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Full Length Research Paper

Energy efficiency and thermal comfort influences of alternatives of single skin façade (SSF) and double skin façade (DSF) in tropical bungalow house

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Sustainable design is an important goal in architecture. Sustainability could be approached with low energy and high thermal comfort buildings. In this study, a bungalow house as a BASECASE model was simulated with “DesignBuilder” software based on “Energy Plus”. Then influence of double glazing, external blind and double skin façade (DSF) on energy consumption and thermal comfort of master bedroom (with cooling) and living room (without cooling) were explored. Results showed that outside blind with high reflectivity slats installed at daytime (8 A.M. to 6 P.M.) could save more cooling energy of master bedroom rather than double glazing. DSF (inner skin: clear, outer skin: double glazing) with full daytime internal blind would reduce energy consumption but its amount was less than other alternatives. If installation of inside blind of DSF is considered at daytime, energy saving difference between DSF and other alternatives would be decreased. DSF pulled down air temperatures of living room and ameliorated its thermal comfort condition. In living room, DSF presented best suitable comfort values. In master bedroom, integration of double glazing and external blind not only saved more energy, it also would give best annual thermal comfort condition.

Key words: Energy consumption, thermal comfort, double skin façade (DSF), single skin façade (SSF).

INTRODUCTION

Appropriate architecture design could decrease energy consumption and increase internal thermal comfort. Various façade designs have been studied in recent decades. Window to wall area ratio (WWR), window type, awning, projections, louvers, fins are instances of factors which would compose a façade. A façade could be defined as single skin façade (SSF) or double skin façade (DSF) (two skins of façade and cavity between them). It also could be airtight or ventilated (Loncour et al., 2004). In this study, façade design and its relation to energy efficiency of bungalow house was considered. Different façade details were examined for simulated BASECASE model. Various factors like different glazing, shading and orientation were considered for SSF and DSF. Results of simulations were presented and discussed. In addition, some suggestions were proposed for façade design with respect to energy consumption.

LITERATURE REVIEW

A considerable amount of studies have been done about SSF and DSF. Most part of these studies was in European countries. Gratia and De Herde (2004, 2007a, b, c, d) simulated an office building with thermal analysis software (TAS) and evaluated performance and influence of DSF. They explored natural ventilation in double skin façade and its influence on temperature of DSF surfaces (Gratia and De Herde, 2004). They showed that DSF is not so energy efficient as it seems in first but it could have other advantages (Gratia and De Herde, 2007a).

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Natural ventilation is a critical issue for DSF. Orientation of DSF had significant importance on greenhouse phenomenon (Gratia and De Herde, 2007b). They also presented guidelines for increasing natural ventilation in office building with DSF. It was considered for both with or without wind conditions (Gratia and De Herde, 2007c). Solar shading could decrease cooling demand. According to Gratia and De Herde (2007d), light colored blinds in middle of cavity could save more cooling energy in comparison to other modes.

Other study has been done in a planned office building in Norway by Høseggen et al. (2008). This building was simulated with ESP-r energy simulation program. Their simulated results showed that DSF increases 20% energy saving in comparison to single skin façade. However, the implementation of improved U-value window evened out this difference. Also, the amount of energy saving did not make economical application of DSF. In Hong Kong, energy efficiency of an office building was investigated by Chan et al. (2009). Their investigation showed that a double skin façade could be able save 26% cooling energy of office building as compared with single skin façade. In hot arid areas, a reflective double skin façade could also be energy efficient than a single skin with reflective glazing (Hamza, 2008). There are some studies explored about DSF in hot and humid climate. Wong et al. (2008) have configured a new type of DSF. They started their research from simple one storey module and extended it to 18-storey office building. They showed that DSF is really possible to be applied for natural ventilation in tropical climate. In another study, Hien et al. (2005) have explored a typical office in Singapore. They found that DSF could be able to lessen cooling energy demand.

An office building was simulated by Haase et al. (2009) for thermal condition and airflow network of ventilated double skin façade in hot and tropical summer of Hong Kong,. They mentioned that careful façade design could have considerable effect on energy consumption of highly glazed building. An appropriate DSF could reduce the amount of heat gain through building envelope.

A house with double skin façade was proposed for a Japanese house by Xu and Ojima (2007). Results of their study showed 10 to 15% energy saving is possible for cooling in summer time for this house. They mentioned that DSF is suitable for energy conservation in residential buildings. In another study, Rahman et al. (2011) explored energy efficiency of two office buildings and explained some design recommendations. They emphasized on design of façade elements such as glazing and shading. In this research, SSF and DSF were examined for a bungalow house in Malaysia.

