# Tropically Adapted Passive Building: The Impact of Building Design and Double Glazing on Ambient Temperature and Windows' Inner Surface Temperature

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## Abstract

The high energy consumptions in buildings has been reported as one of the key contributors to global warming since the energy is mostly generated from fossil sources which is responsible for large emission of carbon dioxide. Hence, there has been series of awareness on the need for an energy efficient building that can drastically reduce energy consumption. In this study, the performance of a tropically adapted passive building (PB) was investigated in real hot tropical climate of Malaysia. Two mock-up buildings were built to represent a "green", made of clay brick double-glazed PB and a conventional, made of concrete "red" building (RB). The ambient temperature of PB was found to be always lower than RB throughout the 7-days experiment during typical sunny/cloudy weather constellations. Besides that, the double-glazed windows installed in PB could better withstand the radiation effect of the sunlight hence maintain a much lower window IST than the single-glazed windows in RB. The average ambient temperatures of PB and RB are 29.9 ºC and 31.6 ºC respectively while the average window ISTs of PB and RB are 31.6 ºC and 33.8 ºC respectively. The study concludes that PB provides a better protection against thermal discomfort and the window is one of the critical contributors that affect ambient temperature in a warm tropical climate.

**Keywords**
passive building, green building, double glazing, window, heat gain, ambient temperature

## 1. Introduction

The quest for energy efficiency in building has placed a demand for designing and modeling energy efficient buildings. During the designing stage of a building, thermal efficiency is often evaluated in terms of energy consumption in order to determine how best energy efficiency can be achieved. The primary objective of every building is to provide essential comfort in the indoor environment. Achieving this will require a good understanding of the external environment such as severe temperature, wind, rain, and so and how these external environments influence the comfort of the indoor environment. Series of parameters that influence the energy performance of residential buildings has been reported by Zhao et al. (2015) using a case study of a Chinese climate zone. Parameters such as window to wall ratio, shading coefficients, thickness of EPS board, heat transfer coefficient of window were found to have varying effects on the energy demand for cooling in the building.

Several authors have also reported the influence of the external environment on the indoor environment comfort. Dhaka et al. (2013) reported the effect of building envelop on the thermal environment conditions of a naturally ventilated building block in tropic climate. The authors measured the building envelop such as the roof U-value, wall U-value, glass U-value and the g-value (glass solar heat gain coefficient), plus the roof reflectance to analyze the indoor temperature. The effects of these parameters were analyzed using the heat balance model and the adaptive model of the thermal comfort. The study revealed that there was variation in the comfortable temperature of the building from 20.3 ºC to 31.5 ºC under warm tropical climate conditions.

In a recent study, Tuck et al. (2019) reported the effectiveness of free running passive cooling strategies for indoor thermal environments in Malaysia. The authors investigated several configurations such as scenario without natural ventilation, i.e. full 24h ventilation, day ventilation, and night ventilation. The findings revealed that the mean indoor temperature under free running natural ventilation was in the range of 27 ºC-37 ºC, while the range was 27 ºC to 33 ºC in the mixed mode. According to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the highest Upper Space Limit (USL) of international tropical standards is 26.1°C (without velocity) or 28.6°C (with velocity of tolerable 0.7 m/second effects in -2.5°C). This study aims to measure the impact of architectural values on the indoor or ambient temperature of a building that affect the tropical thermal comfort level using the USL of 28.6 °C as the tropical residential thermal comfort (TRTC) benchmark (e.g. Sabarinah et al 2007). Besides that, the specific impact of double glazing on window's inner surface temperature (IST) will also be determined. To the best of the authors' knowledge, this is the first ever reported study on the impact of passive green design with a special focus on double-glazed windows on the ambient temperature of mock-up buildings in real outdoor tropical climate.

## 2. Methodology

The project consists the construction of two mock-up buildings which are; i) Passive building (PB) with green house design and ii) Red building (RB) with conventional house design. Each of the mock-up with dimensions of 3 m high, 3 m wide, and 3 m deep was constructed as life lab or room where a person can stand, sit and even sleep inside. The average window-to-wall ratio is 31% East, South and West and North 0%. Positioning was identical and shading was almost equal, a few compromises in terms of the sun path had to be made due to space restrictions. The PB walls are made of double layer clay bricks with a low U-value of 0.88. Meanwhile, the RB portrays the common, typical control unit of a standard low-cost house made of basically sand cemented bricks or concrete. Further details of the design of both buildings are provided in Table 1 below.

