Application of Passive Building Concept

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Abstract. In the current context of increasing global energy demands, buildings contribute to nearly 40% of these demands. To alleviate this issue, the concept of passive buildings has been proposed. Several passive strategies are used for designing a passive building: good insulation and openings, optimal orientation and shading, heat recovery ventilation (HRV) in a heating, ventilation, and air conditioning (HVAC) system, and airtight and thermal bridge reduced design. These four strategies can enhance both energy efficiency and indoor thermal comfort performance. In this study, a new residential passive house, which is located at London, is designed. And its total annual energy consumption and indoor thermal comfort performance are simulated in DesignBuilder. The design of the new passive house makes reasonable integration of the four passive strategies mentioned above, aiming to discuss how well these strategies can help to reach the passive standard. As a result, the simulation results meet the standard, with a total annual energy consumption of 115 kWh/m². Meanwhile, the indoor air temperature of the house is maintained at 20-25°C for almost 98% of the time in a year, as well as the indoor air humidity stays between 30% and 70%. DesignBuilder gives that the energy performance certificate (EPC) of this new passive house achieves Level A, which has much better energy efficiency than other households in England and Wales.

Keywords: Passive House, Passive Design, Energy Efficiency, Indoor Thermal Comfort, DesignBuilder.

1 Introduction

Nowadays, the global population has witnessed an increasing trend, from 5 billion in 1986 to 7.8 billion by mid-2020. In most of the developing countries, the global population would likely keep rising to 9.7 billion by 2050 and 10.9 billion by 2100, even more [1]. This growing trend will push the development of urbanization and increasing demand for house buildings with their huge energy consumption, carbon dioxide (CO2) emissions, and other environmental impacts. Since mid-century, the energy demand had nearly 1% growth annually in global building sector. And this demand has increased from 30% in 2010 to 35% in 2022. Simultaneously, the CO2 emissions also reached the peak in 2022, with 37% of the global CO2 emissions [2]. In this dire situation, the International Energy Agency (IEA) has set a target that all new buildings

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should be net zero from 2030, and both the new buildings and retrofit of existing buildings should achieve zero CO2 emission in 2050 [3]. Therefore, application of the passive building concept is the best approach to alleviating this situation. In this study, a new residential house integrating with the passive house concept will be simulated in DesignBuilder to explore its indoor thermal comfort and energy efficiency.

2 Literature Review

Passive building, which is the symbol of little or no energy usage and CO_2 emission buildings, was firstly developed in Germany [4]. According to the Criteria of Passive Buildings [5], the passive standard of residential house associated with the conditions in London are listed in Table 1.

Table 1. Passive standard of residential house based on weather conditions in London.

Design Criteria	Unit	Optimal Value
Exterior Insulation	W/m^2K	0.15
Interior Insulation	W/m^2K	0.35
Openings	W/m^2K	0.85-1.10
Thermal Bridge	W/mK	0.04
Airtightness	n50/h	0.6
Heat Recovery	%	75
Heating Demand	kWh/m^2	25
Cooling Demand	kWh/m^2	15+variable allowance
Annual Energy Consumption	kWh/m^2	120
Indoor Temperature	°C	20-25
Indoor Humidity	%	40-60
Annual Overheating Hours	h	876

To maintain a comfortable living environment, the indoor air temperature should be kept between 20°C and 25°C, and the indoor humidity should be kept between 40% and 60%, with a possible 10% variation at both ends of the scale (30% to 70%) [6]. Meanwhile, the total annual energy consumption should not exceed 120 kWh/m^2, including heating demand within 25 kWh/m^2. The maximum cooling demand depends on the real situation, because of the inclusion of dehumidification consumption. In addition, the annual uncomfortable time, which is defined as the time out of the temperature and humidity criteria, should not exceed 10% of a year (876 hours). In this case, four passive strategies which are often used in design phase could help to reach the standard.

The first strategy is using good thermal insulation and openings. The building envelope, which is known as external structure of a building including walls, roofs, floors, and openings (windows and doors), is the key factor in improving the indoor thermal performance of the building. Good insulation materials and openings always have small thermal transmittance (U-value, with the unit of W/m^2K). The smaller the U-value is, the better the thermal performance they will be. This reduces heat transfer from the higher temperature side to lower side. Hence, heating and cooling demands could be reduced [7].

