World Sustainable Built Environment Conference 2017 Hong Kong
Transforming Our Built Environment through Innovation and Integration:
Putting Ideas into Action
5-7 June 2017

Registration ID: 2442

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BUNKER HOUSE IN IPOH: Residential Thermal Comfort in Tropics

ABSTRACT

The bunker house is an exploration of adaptive thermal comfort in a residential home in tropical climate. The house is designed to be semi-buried in the earth to maintain a fairly consistent indoor surface temperature, while maintaining the ability to harvest daylight deep into the house.

Instead of attempting to reduce the outdoor air temperature, the bunker house target to reduce the peak surface temperature on the roof, wall, floor and glazing.

Building thermal simulation studies were conducted to test various strategies that is able to reduce the surface temperature in this house. Test was conducted to find the optimum depth of soil to be used on the roof, the optimum thermal mass properties for the internal walls and external walls, the insulation properties of the internal and external walls, the glazing properties to balance the need for daylight and heat rejection, the external blind operation strategy, natural ventilation strategy and daylight strategies to keep the home cool at all hours of a day.

The result of the simulation studies indicates that it is possible to reduce the peak surfaces temperature of the inner space significantly. In addition, the peak air temperature of the internal space was also reduced further due to the improvements made.

Keywords: Climatic Responsive Architecture; Building energy simulation; Residential thermal comfort

1. INTRODUCTION

An attempt was made to optimise thermal comfort for a residential house in Ipoh, Perak, Malaysia. Ipoh is a town located approximately 200 km north of Kuala Lumpur, Malaysia.

Figure 1: Bunker House Model

Figure 1 shows the house is designed to be semi-buried in earth on all side of the building with the exception of the main frontage, resembling a bunker and is called the bunker house. Due to the site conditions, the frontage and opening of the house is facing east.

Building simulation studies was conducted to test the various passive strategies to reduce the internal surface temperature on this bunker house.

2. MALAYSIA CLIMATE

Malaysia is located in the hub of a tropical zone with hot and humid climate. It has only one season all year long - summer. The daily air temperature, relative humidity and solar radiation are consistent throughout the year. A typical day dry bulb temperature and relative humidity is provided in Figure 2 below.

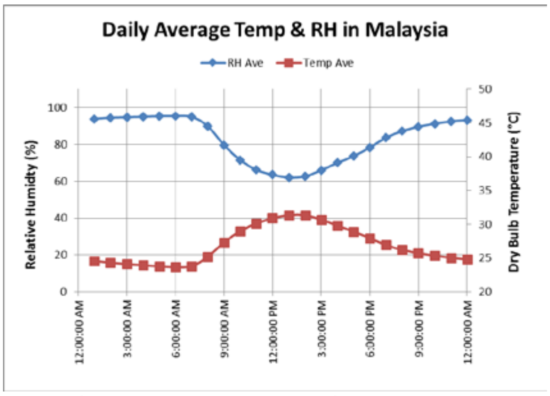

Figure 2 Average Daily Temperature and Relative Humidity in Malaysia

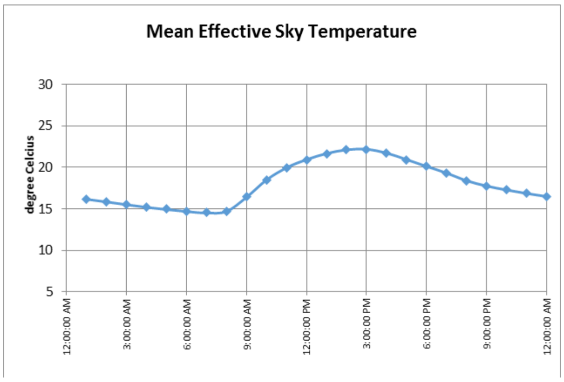

Figure 3 Average Daily Effective Sky Temperature in Malaysia

Based on the available test reference year weather data for Kuala Lumpur; the average peak outdoor air temperature in Malaysia occurs around 1 pm at 31.3□C; and the average low of a day occurs at 6 am at 23.7□C. The daily mean outdoor temperature in Malaysia is 26.9□C. In addition, the mean effective sky temperature in Malaysian averages below 20□C after 6pm and continues to drop until ~15□C around midnight, where it remains until sunrise as shown in Figure 3 [1].

