

# Application of Passive Design in Urban Buildings under Hot Climatic Conditions in China: A Case Study in Hong Kong

Jingyun Lin

Faculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, VIC 3010, Australia

jingyun2@student.unimelb.edu.au

**Abstract.** This paper studies the application of passive design strategies in urban buildings in the hot and humid subtropical climate of Hong Kong. Driven by increasing energy demand and environmental concerns, the study explores the potential of passive design to reduce reliance on mechanical cooling systems and improve occupant comfort. The research is particularly relevant in the context of Hong Kong's unique urban challenges, such as limited land availability, high population density, and a heavy reliance on air conditioning, which collectively contribute to significant energy consumption and urban heat island effects. The study focuses on key passive design elements including building orientation, window-to-wall ratio and glazing material, shading strategies, natural ventilation and building materials. Through a combination of simulation-based analysis and case studies, the paper demonstrates how these strategies can be effectively integrated into building designs to optimize thermal performance and energy efficiency. The analysis considers the limitations of passive design in Hong Kong's high-density urban environment, while also highlighting the potential for future advances through future-oriented climate projections for the future and policy support, ultimately aiming to achieve a more sustainable and energy-efficient built environment.

**Keywords:** Passive design, Urban buildings, Hong Kong.

## 1. Introduction

With the growth of the world's population and the rapid development of cities, the demand for buildings as essential spaces for human survival continues to increase. The building sector consumes a significant portion of primary energy resources, with residential buildings accounting for about 65% of the total energy consumption of the construction industry [1]. Moreover, the negative impacts of the construction industry on the environment are becoming more pronounced, with carbon emissions accounting for more than 25% of the total global carbon emissions [2]. Due to the rapid urbanization and industrialization that China has experienced in recent decades, the energy consumption of its building sector is projected to continue growing. According to Guo et al., it is estimated that China's energy consumption within the building sector by 2050 will account for approximately 20% of the global energy consumption in this sector [2].

In response to these challenges, the concept of sustainable development has gained prominence, and passive design has emerged as a promising approach to reduce operational energy in buildings. By utilizing natural resources such as sunlight, wind, and temperature to enhance energy efficiency and occupant comfort, passive design minimizes reliance on mechanical systems like ventilation and electrical systems. This approach effectively reduces energy consumption and emissions, contributing to more sustainable and environmentally friendly structures.

The concept of passive design was introduced as early as the 1980s, and the first passive houses were constructed in Darmstadt, Germany, in 1991 [3]. Since then, passive design has gained global traction, with European countries adopting passive house standards to optimize building insulation, natural lighting, and ventilation. Similarly, North America and Australia have widely implemented passive design measures tailored to local climate conditions. In China, passive design is gradually gaining momentum, supported by green building standards and energy efficiency codes. Although its adoption in China is not as widespread as in some European countries, it is expected to grow significantly with policy support and technological advancements. Liu et al. highlighted that in a warming climate, passive design applied to cities in hot climates can significantly reduce cooling

demand and improve indoor thermal comfort [4]. Therefore, the application of passive design in hot climate zones holds great potential, particularly in southern regions of China such as Hong Kong. Given Hong Kong's high-density urban environment and humid subtropical climate, passive design offers opportunities to optimize natural ventilation, shading, and energy-efficient building practices, thereby enhancing resident comfort and advancing sustainable development goals. This article focuses on the principles and applications of passive design in urban buildings under hot climatic conditions in China.

## 2. Passive Design Conception and Climate Regions

Passive design focuses on analyzing the local climate and microclimate. Thermal comfort is improved by optimizing building orientation, ventilation systems, shading, and light entry under different climatic conditions [5]. China's extensive continental region can be divided into five primary climate zones: extremely cold, cold, temperate, hot summer and cold winter, as well as hot summer and mild winter [3] (Figure 1). This paper focus on the humid subtropical climate zone with hot summers and warm winters in Hong Kong as an example, which is mainly characterized by hot and humid summers with average temperatures usually ranging from 25°C to 35°C and high humidity, and warm winters with temperatures usually ranging from 10°C to 20°C. This climate zone is also characterized by a strong influence of the monsoon, particularly the southeast monsoon in summer and the northeast monsoon in winter, with precipitation concentrated in the summer months.



