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Full Length Research Paper

Exploring role of different floor, wall and roof details in energy efficiency of a bungalow house in Malaysia

Saber Sabouri[1]*, M. F. M. Zain[2] and M. Jamil[2]

[1]Faculty of Architecture, Seraj Higher Educational Institute, Ark Alley, Shariati Cross, Tabriz, Iran.
[2]Faculty of Engineering and Built Environment, University Kebangsaan Malaysia, 43600 Bangi, Malaysia.

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Energy has undeniable role in sustainable architecture. Building sections consume 15 to 60% of whole energy in different countries. Residential sector includes 19% of energy consumption in Malaysia. In this study, a bungalow house as a common low density house in Malaysia was simulated by Design Builder software based on Energy plus program. Then its different components including floor, wall, roof and their influence were explored by simulations of various alternatives. Results showed that naturally ventilated raised floor in first floor with 19 mm wooden material could save 9.4% of cooling electricity. Changing wall detail of first floor (naturally ventilated floor at night time) from heavyweight to lightweight could save 16% of cooling energy and replacing white painted steel instead of concrete tile could decrease 5.8% more cooling energy. Composition of these components in proposed house presented 28.3% cooling energy saving.

Key words: Cooling energy, floor, wall, roof, bungalow house.

INTRODUCTION

Energy has great importance in sustainable development. Buildings have considerable share in energy consumption in the world. Residential sector has about 16 to 50% of total energy consumption in the world. Malaysia as a developing country has 19% energy consumption in residential sector in comparison with other sections (Figure 1) (EC,2007;Saidur,2009;Saidur et al.,2007).

This issue reminds us of the importance of scrutiny on relation between residential architecture and energy consumption. Buildings are composed of architectural elements. They act as a building envelope. An architect with his/her design can select different composition of a building envelope. So, it seems necessary to have appropriate viewpoint about role and impact of each element in energy consumption of buildings. In this study, a bungalow house as a type of common low density houses in Malaysia is considered for energy simulation. Then, various alternatives for its roofs, walls and floors are selected and simulated. Main concentration in this study is on cooling energy. So, various simulated models have equal energy values for room electricity (for example, appliances), room gas (for example, cooking) and lighting same as BASECASE. Only results of cooling energy are different. These results are investigated in this study's results and discussion. In the beginning, a review of relationship between house envelope and energy consumption are presented.

LITERATURE REVIEW

There have been many studies about buildings and their energy use. But, it is restricted about house design in hot and humid climate. Most of studies are related to

*Corresponding author. E-mail: sbrsabouri@gmail.com. Tel: +60-172559425. Fax: +60-389252546.

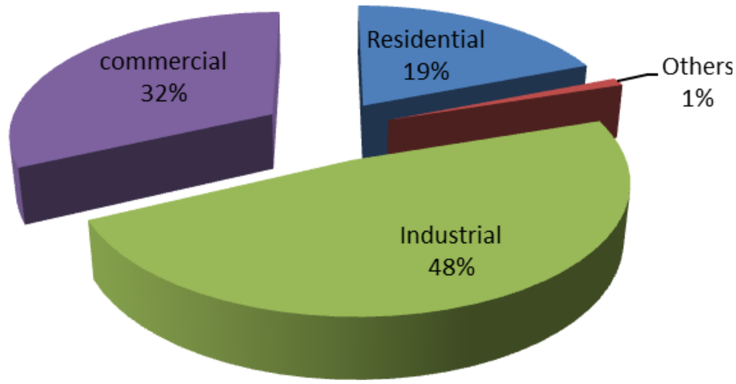


Figure 1. Energy consumption of each section in Malaysia.

European countries with their climatic condition. For example, Wall (2006) has done a research about terrace house in Sweden and their energy efficiency. She found in Scandinavian climate that a building should be highly insulated and airtight for low transmission and ventilation heat losses. In that research, a building envelope was simulated by DEROB-LTH (Dynamic Energy Response of Buildings) program and some parametric studies including indoor temperature set points, solar gains, airtightness, window type and occupancy were explored.

For hot and humid climate, Iqbal and Al-Homoud (2007) have explored a five storey office building by Visual DOE4 software in Saudi Arabia. They found that increasing thickness of insulation has no considerable energy efficiency. In turn, low-e double glazing, appropriate set point temperature, using VAV system, energy efficient lamp and adjustable operation of lighting had significant impact. Integration of these strategies saved 36% of annual energy use. Perez and Capeluto (2009) have explored climatic parameters for designing energy efficient school building in hot and humid climate. They indicated that various strategies could interact with each other. For example, shading could decrease influence of glazing type on energy consumption. They showed that lighting control, shading, infiltration, night ventilation and size of window have considerable influence on energy efficiency of school building design. Wong and Li (2007) have studied passive climate control in naturally ventilated residential building in tropical climate of Singapore. They examined efficiency of influence of microclimatic criteria (orientation, shading of surrounded buildings and wind), minimizing of heat gain by utilization of roof thermal buffer, optimization of building materials and shading of windows. They applied thermal analysis software (TAS) and found that thermal buffer is a most efficient method for energy saving. In other study, energy use of three mosques was assessed in hot and humid region in Saudi Arabia. It was found that appropriate operation of AC, proper thermal zoning and envelope thermal insulation could improve thermal comfort and energy saving of mosques (Al-Homoud et al., 2009). It seems there is lack of research in the residential sector of hot and humid climate. So, the study of energy efficiency of bungalow house in Malaysia would be an appropriate case study.

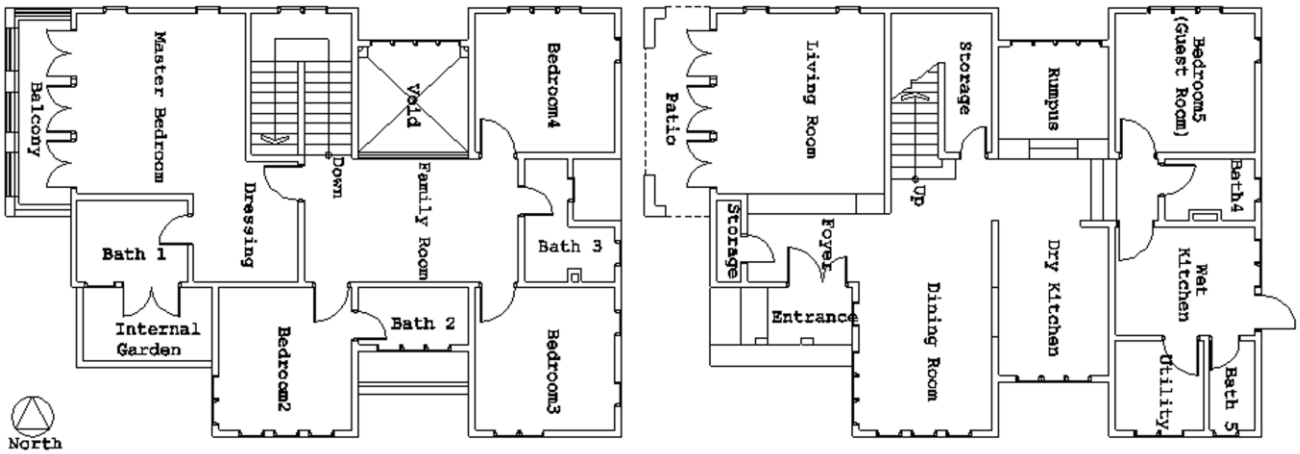
MATERIALS AND METHODS

In this research, a typical bungalow house as a BASECASE model was selected. Then it was simulated according to architectural properties and life style of its occupants. Results of simulation were verified by monthly electrical bills. In the next stage, different components of building envelope including: floors, walls and roofs were studied. Various alternatives for each component and their impact on annual cooling electricity were examined. Subsequently, a refurbished bungalow house was proposed and its influence on cooling energy consumption was compared with BASECASE model. In conclusion, suitable viewpoints for architectural design of a bungalow house were presented.

