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ECOLOGICAL ADAPTABILITY OF HIGH-RISE RESIDENTIAL BUILDINGS - THE CASE OF NORTHERN GUANGXI'S BUILDING TYPOLOGY

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Abstract

The high energy consumption of modern high-rise residential buildings is leading to global warming. In the context of globalisation, western copy high-rise apartments are out of touch with the local climate, resulting in an ecological adaptation crisis. Low thermal comfort and bad experience have seriously affected people's quality of life and physical and mental health. The purpose is to promote the ecological adaptability strategy of high-rise buildings so that they can interact with the surrounding environment. This study examined the ecological adaptation of high-rise residential buildings using a systematic literature review. Using field study and a questionnaire survey, the study collected data on factors affecting the adaptability of high-rise residential buildings to predict and manage the climate and to offer a theoretical foundation for regulating the ecological adaptability of buildings. The study shows that contextualised building design can attain climatic adaptability. to create ecologically adaptable housing based on macro, middle, and microclimates to support the harmonious co-habitation of the environment, architecture, and people.

Keywords: Contextualised design, Ecological adaptability strategies, Hot summer and cold winter area, Modern high-rise residential buildings, Northern Guangxi.

1. Introduction

The high-rise housing cluster is born from urbanisation and a commodity economy. It has effectively solved the problems of land shortage and excessive population expansion. In recent years, with the popularity of green building and sustainable development theory, the design methods that focus on regional characteristics and use natural climate resources have attracted more and more attention from domestic scholars. Foreign research in this field started early, creating and developing bioclimatology. It also pays attention to technical studies in relevant realms and has rich achievements, especially in the study of climate adaptability of high-rise buildings.

1.1. Problem statements

This study examined the climate adaptability of three residential high-rises constructed in northern Guangxi between 2008 and 2018 in the City No. 1, Fengyu, and Tangdizhihua, which has a plot ratio greater than 4.0. (As shown in Fig. 1). According to the collected data, it is concluded that the climate adaptability of high-rise buildings in northern Guangxi is insufficient. The main problems are as follows:

Case Study						
Similarities: High-intensity and High-density						Differences
Development Areas	Cases	Number of Floors	Total Number of Buildings	Plot Ratio	Plot Ratio Standard	Features
Lingui District	City No. 1	33	17	4.5	1.5-2.0 for 11-story high-rise buildings	River & Stores
Lingchuan County	Tangdizhihua	17	33	4.6	1.8-2.5 for 18-story high-rise buildings	Core Landscapes & Facilities
Qixing District	Fengyu	48	14	7.1	2.4-4.5 for houses with 19 stories or more	Convenient External Contact

Fig. 1. Case study of current situation investigation.

As shown in Fig. 2, the insensitivity of high-rise buildings to climate led to environmental, social and economic issues. Environmental issues include the heat island effect [1], ecological and environmental problems [1], noise pollution [2], and urban landscape destruction [3]. Social issues included thermal comfort [4], health problems [1], lack of a sense of belonging [5], and discomfort with wind pressure [6]. High economic pressure is an economic issue [6].

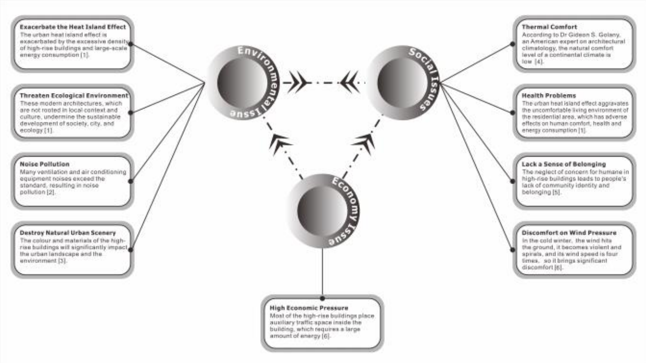


Fig. 2. Problem statements.

The energy and environmental pollution issues caused by rapid urbanisation have seriously threatened the survival of humankind. Sustainable development and environmental protection have become global concerns of paramount importance. Buildings account for a significant share of overall social energy consumption, and their energy conservation has become one of the world's predominant energy conservation trends.

