Bioclimatic Architecture Strategies for Residential Buildings in Yangtze River Delta

Yuan Zheng [1], Zhu Wang [1], Zhenlan Qian [2,*], Zhuoyao Wang [1]

[1] College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China
[2] School of Public Affairs, Zhejiang University, Hangzhou, China

Abstract: The residential building consumes a significant amount of energy worldwide. Therefore, it is important to study, analyze and propose bioclimatic architecture strategies that contribute to the reduction of energy consumption. The main purpose of this paper is to evaluate the climatic conditions of Yangtze River Delta, and then propose appropriate passive design strategies for residential buildings in this area. The results showed that natural ventilation, thermal mass effects, direct evaporative and passive solar heating should be applied in the residential building construction, which could improve interior thermal comfort by 21%, 18%, 8%, and 6% respectively.

Keywords: bioclimatic architecture; thermal comfort; sustainable building; Yangtze River Delta

1. Introduction

Human health and comfort have been perceived as the most important parameters during evaluations of indoor environments [1]. The heating and cooling of a space to maintain thermal comfort are an energy intensive process that represents up to 60-70% of the total energy consumption in non-industrial buildings [2]. The term bioclimatic architecture refers to an alternative method of constructing buildings in which the local climate conditions are considered and diverse passive technologies are used with the aim of achieving thermal comfort while minimizing energy consumption. This paper intends to analyze the climate conditions in Yangtze River Delta and propose appropriate bioclimatic architectural strategies for residential buildings.

1.1. The Situation of Yangtze River Delta

Yangtze River Delta is located in the east of China, and it is at the lower reaches of the Yangtze River. It includes Shanghai, Jiangsu, Zhejiang and Anhui provinces, with an area of 358,000 square kilometers. Since ancient times, this region has been an important area of our country in term of economy, society and culture. Statistically speaking, the total GDP of this region in 2019 reached 237252 billion yuan, which was 0.8% higher than the national economic growth rate, accounting for 23.9% of the total national economy [3].

1.2. Climate Characteristics of This Region

Yangtze River Delta is a typical hot-summer and cold-winter area in China. As shown in Table 1, the highest temperature in summer could be almost 40 ℃ and the lowest temperature in winter could be less than -10 ℃. In addition, annual average relative humidity is as high as 80% and static wind rate throughout the year could reach 30%. It is hot and humid in summer, as well as cold and humid in winter. Thus, People in this region are under conditions of thermal discomfort during most of the year, which forces occupants to use electro-mechanical heating, ventilation and air conditioning.

2. The Concept of Bioclimatic Architecture

The mission of architecture has always been the protection of man from the exterior environment. Throughout history, architectural evolutions have occurred to achieve the thermal comfort in interior spaces; this process has been termed ‘vernacular architecture’ [1]. Since the Industrial Revolution, comfort in modern architecture has been relegated to the use of devices which caused continuously energy consumption. In the 1980s, the environment crisis was recognized, giving rise to the concept of bioclimatic architecture. Since that time, it seems logical for architects to practice bioclimatic design. Bioclimatic design employs appropriate technologies and design principles based on a thoughtful approach to climate and environment [4]. It could optimize the relationship between site, building and climate.

Table 1. Climatic data in the yangtze river delta [5].

Item	Shanghai	Hangzhou	Nanjing	Hefei
Temperature of the hottest month (℃)	27.8	26	28	28.3
Extreme max. temperature (℃)	38.9	39.9	40.7	41
Temperature of the coldest month (℃)	3.5	3.8	2.0	2.1
Extreme min. temperature (℃)	-10.1	-9.6	-14.0	-20.6
Relative humidity of hottest month (%)	83	80	81	81
Relative humidity of coldest month (%)	75	77	73	75

3. Evaluation of Climate Conditions in Yangtze River Delta

To study the appropriate bioclimatic architecture strategies, we must first evaluate the climate conditions in which the building is located. Different bioclimatic diagrams are used as tools to analyze climate conditions which directly related to human comfort. Weather Tool analysis software is a practical tool which is suitable for architects to analyze and judge the climate conditions in the early stage of architectural design.

In the graph, the x-axis represents the dry bulb temperature and the y-axis shows the fresh air humidity; psychometric curves represent the relative humidity [1]. The bioclimatic diagram has been divided into different zones and the exterior climate conditions will place us within a zone. If we are in a comfort zone, building will not have to perform any thermal corrections. If we are outside of the comfort zone, architectural strategies can be implemented to reach the comfort. In this paper, we choose Shanghai (Fig. 1, Fig. 2) (typical representative cities of Yangtze River Delta) as analysis object.