3. ADAPTIVE THERMAL COMFORT

deDear's Adaptive Thermal Comfort model was used as the basis of thermal comfort for this bunker house study. This comfort model is provided in Ashrae Standard 55, Thermal Environment Conditions for Human Occupancy, today. This model says that the comfort of a naturally ventilated space is based on the indoor operative temperature and the prevailing mean outdoor air temperature.

Based on Malaysian climate, the adaptive model showed that an indoor environment with an operative temperature of 29°C will provide 80% acceptability.

An operative temperature of a space is defined as the average of two parameters, the air temperature and mean radiant temperature. This indicates that reducing mean radiant temperature will also help in improving thermal comfort in this climate instead of just focusing on reducing the air temperature via an air-conditioning system.

Based on this model, it can be concluded that air and surface temperatures below 29°C is a desirable comfort target for the indoor space in Malaysia.

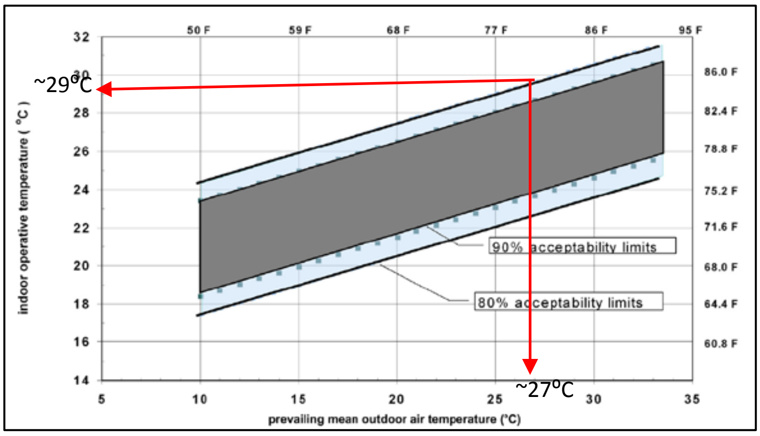

Figure 4 Acceptable operative temperature for 27°C mean outdoor temperature.

4. THERMAL COMFORT STRATEGIES

The key strategy proposed for the bunker house is to maintain indoor surface temperatures to be low at all time using passive strategies. To achieve this objective, the combinations of following passive cooling strategies were proposed:

- Insulation and shading of external envelope to prevent heat from being conducted to the internal surfaces of the bunker house;
- Increase thermal mass to dampen the fluctuation of surface temperatures;
- Night cooling to cool the building thermal mass;
- Radiation cooling via the night sky; and
- Minimizing indoor heat gain from lighting and equipment.

Simulation studies were conducted based on these strategies to find the optimum insulation and thermal mass properties to be incorporated into the bunker house.

4.1. Façade Optimization

The façade is designed as a full height glazed sliding door. In addition, an external adjustable and movable louver was proposed at the edge of façade balcony to provide these functions:

- Direct sunlight in the morning can be diffused by the external louvers; reducing heat gain while benefiting from daylight. The amount of daylight allowed indoor can be adjusted by the louvers opening for different hours of the day. Too much daylight also increases heat gain.

- The louvers can be fully closed to eliminate solar heat gain totally when the house is empty during daytime;
- The louvers also perform as glare protection devices.
- During night time, the louver and sliding door are moved to the side, exposing the indoor spaces to the night sky for radiation cooling.
- The opened façade at night also allowed natural ventilation to cool the indoor spaces using cooler night time air;

A double glazing low-e with light to solar heat gain ratio of ~2.0 was proposed for the sliding door. This will ensure minimum heat gain from the daylight harvested. Simulation studies were conducted to select the lowest possible visible light transmission of the glazing that is required to provide adequate daylight for the entire house. This ensures that the selected glazing will provide adequate daylight while providing the minimum heat gain, when the house is occupied daytime.