1.2. The purpose and significance of the study

The case study focused on high-rise residential buildings in northern Guangxi, which experience hot summers and cold winters. Dr Gideon S. Golany, an American expert on architectural climatology, asserts that regions with hot summers and cold winters are harsh climates [4]. This region requires mechanical cooling and heating for approximately half the year and accounts for nearly one-fifth of China's geographical area and one-third of its population, making it China's most energy-intensive region. To investigate the ecological adaption strategy of high-rise residential buildings and to offer a basis for future work and research. The research aim included the following aspects:

- Promote and ensure the effective implementation of energy-saving buildings with mandatory green building policies and guidelines.
- To provide categorical conclusions on elements offering indoor comfort in contemporary high-rise apartments.
- To provide ecological adaptability design principles and strategies on high-rise apartments in hot summer and cold winter regions.

1.3. Limitations of the study

This study explored the climate-adaptive design method for high-rise residences in a specific climate. The local climate features limited the research on the applicability of climate-adaptive design strategies for high-rise housing. Second, the design of green buildings is an interdisciplinary endeavour. Due to a lack of available experts, the research did not delve into the quantitative analysis of all strategies, building aspects, and node stages.

1.4. Climatic regionalisation of hot summer and cold winter area

In 1993, the "Code for thermal design of the civil building" (GB50176-93) classified China into five climatic regions based on thermal engineering requirements for heat preservation and insulation from the perspective of the building. This classification was based on the average temperatures of January, the coldest month, and July, the warmest month. This guideline offers the fundamental standards for residences in hot summer and cold winter locations (as stated in Table 1) [7].

The hot summer and cold winter zones are delimited by the distribution of building climate characteristics in China, located between the cold and hot areas. This region is comprised of sixteen provinces, municipalities, and autonomous regions. Its urban and rural populations account for around one-third of the country's total population and occupy an area of approximately 1,800,000,000 square kilometres. Its GDP accounts for over 48% of the nation's [8]. In this study, Northern Guangxi refers to the current administrative district of Guilin, located in the northeast of Guangxi and the southwest of the Nanling Mountain range at 109°45'-104°40', north latitude 24°18'-25°41'.

Table 1. Architectural thermal zoning and design requirements [7].

Climatic Zones	Main Indexes	Auxiliary Index	Design Requirements
Hot Summer and Cold Winter Area	The average temperature of the coldest month ranges between 0~10 ℃. The average temperature of the hottest month ranges between 25~29 ℃.	The days with an average daily temperature≤5 ℃ is 0~90 days. The days with an average daily temperature≥25 ℃ is 40~110 days.	Must meet the heat protection requirements in summer and pay attention to heat preservation in winter.

1.5. Factors affecting the effective implementation of eco-adaptive high-rise buildings

Existing green building policies lacked enforcement authority (as shown in Fig.3), real estate developers disregarded climatic factors, architects lacked knowledge of climate adaptation design, and residents lacked knowledge of residential climatic adaptability. These issues affected the implementation of ecologically adaptive high-rise buildings significantly. The ineffective application of passive energy-saving strategies has resulted in poor thermal comfort and low energy efficiency throughout the summer.

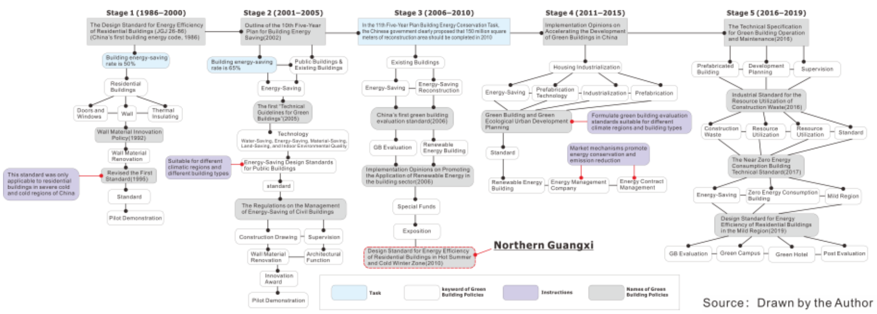


Fig. 3. Existing policies and guidelines on green building

1.5.1. Policy factors

China's five-year plan classified policies from 1986 to 2019 into five stages. Figure 3 shows the policy topics for each of the five phases. The policies' first phase focused on the energy efficiency of the building. For example, modern wall materials can help insulate the building envelope. The Chinese government intends to reduce the stress on building energy demand by increasing the use of new and renewable energy; in the second phase, energy remains the most crucial performance indicator. In the third phase, building waste was increasingly included in policy documents and regarded as an emerging performance indicator. In the fourth stage, innovation and the usage of advanced technologies emerged as additional indicators. In the fifth phase, people-oriented performance metrics replaced environmental protection and resource conservation as the focus of performance metrics.

