buildings

MDPI

Article

Energy Consumption of Apartment Conversion into Passive Houses in Hot-Summer and Cold-Winter Regions of China

Yonghan Li [1,2], Wei Yin [1,2,3,*], Yawen Zhong [1,2], Mingqiao Zhu [1,2], Xiaoli Hao [1,2], Yongcun Li [1,2], Yuwen Ouyang [1,2] and Jie Han [4]

1 School of Civil Engineering, Hunan University of Science and Technology, Xiangtan 411201, China
2 Hunan Engineering Research Center for Intelligently Prefabricated Passive House, Xiangtan 411201, China
3 College of Architecture, Hunan University, Changsha 410012, China
4 School of Architecture and Transportation Engineering, Guilin University of Electronic Technology, Guilin 541004, China
* Correspondence: yinwei@hnust.edu.cn

Abstract: Passive houses have strong thermal insulation and airtightness of doors and windows, and they are generally used in cold climates. This case study aims to evaluate the energy-saving potential of this technology in the hot-summer and cold-winter areas (Cf in Köppen climate classification) of China. The results show that after enhancing the thermal insulation and airtightness, the energy consumption in winter significantly decreased by 62% overall. However, the energy consumption of cooling in the transition season and summer increased, which is caused by overheating. Hybrid ventilative cooling and shading can solve this problem. In particular, when the indoor temperature range is set to the adaptive thermal comfort of natural ventilation, the energy consumption from air conditioner cooling can be greatly reduced by 81% overall. Passive houses combined with ventilative cooling has significant application value in this climate zone.

Keywords: building energy efficiency; passive house; apartment; ventilative cooling; sunshade

check for updates

Citation: Li, Y.; Yin, W.; Zhong, Y.; Zhu, M.; Hao, X.; Li, Y.; Ouyang, Y.; Han, J. Energy Consumption of Apartment Conversion into Passive Houses in Hot-Summer and Cold-Winter Regions of China. *Buildings* **2023**, *13*, 168. https://doi.org/10.3390/buildings13010168

Academic Editor: Cristina Carpino

Received: 29 November 2022
Revised: 28 December 2022
Accepted: 4 January 2023
Published: 9 January 2023

1. Introduction

Global warming has become an issue for all humankind, and thus, efforts should be directed toward reducing the consumption of non-renewable energy. Among them, building energy efficiency is an important means to reduce carbon emissions [1]. The passive house concept started in Germany in 1988, which aims to reduce the energy consumption for heating and cooling and CO_2 emissions and provide a more comfortable indoor environment compared to the usual old building [2]. Technologies to achieve passive houses include enhancing the thermal insulation of the envelope, improving the airtightness of doors and windows, and recovering heat from ventilation to improve energy efficiency.

1.1. Energy Efficiency of Passive Houses

Jürgen et al. [3] compared the energy-saving effect of using passive house technology in Yekaterinburg, Tokyo, Shanghai, Las Vegas, Abu Dhabi and Singapore through a simulation method. The results show that passive houses have energy-saving potential in all climate zones throughout the world, using 75% to 95% less energy than conventional buildings. Fei et al. [4] conducted a three-year performance monitoring and evaluation of a passive house public building located in Qingdao, China (a seaside city in a cold region), and found that the annual energy efficiency was improved by approximately 69% compared to the current standard. Yang et al. [5] monitored the energy system of a new passive house school building in southern Germany for three years. The results show a two-thirds reduction in CO_2 emissions. Egon et al. [6] evaluated three buildings in southern Brazil, and their energy consumption decreased by 83.5%, 56.3% and 55.1%, while their thermal comfort satisfaction increased significantly.

1.2. Overheating

However, the overly high thermal insulation and airtightness of passive houses may produce overheating in the summer and transitional seasons. For example, Ridley et al. [7] carried out detailed monitoring of UK homes certified to passive house standards, which experienced overheating problems in the summer, especially in living rooms. The main reasons are higher internal gain, low sunshade and summer ventilation rate than expected. Rohdin et al. [8] presented the experience of newly built passive houses in Sweden and compared nine passive houses with traditional buildings in terms of the thermal environment and energy. It was also shown that there is a higher number of complaints related to high temperatures during summer in the passive houses. Its main concern is the lack of ventilation, and the indoor temperature is severely affected by internal gains from cooking and showering. Paris et al. [9] measured passive house performance in Cyprus, and there were some overheating problems in all zones during the summer period.

1.3. Ventilative Cooling and the Mixed-Mode Method

One of the methods for reducing overheating in passive houses is to use ventilation cooling, including natural ventilation or night ventilation [8,10]. Therefore, the switch between outdoor air cooling and air-conditioning cooling becomes a method named the mixed-mode.

The mixed-mode combines a ventilative system with an air-conditioning system to use as much outside air as possible to cool the building when the outside conditions are suitable for indoor air. When outdoor air cannot meet cooling needs, machinery should be used to lower indoor temperatures to maintain thermal comfort. Now there are a number of classification schemes that describe the mixed-mode. Usually based on whether they exist in the same space, or run at the same time, can be divided into three operation modes such as Concurrent (Same space, same time), Change-over (Same space, different times) and Zoned (Differed spaces, same time) [11]. Change-over operation mode is used in this paper.

Regarding the thermal comfort of the mixed-mode, Max et al. [12] pointed out that the traditional PMV-PPD theoretical model (the predicted mean vote and the predicted percentage of dissatisfied) cannot well describe the thermal comfort of the occupants in the mixed-mode building. Luo et al. [13] conducted a field investigation in mixed-mode building in subtropical climate. The results show that the adaptive model is more suitable for mixed-mode buildings than the steady-state comfort model (PMV), especially when natural ventilation was being utilized. Ricardo et al. [14] concluded that a wider range than PMV can be used during air conditioning operation in Brazilian temperate and humid climate, and that the adaptive model can be used in mixed-mode buildings when air conditioning is not operating. Many studies in different countries or climate zones have proposed different mixed-mode control methods and comfort models, which show good thermal comfort and energy saving effects. For example, Massimo et al. [15] (New South Wales, Australia), development of a new comfort-oriented control strategy for a mixed-mode building. The comfort-oriented controller was proved to be superior to the baseline controller in terms of maintaining comfort, as well as a reduction in building energy consumption. Elena et al. [16] (Southwest Spain) proposed an adaptive model for hybrid buildings, and the results show that it has energy saving potential without sacrificing the comfort of the occupants. Sherif et al. [17] (arid climates in four countries) evaluated the potential of a range of mixed-mode cooling systems and ventilation strategies. The results show that the mixed-mode of office buildings has great potential for energy saving, and should be able to provide a satisfactory indoor environment. Ricardo et al. [18] (southern Brazil) conducted field studies on thermal comfort and this was conducted in three mixed-mode office buildings, and adaptive thermal comfort models were developed for the natural ventilation and air conditioning mode of mixed-mode buildings. Daniel et al. [19] (south-west of Spain) applied the adaptive comfort algorithms to mixed-mode buildings.

The results show that energy demand is reduced by 74.6% and energy consumption is reduced by 59.7%.

For the control strategy of the mixed-mode, the opening and closing of windows and air conditioning are controlled according to indoor and outdoor air parameters, such as indoor and outdoor temperature, humidity, wind speed (Gwynne et al. [20]), outdoor pollutants (Chen et al. [21]), and indoor CO_2 (Katarina et al. [10]). Laia et al. [22], Hu and Karava [23], Peter et al. [24], and Zhao et al. [25] all demonstrated that model predictive control (MPC) based on future weather data and indoor factors is a more advanced control strategy.

1.4. Shading for Cooling

Another approach to building cooling is shading, which is influenced by equipment (e.g., Hussain et al. [26], Kim et al. [27]), user behaviour (e.g., Kevin [28], William et al. [29]), and control strategies (e.g., Line et al. [30], Amir et al. [31], Yun et al. [32]).

1.5. Goals and Framework of the Paper

In general, passive houses are suitable for cold climates due to the longer winter periods. In northern China, passive houses are suitable for cold climate regions and extremely cold climate regions. In central-south China, there is a climate region named the hot-summer and cold-winter area, in which the suitability of passive house technology is still unknown. Therefore, this paper first investigated the indoor environment of apartments in that area and then predicted its energy efficiency when transformed into a passive house. Finally, solutions to the existing problems are proposed.

2. Investigation in Apartments

2.1. Local Weather

As one of five China's architectural climate zones, the hot-summer and cold-winter region is located from latitude 25° to 35° north and longitude 103° to 123° east, fully or partially including 16 provinces with a population of approximately 500 million, as shown in Figure 1. In this zone, the average dry bulb temperature of the coldest month ranges from 0 to 10 °C, the average temperature of the hottest month is 25 to 30 °C, the number of days with average daily temperature ≤5 °C is 0 to 90 days, the number of days with average daily temperature ≥25 °C is 49 to 110 days, and the average relative humidity is 30% to 80% year-round. This region belongs to Cf in Köppen climate classification.

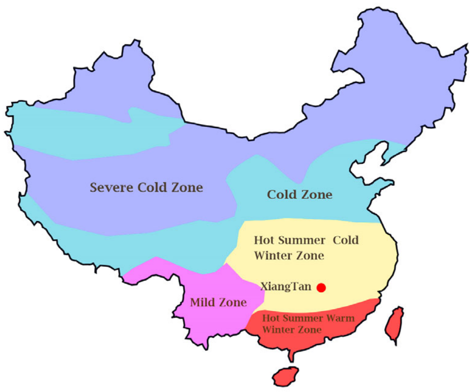


Figure 1. The location of the hot-summer and cold-winter climate zone and Xiangtan, from Bing Maps.