4.2. Daylight Simulation

Initial result of the simulation studies from Radiance indicates that rooms at the back of the bunker will be dark regardless of the façade light transmission. A skylight was proposed to bring daylight to these spaces. The skylight was designed to be diffused by a horizontal reflector located directly below it. The curvature of the reflector is designed to deflect direct sunlight out of the skylight as much as possible, while allowing diffuse daylight to be deflected to the ceiling in the room. In addition, the reflector was also designed to prevent any direct line of sight in the room. Figure 6 below shows the cross section of the bunker house.

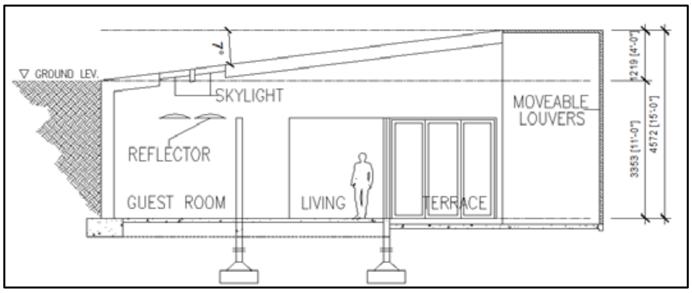

Figure 6 Cross section. Position of skylight, reflector and movable louvers.

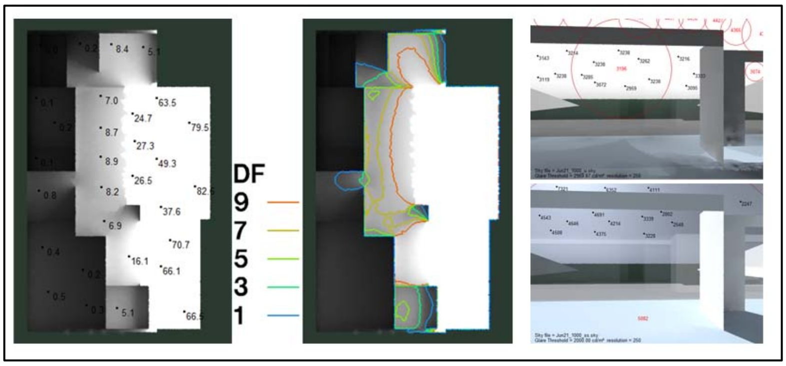

Figure 7, Simulation results. Daylight Factors and Luminance Intensity (cd/m²) before implementation of skylight and external louvers.

Simulation studies were conducted on the skylight and façade to provide a minimum daylight factor of 0.5% for all regularly occupied space. A daylight factor of

0.5% will provide a minimum of 100 lux over 70% of the time from the hours of 8am to 6pm [1].

Glare is controlled by the openable louvers outside the facade. As the façade is orientated east, it received direct morning sun. Simulation studies showed that luminance intensity will be reduced from a high of 4000 cd/m² down to a comfortable value of 700 cd/m² with external louvers, viewing at the direct sun [4].

The availability of daylight will encourage minimal use of electrical lights during daytime. Even the most efficient electrical lights that is available today, has a lower lighting efficacy than diffuse daylight filtered with high performance glazing.