The building industry's management department had emphasised formulating evaluation criteria for thermal environmental quality and theoretical research on evaluation standards. Existing green building policies in China rarely included passive adaption mechanisms between buildings and their climate, and enforcement was lacking. These standards have a low starting point and are relatively regressive. The following are the suggestions:

- Develop evaluation standards, including airflow, sunshine, thermal radiation, temperature and humidity.
- Appropriate mandatory policies and regulations should be adopted in the ecological adaptability design of high-rise residential buildings.
- Update and amend design guidelines in real time.
- Formulate medium-long-term planning for energy conservation.
- Specific ecological adaptation strategies and guidelines.
- More detailed climate zones.

1.5.2. Real estate developers ignore climate factors

The extraordinary level of control exercised by the real estate developers over the high-rise residential building was reflected in the design of this typology of buildings. As capital investors had a greater influence on China's current market mechanism, their preferences were the design standard [9]. Regarding high-rise apartment design, investors hardly consider climatic factors and the influence of climatic adaption strategies on energy conservation. End-users and local contexts are often excluded and become victims of the development of the construction market.

1.5.3. Architects lacked awareness of climate adaptive design

The architectural design sector is highly competitive in an environment of free market competition. Architects continue to enhance their service quality to expand their market share. The design of buildings has evolved into a tool for satisfying investors' business interests [10]. The inclusion of greenbelts and vegetation in the textbook of residential planning principles for urban planning majors in Chinese universities focused on the functions of noise reduction, pollution reduction, and separation spaces but not on the impact on microclimate. In contrast, architects' ignorance of climate-adaptive design was primarily due to the absence of this subject in architectural education.

1.5.4. High-rise residents lack awareness of residential climate adaptability

While purchasing a home, residents primarily examine the surrounding supporting amenities, transportation, and internal environment landscape but rarely consider the building's energy efficiency. As a result of users' lack of awareness of energy-efficient building design, real estate developers allocate more funds to the interior landscape environment to accommodate consumer preferences in project development.

1.6. Studies on climate adaptability of vernacular dwellings

Most of the vernacular architecture has a distinctive appearance that reflects the needs and characteristics of climate adaptation. The vernacular architecture incorporates its inhabitants' accumulated knowledge and experience and is highly climate-sensitive. Nearly every building element is responsible for preventing unfavourable climatic conditions. Vernacular architecture from various cultures exhibits similar characteristics in the same climate region. For example, in hot and dry regions and hot and wet regions, the more restrictive the environment, the more similar the building characteristics; some are different only because the details and decorations originate from various cultures. American Indian homes, Mali dwellings, and Kashgar, Xinjiang, and China dwellings exhibited the architectural characteristics of hot and arid regions (as shown in Fig. 4).

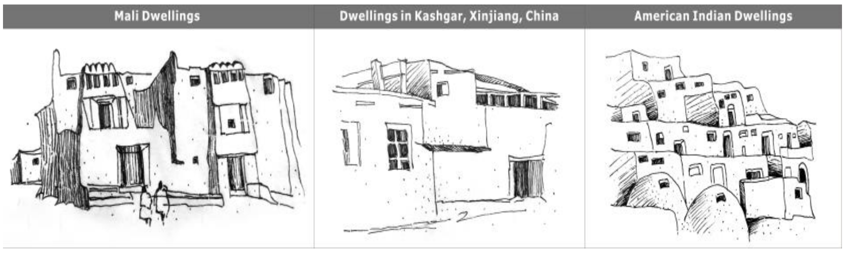


Fig. 4. The architectural features are similar in the same climate.

Wind catchers were also utilised in houses in Turkey and Iran to improve natural ventilation. The wind catches utilised in rural Egypt use the evaporative cooling method. Its fundamental principle is to function as an inverted chimney, where the dominant wind at the roof level is driven down into the tower and through a layer of clay pots filled with cold water and damp wood grilles to cool the air and increase humidity before it enters the room. The high adaptability of vernacular architecture to climate has enticed many architects to use it to solve contemporary architectural challenges, some of which are colossal successes and creative.