The location of the building is Xiangtan, which is located in the middle of the hot-summer and cold-winter area. It is located at latitude 27.83 and longitude 112.94, as shown by the red dot in Figure 1. Figure 2 shows the local dry-bulb temperature monthly in a typical meteorological year. The shaded boxes represent 25–75% of the temperature distribution, and the data are from the China Meteorological Database [33]. The horizontal line is the median, and the small squares represent the monthly mean temperature. The average monthly outdoor temperature in winter (December to February) is approximately 5~7 °C, and the monthly average temperature in summer (June to September) is 20~28 °C. This results in the demand for heating in winter and cooling in summer.

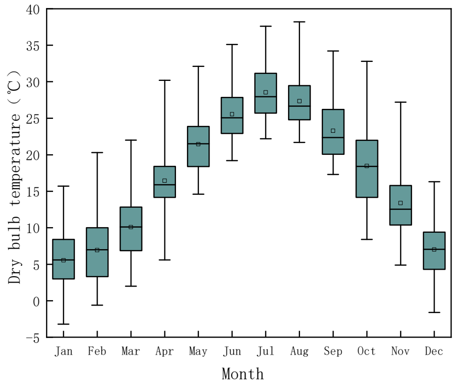
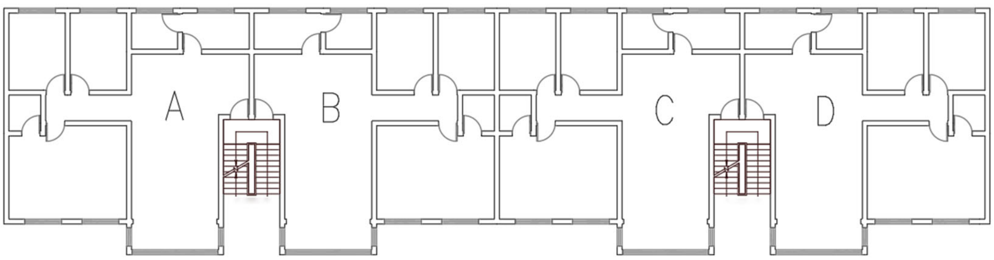


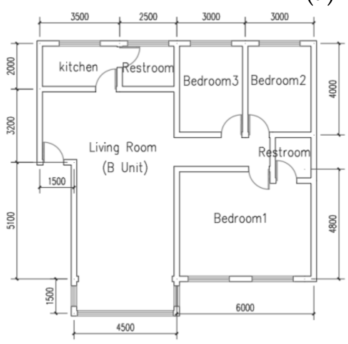
Figure 2. The monthly dry bulb temperature in Xiangtan.

2.2. Building Information

This building is an apartment built in 2005. Before the publication of the new code in 2010, about 60% apartment buildings in China have adopted a similar envelope structure and apartment type. It has a total of six floors, each floor has four households with two ladders, and the floor height is 3.1 m, as shown in Figure 3. Figure 3a shows the floor plan of each floor, where the four households (A–D) are exactly the same, each with an area of 138 m^2. Figure 3b shows the details of the building of household B, in which the south-facing windows of the living room balcony are 2.1 m high and 4.2 m wide, and the east–west windows are 1.5 m high and 0.9 m wide. Bedroom 1 has two windows, and bedrooms 2 and 3 have one window individually, each 1.5 m high and 1.8 m wide. A photo of the south facade is shown in Figure 3c.



(**a**) Floor plan of the apartment



(**b**) Details of household B

(**c**) Photo of the south façade

Figure 3. An apartment building in a hot-summer and cold-winter climate zone in China, households of A, B, C, and D from left to right.

2.3. Occupancy and Heating Equipment

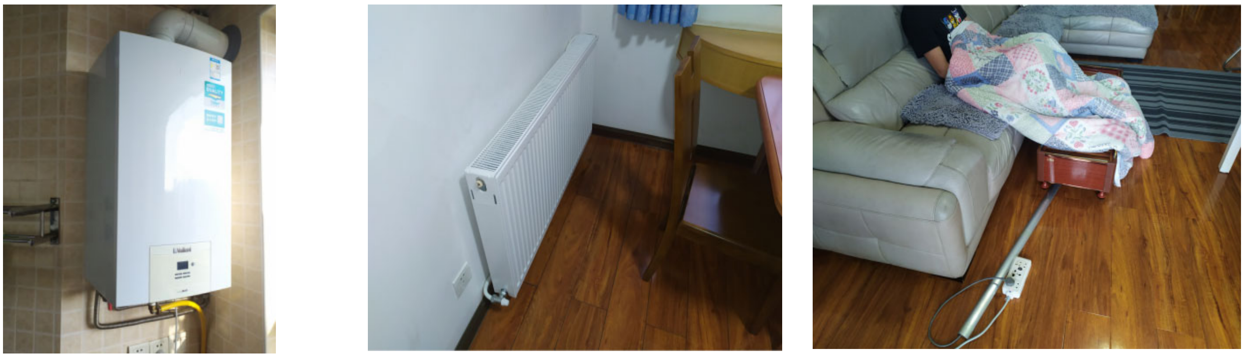
The measurement is carried out in households B and C together. The thermal insulation of their envelope structures is exactly the same, in line with the "Energy-saving Design Standards for Residential Buildings in Hot-summer and Cold-winter Areas" JGJ134-2001 [34]. The specific parameters are similar to those shown in the left column of Table 1. There is no central heating or cooling system for the whole building. Occupants are allowed to use the system as they like. Some owners use electric heaters and others use gas-fired wall mounted boilers for heating. In summer, all users use split air conditioners for cooling. Household B heats the entire house by a gas wall-hung boiler, the maximum heating capacity of the gas boiler is 28 kW, and the temperature of the hot water provided by the boiler shall not be lower than 60 °C, as shown in Figure 4a, and radiators, as shown in Figure 4b. Household C has only three low-power electric ovens covered by quilts for heating, as shown in Figure 4c, each with a power of 50 to 100 W. The total heating capacity of the electric ovens is from 150 to 300 W. This heating method is widely used in hot-summer and cold-winter areas in China. There were four people in each family, including two adults and two children. Due to privacy reasons, this study did not measure the exact house occupancy rate, but since the adults were all teachers and during the winter vacation, it was assumed that the house occupancy rate was similar.

2.4. Measurement Instruments

The environmental parameters recorded in the indoor environment were the indoor temperature and humidity by an Onset HOBO thermometer (±0.21 °C and ±2% RH) placed on a 1.2 m table, as shown in Figure 5a. The CO_2 concentration was recorded by a BoHu Indoor Air Quality Monitor (±50 PPM), as shown in Figure 5b, whose time interval was 10 min. Energy consumption was counted through smart sockets for the statistics of electrical appliances, as shown in Figure 5c. A gas meter was used to record gas consumption. Outdoor parameters such as solar radiation, outside temperature, humidity, wind speed and direction were obtained from local weather stations.

Table 1. Thermal parameters of existing buildings and passive houses.

	Existing Building (Old Standard, JGJ134-2001)		**Passive House (New Standard, DBJ43/T017-2021)**		
	Main Envelope Material	**W/(m^2·K)**	**The Added Envelope**	**The Standard Limit W/(m^2·k)**	**W/(m^2·K)**
Roof	20 mm mixed mortar 120 mm reinforced concrete 30 mm slag concrete 20 mm cement mortar 30 mmXPS board 40 mm waterproof layer	0.81	+160 mmEPS board	0.15~0.35	0.16
Exterior walls	20 mm mixed mortar 240 mm reinforced concrete 20 mm cement mortar 35 mm thermal insulation mortar 10 mm anti-crack mortar	1.08	+140 mmEPS board	0.15~0.40	0.19
Interior wall	20 mm mixed mortar 200 mm shale hollow brick 20 mm mixed mortar	1.85	+two sides 6 mmEPS board	1.0~2.0	1.09
Floor	30 mm cement mortar 120 mm reinforced concrete 20 mm expanded glass bead insulation mortar	1.90	+10 mmEPS board	1.0~2.0	1.19
Windows		4.7	Low-E vacuum glass	≦2.0	1
Doors		3	thermal insulation door	1.0~1.4	1
Number of air infiltration, h^{-1}					
Rooms	1		0.1		



(**a**) Gas boiler in household B (**b**) Radiator in household B (**c**) The oven covered with a quilt, in household C

Figure 4. Equipment for heating.

(**a**) Thermometer (**b**) Air quality monitor (**c**) Electricity-statistics plugs

Figure 5. Instruments for measurement.

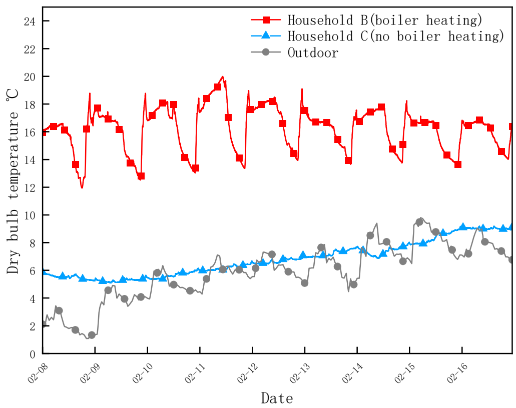
2.5. Survey Results and Analysis

(1) Bedroom 1

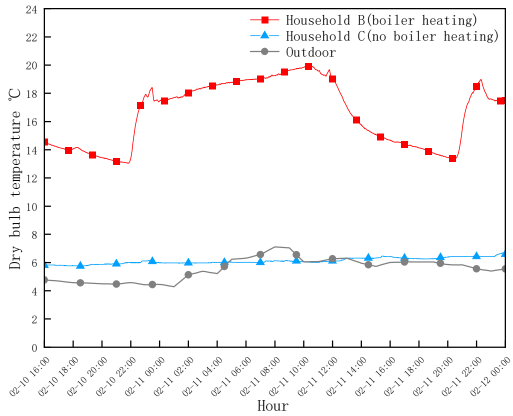
The investigation lasted a total of eight days from 8 to 16 February 2022. As shown in Figure 6a, the heating time of household B is relatively regular. The gas boiler is turned on at about 21:00 to 22:00, and the temperature begins to rise significantly, and the indoor temperature reaches the peak in the early morning. The gas boiler was shut down approximately the next day between 10:00 and 12:00, after which the temperature began to drop.