MATERIALS AND METHODS

For proper evaluation of sustainability of bungalow house, thermal comfort and energy consumption of its spaces could be considered as the main criteria. First, thermal comfort indices and simulation processes are described. Then simulation results are presented and discussed.

Thermal comfort indices

Integrated effect of air, radiant temperature and relative humidity are discussed as thermal comfort indices. Thermal comfort and thermal sensation can be predicted in several ways. More numerical and rigorous predictions are possible by using the PMV-PPD and two-node models. The PMV index predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale. Fanger's model, Pierce PMV model and Kansas TSV are some thermal models.

Fanger (1970) described predicted mean vote (PMV) to the imbalance between the actual heat flow from the body in a given environment and the heat flow required for optimum comfort at the specified activity. The Pierce model converts the actual environment into a standard environment at a standard effective temperature (SET). The SET is the dry-bulb temperature of a hypothetical environment at 50% relative humidity for subjects wearing clothing that would be standard for the given activity in the real environment.

Kansas TSV model predicts thermal sensation (TSV) differently for warm and cold environments. The Kansas TSV two-node model is based on the changes that occur in the thermal conductance between the core and the skin temperatures in cold environments, and in warm environments, it is based on changes in the skin wetness (ISO 7730, 1994).

Simulation of BASECASE model 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. It has many capabilities to simulate different time steps and plant types with zone simulation (U.S. Department of Energy, 2011). Design Builder (DB) is a state of the art software tool for checking building energy, lighting and thermal demands (Tindale, 2002).

In this research, a bungalow house in suburb area of Kuala Lumpur was considered as a BASECASE model. Ground floor of this house composes of living room, guest room, and kitchen. Master bedroom, three single bedrooms and their bathes are in first floor (Figure 1). Ground and first floor areas are 122.5 and 120.5m^2, respectively. Total area of the building is 243 m^2. The reinforced concrete makes up the structure of the building. It has pitched roofs covered with concrete tiles. There are no insulation in walls and roofs. Building orientation is east-west and has aluminum framed windows with single clear glazing. Architectural properties of the building are presented in Table 1.

Master bedroom is the only cooled space with a split cooling system. Area of master bedroom is 24.7 m^2 and its height is 3.8 m and has a pitched roof with 25° slope. Its climax height is 5.76 m. It has two external walls oriented to 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 westward wall. Cooling set point of air temperature for master bedroom was considered as 28°C. Figures 1 and 2 illustrate architecture plans and image of simulated house, respectively.

For simulation in "DB", five categories of data would be implemented including: activity, construction, opening, lighting and heating, ventilation and air conditioning (HVAC) system. Building