1.7. Research on the ecologically sustainable strategies of vernacular dwellings in Northern Guangxi

Vernacular homes in northern Guangxi used strategies that benefited the environment, society, and economy (as shown in Fig. 5).

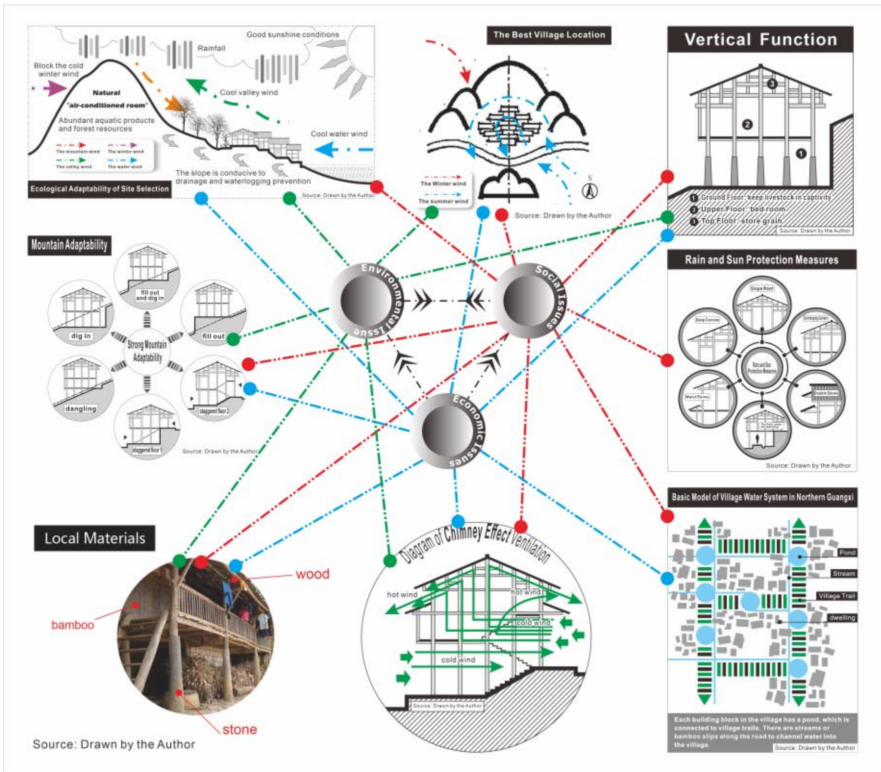


Fig. 5. Ecologically sustainable strategies of vernacular dwellings in northern Guangxi.

1.7.1. Environmental, social and economic strategies

Environmental, social, and economic strategies have advantages in energy conservation, environmental protection, production, living, and cost saving.

- The village's territory extended yearly due to mud deposits: Most villages are on the gentle slope caused by the river's anti-bow surface. It prevented river erosion and increased usable land for farming and habitation.
- Building site selection improved energy efficiency: The village is surrounded by mountains to the north and confronts water to the south, forming a virtuous ecological circle with the natural environment. The village is transformed into a natural "air-conditioned room" by the land-water breeze and valley wind. The surrounding mountains hold the cold winter winds from the northwest at bay.
- The ingenious use of terrain to save costs: Save costs by using strong mountain adaptation, such as cut and fill, suspending, staggered floor, and so on [11], to level the ground without a lot of labour and resources, which was both economical and convenient for construction.
- Local materials, simple construction, and lower costs: Using building materials such as local stone, bamboo, and wood.
- The building's design helps save energy: Through vertical processing such as hanging and overhead, the space at the bottom of the building becomes a

circulation wind belt. Setting a vent at the upper part of the building can discharge dirty hot air from the interior and suck in fresh, cold outside air from the bottom of the building.

- Forms with a functional layout are conducive to living: The ground floor of the Ganlan building is used to shelter livestock, the second floor is the bedroom, and the third floor is for grain storage. This functional vertical layout can better resist the threat of mould and dampness in the forest [12]. This design protects against moisture and wards off wild animal threats.

1.7.2. Social strategies

Social strategies refer to rain and sun protection measures: Rain erosion can be stopped by making the roof of a wooden house into a tiled slope with a slope of about 30 degrees [13]. The building's roof overhangs are built up layer by layer. The double eaves and waist keep rainwater from eroding the wall, which makes it last longer. The south corridor has eaves that block the sun. Double eaves are put up on the west side to block the sun. The path goes through the bottom of the house so pedestrians can be sheltered from the elements.