Figure 1. Geographical distribution of climatic regions in China [3]

## 3. Application of Passive Design in Hong Kong

### 3.1. Orientation

Proper building orientation can utilize sunlight to bring natural light indoors and regulate the temperature needs of buildings in summer and winter. In a subtropical climate city like Hong Kong, the orientation of buildings should provide effective shading in summer, reducing the heat gain from incoming solar radiation and thereby decreasing the demand for air conditioning. Altan et al. introduced that good building rooms should be oriented towards the equator to reduce incoming solar radiation from the east and west [5]. Haase and Amato verified through data analysis that Hong Kong buildings oriented at 192.5° (e.g., southwest) can maximize winter sunlight while avoiding excessive

heat gain in summer [6] (Figure 2). Therefore, the orientation of buildings in Hong Kong should primarily face south to maximize passive design benefits, which can avoid strong afternoon sun exposure in summer, reduce indoor heating, and decrease reliance on cooling equipment (Figure 3). Additionally, increasing thermal comfort through passive design requires combining building orientation with shading measures. Altan et al. stated that roof or horizontal shading devices can effectively provide shading for east and west-facing windows during high sun angles in summer. While a southward orientation allows for adequate daylight in winter, it necessitates proper shading in summer to prevent interior overheating [5]. Consideration should be given to increasing summer shading through blinds, awnings, and planting vegetation. Finally, proper orientation enables buildings to utilize natural winds for ventilation and cooling. Winds in Hong Kong are mainly southerly in summer and easterly in winter. A southward orientation helps to increase natural ventilation in summer and reduces cold wind entry in winter.

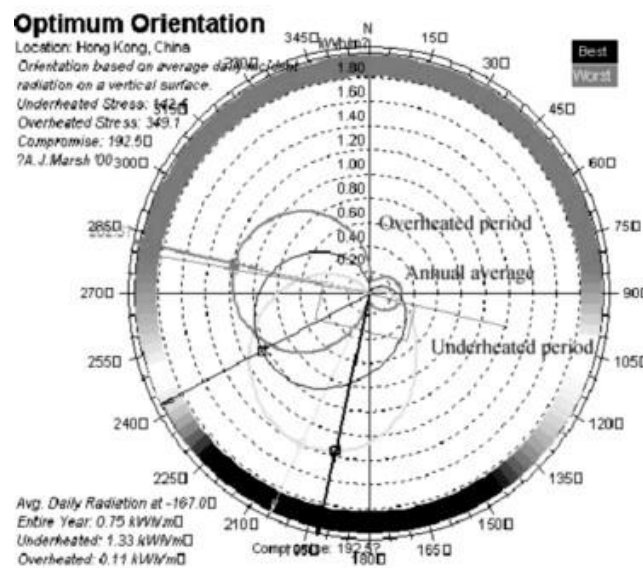


Figure 2. Optimum orientation for Hong Kong [6]

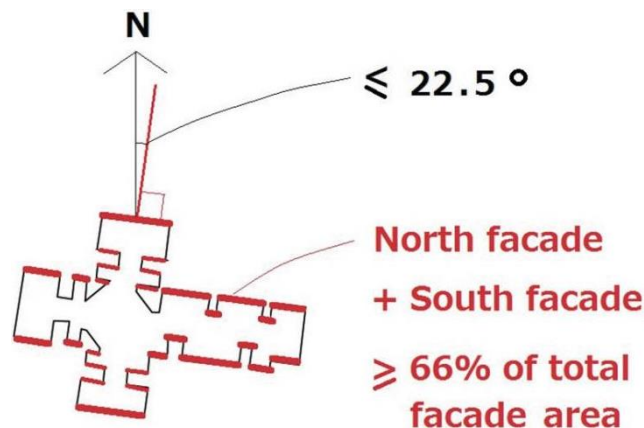


Figure 3. BEAM Plus orientation requirement [7]

### 3.2. Window-Wall Ratio and Glazing Type

In Hong Kong, the majority of public structures feature aluminum-framed windows fitted with standard glass, resulting in significant solar heat entering indoors during the summer, which leads to overheating of the indoor environment [4]. The choice of glazing material and the design of the window-wall ratio are key factors in achieving effective passive design in buildings. High-performance glazing materials, such as low-emissivity glass, can reduce heat transfer in summer while allowing natural light into indoor spaces. Gong et al. selected Guangzhou and Haikou, which share a subtropical humid climate with Hong Kong, as research objects. The data showed that double