BASECASE model

In this survey a two story bungalow house was selected in Bangi-Selangor; region near Kuala Lumpur. Main spaces of this house are living room, guest room and kitchen in ground floor, master bedroom, three single bedrooms and their bathes in first floor (Figure 2). Ground and first floor areas are 122.5 and 120.5 m^2, respectively. Total area of the building is 243 m^2. Reinforced concrete is the structure of the building. The building has pitched roofs covered with concrete tiles. There are no insulation in the walls and roofs. The façade of the building is cement sand render and the main material of external walls is concrete block wall (medium). Building orientation is East-west and it has aluminum framed windows with single clear glazing. Architectural properties of the building are presented in Table 1.

Master bedroom is only a cooled space with a split cooling system. The area of master bedroom is 24.7 m^2 and its height is 3.8 m and



(A) (B)

Figure 2. Architecture plans of bungalow house, first floor (A) ground floor (B)

Table 1. Description of bungalow house (low density house).

Parameters	Value
Balcony	One balcony with 1.6 m depth and 5.1 m length at west side
Internal floor	concrete (medium density) Cast concrete (Dense) (10 cm) + ceramic (1.2 cm)
External walls	Cement sand render (1.3 cm) + concrete block (11 cm) + gypsum plastering (1.3 cm)
Internal walls	Concrete block (11 cm) + inner/outer gypsum plastering 1.3 cm)
Pitched roof	Wooden batons (20 cm) + air gap (10 cm) + concrete tiles (2 cm)
Ceiling	Tiles (10 mm)
Flat roof	Asphalt (1.9 cm) + fiberboard (1.3 cm) + concrete reinforced (10 cm)
Window	Aluminum framed window, single glazing(6 mm)
Infiltration rate	0.5 ac/h
Lighting	Fluorescent, compact (4.6 w/m^2 -100 lux)
Occupancy	48 m^2/ person

has a pitched roof with 25° slope. Its climax height is 5.76 m. It has two external walls oriented northward and westward. Length of Northward wall is 4.1 m and its window to wall area ratio (WWR) is 10.6%. For westward wall, length of wall and WWR are 4.6 m and 43%, respectively. Building windows have no shading and there is one balcony with 1.6 m depth attached to the westward wall. Natural gas as fuel was considered for catering and fluorescent compact light bulbs were considered for lighting.

In hot and humid climate, cooling set point temperature is important and it could be identified in various spaces. This temperature could be defined by local people habituations and adaptive standards. Adaptive thermal comfort temperatures (neutral temperature) have proposed for different spaces of residential buildings by Peeters et al. (2009). According to their study, bedrooms, bathrooms and other rooms are three zones that could have different neutral temperatures with respect to reference external temperature. With assumption that the average external temperature would be 27.5°C (http://www.climatetemp.info/malaysia/kuala-lumpur.html) then upper neutral temperature ranges for bedrooms, bathrooms and other rooms would be 26, 28.7 and 26.5°c, respectively. According to adaptive comfort standard (De Dear and Brager, 2002), acclimatization, physical and psychological adaptations could grow up upper neutral temperature range. So, in this simulation, cooling set point temperature of master bedroom was considered as 28°C. It should be mentioned that it is a more essential experimental study for achieving upper limit of neutral temperature in different countries.

Table 2. Supposed operation schedule of AC and natural ventilation of main spaces.

Abbreviation	Operation type	Operation time of weekdays and holidays	Operation time of weekends
Master bedroom	AC	5 p.m.-9 a.m	5 p.m. – 9 a.m
Three single bedrooms and guest room	Natural ventilation	5 p.m.-9 a.m	5 p.m. – 9 a.m
Living room and kitchen	Natural ventilation	5 a.m.-9 a.m., 5 p.m.-12 a.m.	5 a.m.-12 a.m.

Table 3. Monthly results of electricity consumption of simulated BASECASE model and electrical bill amounts.

Variable	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10	1/11	1/12
Simulated Electricity (kWh)	782	735	880	812	825	920	859	816	772	735	754	727
Bill amount (kWh)	768	714	865	832	842	908	865	828	764	729	735	719

Simulation with "DesignBuilder"

There are some energy simulation programs such as DOE2, Energy-10, Energy plus. In this study, Energy plus is used for simulation. Energy plus as a simulation program models heating, cooling, lighting, ventilating and other energy flows has many capabilities to simulate various time steps and plant integrated with heat balance-based zone simulation, thermal comfort and energy used (U.S. Department of Energy) . "DB" is a state-of-the-art software tool for checking building energy, carbon, lighting and thermal demands (Tindale, 2002).

For simulation in "DB", five categories of data would be implemented including: activity, construction, opening, lighting and HVAC system. Building physical properties were added in accordance with Table 1. Occupation and HVAC operation schedule were entered considering split system and its operation schedule for BASECASE house. It was in congruence with previous researches in Malaysia. It indicated that most of the owners operate splits at nighttime and use cooling systems for sleeping (Kubota et al., 2009).

In BASECASE model, AC (split) system is only in master bedroom and also works at nighttime. The remaining spaces have no cooling system but these spaces use scheduled natural ventilation. Operation schedule of AC and natural ventilation time of main spaces could be seen in Table 2.

Verification of BASECASE

The weather data of simulation was the weather report of Kuala Lumpur, Subang weather station in 2002. This file is available at Energy Plus website (U.S. Department of Energy, 2010). Energy consumption of the BASECASE model is related to master bedroom cooling, electrical consumers (lighting and appliances) and life style of occupants. Simulation was calibrated with respect to monthly electrical bills of bungalow house. Weather of Malaysia has approximately permanent condition throughout the year. Average monthly electrical bills was around 800 kWh and average of simulation was 801.4 kWh. It seems an acceptable resolution. Monthly results of electricity consumption of simulated BASECASE model and monthly electrical bill amounts could be seen in Table 3.

Different building envelope components

In this research, energy performances of different alternatives were studied. In floor section, impact of raised floor and its ventilation were studied. Also, ceramic flooring and wooden flooring were considered. In wall section, heavyweight and lightweight walls were applied for comparison. In roof section, concrete, clay and metal (steel, stainless steel and white painted steel) coverings were examined. Aluminum foil was used as solar radiation barrier in roof construction. Detailed features of components, various design alternatives and their consequences are discussed subsequently.

RESULTS

Results of annual energy consumption (including room electricity, gas consumption, lighting electricity and cooling electricity) were determined for BASECASE model and other alternatives. Annual amounts of electricity use for room electricity (for example, appliances), lighting and gas consumption were 2661.9, 3742 and 1536.4 kWh, respectively. In all simulations, these energy consumption results were permanent and only cooling electricity amount was variable. This issue shows impacts of different alternatives on cooling electricity.