The indoor temperature of household C is between 6 and 8 °C when there is no boiler heating, and the average value is only 6.8 °C. This average temperature is only 0.3 °C higher than the average outdoor temperature of 6.5 °C, indicating that it is very cold indoors. Therefore, the residents generally sit around the stove and obtain thermal comfort by covering themselves with quilts, as shown in Figure 4c. Figure 6a also shows that the trend of indoor temperature rises slightly with increasing outdoor temperature, which indicates that the thermal insulation and airtightness of the building are relatively poor. However, the average indoor temperature of household B increased to 16.2 °C when there was boiler heating. However, the changing trend of the indoor temperature was not affected by the outdoor conditions.

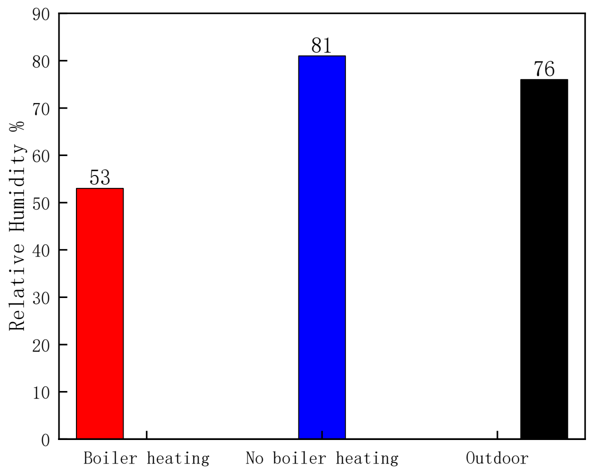
Regarding the temperature change during the day, Figure 6b shows the situation on February 11. It is clear that bedroom 1 is only above 16 °C for part of the day, from 22:00 the previous day to 12:00 the next day. When the heating was stopped, the temperature in room one quickly dropped below 16 °C. While this average temperature met the minimum requirements of the Chinese heating standard "Code for Design of Heating, Ventilation and Air Conditioning in Civil Buildings" GB 50736-2012 [35] in hot-summer and cold-winter regions, occupants complained that the room was cold.



(**a**) Indoor temperature over 8 days



(**b**) Indoor temperature on 11 February



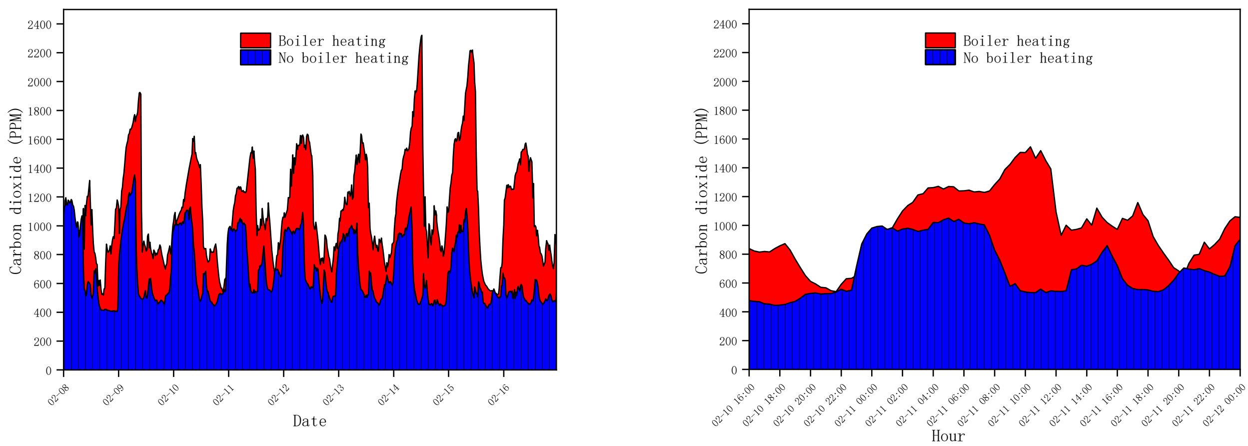
(**c**) Average relative humidity on 11 February

Figure 6. Thermal environment in bedroom 1.

Further observation in Figure 6b shows that there was someone in the bedroom from 20:00 the night before to 12:00 the next day, and the temperature continued to rise. The heating was turned off after 12:00, and thus the temperature dropped continuously. Heating was started at 20:00 in the evening again.

As shown in Figure 6c, the humidity of household C without boiler heating is higher than that outdoors, which is caused by humidity sources such as the human body and cooking. However, when the temperature of household B with boiler heating increases, the relative humidity decreases.

The concentration of CO_2 in the two bedrooms is shown in Figure 7. The CO_2 concentration of the room with heating is significantly higher than that of the room without heating. This is because the users of household B added sealing strips to the windows to increase the airtightness of the room. Apartment C does not have added sealing strips. According to the attenuation of CO_2 concentration to estimate, the air exchange rate of apartment B with sealing strips is from one to three times per hour, and that of apartment C without sealing strips is from 3 to 10 times per hour. This also explains why the temperature of household C in Figure 6 is very low.



(**a**) CO_2 concentration over 8 days (**b**) CO_2 concentration in 11 February

Figure 7. CO_2 concentration in bedroom 1.

Figure 7a shows that the CO_2 concentration of heated bedroom 1 continues to rise from 0:00 a.m. to 8:00 a.m. every day. The CO_2 concentration in the bedroom dropped significantly when the person left the bedroom during the day. The average concentration in heated rooms was 1085 ppm, which exceeded the limit of 1000 ppm required in China's norm "Indoor Air Quality Standard" GBT18883-2022 [36]. The unheated room had an average concentration of 686 ppm.

The variation of CO_2 concentration during the day, Figure 7b shows the situation on February 11.

CO_2 concentrations continued to rise from 22:00 the night before to 12:00 the next day. After 12:00, CO_2 concentration began to decrease with human activity. The CO_2 concentration of household C did not change significantly.

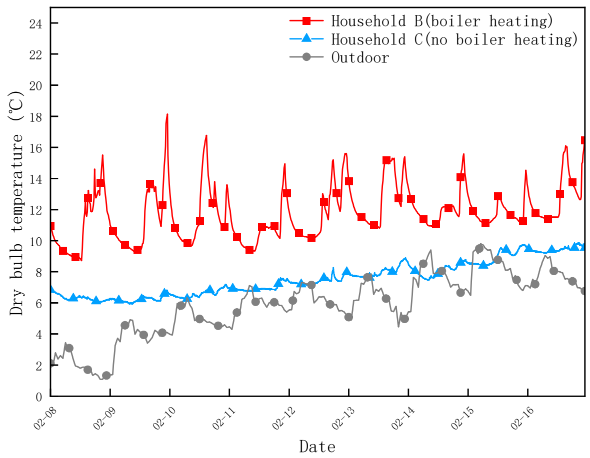
The situation in bedroom 2 is very similar to that in bedroom 1, and thus it is omitted.

(2) Living room

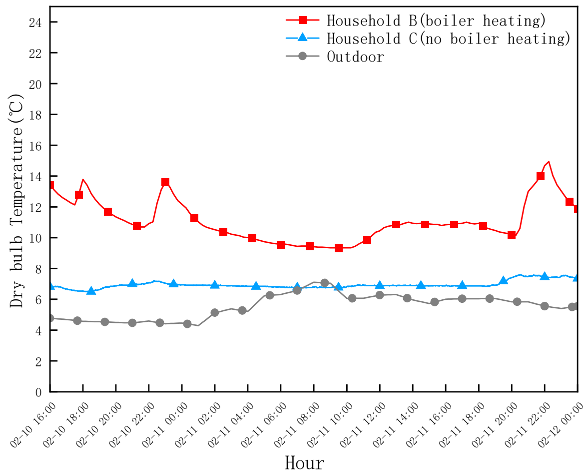
As shown in Figure 8a, compared with the bedroom 1 of household B, the heating control strategy of household B's living room is relatively complex. Generally, when the gas boiler is turned on for heating at around 12:00, the temperature begins to rise significantly. Then, around 23:00 when the gas boiler heating was turned off, the temperature started to drop noticeably. However, during this period, the temperature rose and fell significantly, because people went out and other behaviours to turn off the heating of the gas boiler.

The indoor temperature of the living room of household C was between 6 and 9 °C when there was no heating, with an average value of 7.6 °C. It is 0.8 °C higher than the temperature of bedroom 1 because, during the winter vacation, people spent a lot of time in the living room. Another reason may be that the living room is adjacent to the kitchen, and its cooking and other behaviours increase the indoor temperature. The temperature of the living room of household B with heating is 11.8 °C, which is significantly lower than that of the bedroom. This is because the living room has a large area, many windows and more infiltrated air.

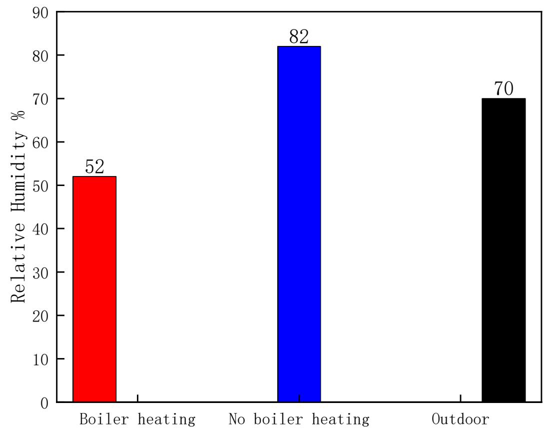
As shown in Figure 8b, the living room temperature of household B began to rise after 12:00. The reason is that the resident just got up, went to the living room, and turned on some heat. Starting at 20:00 at night, the heating power reaches the maximum, and thus the maximum indoor temperature is reached at 23:00. For the unheated living room of household C, the indoor air temperature is 6.9 °C, which is only 1 °C higher than the outdoor temperature of 5.9 °C.