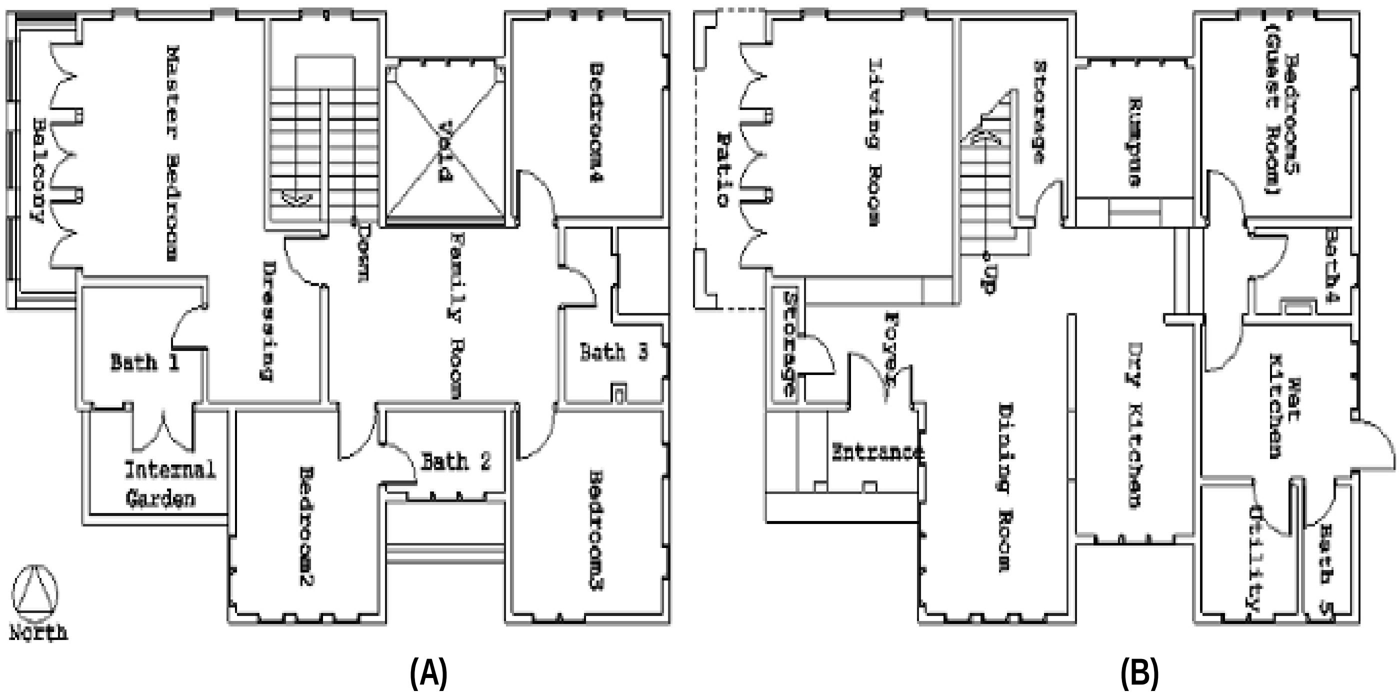

Figure 1. Architecture plans of bungalow house, first floor (A), ground floor (B).

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

Parameter	Value
Number of floors	2
Ground floor area	122.5 m^2
First floor area	120.5 m^2
Total area	243 m
Orientation	East-west
Balcony	One balcony with 1.6 m depth and 5.1 m length at west side, concrete (medium density)
Internal floor	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

physical properties were added in accordance with Table 1. Occupation and HVAC operational schedules were entered in congruence with previous researches in Malaysia. It indicates that most of the owners operate splits at night and use cooling systems for sleeping (Kubota et al., 2009). In BASECASE model, split system was only considered in master bedroom and it was used at nighttime. Rest of spaces had no cooling system but these spaces used scheduled natural ventilation. Operational schedule of HVAC system of main space types could be seen in Table 2.

Verification of BASECASE

The weather data of simulation was weather report of Kuala Lumpur, Subang weather station in 2002. This file is available at Energy plus website (U.S. Department of Energy, 2010). Simulation results of energy consumption of BASECASE model were calibrated with respect to monthly electrical bills of bungalow house. Malaysia has approximately permanent weather condition throughout the year. The average monthly electrical bill was around

Figure 2. Image of bungalow house simulated by “DB”.

Table 2. Supposed HVAC operation schedule.

Abbreviation	Weekdays and holidays	Weekends
Bedroom	5 P.M.-9 A.M	5 P.M. – 9 A.M.
Living room, Kitchen	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.

Month	1/1	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/9	1/10	1/11	1/12
Electricity (kWh)	782	735	880	812	825	920	859	816	772	735	754	727

Table 4. Solar properties of high reflectivity slats.

Parameter	Value
Slat beam solar reflectance	0.8
Slat beam visible reflectance	0.8
Slat diffuse visible reflectance	0.8
Slat beam solar transmittance	0
Slat hemispherical emissivity	0.9
Slat angle	45°

800 kWh and average simulation was 801.4 kWh. Table 3 displays simulation results of monthly electricity use of BASECASE model.

Simulation of single and double skin facades

For exploring influence of façade design, balcony of west wall was omitted. Building was also rotated for scrutiny on effect of orientation. Concentration of study was considered on west wall of BASECASE model with 43% of WWR.

Single Skin Façade (SSF)

Shading devices have more importance in topical areas because sun radiates intensively to building surfaces. So, blinds and their operational schedule would be effective for thermal behavior and energy saving of a façade. In selected SSFs, outside blinds were defined to prevent penetration of solar radiations into the building, because they act better than inside blinds and they do not let solar radiations trapped in the house spaces. Solar properties of slats are presented in Table 4.

Also, single or double glazing types of windows were assumed as other changeable feature of façade. Double glazing was considered as reflective metal colored glazing in outer pane and clear glazing in inner pane. It had 6 mm air cavity.

Double skin façade (DSF)

DSF has some main properties that should be considered in its design. Pappas and Zhai (2008) introduce these properties as depth, width and height of cavity, locations and structure of opening, materiality of cavity, shading devices and airflow control.
Based on previous studies, DSF geometries and ventilation type could be divided into four types including:

1. Box window type: horizontal and vertical division of façade to small and independent boxes.
2. Shaft box type: A set of box window elements are placed in façade and connected vertically for increased stack effect.
3. Corridor façade: Horizontal partitioning is done for acoustical, fire, security or ventilation aims.
4. Multi storey double skin façade: There is no horizontal or vertical partitioning and airflow is implemented via large inlets and outlets near the floor and roof of the buildings (Poirazis, 2006).