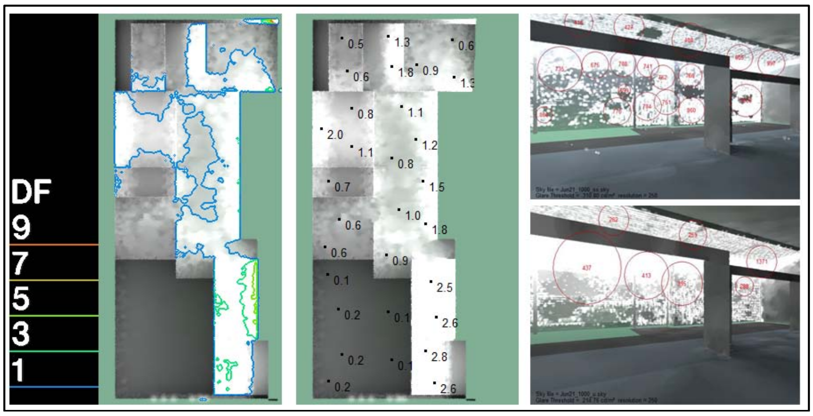

Figure 8, Simulation results. Daylight Factors and Luminance Intensity (cd/m²) after implementation of skylight and external louvers to control glare.

4.3. Optimization of Mean Radiant Temperature

Simulation studies were conducted using IES<VE> to optimize the specification of building material ensure indoor spaces have the lowest possible mean radiant temperature at all time.

<u>Soil on Roof</u>

Simulation studies were conducted to test various soil thickness on the roof from a scenario without any soil to 500mm of soil. Figure 8 displayed the result of this study. The optimum soil thickness was found to be 300mm depth. Increasing the soil thickness beyond 300mm provided little improvements. With a soil thickness of 300mm, the peak internal surface temperature was simulated to be ~9.8□C lower than the case without any soil on the roof.

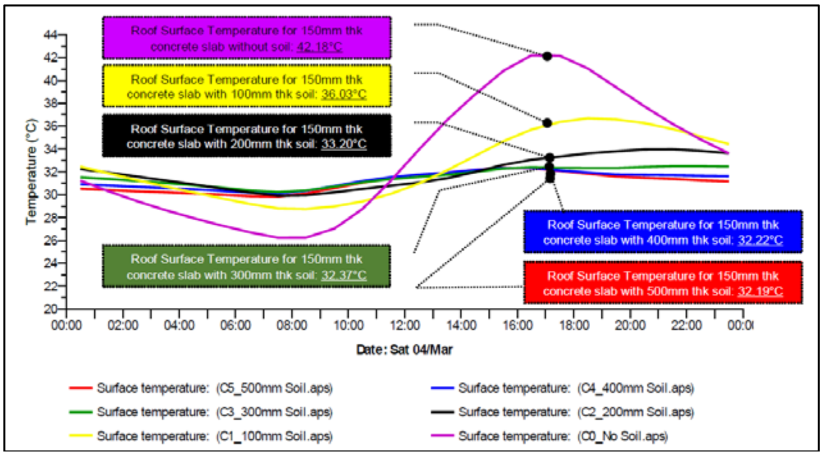

Figure 8: Soil Thickness Studies on the Roof

Concrete Roof Thermal Mass

The thermal mass on the concrete roof was increased by thickening the concrete roof slab from 150mm to 300mm. This option reduces the roof peak surface temperature by 1.2□C. The internal ceiling now peaks at 30.7□C instead of 31.9□C as shown in Figure 9.

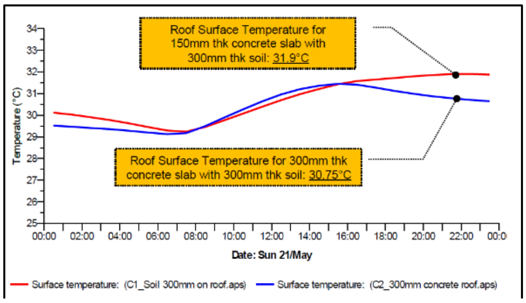

Figure 9: Thermal Mass Study on Concrete Roof

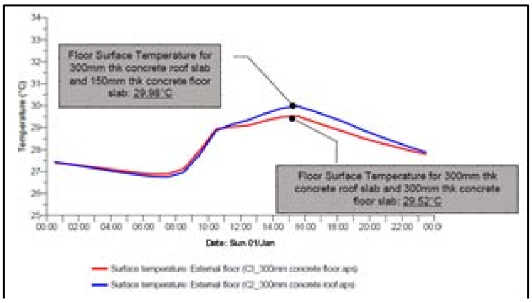

Figure 10: Thermal Mass Study on Concrete Floor

Concrete Floor Thermal Mass

The thermal mass of the concrete floor was increased by thickening it from 150mm to 300mm. Figure 10 showed the concrete floor was simulated to peak at 29.5□C instead of 30□C, providing a reduction of 0.5□C