(**a**) Indoor temperature in 8 days



(**b**) Indoor temperature on 11 February



(**c**) Relative humidity on 11 February

Figure 8. Thermal environment in the living room.

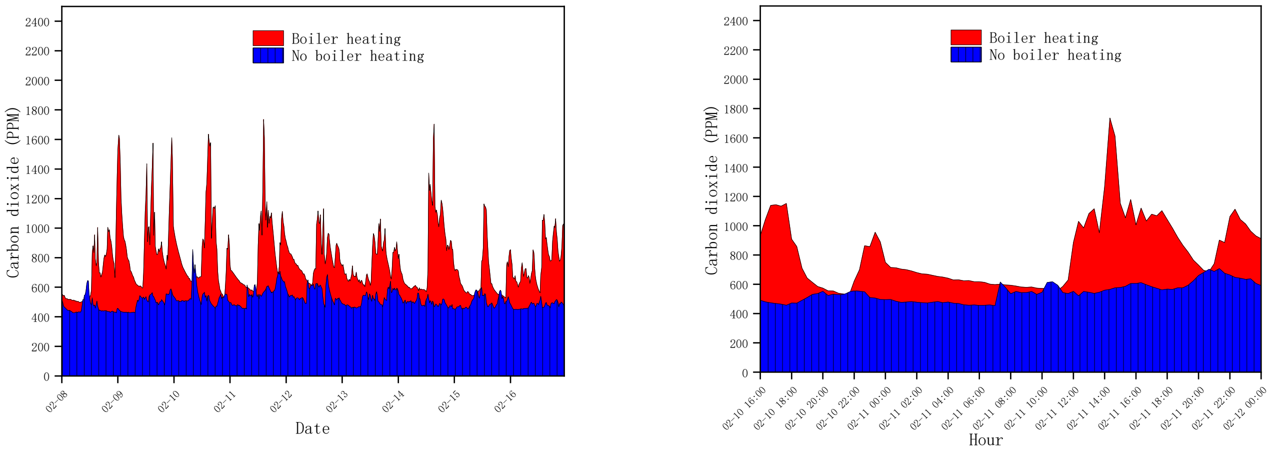
For the relative humidity, as shown in Figure 8c, the unheated room is close to the indoor humidity. The humidity of household B with heating is significantly lower than that of household C without heating, which is still due to the increase in temperature.

Figure 9a shows that the CO_2 concentration of household B (with boiler heating) is higher than that of household C (without boiler heating), which is due to the addition of sealing strips to the windows of household B's living room, which enhances the airtightness. However, compared to bedroom 1 (Figure 7), the time with a concentration over 1000 ppm is much less because the living room has more windows and more infiltrated air.

As shown in Figure 9b, the CO_2 concentration of household b increased significantly from 12:00 to 18:00, and its average value obviously exceeded 1000 ppm. CO_2 levels start to fall after 6:00 but start to rise again at 9:00.

(3) Energy consumption

In household C (no boiler heating), the power consumption of the electric oven covered with a quilt (Figure 5c) is counted through the power socket (Figure 3c). The energy consumption of household B (boiler heating) is calculated by gas meter, excluding domestic hot water and cooking gas. For comparison, the gas consumption is converted into electricity consumption (the conversion factor is 0.342) according to the Source Energy Conversion Factors in EnergyPlus, and the results are shown in Figure 10. The energy consumption of household B in a week was 725 kWh, while household C only used 28 kWh of electricity, and the ratio of the two was about 19:1.



(**a**) CO_2 concentration over 8 days (**b**) CO_2 concentration on 11 February

Figure 9. CO_2 concentration in the living room.

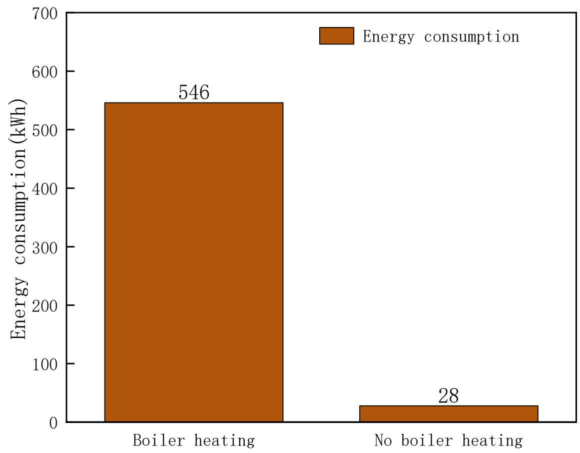
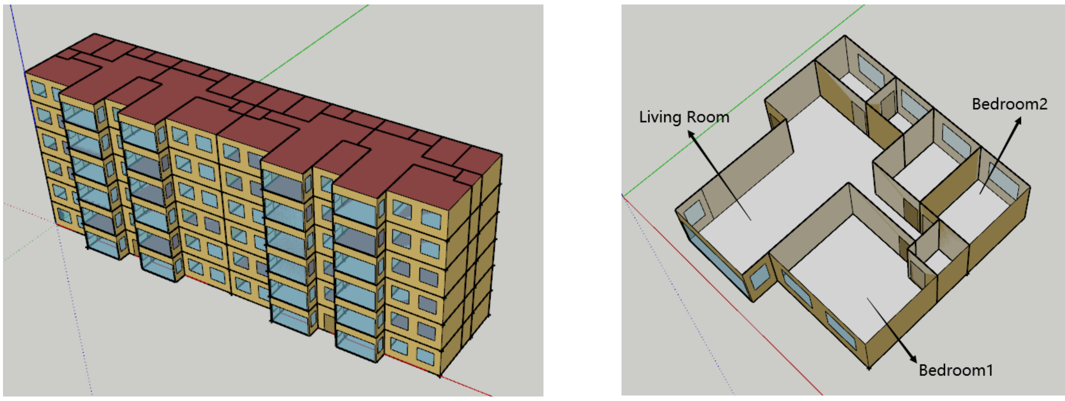


Figure 10. Energy consumption.

3. Building Models

3.1. Building Geometry and Envelope

The model of this apartment is modeled by SketchUp, with a total of six floors and four households on each floor, as shown in Figure 11. Then, the envelope parameters are set by OpenStudio, as shown in Table 1. The parameters in the left column of Table 1 are from the architectural drawings. The building was designed to composite" Design Standard for Energy-saving Residential Buildings in Hot Summer and Cold Winter Areas" JGJ134-2001. If it is converted into a passive house, its thermal parameters come from the "Hunan Province Passive Ultra-low Energy Residential Building Energy Saving Design Standard" DBJ43/T017-2021 [37] and the "Design Standard for Energy Efficiency of Residential Buildings in Hot-summer and Cold-winter Zone" JGJ134-2010 [38], as shown in the right column of Table 1. Obviously, the indicators of thermal insulation and airtightness in the new standard are significantly enhanced. Finally, the model was exported from OpenStudio V2.9.1 to EnergyPlus V9.2 software for the setting of ventilation and shading control strategies.



(**a**) Axonometric view of the entire building (**b**) Rooms in each household

Figure 11. The apartment model in SketchUp.

The occupations of the two surveyed families are teachers, and they are on winter vacation. According to the weekend situation in the new standard DBJ43/T017-2021, settings such as the occupancy rate, utilization rate of electrical equipment, and lighting turn-on time are shown in Figure 12. Among them, the personnel density is 32 m^2/person, the electrical equipment power density is 8 W/m^2, the lighting power density is 5 W/m^2, and the per capita fresh air volume is 30 m^3/(h.p).

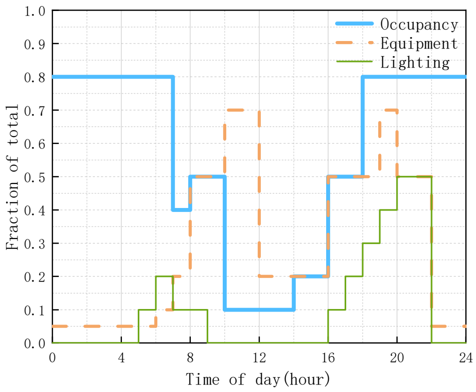


Figure 12. Occupancy rate and equipment power.

3.2. Model Calibration

The temperatures of bedroom 1 in household B from simulation and measurement are shown in Figure 13. There is a difference between the two in the details, which is due to the difference between the occupancy rate in the simulation and the actual situation. Nonetheless, the trends of the two are very similar, and the averages are almost the same. The simulated temperatures of other rooms are also very close to the measured temperatures. Coefficient of Variation of the Root-Mean-Square Error (CV[RMSE]) is 22.2%. Normalized Mean Bias Error (NMBE) is 10.6%.

3.3. Control Strategies for Ventilation and Shading

Natural ventilation is calculated using the airflow network model in EnergyPlus [39]. The infiltration ventilation is mainly carried out through the windows on the outer wall, the air mass flow exponent is set to 0.667, and the air mass flow coefficient is set to 0.001 kg/s. The module for the air-conditioning system was the ideal loads air system, which is used for prediction for building performance but does not require full modelling. The ideal load air system is usually the only air conditioning component, and the user does not need to specify the air loop, water loop, etc. [39].