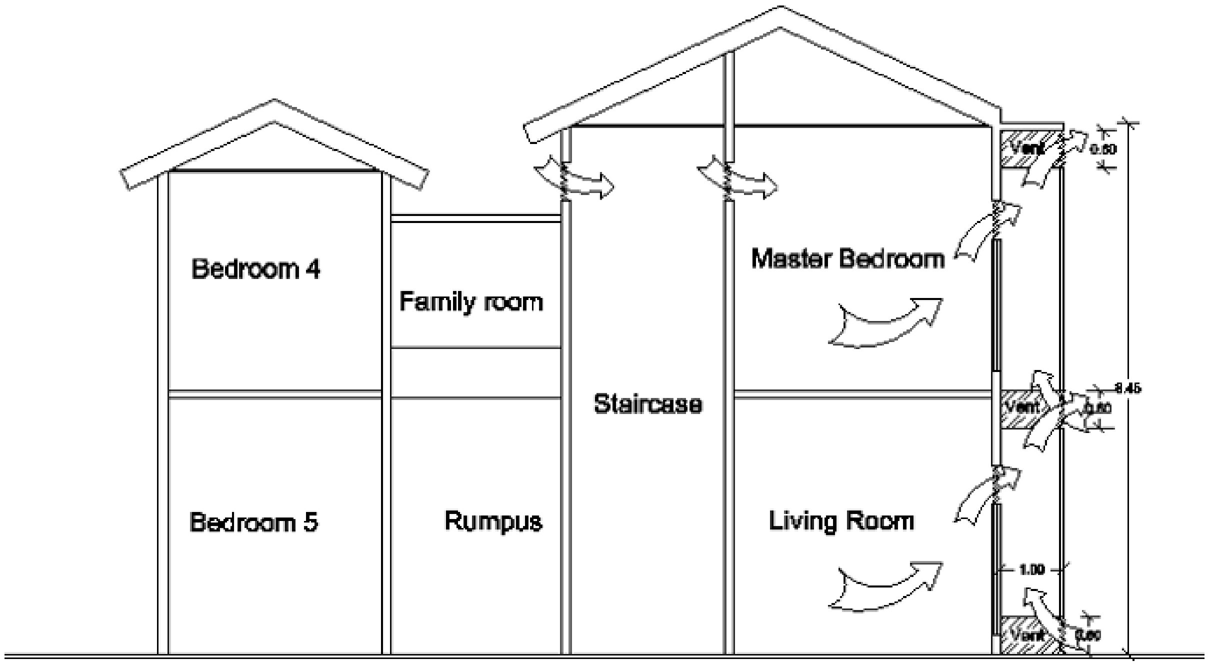

Figure 3. Section of bungalow house with double skin façade.

Figure 4. Image of Bungalow house with double skin façade.

In this survey, the DSF which is used for west wall was shaft box type. Three window boxes had 1 m depth and 1.47 m length. Their heights were same as height of each floor. Section of building and location of vents are shown in Figures 3 and 4. Airflow in DSF could remove indoor air (exhaust air) or supply air to indoor (supply air). It also could act as a buffer with convective air movement only within the cavity (statistic air buffer) or as internal or external air curtain (Haase et al., 2009). In tropical climate, outside temperature at daytime is hotter than inside temperature. So, at daytime DSF could be external air curtain to prevent penetration of hot air to inside. In nighttime, due to cooler temperature of outside, DSF could act as an exhaust air system to evacuate inside hot air. Therefore, vents were considered for external and internal skins of DSF. The size of each vent was 0.6 m × 1.47 m. Vents of external skins is operated at full daytime while vents of internal skin is only operated at nighttime.