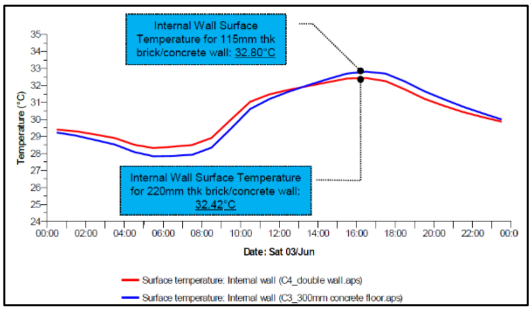

Figure 11: Thermal Mass Study on Internal Wall

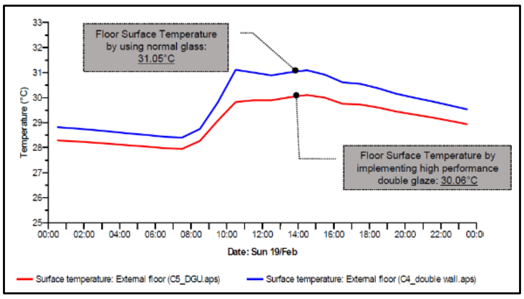

Figure 12: Glazing Effect on Floor Surface Temperature

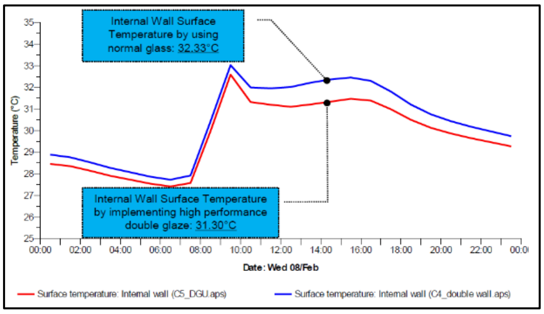

Figure 13: Glazing Effect on Internal Wall Surface Temperature

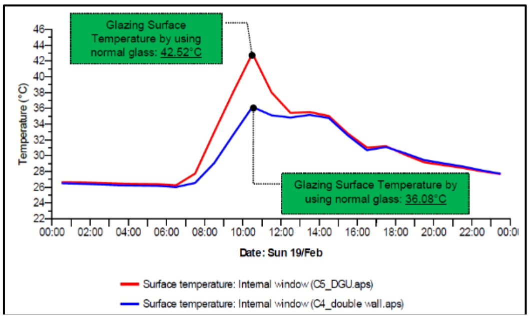

Figure 14: Glazing Effect on Glazing Surface Temperature

Internal Wall Thermal Mass

Figure 11 is the result of implementing a full brick wall of 220mm thick instead of half brick wall of 110mm thick. It reduces the wall surface temperature by 0.4°C. The peak surface temperature of the internal wall is now at 32.4□C instead of 32.8□C.

Glazing Properties

It was found that the implementation of high performance double glazing with low emissivity, brings significant reduction in the surface temperature of the floors and walls, in addition to the reduction of the glazing surface temperature. Figure 12 shows the effect of surface temperature on floor due to the use of high performance glazing. Figure 13 showed reduction on wall surface temperature by 1°C due to this implementation. Finally, the glazing surface temperature was shown to reduce by 6.5°C in Figure 14.