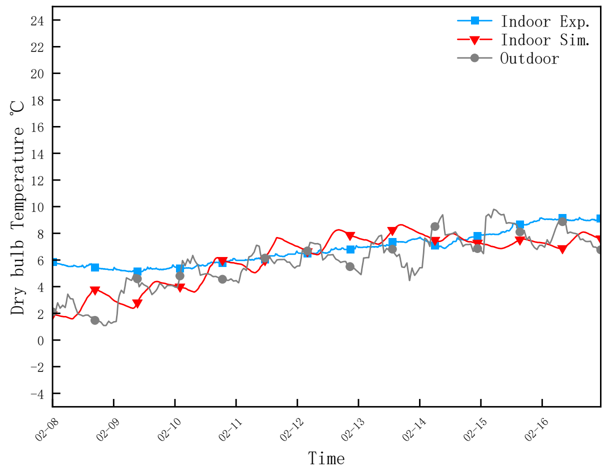


Figure 13. Simulated and measured temperatures of bedroom 1 in household C.

This study proposes four control strategies:

Control strategy 1, air-conditioning + infiltration wind. The ideal air conditioning system is chosen for 24-h continuous control of the room. The indoor temperature is maintained at 20–26 °C, and the windows are closed at all times. When the indoor temperature is >26 °C, the air conditioner is used for cooling. Heating is started when the indoor temperature is lower than 20 °C, and the per capita fresh air volume is 30 m^3/(h.p).

Control strategy 2, hybrid ventilation + infiltration wind. It is based on control strategy 1, which increases natural ventilation. Natural ventilation is performed when the indoor temperature met the following three conditions: 20 °C < indoor temperature < 26 °C, indoor temperature > outdoor temperature, and 15 °C < outdoor temperature < 30 °C.

Control strategy 3, hybrid ventilation with adaptive thermal comfort model in ASHRAE55. Richard et al. [40] proposed that the acceptable mean outdoor temperature is between 10 °C and 33.5 °C under natural ventilation. Based on the suggestion from Chen et al. [41], the acceptable indoor operative temperature for 90% of the month was set in Table 2 by the hybrid ventilation availability manager in EnergyPlus. It can be seen that the local period from March to November is suitable for hybrid ventilation. When the indoor operative temperature is within the range in Table 2, natural ventilation is performed. Otherwise, the window is closed and heating or cooling is performed.

Table 2. Indoor operative temperature for adaptive thermal comfort under natural ventilation, °C.

Month	Monthly Mean Outdoor Temperature	90% Acceptance	
		Lower Temperature Limit	Upper Temperature Limit
1	5.5		
2	6.9		
3	10.1	18.4	23.4
4	16.4	20.4	25.4
5	21.5	22.0	27.0
6	25.6	23.2	28.2
7	28.5	24.1	29.1
8	27.3	23.8	28.8
9	23.3	22.5	27.5
10	23.3	22.5	27.5
11	13.4	19.4	24.4
12	7.0		

Control strategy 4, automatic sunshade. Based on control strategy 1, the automatic sunshade of the outer roller blind is added, which is opened when the indoor temperature is higher than 22 °C from 9:00 a.m. to 5:00 p.m. It has no natural ventilation, but the infiltration air volume is 0.1 h^{-1}, which is the same as that of control strategy 1.

3.4. Cases for Simulation

Based on the existing buildings and the four control strategies above, as shown in Table 3, the following five scenarios are summarized for the energy simulation in the next chapter.

Table 3. Description of cases for simulation.

Scenarios	Description	Insulation of Envelope	Control Strategy, Infiltration and Sunshade
Case 1	Existing apartment +air-conditioning	Old standards, JGJ134-2001	Control strategy 1 Infiltration, 1 h^{-1} No shading
Case 2	Passive apartment +air-conditioning	New standards, DBJ43/T017-2021	Control strategy 1 Infiltration, 0.1 h^{-1} No shading
Case 3	Passive apartment +hybrid ventilation	New standards, DBJ43/T017-2021	Control strategy 2 Infiltration, 0.1 h^{-1} No shading
Case 4	Passive apartment +hybrid ventilation with adaptive thermal comfort	New standards, DBJ43/T017-2021	Control strategy 3 Infiltration, 0.1 h^{-1} No shading
Case 5	Passive apartment +automatic sunshade	New standards, DBJ43/T017-2021	Control strategy 4 Infiltration, 0.1 h^{-1} Automatic shading

4. Simulation Results and Analysis

4.1. Effect of a Passive House

As shown in Figure 14, Case 1 represents an existing building, which is similar to the apartment investigated above. Case 2 represents a passive house, which is equivalent to adding thermal insulation and airtightness to Case 1. The heating energy consumption of Case 1 is 14 times that of Case 2, but the cooling energy consumption of the former is 4% lower than that of the latter. Obviously, the enhancement of thermal insulation and airtightness is very significant for the reduction of heating energy consumption, but it has the effect of increasing the cooling energy consumption.

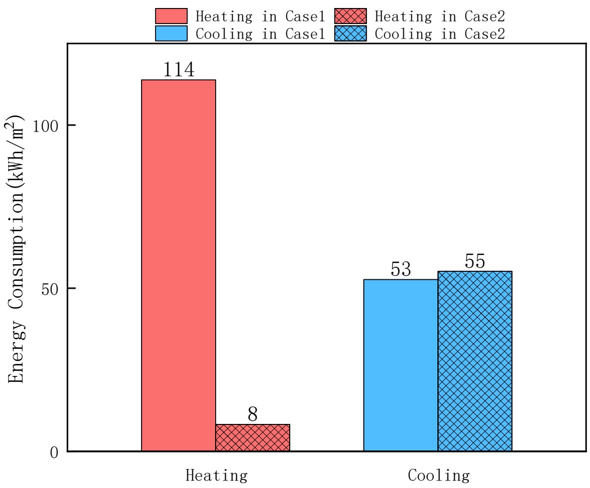
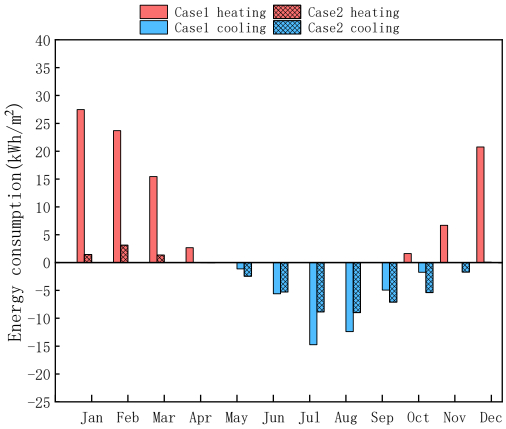
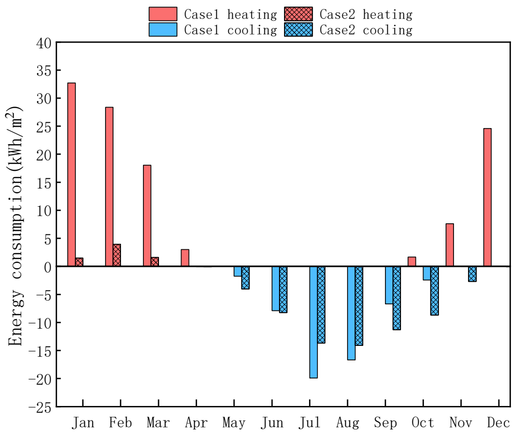


Figure 14. The impact of a passive house on energy consumption, Case 2 (passive apartment +air-conditioning) vs. Case 1 (existing apartment +air-conditioning).

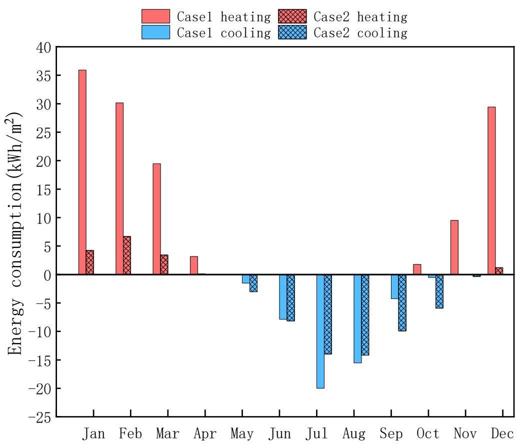
To further analyse the composition of energy consumption, Figure 15 shows the monthly average energy consumption of the living room, bedroom 1 and bedroom 2. The heating energy consumption of the living room dropped significantly in January, February, March, November and December, with an average drop of 92%. Among them, the heating energy consumption in April was reduced to 0, which means that the indoor comfortable temperature can be maintained completely relying on the thermal insulation of the building envelope. October's fall weather temperatures drop significantly, and thus there is a small amount of heating demand.



(**a**) Bedroom 1



(**b**) Living room 1



(**c**) Bedroom 2

Figure 15. Monthly energy consumption, Case 1 (existing apartment + air-conditioning) vs. Case 2 (passive apartment + air-conditioning).

May, June, September, and October are typical transition seasons in the region, and their cooling energy consumption rose by 67%. This shows that the building is overheated due to the enhancement of thermal insulation and airtightness. Even during the hotter days of November, there was a need for cooling. July and August are the summer months in the region, and cooling energy consumption dropped by 29%.

The changing trends and proportions of the living room and bedroom 2 are similar, as shown in Figure 15b,c, respectively.

Therefore, passive house renovation has a significant reduction effect on heating energy consumption. The cooling energy consumption in summer is slightly lower, but the overheating in the transition season causes the air conditioning energy consumption to increase. The combined effect of the two is a slight increase in cooling energy consumption. Therefore, to solve the problem of the overheating of passive houses, the cooling effect of hybrid ventilation and automatic shading will be discussed below.