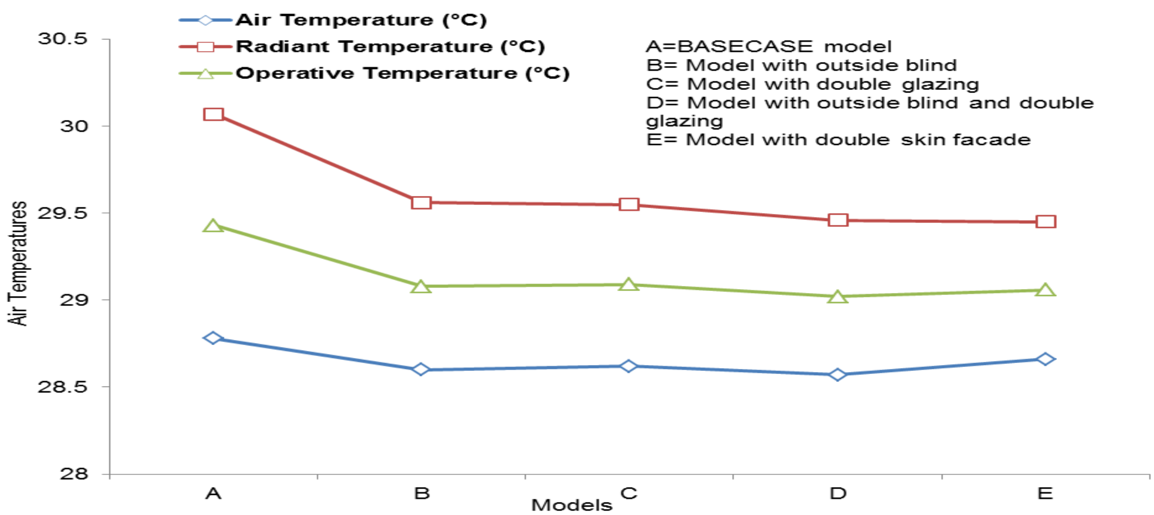

Figure 5. Annual results of air temperatures of master bedroom with different facades.

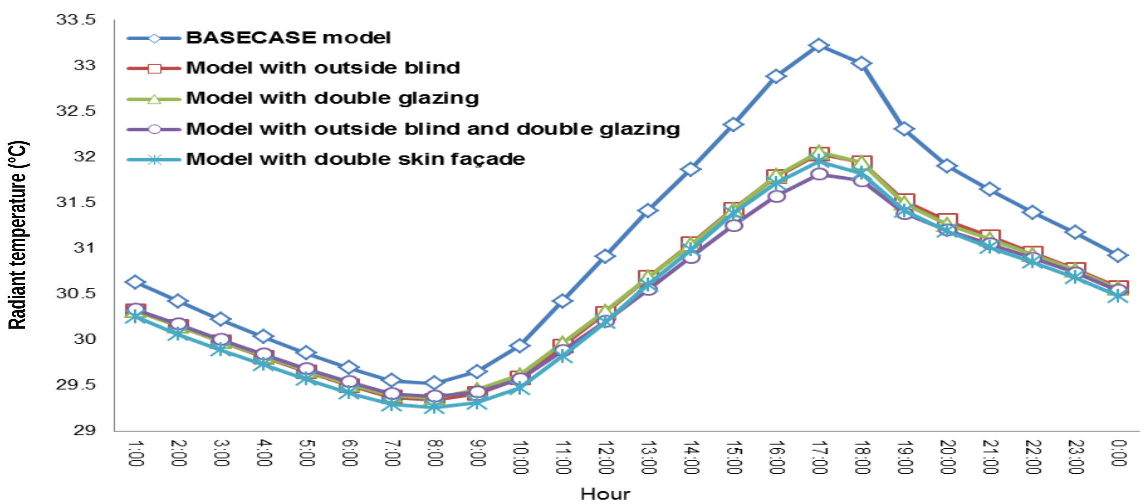

Figure 6. Hourly radiant temperatures of master bedroom with different facade alternatives on 15th July.

Various façade alternatives for simulation

According to the aforementioned factors, the supposed façade alternatives are defined as follows:

BASECASE model
BASECASE model within outside blind
BASECASE model within double glazing
BASECASE model within outside blind and double glazing
BASECASE model within double skin façade (DSF)

Results of simulations are indicated subsequently.

RESULTS AND DISCUSSION

Results are argued in two subjects. First, thermal comfort indices are compared and secondly demands of cooling energy are indicated.