Floor construction

Two types of flooring materials were assumed for

Table 4. Thermal properties of ceramic and wood.

Variable	*Conductivity (W/m-k)*	*Specific heat (J/Kg-K)*	*Density (kg/m3)*	*Thermal absorptance*	*Solar absorptance*	*Visible absorptance*
Ceramic	1.3	840	2300	0.9	0.4	0.4
Wood	0.14	1200	650	0.9	0.78	0.78

Figure 3. Image of bungalow house simulated by "DB".

simulation: Ceramic and wooden flooring as heavyweight and lightweight materials, respectively. Thermal properties of ceramic and wood are described in Table 4. In Table 4, it could be seen that wood has higher solar absorptance than ceramic. In other words, wood has darker color than ceramic. Wood also has higher specific heat or thermal capacity value. But, it does not have high conductivity in comparison with ceramic. Other studied floor types were about raised floor. Three groups of different floorings were considered for comparison including: 1) without raised floors 2) with raised floors 3) with raised and naturally ventilated floors.

Figure 4 shows simulation results for without raised floors. It could be understood that model with ceramic floor in ground floor and wooden floor in its first floor has best performance. While model with insulated ground floor has worst performance. Main reason for this issue could be related to heat absorption by ground. Because data retrieved from weather file of Kuala Lumpur (U.S. Department of Energy, 2010) indicate that ground temperature is 26°C from February to July and it is 27°C from August to January. On the other hand, inside temperature of BASECASE model spaces without mechanical cooling is higher than these amounts in whole year. So, ground floor can act as a heat sink. It is clear that insulation declines heat flow and it has unsuitable effect on cooling energy demand of ground floor. In comparison between wood and ceramic for ground floor, high conductance of ceramic floor makes it more appropriate than wooden floor. Wooden floor with screed has worse condition, because low conductivity is accompanied with detained thermal energy. So, it makes inside space warm and unsuitable. For master bedroom with cooling in first floor, it seems wooden floor could be a little better than ceramic floor, but the difference is not significant (around 1%). According to results model with wooden floor with screed consumes 12.95% more cooling energy than the model with ceramic and wooden

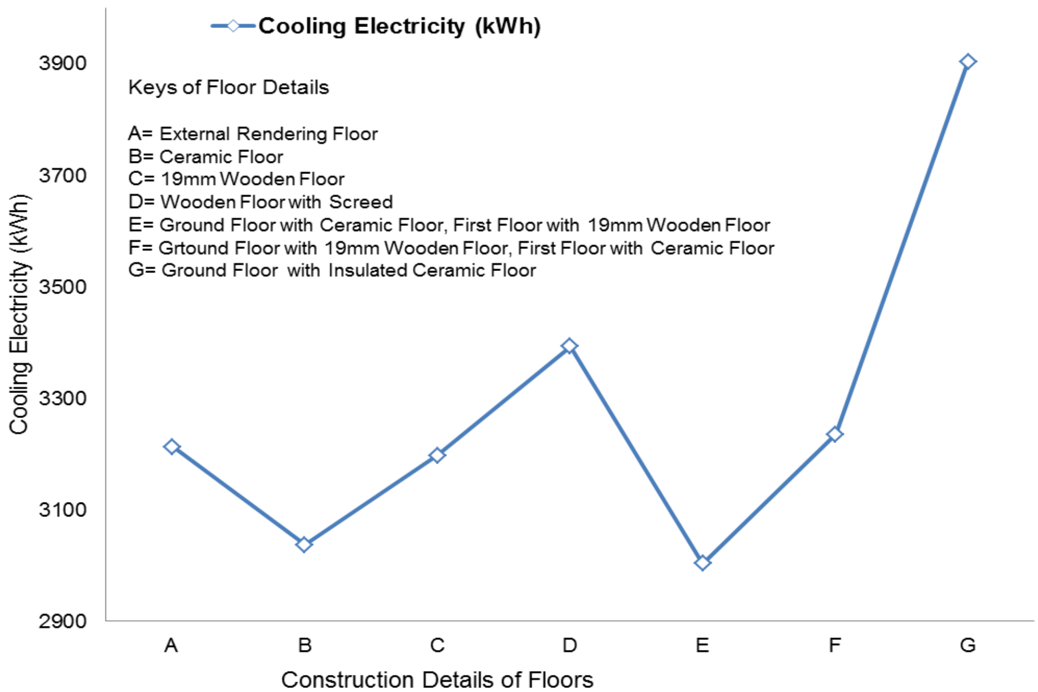


Figure 4. Comparison of alternatives without raised floors.

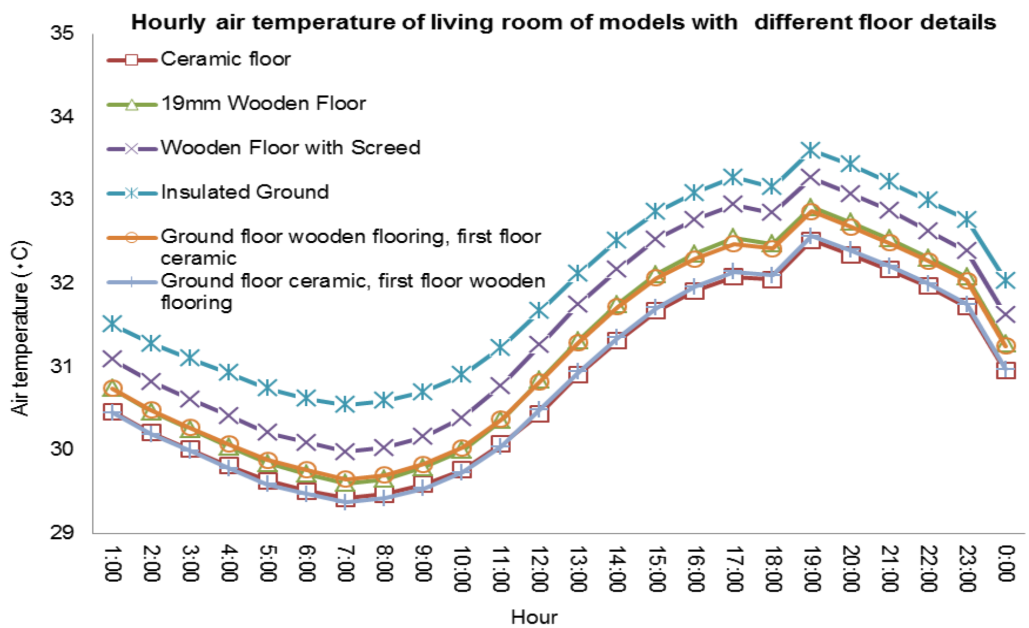


Figure 5. Hourly air temperature of living rooms with different floor details.

floor for its ground and first floor, respectively. These results are in congruence with air temperature of indoor spaces like living room for different models. As, it could be seen in Figure 5, living room with insulated ground is