Table 1: Architectural design of passive building (PB) and red building (RB).

| Mock-Up Passive Building (PB) | Mock-Up Red Building (RB) |
|---|---|
|  |  |
| • Almost airtight<br>• High insulation capability walls<br>• Ventilated roof<br>• Solar panels for LED lighting<br>• Sun protection double-glazed windows<br>• UPVC window frame<br>• External shutters | • Open air (closed for the experiment)<br>• Standard concrete and bricks<br>• Uninsulated roof<br>• Apron with drain<br>• Single-glazed windows<br>• Aluminium window frame<br>• Fluorescent lights |

We would like to take note that for the purpose of the experiment we had closed the single glazed windows of the RB to measure the impact of the double glazing in the PB. With all windows and doors tightly closed, the ambient temperature of the buildings was measured by Voltcraft data loggers. Meanwhile, the inner surface temperature of the single-glazed of RB and double-glazed window of PB was measured by Voltcraft digital infrared thermometer. The period for the simulation was from the dry months of March to April 2016 with a total of 7 selected sunny-cloudy days (with hardly any significant rain). The buildings are located at British-Malaysian Institute of Universiti Kuala Lumpur (BMI-UniKL) at Gombak, Selangor, Malaysia.

The performance of PB was evaluated based on the following indicators: (1) mean and maximum temperatures of ambient and window inner surface, (2) temperature difference ratio (TDR), and (3) the percentage of overheated hours based on the sigma level. The three variables are adapted from Amos-Abanyie et al. (2013).

The TDR formula proposed by Givoni (1999) are modified to imply cooling requirement of the building as the following;

$$TDR = \frac{(T_{maxout} - T_{minout})}{(T_{maxout} - T_{maxin})}$$

where $T_{maxin}$ is the maximum indoor (ambient) temperature, $T_{maxout}$ is the maximum outdoor temperature, and $T_{minout}$ is the minimum outdoor temperature. The sigma test was conducted in stages by using Minitab software.

## 3. Results and Discussions

Figure 1 presents the first "bird view" comparison between PB and RB via time series plots of the average ambient temperature of the 7-day experiment. The difference in the range of ambient temperature between these two sets could be clearly seen. Basically, PB ambient temperature stays stably below RB by 2-3 ºC between 10.30 a.m. to 5.30 p.m. The overheating effect of the ambient temperature above the tropical thermal comfort level with USL of 28.6 ºC is much slower in PB compared to RB which often trails the outdoor temperature. In this particular study, the ambient temperature of PB starts to rise above the USL at 10.30 am while it is much earlier for RB which is near 8.30 a.m.

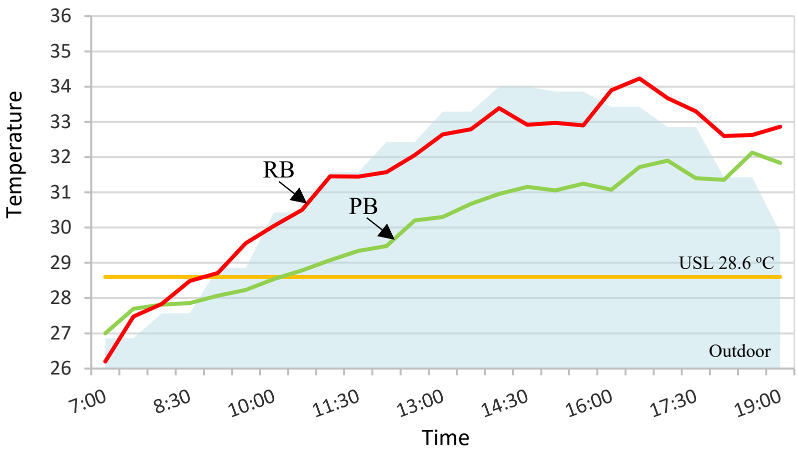


Figure 1: Time series plots of the average ambient temperature of PB and RB against outdoor temperature.