The second strategy is using optimal orientation and shading. Making sure that the window side of the building facing the true south within a 20-degree range to receive the maximum sunlight can enhance the energy efficiency. This design enables sunlight to heat the building naturally to reduce the energy consumption. Additionally, some shading features such as growing trees or sunshield can provide extra shading to prevent overheating, especially the overmuch sunlight in summer [8,9].

The third strategy is using good ventilation. Integration of HRV in HVAC system is commonly used in passive buildings. This ventilator uses the emitted indoor air to preheat the intake outdoor air due to the proximity of two air flows. This not only saves substantial amounts of energy, but it also has a lower cost than the normal air conditioning system [10,11].

The fourth strategy is mitigating the thermal bridge and air leakage. They always occur in building envelope, such as edges, corners, or connections between floors, walls, roofs, and openings. Existence of them will lead to significant heat loss through these weak points. To improve the thermal performance and energy efficiency, the thermal bridge in the building envelop should be maximally eliminated and the whole building should be extremely airtight [12,13].

The core concept of passive building design is using a series of strategies to prevent heat loss happening in the building envelope. By simultaneously achieving the four strategies introduced above, the energy consumption of the house can be maintained within the standard values. Meanwhile, the indoor thermal performance of the house can also be effectively enhanced.

3 Design and Modelling

To learn more about the building envelope of the passive house, some case studies in London area have shown that building envelope is typically composed of 4 layers with different materials and thickness: external cladding, inner load-bearing structure, insulation material, and internal finish. The building envelope of each case is within the passive standard (U-value lower than 0.15 and 0.35 for exterior and interior wall). As for the openings, U-value for each case is between 0.5 and 0.9, which also meet the passive standard.

The new-designed passive house with a total area of 267 m^2 consists of two floors. The floor plan of the ground floor and first floor are shown in Figure 1, which have been divided into nine zones in total. Based on the information learnt from the case studies, the building envelope in this study will use brick as external cladding, oriented strand board as inner load-bearing structure covered with polyethylene airtightness membrane, fiberglass as the insulation material, and plasterboard used for internal finish. The U-value of the exterior wall, interior wall, floor, and roof are obtained from DesignBuilder, with 0.052, 0.143, 0.053, and 0.052 respectively. A quadruple glazing template in DesignBuilder is used for openings, with the value of 0.78. The whole building envelope meets the passive standard.

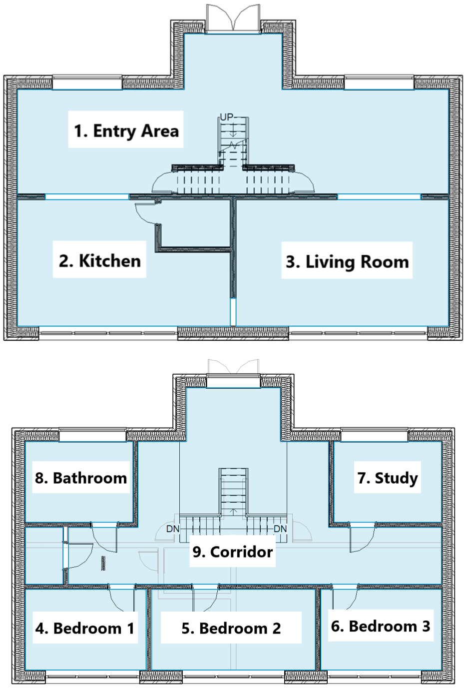


Fig. 1. Ground floor plan and first floor plan of the house.