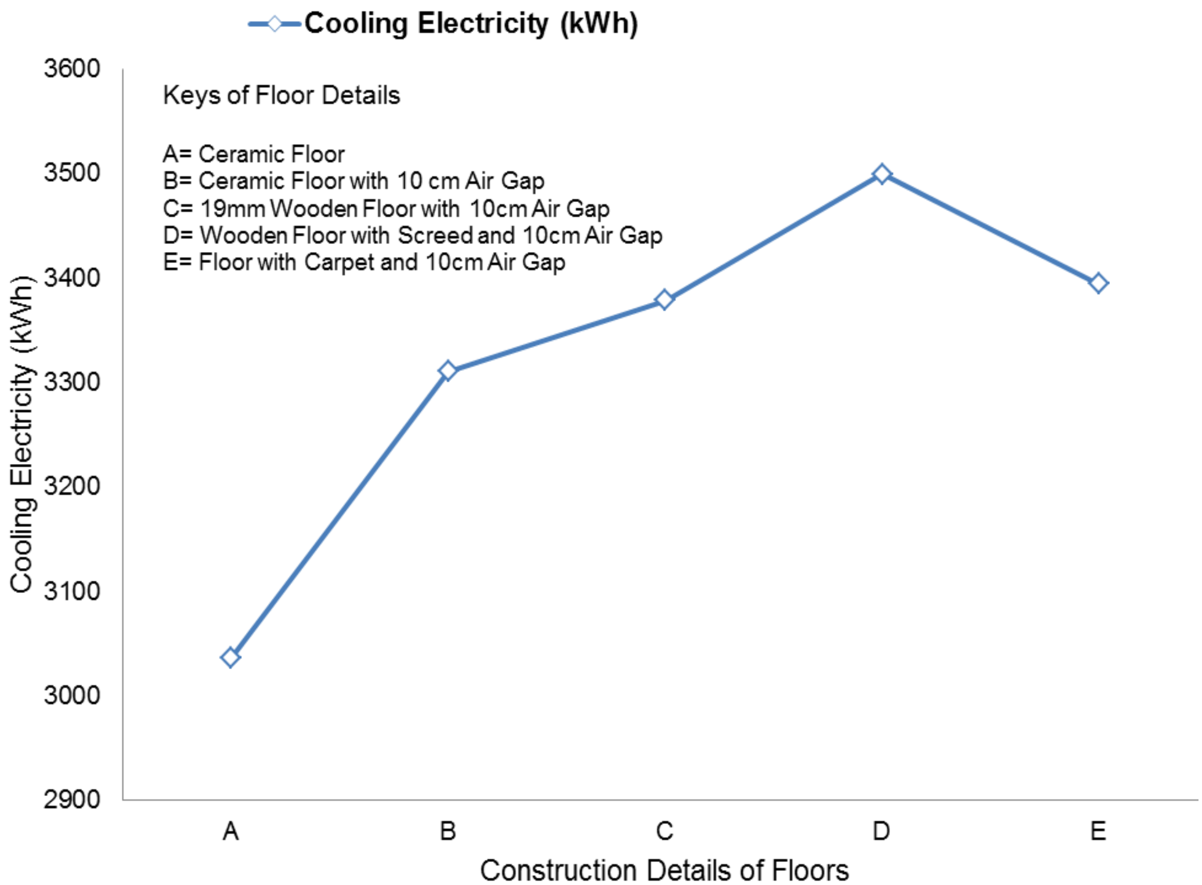


Figure 6. Comparison of alternatives with raised floors.

around1°C warmer than living room with ceramic floor. Also, the space with ceramic floor is around 0.3°C cooler than same space with 19 mm wooden floor. Moreover, wooden floor with screed makes the space around 0.3°C warmer than only wooden floor.

Figure 6 shows simulation results for raised floors without ventilation. It expresses that raised floor has negative effect on cooling energy consumption of building. Air gap between concrete slab and ceramic flooring increased 9% cooling energy in comparison with same floor without air gap. Among alternatives, wooden floor with screed has worst condition. It has 15.2% more cooling energy consumption than ceramic floor with 10 cm air gap.

Hourly air temperature results in raised floor group could be seen in Figure 7. These results emphasized on importance of evacuation of accumulated heat of inside space to ground because 10 cm air gap without ventilation and acts like insulation. This issue makes inside space around 0.5 to 1°C warmer than model with simple ceramic floors. Naturally, living room with raised wooden floor is warmer than same space with raised ceramic floor.

Figure 8 illustrates energy consumption of raised floors with natural ventilation. Use of natural ventilation for raised floor decreased their cooling energy consumption. But, their condition is not better than the model with simple ceramic flooring. Natural ventilation decreased 0.5% cooling energy of ceramic raised floor and 6.8% of cooling energy raised wooden floor with screed.

Figure 9 displays air temperature of living room for different ventilated floor details. Air temperature of models with naturally ventilated floor in their ground and first floor is 0.5 to 1°C higher than model with ceramic floor. These differences are intensified from 2 p.m. till 6 p.m. Also, it is realized that models with only naturally ventilated raised floor in their first floor have acceptable thermal condition in comparison with ceramic floor model. These models have lower air temperature than model with ceramic floors in nighttime and morning (8 p.m. to 11a.m.). Reasons of this matter would be related to the role of ground as a heat sink and also decreasing heat

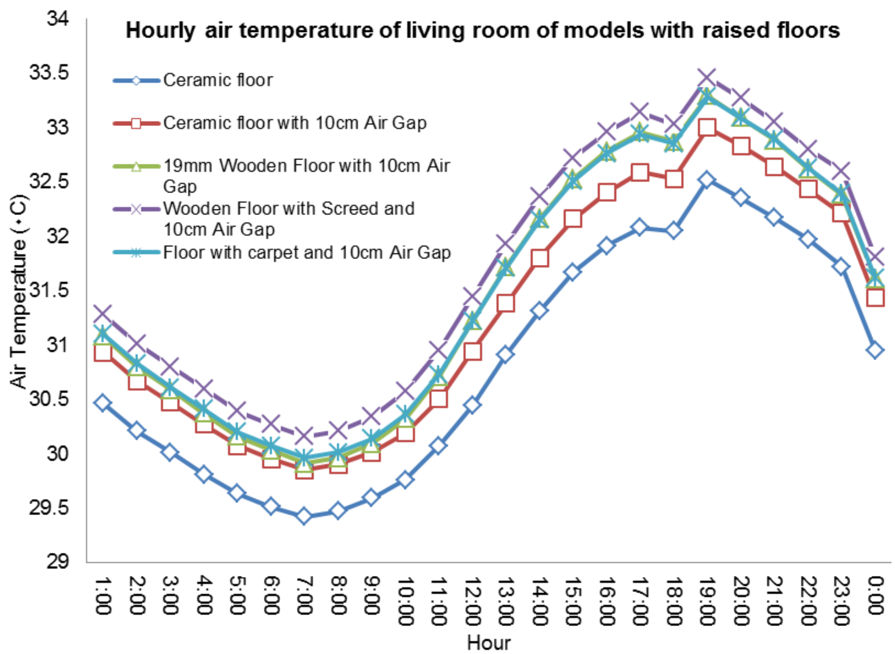


Figure 7. Hourly air temperature of living rooms with different raised floor details.