Thermal comfort

Environmental indices of rooms with mentioned facades are illustrated in Figures 5 to 12. Figure 5 displays that façade with integration of outer blind with high reflectivity slats and double glazing caused lowest annual air temperature for master bedroom. Results also showed that annual air temperature of master bedroom with DSF was higher than other alternatives with an exception of BASECASE model. But radiant temperature of master bedroom with DSF had good condition. This issue is in

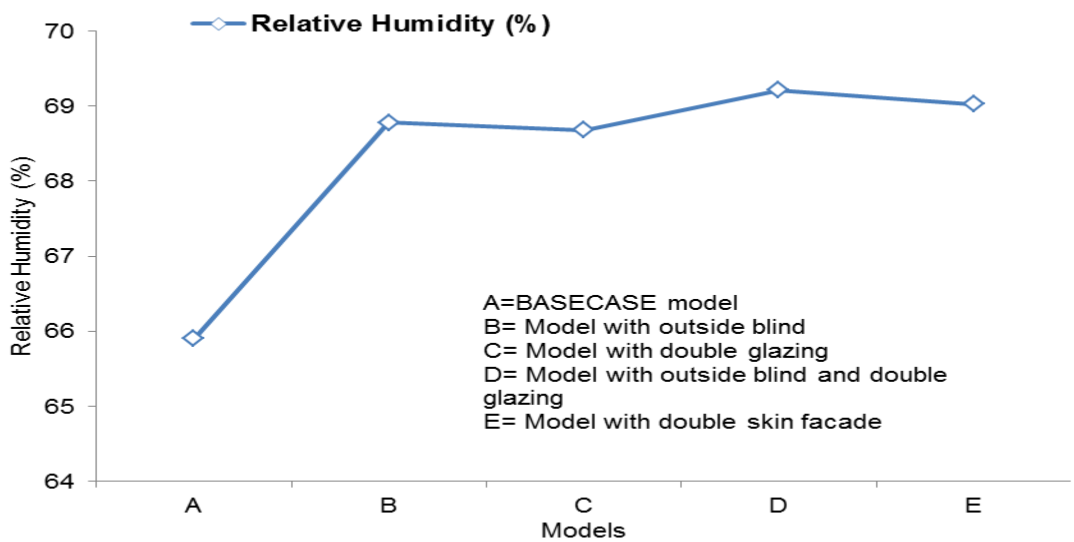

Figure 7. Annual results of relative humidity of master bedroom with different facades.

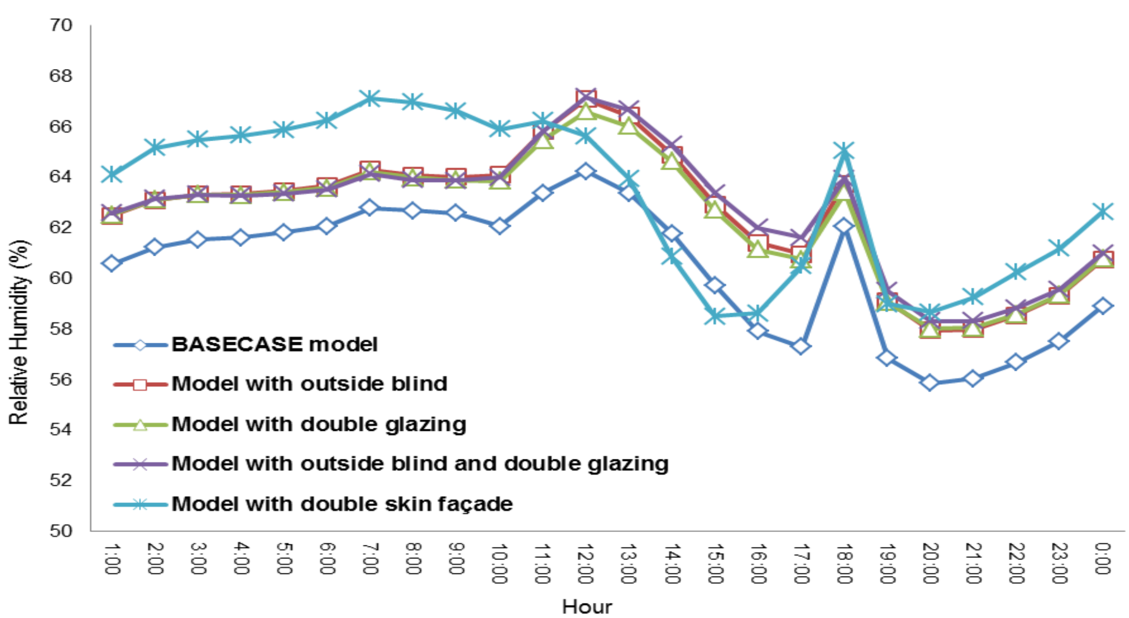

Figure 8. Hourly results of relative humidity of master bedroom with different facade alternatives on 15th July.

congruence with daily results of radiant temperatures of facades. Figure 6 shows that master bedroom with DSF had lowest radiant temperatures from 7 P.M. to 10 A.M. on 15th July. Model with double glazing and outside blind has obtained lowest radiant temperatures from 2 P.M to 6 P.M. It should be mentioned that differences between air temperatures of various façade alternatives for master bedroom were not considerable.