The predominant hot days with little to no downpour makes the ambient temperature fall outside of the human comfort zone for most times of the day. Thus it requires active cooling measures in both buildings. Nevertheless, the cooling load will be much lower in PB than RB due to the lower range of ambient temperature and shorter duration of the overheated hours. In order to compare the cooling requirement of the buildings more objectively, the TDR concept is used and calculated based on the range of outdoor and indoor temperatures between 9.00 a.m (when the outdoor temperature steps out of USL) and 2.00 p.m (when outdoor temperature reaches its peak). The TDR values of PB and RB were determined as 1.7 and 8.4 respectively. The significantly lower value of PB's TDR (5-fold decrease) indicates that there is a larger temperature difference between outdoor and indoor and therefore lesser requirement for cooling and higher energy saving.

Meanwhile, Figure 2 shows the comparison of window IST between (a) PB and (b) RB against the ambient temperature of the buildings. Again, the window IST of PB in overall is much lower than that of RB. The windows in RB quickly surpass and skyrocket to a higher level after 8.00 am. The highest window IST of RB is 33.7 ºC, which is 2 ºC higher than PB. Furthermore, it is interesting to note that in both sets, the window ISTs are always higher than the base ambient temperature of the building with a strikingly almost similar increasing trends. For example, as shown in Figure 2 (b), the 3 dominant peaks of the ambient temperature and window IST of RB are at close or exact time intervals which are at 11.00-11.30 am for the first peaks, 1.00-1.30 pm for the second peaks and at exactly 4.30 pm for the third peaks. This implies that the window could be one of the most critical contributors among building enclosure components that directly affects a building's ambient temperature.

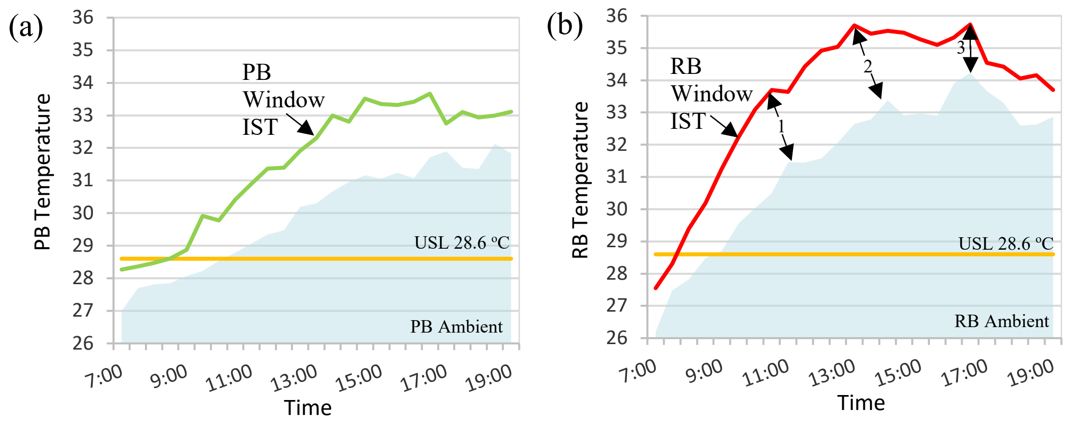


Figure 2: Window IST of (a) PB and (b) RB against the building's ambient temperature.

Furthermore, the authors measured the occupants' satisfaction level not to exceed the USL temperature levels by performing the sigma test in stages. Both window ISTs as illustrated in Figure 3 indicate that during dry and sunny days, 11% of PB's double-glazed windows are still in range below the USL, whereas only 3% for the RB's single-glazed windows. That means during the hotter days, even the expensive sophisticated double-glazed with tinted film could not provide a barrier from sunlight radiation by 89% of the time. Finally, across the bench of all 7 days, Table 2 shows the overall comparison between PB and RB in terms of ambient temperature and window IST.

