors of the main body by external walls. It introduces sufficient natural light in the building and expels the polluted air outdoors by means of hot-press ventilation.

4.2. Thermal Heating
Increasing the heat storage capacity of the envelope during the warming period is still one of the main needs of indoor personnel through the above analysis. The heat loss of building envelope mainly comes from external walls, windows and roofs. As the area of external wall accounts for a relatively high proportion, it is our key consideration.

Choosing reasonable structure materials is the main factor of heat preservation and insulation to reduce heat transfer coefficient. External wall thermal insulation system can be divided into three types: external-thermal insulation, internal-thermal insulation and self-thermal insulation [14]. Because Shenzhen is near the sea, the wind pressure is relatively high, the wind erosion is serious, and the rainfall is abundant, the external-thermal insulation and self-thermal insulation are not suitable for this area. Therefore, the internal-thermal insulation system can be adopted. Through the comparison of Table 2, it can be found that the reinforced gypsum polyphenyl board has the smallest thermal conductivity, small dry density and good impact resistance, so its thermal insulation effect is the best. Therefore, the reinforced gypsum polyphenyl board can be used as the preferred thermal insulation material.

| Material                  | Reinforced Gypsum Polyphenyl Board | Inorganic Thermal Insulation Dry Mortar | AC Microcrystalline Inorganic Thermal Insulation Mortar |
|---------------------------|-----------------------------------|----------------------------------------|--------------------------------------------------------|
| Dry Density (kg/m³)       | 18-22                             | <300                                   | 350-470                                                |
| Moisture Content (%)      | <5                                | 0.5                                    | 0.5                                                    |
| Compressive Strength (Kpa)| >100                              | >400                                   | >100                                                   |
| Impact Resistance (Times) | >10                               | >3.0                                   | >3.0                                                   |
| Combustion Performance(grade)| B1                              | B1                                     | B1                                                     |
| Thermal Conductivity (w/mk)| <0.041                           | <0.06                                  | 0.08                                                   |

4.3. Passive Solar Heating
According to the solar track analysis (Figure 6) in WeatherTool, it can be seen that Shenzhen is a region with abundant solar energy, and the solar radiation fluctuates between 1000 and 3000 kwh/m. Therefore, Shenzhen can make full use of passive solar energy for building heating and cooling design. Through the best orientation of local buildings and building environment, the suitable passive solar energy utilization method can be found out.
4.3.1 Optimal orientation. Figure 7 is the best orientation analysis chart of Shenzhen. It can be seen that the orientation of hotter month (June to September) is northeastern 92.5°, while the orientation is northeastern 172.5° in colder months (December, January, February). According to the comprehensive analysis in WeatherTool, the best orientation of Shenzhen is northeastern 182.5°.

4.3.2 Building environment. The types of public buildings in Shenzhen are complex and diverse, and the density distribution is uneven. Some commercial buildings are dense, large and high-rise. The influence between buildings is great, which easily hinders the sunlight passage of adjacent buildings. For some government-related public buildings, the distribution is relatively spacious, so different passive solar energy utilization methods can be used for different types public buildings, such as direct solar energy system and indirect solar energy system [16-17]. At present, Many analysis methods including Simple Angular Criteria, Angular Zones, Sunpath Diagrams, and Shadowing Studies, and computer programs/software such as TOWNSCOPE and GOSOL are already used to estimate solar access. Therefore, passive solar heating is one of the most worthwhile passive strategies to study[18].

5. Conclusion
Climate and personnel thermal comfort requirements have a direct impact on the energy consumption of public buildings in Shenzhen. The passive design scheme which combines Natural Ventilation, Thermal Heating and Passive Solar Heating provides good autonomy and flexibility for energy saving design of public buildings. Suitable atrium forms can be designed during the ventilation period (March to May and October to November) to improve the natural ventilation effect. For the envelope, the inner-thermal insulation material of the reinforced gypsum polyphenyl board can be used to improve the heat storage property of the exterior wall. According to the best orientation and building environment, direct or indirect solar energy systems are selected to reduce the use of non-renewable energy. Such passive combination will integrate building and environment, greatly reducing energy consumption. However, many problems have been found in the research. For the adoption of these three passive design strategies in Shenzhen, a large amount of empirical data support is needed. In addition, passive design should be more flexible, combined with active equipments more in line with the development trend of modern society. How to combine passive design with active equipment to maximize benefits will be the direction of follow-up research.

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