4.2. Hybrid Ventilation

It can be seen from Section 4.1 that, after the enhancement of thermal insulation and airtightness, the building has overheated, and thus Section 4.2 discusses the energy-saving effect of adding automatic window ventilation, namely, Case 3. Among them, the apartment limits the indoor temperature between 20 °C and 26 °C by opening windows for natural ventilation. Since the trends and proportions of energy consumption changes in the three rooms are similar, the next analysis is only for the data of bedroom 1, as shown in Figure 16.

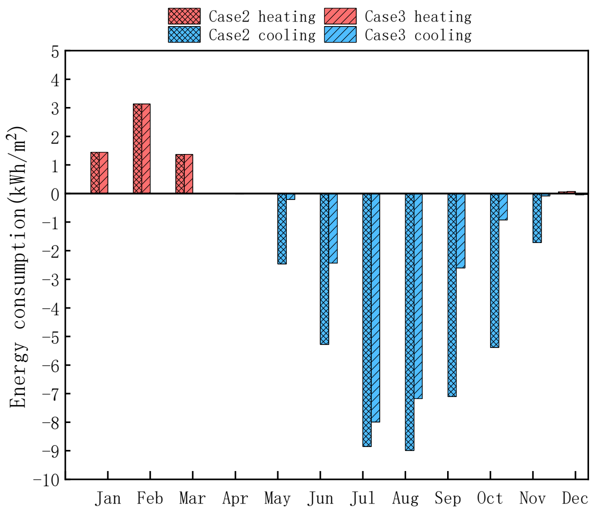
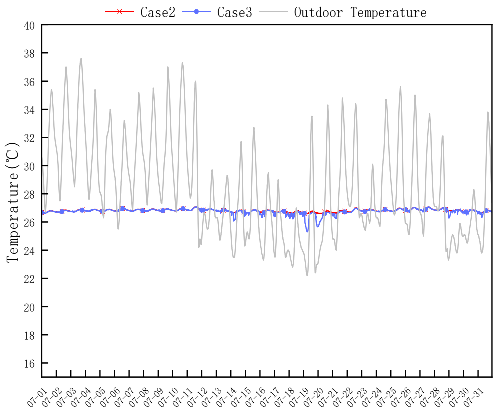


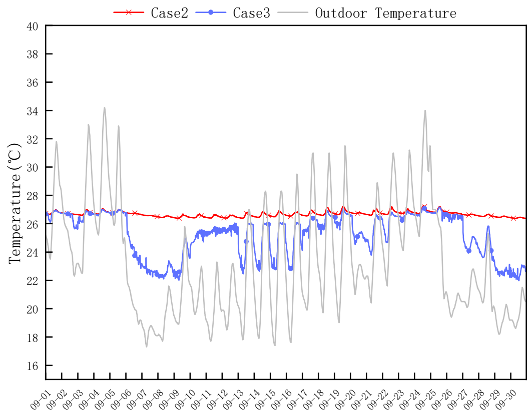
Figure 16. Monthly energy consumption, Bedroom 1, Case 3 (passive apartment + hybrid ventilation) vs. Case 2 (passive apartment + air-conditioning).

As seen from Figure 16, compared to Case 2 (passive apartment + air-conditioning), in Case 3 (passive apartment + hybrid ventilation) in the transition season (May, June, September, October, and a few days in November), the average energy consumption for cooling decreased by an average of 72%. Furthermore, in summer (July and August), the cooling energy consumption decreased by an average of 15%. However, the energy consumption for heating hardly changed.

To determine the reasons for the cooling energy consumption in the transition season and summer, we chose two typical months, July (transition season) and September (summer), and gave the curves of indoor and outdoor temperature changes. As shown in Figure 17a, the local outdoor temperature in July was much higher than 26 °C, and the temperature was lower than 26 °C on only a few days. Therefore, the indoor temperature of the two cases is higher than 26 °C most of the time, and the natural ventilation cooling potential is very small.



(**a**) July



(**b**) September

Figure 17. Hourly temperature, Bedroom 1, Case 2 (passive apartment + air-conditioning) vs. Case 3 (passive apartment + hybrid ventilation).

As shown in Figure 17b, the outdoor temperature was lower than 26 °C more than 50% of the time in September, and thus the ventilation cooling potential was obvious. The average temperature of Case 3 is 1.5 °C lower than that of Case 2 after using hybrid ventilation. According to statistics, the annual cooling energy consumption of the entire house is reduced by 43% on average. The Section 4.3 advances the discussion of larger temperature ranges when considering adaptive thermal comfort.

4.3. Hybrid Ventilation with Adaptive Thermal Comfort

According to the statistics of Richard et al. [39], the thermal comfort range of the human body under natural ventilation is significantly larger than that in an air-conditioned environment or heating environment. Case 4 uses the temperature range for adaptive thermal comfort in ASHRAE55. As shown in Figure 18, the average energy consumption for cooling during the transition season (May, June, September, October, and a few days in November) decreased by an average of 90%. Furthermore, in summer (July and August), the cooling energy consumption dropped by an average of 76%. Even in winter, heating energy consumption dropped by 24%. Obviously, this is due to the broadening of the temperature range.

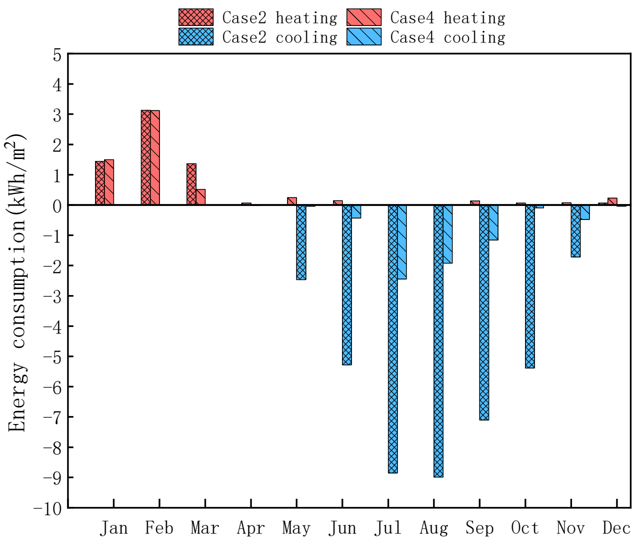
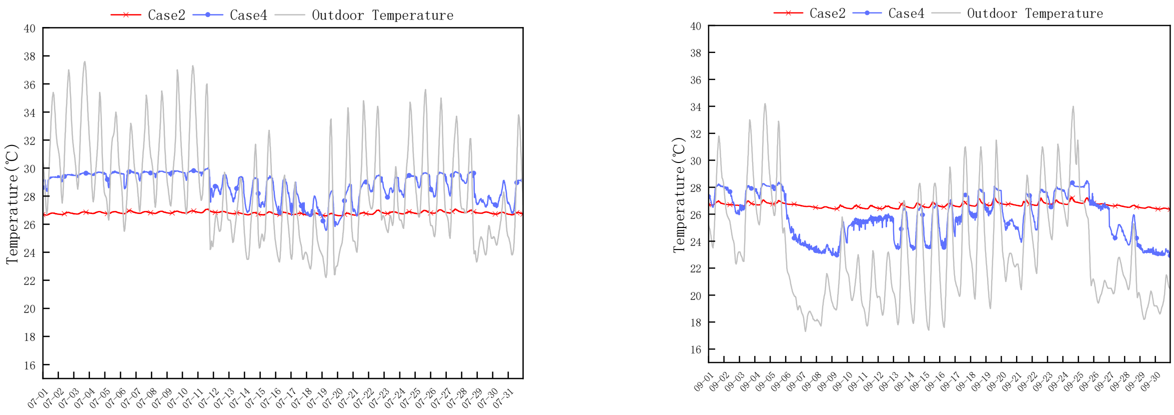


Figure 18. Monthly energy consumption, Bedroom 1, Case 4 (passive apartment + hybrid ventilation with adaptive thermal comfort) vs. Case 2 (passive apartment + air-conditioning).

Figure 19 shows the indoor and outdoor dry bulb temperatures for bedroom 1 in summer (July) and in the transition season (September). Figure 19a shows that in July, the indoor temperature of Case 4 was higher than 26 °C but less than 30 °C. The average temperature of Case 4 was 1.9 °C higher than that of Case 2.



(**a**) July (**b**) September

Figure 19. Hourly temperature, Bedroom 1, Case 4 (passive apartment + hybrid ventilation with adaptive thermal comfort) vs. Case 2 (passive apartment + air-conditioning).

As shown in Figure 19b, in September, the cooling effect of Case 4 was more obvious, which was 1.5 °C lower than that of Case 2. Compared to Case 3, Case 4 makes full use of natural ventilation for cooling.

In summary, the annual cooling energy consumption drops even more when the temperature range is the natural ventilation thermal comfort temperature range.

4.4. Automatic Sunshade

In addition to ventilation, shading is another means of eliminating overheating in a building. On the basis of Case 2, Case 5 adds an automatic sunshade. As shown in Figure 20, in bedroom 1, the energy consumption of Case 5 is reduced compared to that of Case 2 in the transition season and summer, and the reduction is 22.7%.