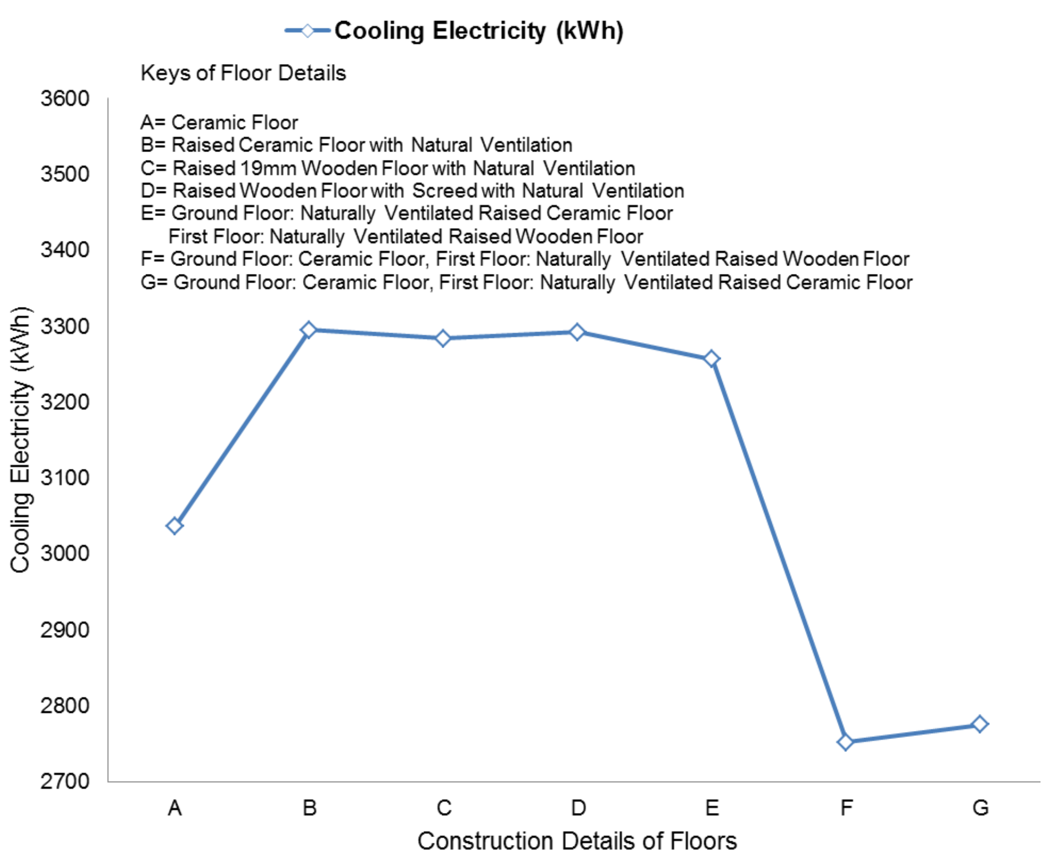


Figure 8. Comparison of alternatives with raised and naturally ventilated floors.

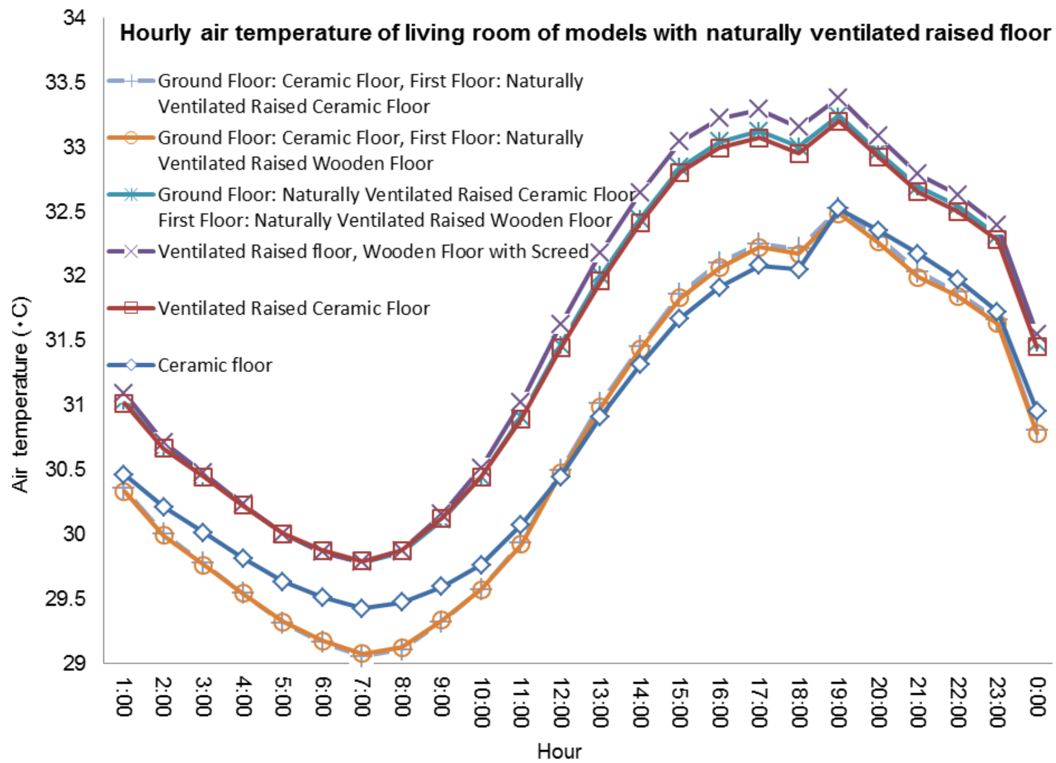


Figure 9. Hourly air temperature of living rooms with different naturally ventilated raised floors.

exchange of two levels of building and removing warm air by nighttime natural ventilation. Between 12 p.m. till 7 p.m., outside temperature would be higher than inside temperature and consequently, natural ventilation of first floor maybe increases inside temperature.

In floor details, the role of ground heat loss accentuated by simulation results. In other words, if ventilated raised floor would be only applied in first floor, then energy efficiency will ameliorate in comparison with BASECASE model. For example, models with naturally ventilated raised wooden and ceramic flooring in their first floor consumed 9.4 and 8.6% less cooling energy in comparison with simple ceramic flooring model. Table 5 displays simulated models and details of their flooring in ground and first floors.

Wall construction

Table 6 describes different wall details which were simulated by "DB". Results of simulations (Figure 10) illustrate that brick wall and concrete block as heavyweight materials with high specific heat need more energy for the cooling of master bedroom rather than a model with lightweight wall. For example, model with lightweight walls saves 22% of cooling energy consumed by BASECASE model with concrete block wall (Medium). Adding air gap (10cm) will increase cooling energy for concrete block and brickwork walls. Because, it detains internal heat gained during daytime. For example this growth of cooling energy for concrete block wall is 4.2%.

Figure 11 shows air temperatures of models with heavyweight and lightweights walls. It shows temperature of model with lightweight walls is more than heavyweight walls between 10 a.m. to 6 p.m. So, for spaces with daytime occupation schedule, heavyweight walls are relevant. Despite highest energy saving of model with lightweight walls, it seems model with lightweight wall in first floor and heavyweight wall in ground floor is more appropriate than it.

Figure 10 indicates that model with heavyweight walls in ground floor and lightweight wall in first floor saves 16% of annual cooling energy in comparison with BASECASE model.

Roof construction

In this study, some roof details, based on commonly used and their application in Malaysian houses were considered. Three types of covering including of concrete tiles, clay tiles and metal covered (including steel,

Table 5. Different simulated details of ground and first floor of bungalow house.