5. NATURAL VENTILATION STRATEGY

Simulation studies made were based on an ‘intelligent occupant’ natural ventilation scenario. I.e. Natural ventilation is used when the outside air temperature is low during night time and natural ventilation is not used when the outdoor air temperature is high during daytime. Doors and windows were modelled to be closed whenever the outdoor air is hotter than indoor air temperature. In addition, the occupancy profile has to be modelled as well because these strategies are manually applied. A discussion with th house owner provided these assumptions on the likelihood of natural ventilation strategy:

- sliding doors are open from the hours of 8am to 10am in the morning, during the breakfast hours;
- sliding doors are closed from 10am to 6pm to prevent hot afternoon air from indoor spaces;
- sliding doors are open from 6pm to 12 midnights, allowing outdoor air to cool down the indoor spaces; and
- closed from 12 midnights onwards, sleeping hours for safety and security concern.

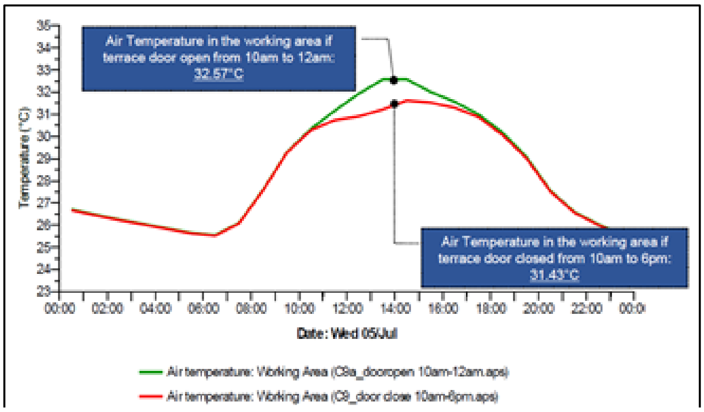

Figure 15: Different Natural Ventilation Strategies

A simulation study was conducted the result of keeping the sliding door open during daytime hours of 10am to 6pm as compared to keeping it closed at these hours. The result of this simulation is shown in Figure 15. The indoor air temperature is higher by 1.2°C with the door open during daytime instead of keeping it closed. This result indicates that it is a better strategy to keep the main façade door closed whenever the outdoor is air temperature is higher than indoor.

6. SUMMARY

Comparing the base case building (as designed conventionally) with the proposed case building with the proposed increased thermal mass implemented, the indoor air temperature of the house was simulated to have a reduction of 2.2 □C peak air temperature on the peak day, Figure 16. The peak ceiling surface temperature was reduced by ~10.4□C, the peak floor surface temperature was reduced by ~2.1□C, the internal wall surface temperature was reduced by 3.2□C, the internal surface of external wall was reduced by ~2.7□C.

Even with the implemented strategies to reduce surface temperatures, the resultant peak air temperature and peak surface temperature occurs around 30□C on the peak day of the year. This indicates that on the hottest day of the year, it will not meet the adaptive thermal comfort requirement of keeping an operative temperature below 29□C. However, compared to a conventional house in Malaysia with and average mean radiant temperature up to 39□C [3], the bunker house is a significant improvement.

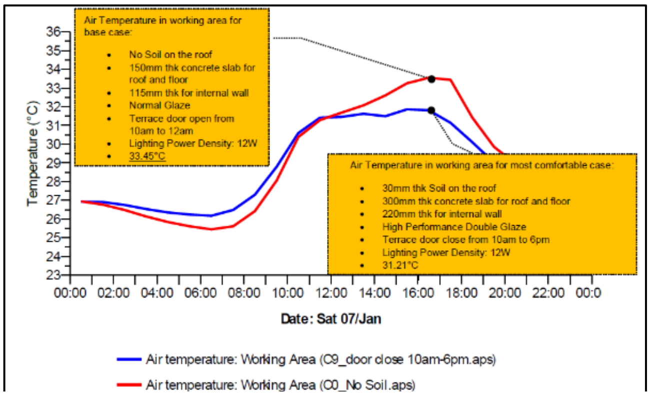

Figure 16: Base Building vs. Heavy Thermal Mass Building

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