1.7.3. Social and economic strategies

Social and economic strategies point to economics of ponds: This is an excellent example of how ponds can be used for many different situations, such as fire water, climate control, fish farming, landscaping, and generating economic income.

These valuable ecologically sustainable strategies of vernacular dwellings in northern Guangxi serve as a point of reference for the study of ecological adaptation strategies of high-rise dwellings.

2. Research Methodology

The Methodology of this research mainly adopts the combination of qualitative and quantitative analysis as follows.

2.1. Data collection methods

Field investigation method was used to obtain first-hand information for the empirical study through field research, sketching, photography, observation, and analysis. Determine the design scenario of northern Guangxi's residential high-rises. Use a combination of the literature review, induction and deduction, chart analysis, statistical analysis, and other scientific argumentation methods to analyse its bioclimatic adaption principles and then summarise them.

Questionnaire Survey was adopted among users and local architects. The study used a random sample technique to administer multiple-choice and open-ended questionnaires using WeChat groups. In addition, some questions employed the "Likert Scale", ranging from "extremely satisfied" to "very dissatisfied" to determine the level of satisfaction. The status quo of residents living in high-rise residential neighbourhoods and the most pressing real-world issues were determined. The challenges were examined and discussed, and then solutions were proposed.

Summarized and organized data. Integrated the current research results and strategies with the regional bioclimatic design to determine the climate adaptation design strategy and the principles of high-rise residential buildings in northern Guangxi.

2.2. Data analysis methods

The data from the field study were analysed using a correlational approach, thoroughly analysing how various elements relate to one another while highlighting the key distinguishing characteristics. Data from the survey were analysed using regression analysis.

3. Data Analysis

The survey was administered to one hundred residents of Zhangtai City No. 1, Lingui District. The internal factors considered by residents when acquiring high-rise housing and the levels of ecological adaptation satisfaction were investigated. Figure 6 shows that when acquiring a home, high-rise residents primarily considered Landscape and Greenery (39%) and Internal Supporting Facilities (22%); only 4% of residents were concerned about the energy efficiency of buildings.

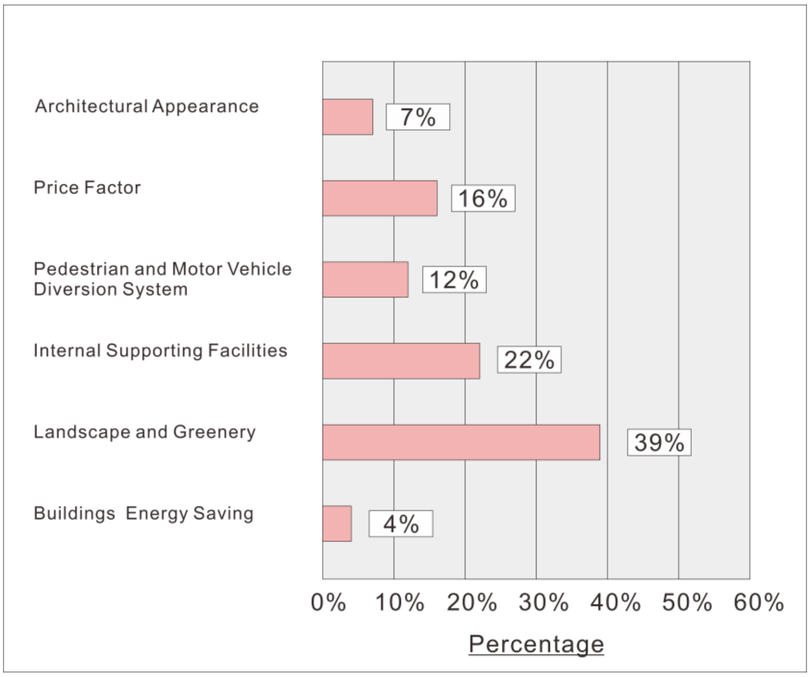


Fig. 6. High-rise residents lack awareness of building energy conservation.

Findings revealed that 59% of respondents claimed ventilation and cooling in summer are more significant than heat preservation in winter (Fig. 7). This shows the need to prioritise climate adaptation strategies during summer and winter. About 42% of respondents were unhappy with the air circulation in the kitchen and bathroom (Fig. 8). This is because the layout of most kitchens and bathrooms that require ventilation did not consider the wind direction. Sadly about 41% reported that they had no opinion regarding the landscape water systems. Interestingly about 73% of respondents were satisfied with the plant and greenbelt, and 50% were dissatisfied with acoustic comfort, which includes noise from wind, elevators, and air conditioning systems.