Group/ number of model	Ground floor (*GF*) and first floor (*FF*) construction (from outside layer to inside layer)	Cooling (electricity) (kWh)
A/1	*GF*: External rendering (2.5 cm), air gap (2 cm) *FF*: Cast concrete (dense)(10 cm), ceramic (1.2 cm)	3212.53
A/2	*GF*: Cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Cast concrete (dense)(10 cm), mortar (2.5 cm), ceramic (1.2 cm)	3036.93
A/3	*GF*: Cast concrete (10 cm), wooden flooring (1.9 cm) *FF*: Cast concrete (dense) (10 cm), wooden flooring (1.9 cm)	3197.56
A/4	*GF*: Cast concrete (10 cm), screed (7 cm), wooden flooring (1.9 cm) *FF*: Cast concrete (dense) (10 cm), screed (7 cm), wooden flooring (1.9 cm)	3393.2
A/5	*GF*: Cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Cast concrete (dense) (10 cm), wooden flooring (1.9 cm)	3003.95
A/6	*GF*: Cast concrete (10 cm), wooden flooring (1.9 cm) *FF*: Cast concrete (dense)(10 cm), mortar (2.5c m), ceramic (1.2 cm)	3235.67
A/7	*GF*: UF foam (5 cm), cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Cast concrete (dense)(10 cm), mortar (2.5 cm), ceramic (1.2 cm)	3903.36
B/1	*GF*: Cast concrete (10 cm), air gap (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Cast concrete (dense) (10 cm), air gap (10 cm), mortar (2.5 cm), ceramic (1.2 cm)	3310.63
B/2	*GF*: Cast concrete (10 cm), air gap (10 cm), wooden flooring (1.9 cm) *FF*: Cast concrete (dense) (10 cm), air gap (10 cm), wooden flooring (1.9 cm)	3378.37
B/3	*GF*: Cast concrete (10 cm), air gap (10 cm), screed (7 cm), wooden flooring (1.9 cm) *FF*: Cast concrete (dense) (10 cm), air gap (10cm), screed (7 cm), wooden flooring (1.9 cm)	3499.41
B/4	*GF*: Cast concrete (10 cm), air gap (10 cm), cast concrete (2cm), cellular rubber underlay (0.5 cm), carpet (0.5 cm) *FF*: Cast concrete (dense)(10 cm), air gap (10cm), cast concrete (2cm), cellular rubber underlay (0.5 cm), carpet (0.5 cm)	3394.29
C/1	*GF*: Naturally ventilated raised floor 50cm above earth level, cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Naturally ventilated raised floor with 50 cm plenum and cast concrete (dense)(10 cm), mortar (2.5 cm), Ceramic (1.2 cm)	3294.46
C/2	*GF*: Naturally ventilated raised floor 50cm above earth level, cast concrete (10 cm), wooden flooring (1.9 cm) *FF*: naturally ventilated raised floor with 50cm plenum and cast concrete (dense) (10cm), wooden flooring (1.9 cm)	3283.24
C/3	*GF*: Naturally ventilated raised floor 50 cm above earth level, cast concrete (10 cm), screed (7 cm), wooden flooring (1.9 cm)	3292

Table 5. Contnd

	FF: Naturally ventilated raised floor with 50 cm plenum and cast concrete (dense) (10 cm), screed (7 cm), wooden flooring (1.9 cm)	
C/4	*GF*: Naturally ventilated raised floor 50cm above earth level, cast concrete (10cm), mortar (2.5cm), ceramic (1.2 cm) *FF*: Naturally ventilated raised floor with 50cm plenum and cast concrete (dense) (10cm), wooden flooring (1.9 cm)	3255.98
C/5	*GF*: Cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Naturally ventilated raised floor with 50cm plenum and cast concrete (dense) (10cm), wooden flooring (1.9 cm)	2752.2
C/6	*GF*: Cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) *FF*: Naturally ventilated raised floor with 50 cm plenum and cast concrete (dense)(10 cm), mortar (2.5 cm), ceramic (1.2 cm)	2774.76

A= without raised floors B= with raised floors C= with raised and naturally ventilated floors.

Table 6. Details of simulated walls.

Variable	Wall Construction Details (from outside layer to inside layer)
Concrete block wall	Cement sand render (1.3 cm), concrete block (medium) (11 cm), gypsum plastering (1.3 cm)
Concrete block wall + air gap	Cement sand render (1.3 cm), concrete block (medium) (11cm), 10cm air gap, gypsum plastering (1.3 cm)
Brick wall	Cement sand render (1.3 cm), brick wall (11 cm), gypsum plastering (1.3 cm)
Brick wall + air gap	Cement sand render (1.3 cm), brick wall (11 cm), 10 cm air gap, gypsum plastering (1.3 cm)
Lightweight wall	lightweight metallic cladding (6 mm), air gap (5 cm), gypsum plastering (1.3 cm)

stainless steel and white painted steel) types were simulated. The typical simulation detail of roof was:

Wooden Batons (20cm) + Aluminum Foil + 10 cm air gap + Roof Covering

Table 7 shows thermal and solar absorptance of different roof alternatives.

Results of simulations purport that cooling electricity consumptions of the houses with concrete and clay tiles are approximately same and steel roof has only 1.34% less energy consumption than the house with clay roofs. This discrepancy for stainless steel roof is 4.6% and for white painted steel roof is 5.9%. In Figure 12, annual result of cooling electricity presented for each alternative. It seems white painted steel roof with high thermal emissivity and low solar absorptance has best performance of these alternatives.

Figure 13 illustrates hourly radiant temperature of master bedroom with different roof details. It expresses that model with white painted steel roof has lowest temperature. It represents that white painted steel roof could act as a cool roof which absorbs low amount of solar radiation and emits high thermal energy.

Energy performance of proposed bungalow house

Based on mentioned results, a refurbished bungalow house was proposed. Table 8 compares construction details and annual cooling energy of proposed house and BASECASE model. Simulation results showed that