low-emissivity glass generally exhibited the best thermal insulation performance, while the thermal load increased gradually with triple and double glazing, and the highest thermal load was observed in single glazing, indicating the poorest thermal insulation [3]. Although the type of glass has the least impact on thermal load in subtropical humid climate areas, it still helps reduce indoor temperature rise, creating a comfortable living environment and reducing cooling energy consumption. In addition to glazing materials, the window-wall ratio plays a crucial role in optimizing daylighting and ventilation. According to Gong et al., the window-wall ratio has the most significant impact on thermal load variation in subtropical humid climate areas. When the window-wall ratio is 0.15, the thermal load is less than 20 kWh/m<sup>2</sup>per year, while with a window area covering 60% of the exterior walls, the thermal load rises to 60 kWh/m<sup>2</sup>per year [3]. However, as high-rise buildings become more prevalent, a higher window-wall ratio is increasingly popular for maximizing daylight. Xie et al. suggest that an optimal window-wall ratio in Hong Kong is around 0.4. When increasing the window-wall ratio to gain sufficient daylight, radiative cooling glass can be considered to reflect solar radiation while allowing visible light to enter, thus blocking summer heat gain [8]. Therefore, by considering local climatic conditions and balancing the glass areas on different facades, the overall energy performance of buildings can be enhanced. Selecting different types of glazing materials and optimizing the window opening size can achieve environmentally sustainable and energy-efficient buildings.

### 3.3. Shading Strategy

As a subtropical climate characterized by hot and humid summers, Hong Kong needs to enhance the role of passive design through effective shading strategies. Data from experiments conducted in Singapore, which has a similarly hot and humid climate, indicate that the installation of horizontal shading devices can save between 2.6% and 10.1% in energy consumption [9]. Altan et al. indicate that shading devices can reduce energy consumption by minimizing direct sunlight and improving visual comfort for occupants [5]. The high density of housing in Hong Kong and the high-rise buildings increase the proportion of window area for natural daylight and well-designed solar shading installations such as overhangs, canopies and vertical fins can significantly reduce the reliance on mechanically cooled systems. The Hong Kong Transport Department Vehicle Examination Complex achieves optimal shading performance in both winter and summer by installing vertical fins on the building surface [10]. In addition, Altan et al. explain that different shading designs can be utilized for windows with different orientations; horizontal shading devices can be used for windows in the north-south orientation, while vertical ones are required for the east-west orientation [5]. Using horizontal shading devices in the north-south direction is to effectively block the incoming sunlight from above to reduce heat entry in the summer while still allowing low angle sunlight to enter in the winter to keep the room warm. As the sun ascends in the east and descends in the west, windows facing east and west experience varying levels of solar heat gain during the morning and afternoon. Employing vertical shading structures can efficiently obstruct lateral sunlight, significantly reducing direct solar radiation during these times and preventing excessive interior heating. (Figure 4). Altan et al. emphasize the need for a combination of both shading strategies for southwest and southeast facing windows to reduce glare [5]. Overall, passive shading in passive design plays a crucial role in optimizing energy performance and ensuring thermal comfort for occupants.

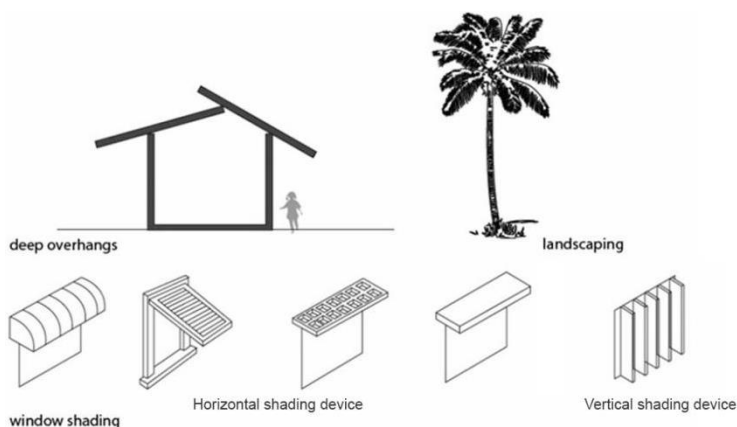


Figure 4. Different shading strategies [5]