DSF caused high annual relative humidity for master bedroom (Figure 7). Moreover, daily results of relative humidity showed that DSF caused highest relative humidity from 8 P.M. to 10 A.M. while, it declined relative humidity from 12 P.M. to 5 P.M (Figure 8).

DSF for Living room (without cooling system) had best annual air temperature condition. In addition, there was no considerable difference between annual air and radiant temperatures for living room with DSF (Figure 9). Daily simulation results demonstrated that living room with DSF could have around 0.4°C lower air temperature than other alternatives from 7 P.M. to 8 A.M. (Figure 10).

Living room with DSF had low amount of annual relative humidity in comparison with other alternatives.

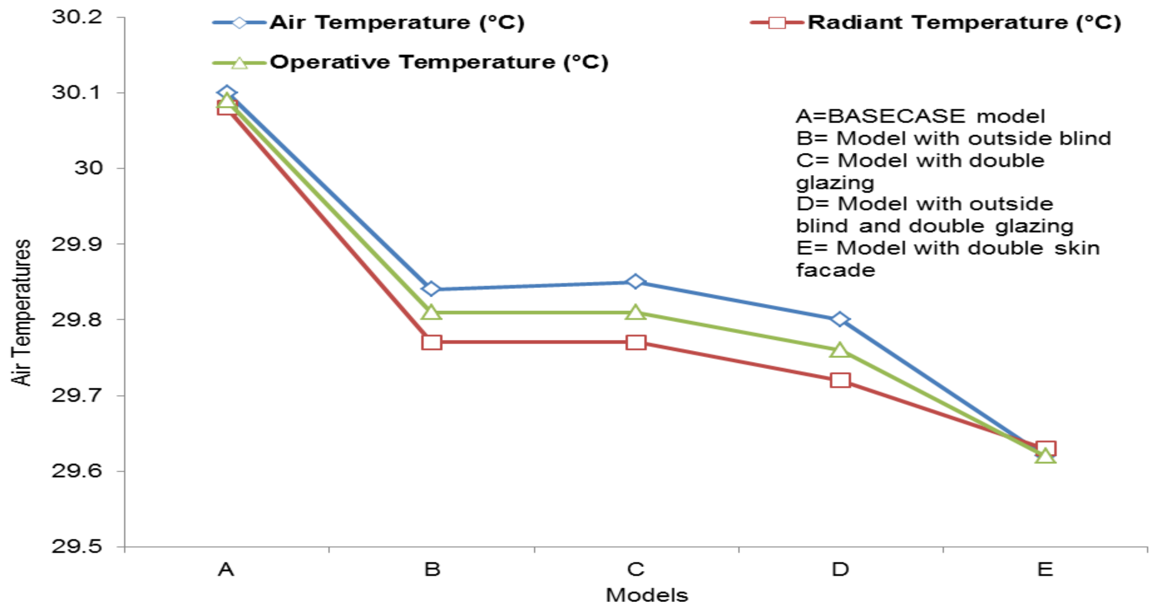

Figure 9. Annual results of air temperatures of living room with different facades.