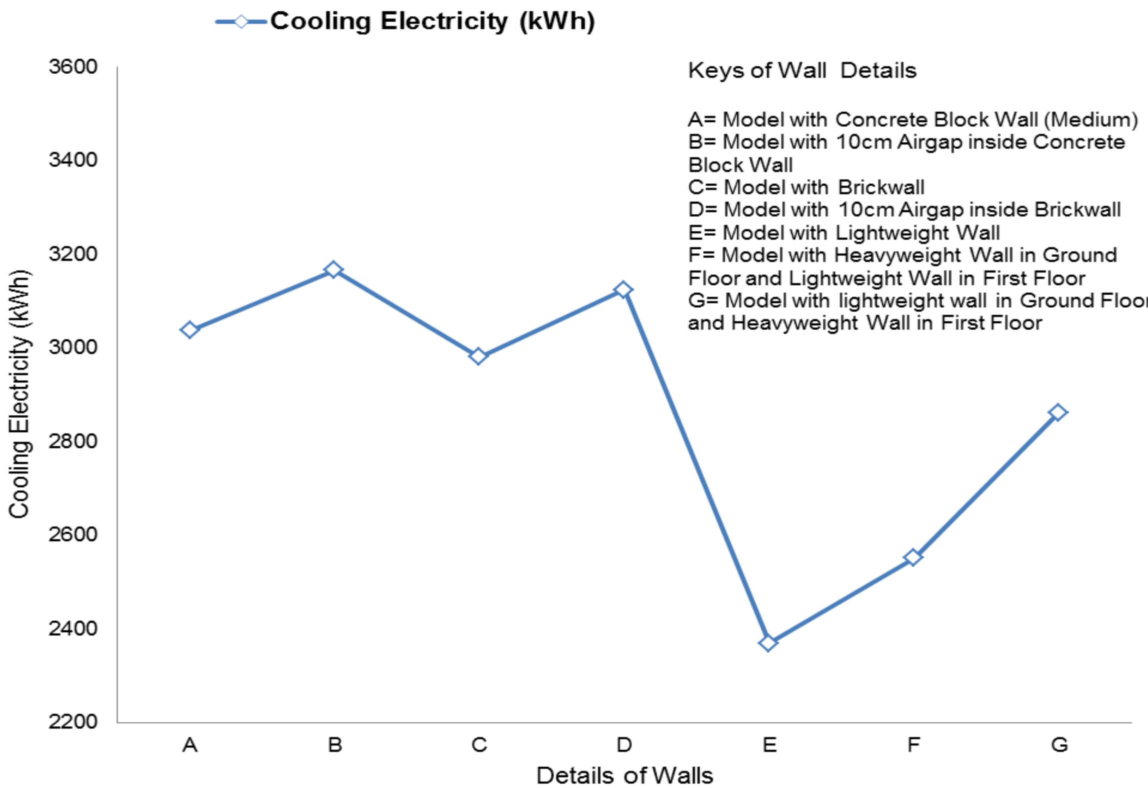


Figure 10. Comparison of different wall constructions and their effect on cooling energy.

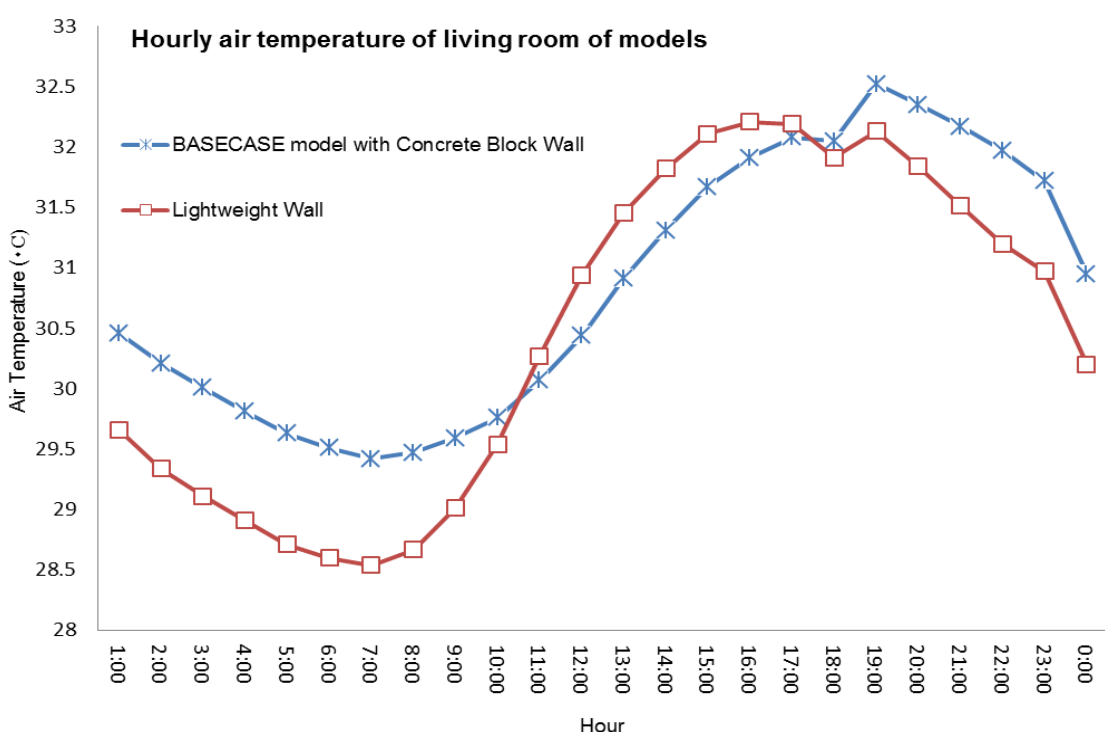


Figure 11. Hourly air temperatures of models with heavyweight (BASECASE) and lightweight walls.

Table 7. Supposed surface properties of examined materials.

Variable	Clay tile	Concrete tile	Steel	Stainless steel	White painted steel
Thermal absorptance (emissivity)	0.9	0.9	0.3	0.3	0.9
Solar absorptance	0.7	0.7	0.3	0.2	0.4

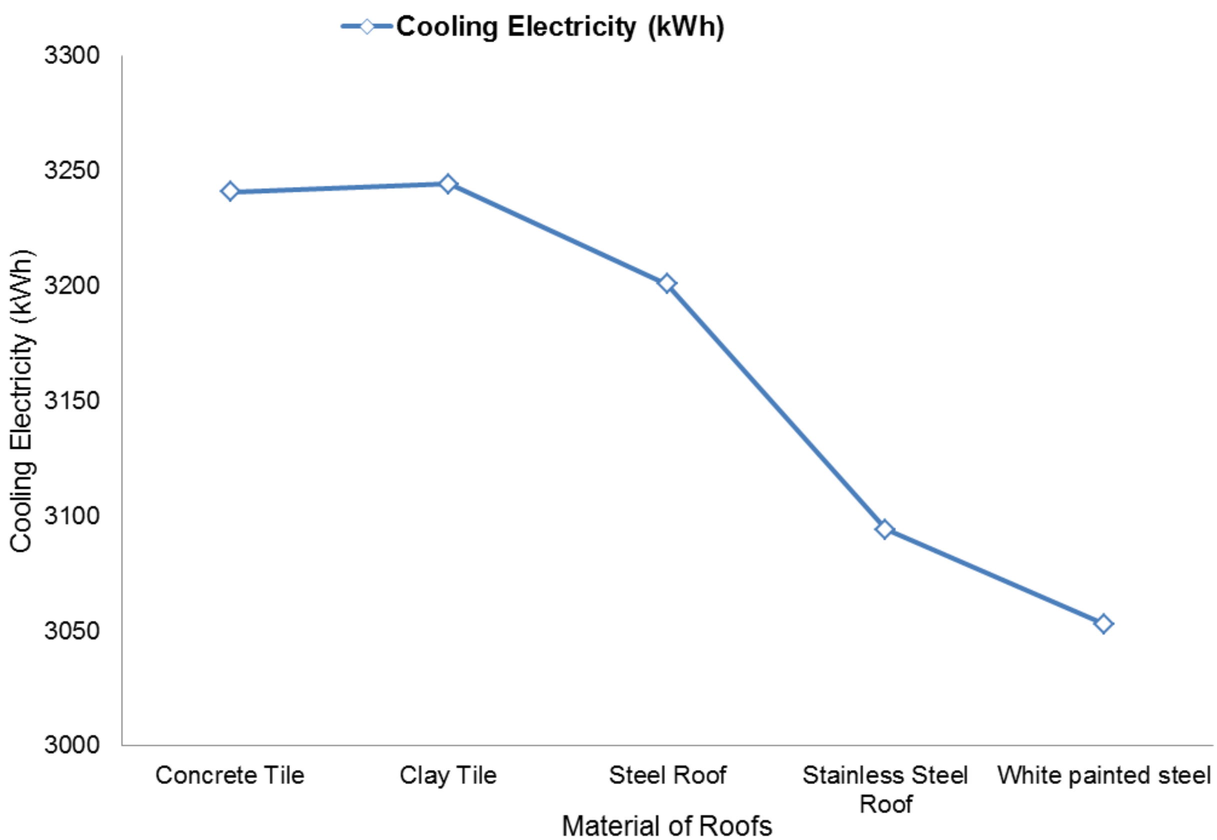


Figure 12. Annual energy consumption of models with different roof details.

proposed house could save 28.3% of cooling energy of BASECASE model.