### 3.4. Ventilation

Airflow accelerates heat transfer and sweat evaporation, and at an indoor wind speed of 1 meter per second and a relative humidity of 50%, individuals can remain comfortable even at 29°C, and the adaptable temperature rises as indoor wind speed increases [11]. Therefore, natural ventilation is an important part of passive design, and by strategically positioning windows and vents to increase natural airflow from prevailing winds, it is possible to reduce reliance on ventilation and cooling systems and improve indoor air quality. Considering increased convective airflow is more effective than relying on natural ventilation from unilateral ventilation, but the detrimental effects of cross ventilation on natural ventilation should be avoided [12]. Lau emphasized that adherence to the BEAM Plus cross-ventilation requirement, such as maintaining specific angles and distances between windows, can ensure effective natural ventilation [7] (Figure 5). In addition, Deng et al. note that architectural elements like courtyards, corner windows, and balconies play a crucial role in enhancing natural ventilation [12]. Finally, by aligning openings with the predominant wind direction (e.g., southeast trade winds in the summer), buildings can facilitate the flow of fresh air through the living environment. Based on Deng et al., facade orientation towards prevailing winds and changes in window orientation enhance indoor air exchange rates, and ventilated interiors should be oriented towards the windward direction as much as possible to maximize natural ventilation [12]. Hong Kong should create sustainable, energy-efficient and health-promoting living environments by incorporating natural ventilation into the design process.

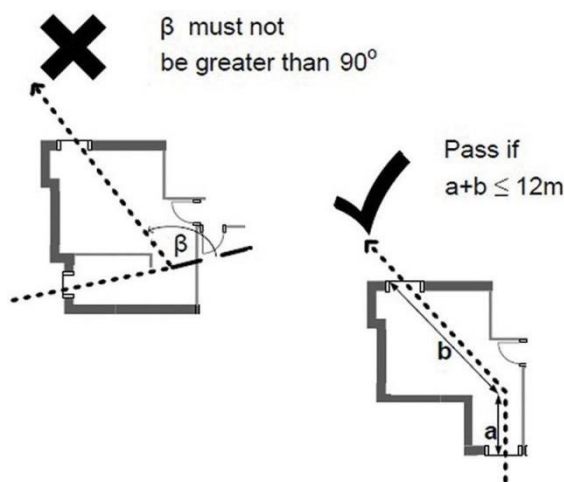


Figure 5. BEAM Plus cross-ventilation requirement [7]

### 3.5. Building Materials

The color of building materials, their assembly methods, and insulation properties all significantly influence the absorption and release of heat in buildings [5]. In Hong Kong, where buildings are

predominantly high-rise structures, the surface area of walls far exceeds that of roofs. As a result, the thermal mass and performance of the facade play a critical role in enhancing the building's energy efficiency [4]. Altan et al. emphasize that the color of the building's exterior finish affects its ability to absorb or reflect light and heat, with lighter-colored facades reflecting more sunlight and reducing heat absorption [5]. Liu et al. further highlight that using white facades in Hong Kong can significantly enhance the effectiveness of passive design strategies [9].

Additionally, Hong Kong's hot and humid summers necessitate innovative approaches to regulate indoor temperatures. One effective method is the use of high thermal mass materials, which absorb excess heat and solar radiation during the day and release stored heat during cooler nights. Thermal mass refers to the ability of building materials, such as concrete, brick, or stone, to absorb, store, and release heat. This thermal hysteresis effect helps reduce reliance on mechanical cooling systems, thereby lowering energy costs and improving occupant comfort. Furthermore, well-insulated materials can minimize heat exchange between the building's exterior and interior, contributing to energy efficiency [5]. Chen et al. demonstrated that increasing the thickness of wall insulation can reduce annual heat load by approximately 70% [13]. In Hong Kong, the use of well-insulated and thicker external wall materials can effectively reduce heat infiltration during summer and maintain stable indoor temperatures during winter.

In conclusion, combining thermal mass with effective ventilation and shading strategies can create a balanced indoor environment and significantly improve energy efficiency. These integrated approaches are particularly valuable in high-density urban settings like Hong Kong, where optimizing building performance is essential for sustainability and occupant comfort.

#### **4. Limitations of Passive Design**

While passive design offers significant advantages in enhancing building energy efficiency and occupant comfort, it is not without limitations. One major challenge is Hong Kong's complex topography and high building density, which often hinder the optimal implementation of natural ventilation and daylighting strategies, thereby limiting the effectiveness of passive design. Furthermore, the hot and humid summer climate in Hong Kong may not fully meet occupants' comfort needs through passive measures alone, as natural ventilation and reduced heat transfer may be insufficient to maintain comfortable indoor temperatures. As a result, mechanical cooling systems are often still required to ensure thermal comfort. Another consideration is the higher initial costs associated with passive design, particularly due to the selection of high-performance insulation, windows, and other components, which increase input costs during the material selection and design stages.

Although this paper highlights the significant potential of passive design in Hong Kong's climate, it is important to note that each building project requires a detailed analysis of its microclimate to achieve precise design and effective planning. This level of analysis can increase the complexity of the design process. Lau points out that while passive house design and research are well-established in many countries, Hong Kong is still in the early stages of adoption. There is a pressing need to develop more comprehensive guidelines, laws, and standards to promote passive design in both residential and commercial developments [7].