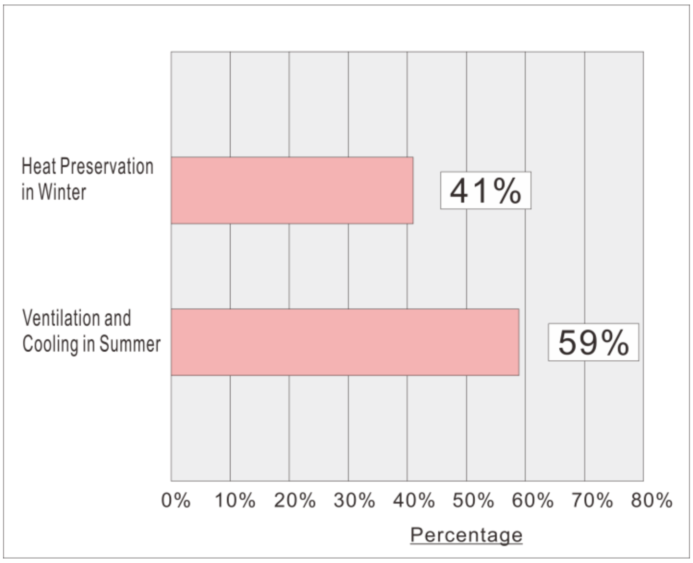


Fig. 7. Attitudes towards heat preservation in winter and ventilation in summer.

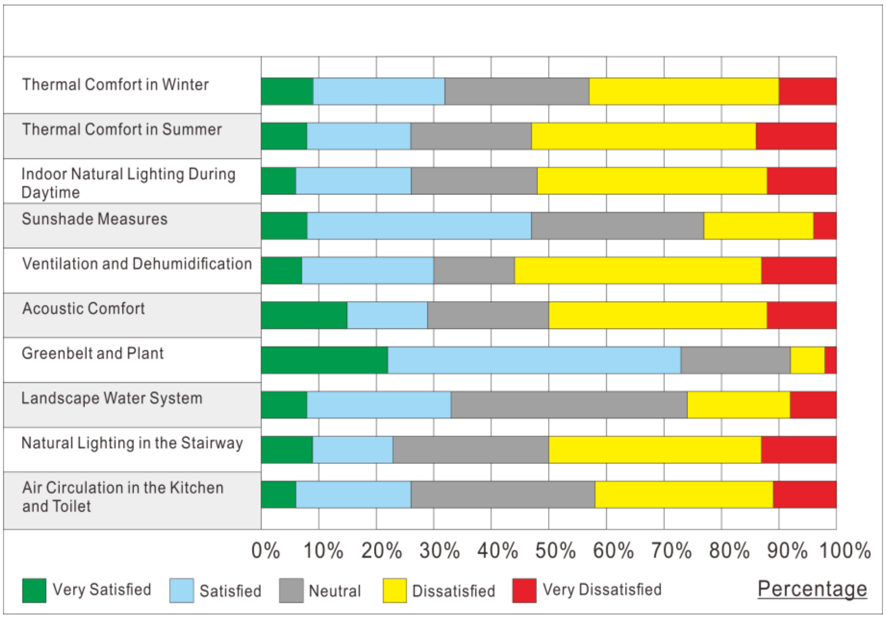


Fig. 8. Respondents' degree of satisfaction with the ecological adaptability of high-rise residential buildings.

The building's unreasonable window-to-wall ratio was the main reason for low thermal comfort that must be addressed by heating equipment. Furthermore, the building's design had no impact on noise reduction. The higher the floor, the greater the noise from the wind. More than half (56%) of respondents were dissatisfied with the ventilation and dehumidification systems. Sun shading measures were satisfactory to less than half (47%) of respondents. Almost half (52%) of respondents were unsatisfied with daytime indoor natural lighting. Since the house's design did not use natural lighting, 43% of respondents were dissatisfied with winter thermal comfort, and 53% were dissatisfied with summer thermal comfort.