According to the orientation and shading passive strategy, the window side of the house is designed to face the true south. The roof overhang is designed to extend 2.5 m outward, and the window side is covered with 1.5 m panels, which are both shown in Figure 2. This can prevent overmuch sunlight coming into the house to cause overheating in summer. For the HVAC system, an air-to-water dedicated outdoor air system (DOAS)is used, where the heating and cooling coils are connected to the domestic water chiller and boiler. When the temperature of intaking air is lower or higher than the setting values, which is defined from 20℃ to 21℃ in DesignBuilder, the air will be preheated or precooled before entering the house. Another humidifier is added to control the indoor humidity within the standard level, with the setting range from 30% to 60%. HRV with 75% efficiency is installed in DOAS. To reduce the heat loss within the building envelope, the thermal bridge should be mitigated in building envelope. However, it is not always possible to reduce thermal bridge into zero at reasonable costs and with standard methods. The Criteria of Passive Buildings gives a reference value for installation with a thermal bridge value of 0.04, which is a reasonable value for time-saving design [5]. As for building airtightness, the value should be lower than 0.6 n50/h according to passive standard. To have the best indoor thermal performance, the airtightness has been set at 0.2 n50/h in the following analysis section[14].

The model of the new-designed passive house in DesignBuilder is shown in Figure 2. In addition, the operating schedule for each zone needs to be set. In this study, a family of four (parents with their two children) is assumed living in this passive house.

During the weekdays, all family members are assumed to go to work and school. While during the weekends and holidays, they will go out for trips or dining. Hence, the operating schedule of the facilities and equipment of each zone are assumed to work for 12 hours a day. Furthermore, to ensure good airtightness and thermal comfort of the house, natural ventilation will not be considered, but HVAC system and mechanism ventilation of each zone are set to work for 24 hours a day.

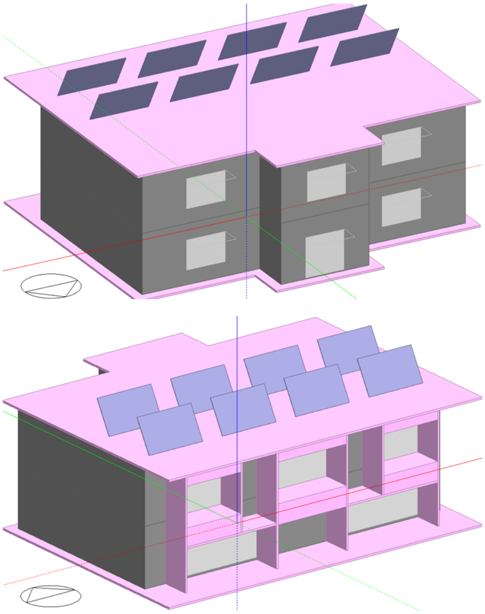
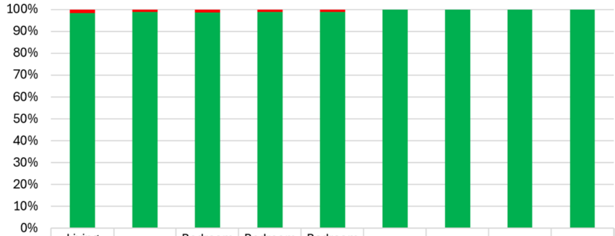


Fig. 2. Model of the new-designed passive house in DesignBuilder, with eight photovoltaic solar collectors and 2.5m sunshield on the roof, 1.5m sunshield around windows.

4 Result and Discussion

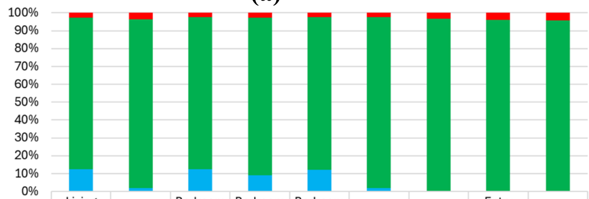
From Figure 3, the result indicates that the indoor air temperature exceeds 25℃ for only approximately 2% of the year (175 hours). As for the indoor air humidity, the average time when the humidity is smaller than 40% and larger than 60% is equal to nearly 9% of the time in a year (788 hours). Since the indoor air humidity has a possible variation of 10% and both ends of the scale are allowable, the average time for the humidity ranging from 30% to 70% will be reduced to only 0.1% of the time in a year (9 hours). Considering both the indoor air temperature and humidity, the total uncomfortable time of this new-designed passive house meets the passive standard, which is 2.44% of the time in a year (213.5 hours) given by the DesignBuilder.