To address these challenges, the Hong Kong government should continue to support the development of green buildings and projects compliant with BEAM Plus, which provides systematic guidance on passive design and promotes sustainable building practices. Additionally, future passive design criteria should incorporate more robust climate predictions and simulations to better adapt to the impacts of climate change and achieve long-term sustainability. By addressing these limitations and leveraging policy support, Hong Kong can advance its adoption of passive design and move closer to achieving its sustainability goals.

## 5. Conclusion

This study discusses the great potential of passive design approaches to reduce energy consumption and improve thermal comfort in subtropical climate of Hong Kong. By carefully selecting building orientation to maximize natural lighting and employing high-performance glazing, optimized window-to-wall ratios, and strategic shading, it is possible to mitigate indoor overheating caused by intense summer sunlight. Additionally, thoughtful placement of windows can improve natural ventilation, enhancing convective airflow and indoor air circulation, thereby increasing occupant comfort. The choice of building and facade materials with high insulation capacity further minimizes heat transfer and reduces solar heat absorption during summer months.

While challenges remain, such as high initial investment costs and complex urban environments, integrating passive design principles provides an important avenue for sustainable building practices in Hong Kong. Future research should explore microclimate changes within the city and predict the overall impact of future climate on buildings to further refine passive design applications. Continued support from the government through policies and regulations, such as the BEAM Plus rating system, is essential to accelerate the adoption and effectiveness of Passive Design in Hong Kong's built environment.

## References

- [1] Harkouss, F., Fardoun, F., Biwole, P.H. Passive design optimization of low energy buildings in different climates. *Energy*, 2018, 165: 591-613.
- [2] Guo, S., Zheng, S., Hu, Y., Hong, J., Wu, X., Tang, M. Embodied energy use in the global construction industry. *Applied Energy*, 2019, 256.
- [3] Gong, X., Akashi, Y., Sumiyoshi, D. Optimization of passive design measures for residential buildings in different Chinese areas. *Building and environment*, 2012, 58: 46-57.
- [4] Liu, S., Kwok, Y.T., Lau, K.K., Ouyang, W., Ng, E. Effectiveness of passive design strategies in responding to future climate change for residential buildings in hot and humid Hong Kong. *Energy and Buildings*, 2020, 228.
- [5] Altan, H., Hajibandeh, M., Tabet Aoul, K.A., Deep, A. Passive design. ZEMCH: Toward the delivery of zero energy mass custom homes: 2016, 209-236.
- [6] Haase, M., Amato, A. An investigation of the potential for natural ventilation and building orientation to achieve thermal comfort in warm and humid climates. *Solar energy*, 2009, 83: 389-399.
- [7] Lau, E.T. Does Hong Kong have a passive house standard? *HK Engineer*. 2014. Retrieved on March 1, 2025. Retrieved from: [https://www.hkengineer.org.hk/issue/vol45-apr2017/feature\\_story/?id=12745](https://www.hkengineer.org.hk/issue/vol45-apr2017/feature_story/?id=12745).
- [8] Xie, X., Xu, B., Fei, Y., Chen, X.N., Pei, G., Ji, J. Passive energy-saving design strategy and realization on high window-wall ratio buildings in subtropical regions. *Renewable Energy*, 2024, 229.
- [9] Liu, C., Sharples, S., Mohammadpourkarbasi, H. A review of building energy retrofit measures, passive design strategies and building regulation for the low carbon development of existing dwellings in the hot summer–cold winter region of China. *Energies*, 2023, 16.
- [10] Architectural Services Department. Case Study: Tsing Yi. *Innovating Beyond the Moment: Adopting Sustainable and Green Building Design*, 2021. Retrieved on March 1, 2025. Retrieved from: <https://www.archsd.gov.hk/archsd/html/report2021/en/case-study-1-tsing-yi.html>.
- [11] Wang, S., Liu, Y., Cao, Q., Li, H., Yu, Y., Yang, L. Applicability of passive design strategies in China promoted under global warming in past half century. *Building and Environment*, 2017.
- [12] Deng, J.Y., Wong, N.H., Hii, D.J., Yu, Z., Tan, E., Zhen, M., Tong, S. Impact of architectural design strategies on the indoor natural ventilation of public residential buildings in Singapore. *Urban Climate*, 2023, 52.
- [13] Chen, X., Yang, H., Lu, L. A comprehensive review on passive design approaches in green building rating tools. *Renewable and Sustainable Energy Reviews*, 2015, 50: 1425-1436.