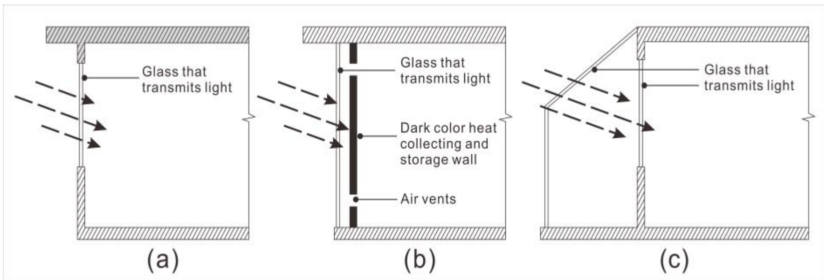
4. Results and Discussions

The questionnaire surveyed residents' living experiences, which revealed that some of the corresponding climate adaptation measures were required in northern Guangxi with hot summer and cold winter climates.

4.1. Heat preservation and heating strategies in winter

Heat preservation in winter: This should prevent cold air infiltration, improve the window's thermal performance and air tightness, and keep most of the exterior surface away from the dominant winter wind direction. External and interior thermal insulation is the most common technology in high-rise residences.

Solar heating strategies: Passive heating uses radiation, conduction, and convection to allow solar heat to move passively through the building, manage the heat flow, and ultimately produce the heating effect [14]. In buildings, three standard passive solar heating methods can be applied (as shown in Fig. 9):



(a) Direct gain heat. (b) Heat storage wall. (c) Glass greenhouse.

Fig. 9. Three common passive solar heating ways.

- The south wall was used for direct gain heat. It is the most basic form of heating. Direct daylight entered the area through the south-facing glass windows. Heat is absorbed by the interior floor, walls, and furniture and transformed into energy for room heating.
- A heat storage wall is a thermal storage wall that includes vents. When sunlight strikes through the glass on this wall, heated air rises and circulates with the inside air through the higher and lower vents. Simultaneously, this heat-collecting wall absorbed some heat and heated the interior.
- Building a greenhouse at the south orientation of the building. This strategy combines direct heat and heat storage walls to produce additional heat and acts as a buffer to minimise heat loss.

4.2. Insulation and cooling strategies in summer

Insulation and cooling strategies in summer include improving the heat dissipation of the building and sunshade as follows.

- Improve the heat dissipation of the building: Reduce the heat entering the room. This technique assumes that the outdoor temperature is lower than the indoor temperature; otherwise, the indoor temperature will be higher. A green buffer in the windward passage can filter the hot air, thus reducing the temperature.
- Sunshade: Applying sun shading devices to the side windows, skylights, and atrium. To achieve climate adaptability, installing artificial shading devices that are adjustable and connected with a seasonal switch for control. Besides, shadows between buildings and their components can provide self-shading and reduce heat gain from the roof and walls. Trees or climbing plants shade the sun, create shadows, and reduce the wall's temperature.

4.3. Ecological adaptation strategies based on the results of the questionnaire

Propose effective strategies according to the respondents' satisfaction with the ecological adaptability of high-rise residential buildings.

- Increase indoor natural lighting: A section of the residential tower's natural lighting is inadequate; however, combining the sky garden and the building's design can provide sufficient sunlight.
- Natural lighting and ventilation of the vertical transportation core: The traditional approach is to place the vertical transportation core in the centre, and arrange rooms around it, which leads to a poor thermal comfort experience in the room located at the East and West. Alternating the placement of these rooms with the core of vertical transportation can be a practical option.
- Reduce wind noise: As building height and wind speed increase, the noise level increases. Architectural design and the layout of neighbouring buildings can be used to control the wind direction and reduce noise levels.
- Air Circulation in the kitchen and toilet: Emphasise the placement of these functional spaces to prevent air cross-contamination, which harms indoor air quality, the living environment, and residents' health.
- Landscape and water system: Landscape and water systems can be used to modify the microclimate. Rapid cooling can be assisted by water evaporation and the green belt's buffering effect.

5. Conclusions

The design of high-rise residential buildings in northern Guangxi must consider cooling in summer and thermal insulation in winter. Concerns highlighted in the field survey and questionnaire include ecological adaptation design strategies for high-rise residential buildings in regions with hot summers and cold winters. Establishing the building orientation, function layout, aerial garden design, lift core location, ventilation, dehumidification, passive solar heating, and other factors that promote the benign interaction between the building and the environment and meet ecological adaptability design specifications.

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