To check whether the energy consumption meets the passive standards, each consumption will be divided by the total house area 267 m^2. Figure 4 indicates the total annual energy consumption for each section, with 4.24 and 32.4 kWh/m^2 for heating and cooling. Heating consumption is much smaller than the passive standard (25 kWh/m²), however, the cooling consumption is much larger than the standard (15 + variable allowance kWh/m²). A reasonable explanation is that during the simulation stage in DesignBuilder, the dehumidification consumption was included in cooling consumption, hence a relatively large number has occurred. As a result, the energy consumption for one year is equal to 137 kWh/m² in total. Although this value is larger than the 120 kWh/m² in passive standard, after offsetting the photovoltaic power generated by the eight photovoltaic solar collectors, with the value of 23.7 kWh/m², the total energy consumption will be reduced to 113.3 kWh/m². This value meets the passive standard.



	Living Room	Kitchen	Bedroom 2	Bedroom 1	Bedroom 3	Study	Bathroom	Entry Area	Corridor
T > 25°C	1.68%	1.19%	1.26%	0.99%	1.14%	0%	0%	0%	0%
20°C < T < 25°C	98.32%	98.81%	98.74%	99.01%	98.86%	100%	100%	100%	100%
T < 20°C	0%	0%	0%	0%	0%	0%	0%	0%	0%

(a)



	Living Room	Kitchen	Bedroom 2	Bedroom 1	Bedroom 3	Study	Bathroom	Entry Area	Corridor
Hu > 70%	0.03%	0.26%	0.05%	0.06%	0.05%	0.03%	0.09%	0.18%	0.19%
Hu > 60%	2.52%	3.62%	2.43%	2.55%	2.29%	2.40%	3.22%	3.81%	4.25%
40% < Hu < 60%	85.03%	94.37%	84.95%	88.28%	85.59%	95.83%	96.78%	96.19%	95.75%
Hu < 40%	12.44%	2.01%	12.61%	9.18%	12.11%	1.77%	0%	0%	0%
Hu < 30%	0%	0%	0%	0%	0%	0%	0%	0%	0%

(b)

Fig. 3. (a) Indoor air temperature results; (b) indoor air humidity results.

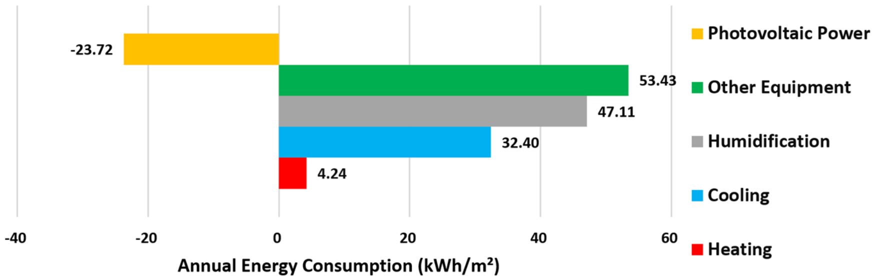


Fig. 4. Total annual energy consumption per area from DesignBuilder.

5 Conclusion

In conclusion, the analysis results of this new-designed passive house are in agreement with the passive standard. Although the total energy consumption is larger than the passive standard, photovoltaic power as a renewable energy used in this passive house has successfully reduced the consumption within the standard value. For almost 98% of the time in a year, the indoor air temperature and humidity can be maintained at a level from 20°C to 25°C and from 30% to 70% respectively. Only 115 kWh/m² of the total annual energy consumption achieved this performance. This result has shown a strong effectiveness of the application of these four passive strategies in the design phase of a building. Furthermore, the EPC of this new-designed passive house has also been simulated in DesignBuilder. EPC is intended to inform potential buyers or tenants about the energy performance of a building. This certificate will provide an energy rating of the building from A to G, where A is very energy-saving, and G is extremely energy-consuming [15]. For this house, it achieves a grade of 17, which belongs to Level A. And this result is much better than the average Level D in England and Wales. As the next step, more detailed and deeper research should be conducted for each passive strategy to understand the improvements provided by each strategy more accurately.

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