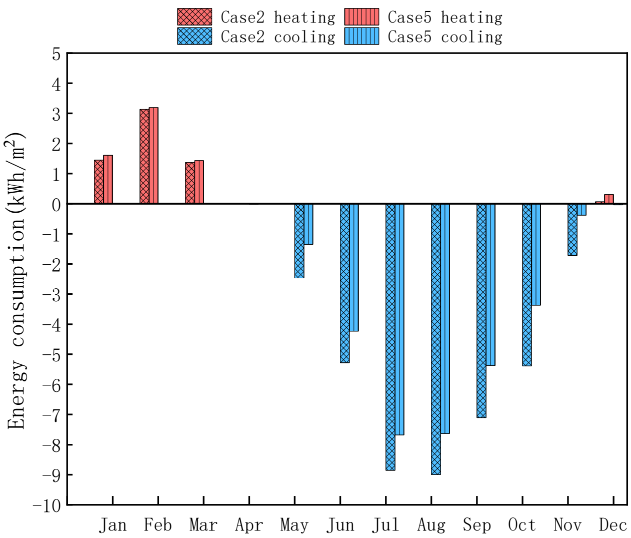
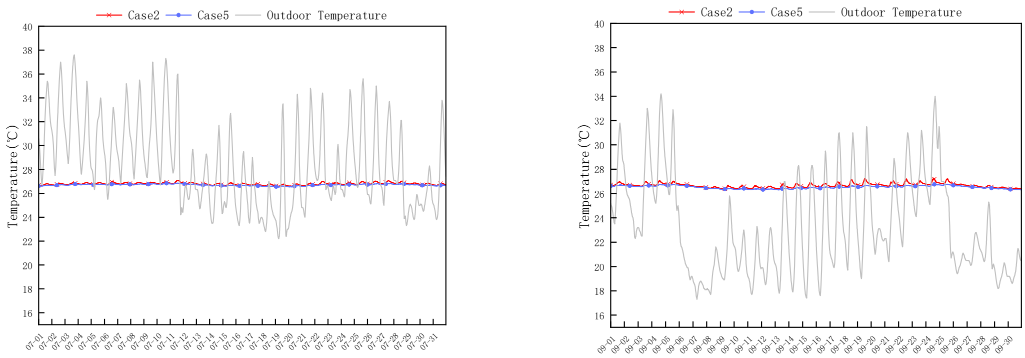


Figure 20. Monthly energy consumption, Bedroom 1, Case 5 (passive apartment + automatic sunshade) vs. Case 2 (passive apartment + air-conditioning).

As shown in Figure 21, the average temperature drops of Case 5 under shading control in summer (July) and the transitional season (September) were 0.05 °C and 0.07 °C, respectively, compared to Case 2.



(**a**) July (**b**) September

Figure 21. Hourly temperature, Case 5 (passive apartment + automatic sunshade) vs. Case 2 (passive apartment + air-conditioning).

After calculation, the annual cooling energy consumption of the entire apartment has been reduced by 17%. Thus, shade-controlled automatic shades have some cooling potential but are not as good as hybrid ventilation locally.

4.5. Airflow Rate

As shown in Figure 22, the monthly ventilation volumes of Case 1, Case 2, Case 3, and Case 4 are drawn on a graph, as shown in 22. Compared to the existing building (Case 1), the ventilation volume of the passive house (Case 2) is reduced by one tenth. After the use of hybrid ventilation (Case 3), the ventilation volume increased significantly in the transition season and summer. When considering the adaptive thermal comfort of natural ventilation (Case 4), the fresh air volume is further increased. However, ventilation is still low during the four winter months.

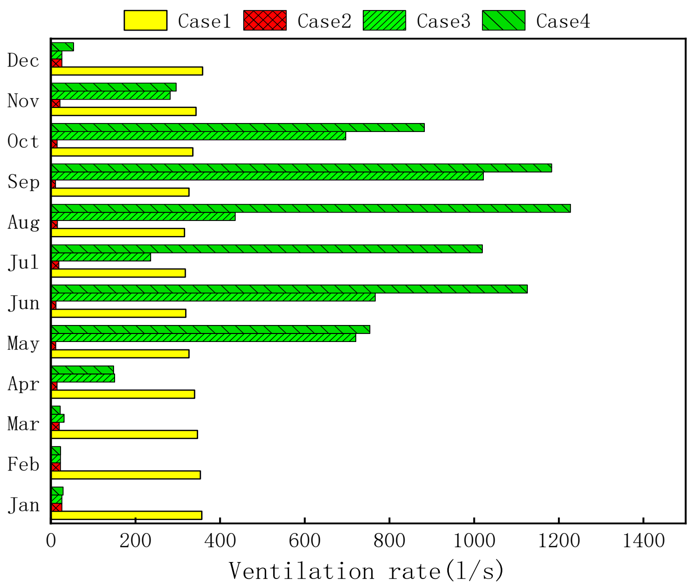


Figure 22. Monthly airflow rate, Bedroom1, Case 1 vs. Case 2 vs. Case 3 vs. Case 4.

5. Discussion

This paper first investigates the indoor thermal environment of two existing apartment buildings in winter. Two typical heating models in the existing building were investigated. One is high energy consumption and not warm enough, and another is low energy consuming but cold. The survey data show that the average indoor temperature is only 6.8 °C in the apartment without boiler heating. When there is boiler heating, the average temperature can only reach 16.2 °C. This shows that the thermal insulation and airtightness of the existing buildings are very poor.

Based on the survey data, this study established a similar model (Case 1) in EnergyPlus and enhanced the thermal insulation and airtightness of the envelope (Case 2). The predicted results show that when the thermal insulation and airtightness of the envelope structure are enhanced, the heating energy consumption in winter is reduced by 93%. However, the energy consumption of cooling in the summer and transitional seasons increased by 4%. This shows that the building has overheating problems, which came from the side effect of strengthening the thermal insulation and airtightness.

The overall energy consumption is reduced by 62%, which is similar to the results obtained in the Qingdao passive house located in a cold region of China (with an annual energy efficiency improvement of about 69% compared to current standards) [4]. In the concept of optimized passive house located in Brazil, the energy demand can be reduced by 55% to 83% [6]. If the passive house model in this study is optimized, further energy saving potential can be achieved.

As for the problem of overheating, we have adopted hybrid ventilation measures to solve it. When the indoor temperature range is set to 18–26 °C (Case 3), the cooling energy consumption can be reduced by approximately 40% compared to Case 2. When the temperature range is set in the thermal adaptation range (Case 4, approximately 10–33 °C), the cooling energy consumption can be reduced by 81% compared to Case 2.

Proof in reality is that the occupants need to turn on the air conditioner to cool down the house during the transition season in another apartment that has been converted into a passive house. In fact, according to our living experience in these areas of China named hot-summer and cold-winter, people are very accustomed to natural ventilation by opening windows. The reason for overheating was that the openable area on the windows was too small, which caused complaints from residents, as shown in Figure 23. These overheating phenomena and complaints are similar to findings in the literature [7–9].

Figure 23. The openable area of the window is very small in a local passive house for experiments.

In addition, the case of an automatic sunshade (Case 5) is also discussed. The results show a reduction in cooling energy consumption of approximately 17% relative to Case 2. Shading has a certain cooling effect, but it is not as good as natural ventilation by 76%.

In summary, the energy-saving effect of passive house technology in China's hot-summer and cold-winter regions is mainly reflected in winter. In the summer and transitional seasons, natural ventilation and shading are required for cooling; otherwise, the building will overheat.

Limitations of this study: The heat transfer coefficient and airtightness settings of the envelope are too simplified, and only two types of hybrid ventilation strategies and one shading control strategy are simulated. The effect of heat recovery is not discussed in this paper, and more field measurements are needed to validate the predictions. This article is a case study, the parameters are also approximate, and the results may have certain errors. Nonetheless, the simulated energy efficiency rate of change is similar to the real situation. The results provide a basic direction for local passive house reconstruction and provide a reference for the construction of passive houses in similar climate regions throughout the world. As a preliminary study, we have only made a short-term simulation forecast, and the conversion of apartments to passive houses is in progress. Due to the difficulty in adding too thick of an insulation structure in old buildings and the difficulty in ensuring air tightness during construction, the renovation of passive houses may not reach the level predicted by simulation. In the next step, we will study the renovated passive houses. Additionally, we try to simulate and predict the optimal envelope structure in the region through sensitivity analysis to reduce energy consumption.

6. Conclusions

In China's hot-summer and cold-winter areas, there is a large number of old apartments. Upon converting them into passive houses, the energy saving potential is still unknown. This study investigated the existing apartment building and then simulated the energy saving potential of the building with enhanced thermal insulation and airtightness through EnergyPlus. The results show the following:

1. The thermal insulation and airtightness of the existing local apartments are very poor. Enhancing the thermal insulation and airtightness of doors and windows can significantly reduce the energy consumption in winter by 62% overall. However, overheating will occur in transitional seasons and summer, which will increase the energy consumption for cooling.
2. Hybrid ventilation can solve the problem of overheating well, especially considering the adaptive comfort range for natural ventilation. The energy consumption will reduce by 81% overall.
3. Automatic shading has a certain cooling effect by 17% reducing of energy consumption of cooling, but it is lower than ventilation cooling by 76% reducing.

In future research, we will conduct measurements in an apartment which has just been refurbished as passive house to determine air quality, thermal comfort, and energy consumption in this area, and study the optimum level of the thermal insulation for the retrofit building.

Author Contributions: Writing—original draft preparation; investigation, Y.Z. and Y.L. (Yonghan Li); writing—review and editing, W.Y., M.Z. and X.H.; supervision, Y.L. (Yongcun Li), Y.O. and J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Natural Science Foundation of China (No. 51308206), International Science and Technology Cooperation Program of China (No. 2014DFA72190), National Natural Science Foundation of Hunan Province of China (No. 2021JJ30269, 2021JJQNJJ0546, 2020JJ6028), Natural Science Foundation of Guangxi (No. 2018GXNSFAA281212).