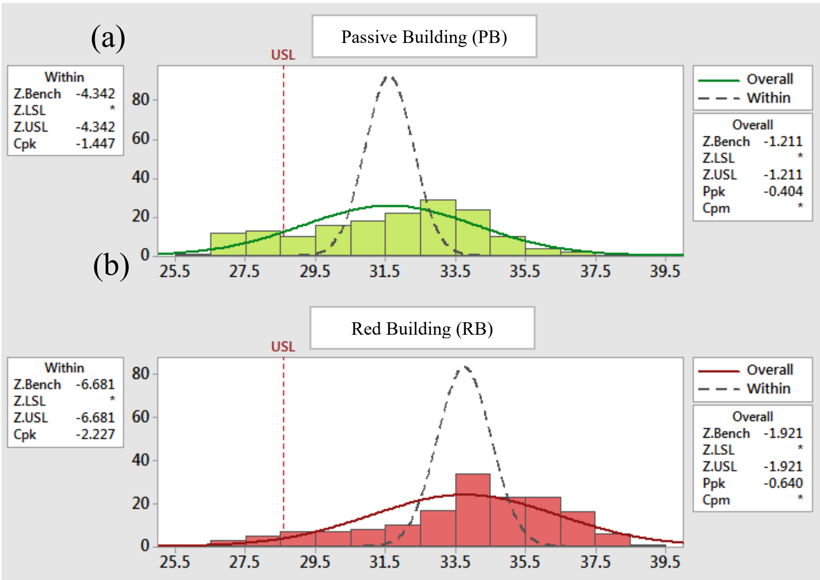


Figure 3: Sigma (customer satisfaction) scores in the 7 days comparison of window IST of PB and RB with 28.6°C upper space limit (USL) benchmark.

Table 2: Performance of PB and RB.

| Building Type/ Temperature (°C) | Passive building (PB) | Red building (RB) |
|---|---|---|
| Ambient $_{max}$ | 32.1 | 34.2 |
| Ambient $_{mean}$ | 29.9 | 31.6 |
| Window IST$_{max}$ | 33.7 | 35.7 |
| Window IST$_{mean}$ | 31.6 | 33.8 |

| | | |
|---|---|---|
| TDR-cooling requirement | 1.7 | 8.4 |
| Overheated hours | 89% | 97% |

Based on the results of this preliminary study, we received indications that the well-insulated, almost airtight and optimum shaded PB is always cooler than RB during the daytime. Under the weather conditions of tropical Malaysia with a residential comfort level of not exceeding 28.6 °C, the passive design will work best in a combination of nighttime usage of green cooling (i.e. forced mechanical ventilation), and daytime airtight and shaded – best of course without occupants as interfering heat generators. If an air conditioner was used, a lot of energy can still be saved by using an energy efficient, inverter-type air set-pointed conditioner or a non-inverter type in combination with a simple smart power interrupter system.

## Conclusion

The configuration of the façade was found to have a tremendous impact on the ambient temperature thus the overall energy consumption of the building. Window commonly presents a small area of a building, but it has a significant effect on the immediate heat inflow to the building. Whereas this work so far measures the impact of double-glazed window, moving forward, the impact of other parameters such as the floors, walls, ceilings, and even shadings are being investigated by the research team to determine the contribution of all these building enclosures in order to achieve tropical residential thermal comfort. The challenge is to bring all these relevant parameters into play in different weather situations for a more sustainable green living in the age of global warming.

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## Biographies

**Karl Wagner** graduated in Sociology and Business at the University of Munich. He obtained his Ph.D. at the Faculty of Business at University of Münster in 1991. Hereafter, he spent three years in industry and worked as

Professor and consultant at the University of Applied Sciences Rosenheim / Germany. Since 1998, Karl Wagner accompanied the upbringing and research of the mock-up buildings since 2012. He has received wide international exposure and reputation in green technology, especially in Malaysia and Singapore. Karl Wagner is a member of the globally operating ZEMCH (Zero Energy Mass Customised Homes) committee.

**Siti Fatihah Salleh** earned a PhD in Bioprocess Engineering from Universiti Sains Malaysia and a B.Eng (Hons) in Chemical Engineering from Universiti Teknologi PETRONAS. Her research interest includes renewable energy, energy efficiency and sustainable building.

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