DISCUSSION

Floor

According to Schiavon et al. (2010) raised floor has largely effect on cooling load (almost increasing amount of cooling load) of commercial building in San Francisco with warm and marine climate. They explored unventilated raised floor. Here, effect of raised floor was scrutinized in hot and humid climate, with different functions and also with natural ventilation. Raised floor without ventilation also increased cooling energy demand. But, use of ground as a heat sink and naturally ventilated raised floor in first floor ameliorated cooling energy consumption. It seems, results of floor section are compatible with Schiavon et al. (2010)'s study results.

Wall

According to Szokolay (2008), in hot and humid climate, low diurnal thermal fluctuations cause that high thermal mass to lose its effect as passive strategy. On the other hand, master bedroom is cooled only in the nighttime and it could expect lightweight material as external wall could decrease cooling load of bedroom because it loses daily

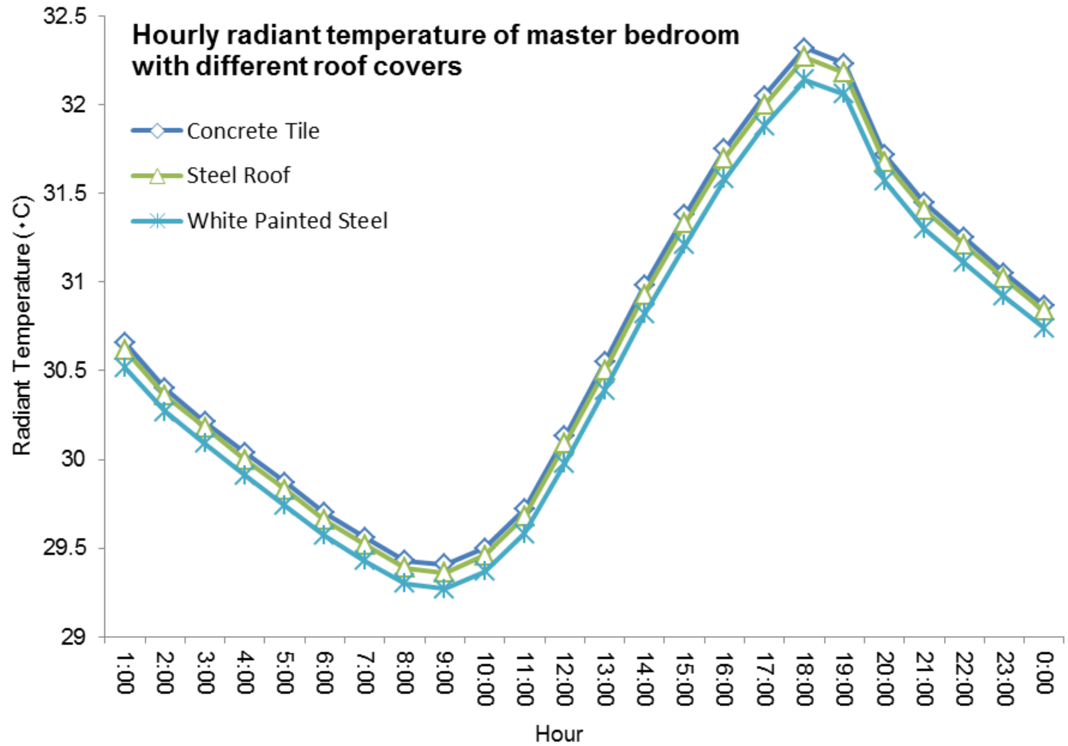


Figure 13. Hourly radiant temperature of master bedroom with supposed roof details.

Table 8. Construction details of proposed house and BASECASE model.

Variable	BASECASE model	Purposed house
Floor	GF[1]: Cast concrete (10 cm), mortar (2.5 cm), ceramic (1.2 cm) FF[2]: Cast concrete (dense)(10 cm), mortar (2.5 cm), ceramic (1.2 cm)	GF: Cast concrete (10cm), mortar (2.5cm), ceramic (1.2cm) FF: Naturally ventilated raised floor with 50cm plenum and cast concrete (dense) (10cm), wooden flooring (1.9cm)
Wall	GF, FF: Cement sand render (1.3 cm), concrete block (medium) (11 cm), gypsum plastering (1.3 cm)	GF: Cement sand render (1.3cm), concrete block (medium) (11cm), gypsum plastering (1.3cm) FF: lightweight metallic cladding (6mm), air gap (5cm), gypsum plastering (1.3cm)
Roof	Wooden batons (20 cm) + 10 cm air gap + concrete tile (2 cm)	Wooden batons (20cm) + aluminum foil + 10 cm air gap + white painted steel
Annual cooling energy (kWh)	3036.93	2177.72

1 = Ground floor, 2 = First floor.

heat rapidly than heavyweight material. So, it seems for nighttime to occupy spaces, lightweight wall would save cooling energy while it would not be appropriate for daytime occupied spaces.

Roof

For roof section, white painted steel roof could be considered as a cool roof which has high solar reflectivity and low thermal emissivity in comparison with other alternatives. This issue is in accordance with Akbari et al. (2005). They indicated that cool roofs could be economical by appropriate saving of cooling load. Integration of these strategies in proposed house saved significant amount of annual cooling energy (28.3%) and it would be economical because of cost effectiveness of cool roof, natural ventilation and lightweight materials. However, it would explore precisely economic effect of the proposed bungalow house and energy saving assessment in its life cycle in future research.

Conclusion

Some changes in floor, wall and roof construction of BASECASE model ameliorated its energy consumption condition. In this bungalow house, flooring in ground level could act as a heat sink and first floor could have naturally ventilated plenum on its floor. This floor layout decreased 9.4% of cooling energy of BASECASE model.

The use of lightweight wall (lightweight metallic cladding (6 mm), air gap (5 cm), gypsum plastering (1.3 cm)) in first floor instead of heavyweight wall of BASECASE model (Cement sand render (1.3 cm), Concrete block (Medium) (11 cm), Gypsum plastering (1.3 cm)) pulled down 16% of cooling energy. It should be mentioned, applying lightweight wall for whole building saved 22% cooling energy but it increased internal temperature and discomfort condition of daytime occupied spaces.

A model with white painted steel roof (Wooden batons (20 cm) + Aluminum foil + 10 cm Air gap + White painted steel) could save 5.8% more cooling energy rather than BASECASE model (Wooden batons (20 cm) + Aluminum foil + 10 cm Air gap + Concrete tile (2 cm). Composition of mentioned details presented a proposed house which could be able to decline 28.3% of cooling energy in comparison with BASECASE model.

These results could be used for correct understanding of different components of a bungalow house. Appropriate selection of passive strategies would be essential in architectural design stage of a building. In this study, comparison of different passive strategies with respect to function and occupation schedule cleared their important role for appropriate decisions. In subsequent researches, different floors of house alternatives could be presented and compared with their energy consumption and room temperatures. These studies would help to clarify architects imaginations for energy efficient design of a bungalow house.

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