Acknowledgments: The original idea for the study came from the collaboration with IEA- EBC-Annex62 Ventilative Cooling and IEA-EBC-Annex 80 Resilient Cooling.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Research Center of Tsinghua University for Building Energy Efficiency. *2020 Annual Report on China Building Energy Efficiency*; China Construction Industry Press: Beijing, China, 2021. (In Chinese)
2. Ionescu, C.; Baracu, T.; Vlad, G.-E.; Necula, H.; Badea, A. The Historical Evolution of the Energy Efficient Buildings. *Renew. Sustain. Energy Rev.* **2015**, *49*, 243–253. [CrossRef]
3. Schnieders, J.; Feist, W.; Rongen, L. Passive Houses for Different Climate Zones. *Energy Build.* **2015**, *105*, 71–87. [CrossRef]
4. Han, F.; Liu, B.; Wang, Y.; Dermentzis, G.; Cao, X.; Zhao, L.; Pfluger, R.; Feist, W. Verifying of the Feasibility and Energy Efficiency of the Largest Certified Passive House Office Building in China: A Three-Year Performance Monitoring Study. *J. Build. Eng.* **2022**, *46*, 103703. [CrossRef]
5. Wang, Y.; Du, J.; Kuckelkorn, J.M.; Kirschbaum, A.; Gu, X.; Li, D. Identifying the Feasibility of Establishing a Passive House School in Central Europe: An Energy Performance and Carbon Emissions Monitoring Study in Germany. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109256. [CrossRef]
6. Vettorazzi, E.; Figueiredo, A.; Rebelo, F.; Vicente, R.; Grala da Cunha, E. Optimization of the Passive House Concept for Residential Buildings in the South-Brazilian Region. *Energy Build.* **2021**, *240*, 110871. [CrossRef]
7. Ridley, I.; Clarke, A.; Bere, J.; Altamirano, H.; Lewis, S.; Durdev, M.; Farr, A. The Monitored Performance of the First New London Dwelling Certified to the Passive House Standard. *Energy Build.* **2013**, *63*, 67–78. [CrossRef]
8. Rohdin, P.; Molin, A.; Moshfegh, B. Experiences from Nine Passive Houses in Sweden—Indoor Thermal Environment and Energy Use. *Build. Environ.* **2014**, *71*, 176–185. [CrossRef]
9. Fokaides, P.A.; Christoforou, E.; Ilic, M.; Papadopoulos, A. Performance of a Passive House under Subtropical Climatic Conditions. *Energy Build.* **2016**, *133*, 14–31. [CrossRef]
10. Cakyova, K.; Figueiredo, A.; Oliveira, R.; Rebelo, F.; Vicente, R.; Fokaides, P. Simulation of Passive Ventilation Strategies towards Indoor CO_2 Concentration Reduction for Passive Houses. *J. Build. Eng.* **2021**, *43*, 103108. [CrossRef]
11. About Mixed-Mode. Available online: https://cbe.berkeley.edu/mixedmode/aboutmm.html (accessed on 28 December 2022).
12. Deuble, M.P.; de Dear, R.J. Mixed-Mode Buildings: A Double Standard in Occupants' Comfort Expectations. *Build. Environ.* **2012**, *54*, 53–60. [CrossRef]
13. Luo, M.; Cao, B.; Damiens, J.; Lin, B.; Zhu, Y. Evaluating Thermal Comfort in Mixed-Mode Buildings: A Field Study in a Subtropical Climate. *Build. Environ.* **2015**, *88*, 46–54. [CrossRef]
14. Forgiarini Rupp, R.; Ghisi, E. Predicting Thermal Comfort in Office Buildings in a Brazilian Temperate and Humid Climate. *Energy Build.* **2017**, *144*, 152–166. [CrossRef]
15. Fiorentini, M.; Serale, G.; Kokogiannakis, G.; Capozzoli, A.; Cooper, P. Development and Evaluation of a Comfort-Oriented Control Strategy for Thermal Management of Mixed-Mode Ventilated Buildings. *Energy Build.* **2019**, *202*, 109347. [CrossRef]
16. Barbadilla-Martín, E.; Salmerón Lissén, J.M.; Guadix Martín, J.; Aparicio-Ruiz, P.; Brotas, L. Field Study on Adaptive Thermal Comfort in Mixed Mode Office Buildings in Southwestern Area of Spain. *Build. Environ.* **2017**, *123*, 163–175. [CrossRef]
17. Ezzeldin, S.; Rees, S.J. The Potential for Office Buildings with Mixed-Mode Ventilation and Low Energy Cooling Systems in Arid Climates. *Energy Build.* **2013**, *65*, 368–381. [CrossRef]
18. Rupp, R.F.; de Dear, R.; Ghisi, E. Field Study of Mixed-Mode Office Buildings in Southern Brazil Using an Adaptive Thermal Comfort Framework. *Energy Build.* **2018**, *158*, 1475–1486. [CrossRef]
19. Sánchez-García, D.; Rubio-Bellido, C.; del Río, J.J.M.; Pérez-Fargallo, A. Towards the Quantification of Energy Demand and Consumption through the Adaptive Comfort Approach in Mixed Mode Office Buildings Considering Climate Change. *Energy Build.* **2019**, *187*, 173–185. [CrossRef]
20. Mhuireach, G.Á.; Brown, G.Z.; Kline, J.; Manandhar, D.; Moriyama, M.; Northcutt, D.; Rivera, I.; Van Den Wymelenberg, K. Lessons Learned from Implementing Night Ventilation of Mass in a Next-Generation Smart Building. *Energy Build.* **2020**, *207*, 109547. [CrossRef]
21. Chen, J.; Brager, G.S.; Augenbroe, G.; Song, X. Impact of Outdoor Air Quality on the Natural Ventilation Usage of Commercial Buildings in the US. *Appl. Energy* **2019**, *235*, 673–684. [CrossRef]
22. Ledo Gomis, L.; Fiorentini, M.; Daly, D. Potential and Practical Management of Hybrid Ventilation in Buildings. *Energy Build.* **2021**, *231*, 110597. [CrossRef]
23. Hu, J.; Karava, P. Model Predictive Control Strategies for Buildings with Mixed-Mode Cooling. *Build. Environ.* **2014**, *71*, 233–244. [CrossRef]
24. May-Ostendorp, P.; Henze, G.P.; Corbin, C.D.; Rajagopalan, B.; Felsmann, C. Model-Predictive Control of Mixed-Mode Buildings with Rule Extraction. *Build. Environ.* **2011**, *46*, 428–437. [CrossRef]
25. Zhao, J.; Lam, K.P.; Ydstie, B.E.; Loftness, V. Occupant-Oriented Mixed-Mode EnergyPlus Predictive Control Simulation. *Energy Build.* **2016**, *117*, 362–371. [CrossRef]
26. Alzoubi, H.H.; Al-Zoubi, A.H. Assessment of Building Façade Performance in Terms of Daylighting and the Associated Energy Consumption in Architectural Spaces: Vertical and Horizontal Shading Devices for Southern Exposure Facades. *Energy Convers. Manag.* **2010**, *51*, 1592–1599. [CrossRef]

27. Kim, G.; Lim, H.S.; Lim, T.S.; Schaefer, L.; Kim, J.T. Comparative Advantage of an Exterior Shading Device in Thermal Performance for Residential Buildings. *Energy Build.* **2012**, *46*, 105–111. [CrossRef]
28. Van Den Wymelenberg, K. Patterns of Occupant Interaction with Window Blinds: A Literature Review. *Energy Build.* **2012**, *51*, 165–176. [CrossRef]
29. O'Brien, W.; Kapsis, K.; Athienitis, A.K. Manually-Operated Window Shade Patterns in Office Buildings: A Critical Review. *Build. Environ.* **2013**, *60*, 319–338. [CrossRef]
30. Karlsen, L.; Heiselberg, P.; Bryn, I.; Johra, H. Solar Shading Control Strategy for Office Buildings in Cold Climate. *Energy Build.* **2016**, *118*, 316–328. [CrossRef]
31. Tabadkani, A.; Roetzel, A.; Li, H.X.; Tsangrassoulis, A. A Review of Automatic Control Strategies Based on Simulations for Adaptive Facades. *Build. Environ.* **2020**, *175*, 106801. [CrossRef]
32. Yun, G.; Yoon, K.C.; Kim, K.S. The Influence of Shading Control Strategies on the Visual Comfort and Energy Demand of Office Buildings. *Energy Build.* **2014**, *84*, 70–85. [CrossRef]
33. Meteorological Information Center of China Meteorological Administration; Department of Building Technology and Science, Tsinghua University. *Meteorological Data Set for Building Thermal Environment Analysis in China*; China Architecture & Building Press: Beijing, China, 2005. (In Chinese)
34. Ministry of Housing and Urban-Rural Development of the People's Republic of China. *JGJ134-2001*; Design Standard for Energy Efficiency of Residential Buildings in Hot-Summer and Cold-Winter Zone. China Architecture & Building Press: Beijing, China, 2001. (In Chinese)
35. Ministry of Housing and Urban-Rural Development of the People's Republic of China. *GB 50736-2012*; Design Code for Heating Ventilation and Air Conditioning in Civil Buildings of China. China Architecture & Building Press: Beijing, China, 2012. (In Chinese)
36. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China. *GBT18883-2002*; Indoor Air Quality Standard. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China: Beijing, China, 2002. (In Chinese)
37. Ministry of Housing and Urban-Rural Development of Hunan Province in China. *DBJ43/T017-2021*; Design Standard for Energy Efficiency of Passive Ultra-Low Energy Residential Buildings in Hunan. China Architecture & Building Press: Beijing, China, 2021. (In Chinese)
38. Ministry of Housing and Urban-Rural Development of the People's Republic of China. *JGJ134-2010*; Design Standard for Energy Efficiency of Residential Buildings in Hot-Summer and Cold-Winter Zone. China Architecture & Building Press: Beijing, China, 2010. (In Chinese)
39. U.S. Department of Energy. *EnergyPlus Documentation*; U.S. Department of Energy: Washington, DC, USA, 2021.
40. de Dear, R.J.; Brager, G.S. Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55. *Energy Build.* **2002**, *34*, 549–561. [CrossRef]
41. Chen, X.; Yang, H.; Zhang, W. Simulation-Based Approach to Optimize Passively Designed Buildings: A Case Study on a Typical Architectural Form in Hot and Humid Climates. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1712–1725. [CrossRef]