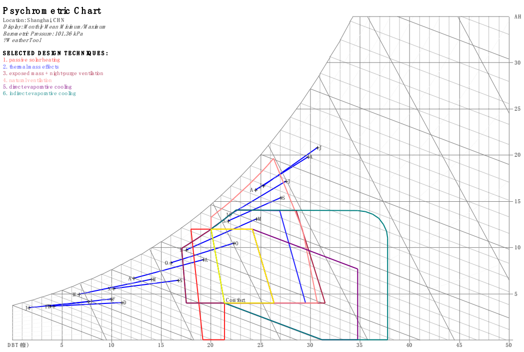

Figure 1. Bioclimatic diagram of Shanghai.

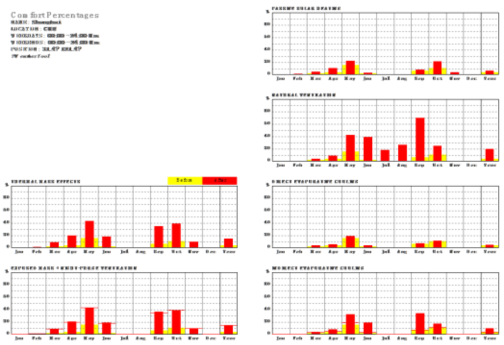

Figure 2. Comfort percentages of diverse strategies in Shanghai.

As stated in the above-mentioned figures and tables, the comfortable time ratio in the Yangtze River Delta region is around 6.8%, mainly concentrated in April, May and October. The overall effectiveness of the whole year with natural ventilation is the most significant, which can increase the comfort time by 21%, especially in June and September. Additionally, thermal mass effects strategy can add about 18%. Indirect evaporative cooling is also one of the effective measures, which can increase comfort time ratio by 8% while passive solar heating strategy can also add 6% of the time. Applying these strategies properly can greatly improve the thermal comfort of interior spaces in the Yangtze River Delta. The efficiency of each strategy (Fig. 3) can help architects to consider which strategy must be adopted, and which strategy may not be considered under limited conditions.

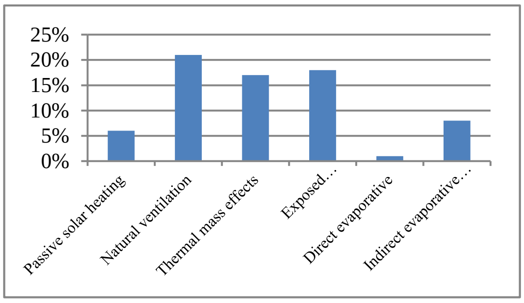

Figure 3. Annual effective time ratio of passive strategies in the Yangtze River Delta.

4. Appropriate Bioclimatic Architecture Strategies for Residential Buildings

4.1. Natural Ventilation

A greater thermal sensation can be achieved by using natural cooling ventilation in summer. The most basic principles of ventilation include “cross ventilation” and “buoyancy ventilation”. Cross ventilation utilizes wind pressure to complete air exchange and requires wind velocity. Buoyancy ventilation utilizes the principle of “hot air rises and cold air descends” and needs only temperature differential to induce air change by convection [6]. Therefore, this strategy can be achieved by using cross-ventilation (Fig. 4a), the chimney effect (Fig. 4b), vertical spaces within a building (Fig. 4c) or patios (Fig. 4d).

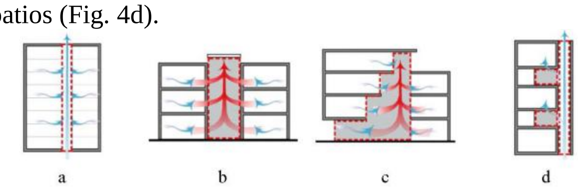

Figure 4. Natural cooling ventilation techniques: (a) Cross-ventilation; (b) chimney effect; (c) vertical spaces within a building; (d) Patio as a natural ventilation-mediated cooling solution.

4.2. Thermal Mass Effects

This strategy comprises the thermal mass of the building envelope that receives and transmits radiation to interior space with a phase difference to achieve climate uniformity throughout the day. Capacity materials (such as brick, stone, concrete, etc.) help to reduce the impact of outdoor temperature fluctuations on indoor environment. This strategy can also combine with nocturnal renovation. The building closes its openings during the daytime to avoid heat gains, and natural ventilation favors nocturnal dissipation to dissipate the heat absorbed by the enclosure during the day.

4.3. Indirect Evaporative Cooling

Evaporative cooling is divided into direct evaporative cooling and indirect evaporative cooling. Direct evaporative cooling refers to the temperature of outdoor air is reduced by flowing through the water components, which is mainly suitable for dry and arid climates. Indirect evaporative cooling refers to the method of using solar radiation to evaporate water on the surface of the building to obtain cooling, such as water spraying roof and water storage roof. It could achieve comfort by reducing temperature through water evaporation while not increasing the relative humidity, so indirect evaporative cooling is more advisable in the Yangtze River Delta, where relative humidity is high throughout the year. This can be achieved using vegetative cover (Fig. 5a, c and d), the spraying of water on roof (Fig. 5b).

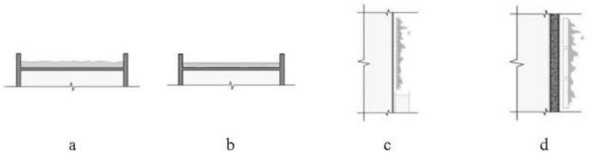

Figure 5. Indirect evaporative cooling techniques: (a) roof vegetation for evaporative cooling; (b) roof watering for evaporative cooling; (c and d) wall vegetation for evaporative cooling.

4.4. Passive Solar Heating

The term ‘passive’ relates to passive design, whereas ‘active’ heating relates to the use of external energy source. This strategy has been used extensively throughout history with great success [7]. But it needs to depend on the outdoor temperature and the amount of solar radiation in the area. If the temperature is too low or the solar radiation is small, passive solar heating cannot be achieved. In the term of building design, the fundamental objective is that the building envelope needs to favor the accumulation of solar radiation and allow energy into the interior space.

The heating energy can be captured by any part of the building envelope, including roof, walls and especially windows. The roof space could be used to accumulate heating energy from solar radiation and latter emit this energy to its connected spaces (Fig. 6a). The Trombe wall is also a very similar bioclimatic strategy that captures solar radiation (Fig. 6b). In addition, the large windows can strongly contribute to building space heating. Fig. 6c shows an example of an awning that allows solar radiation capture during the winter, and limiting this process during the summer season. The adjoined greenhouse on the south-oriented façade is also an advisable solution in this area that captures even more solar radiation because of ‘greenhouse effect’ (Fig. 6d).

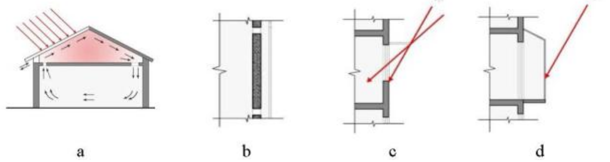

Figure 6. Passive solar heating techniques: (a) The roof as a space in the passive solar heating zone; (b) representation of Trombe wall for an area in the passive solar heating zone; (c) the awning as a passive solar heating solution; (d) representation of an adjoined greenhouse for an area in the passive solar heating zone.

5. Conclusions

This paper evaluated the climatic conditions of Yangtze River Delta, and proposed appropriate passive design strategies for residential buildings in this area. Following conclusion were drawn.

1. The bioclimatic diagram showed that the comfortable time ratio in the Yangtze River Delta region is around 6.8%, mainly concentrated in April, May and October.

2. Six main strategies, including passive solar heating, natural ventilation, thermal mass effects, exposed mass + night-purge ventilation, direct evaporative and indirect evaporative cooling, can improve interior thermal comfort by 8%, 21%, 18%, 18%, 6% and 1% respectively.

3. Natural ventilation, thermal mass effects, direct evaporative and passive solar heating are more advisable strategies for residential building construction in Yangtze River Delta.

Acknowledgment

This work was supported in part by a grant from “Thirteenth Five-Year” National Key Research and Development Program (2017YFC0702504).

References

[1] Francisco, M.A., et al. Review of bioclimatic architecture strategies for achieving thermal comfort. *Renewable and Sustainable Energy Reviews*, **2015**, vol. 49, pp. 736-755.

[2] Omer, A.M. Energy, environment and sustainable development. *Renew Sustain Energy Rev.*, **2008**, vol. 12, no. 9, pp. 265-300.

[3] Zhou, H.M. Analysis of the economic operation and situation of ports in the Yangtze River Delta in 2019. *China Ports*, **2020**, vol. 3, pp. 25-28.

[4] Vissilia, A.M. Evaluation of a sustainable Greek vernacular settlement and its landscape: Architectural typology and building physics. *Building and Environment*, **2009**, vol. 44, pp. 1095-1106.

[5] Han, A.X. The quality of the living environment in hot summer and cold winter areas is expected to be improved and enhanced. *Insulation Materials and Building Energy Saving*, **2002**, vol. 3, pp. 25-27.

[6] Lin, H.T. Green Architecture- an Asian Perspective. Pace Publishing Limited, 2011. p. 69.

[7] Butti K.; Perlin J. A golden thread: 2500 years of solar architecture and technology. New York: Cheshire Books, 1980.