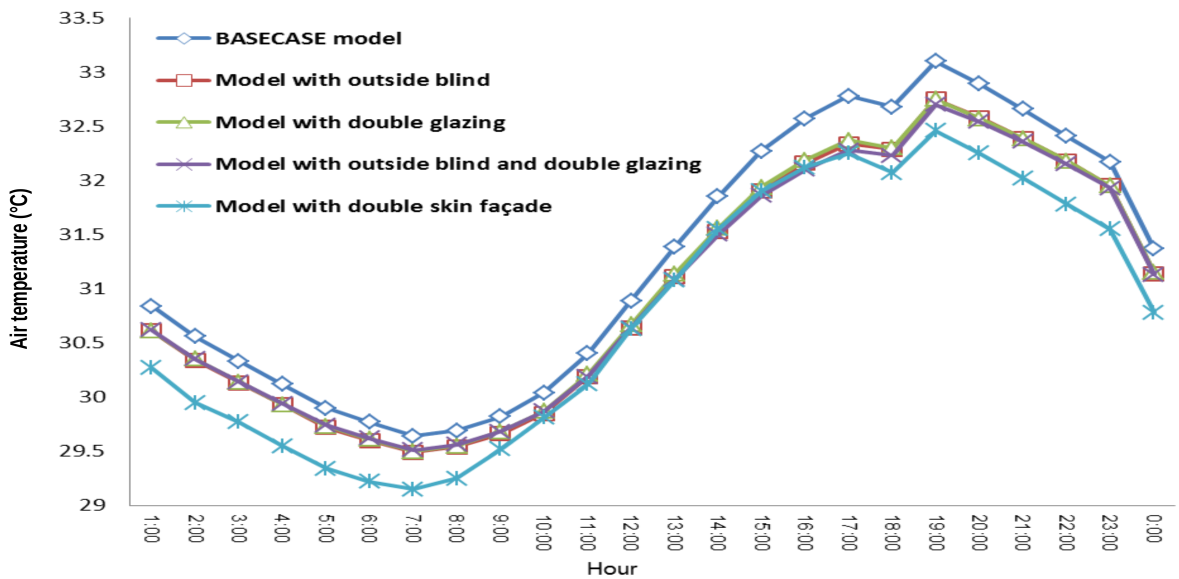

Figure 10. Hourly air temperatures of living room with different facade alternatives on 15th July.

But model with outer blind and double glazing had highest relative humidity (Figure 11). In daily results, it could be realized that DSF raised relative humidity of living room between 8 P.M and 8 A.M. in comparison with other façade alternatives while it decreased relative humidity between 12 P.M. and 6 P.M. (Figure 12). It should be mentioned that BASECASE model without shading had lowest relative humidity for living room.

Figures 13 and 14 show annual Pierce PMV (SET) values for master bedroom and living room with different façade alternatives. It could be seen that master bedroom with DSF façade had better thermal comfort condition than master bedrooms of BASECASE model, model with outside blind and model with double glazing. However, integration of outside blind with high reflectivity slats and double glazing could cause best thermal indices for master bedroom (Figure 13). For living room, best annual thermal comfort condition could be achieved with DSF (Figure 14). Fanger PMV and Kansas TSV values emphasized on same thermal conditions for master

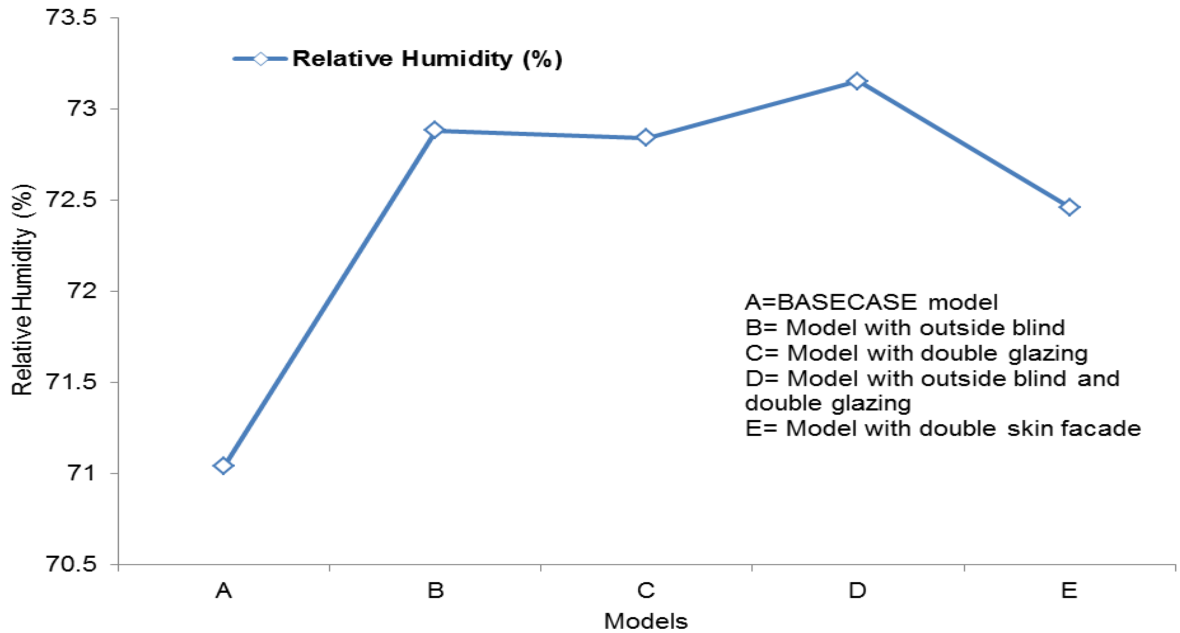

Figure 11. Annual results of relative humidity of living rooms with different facades.

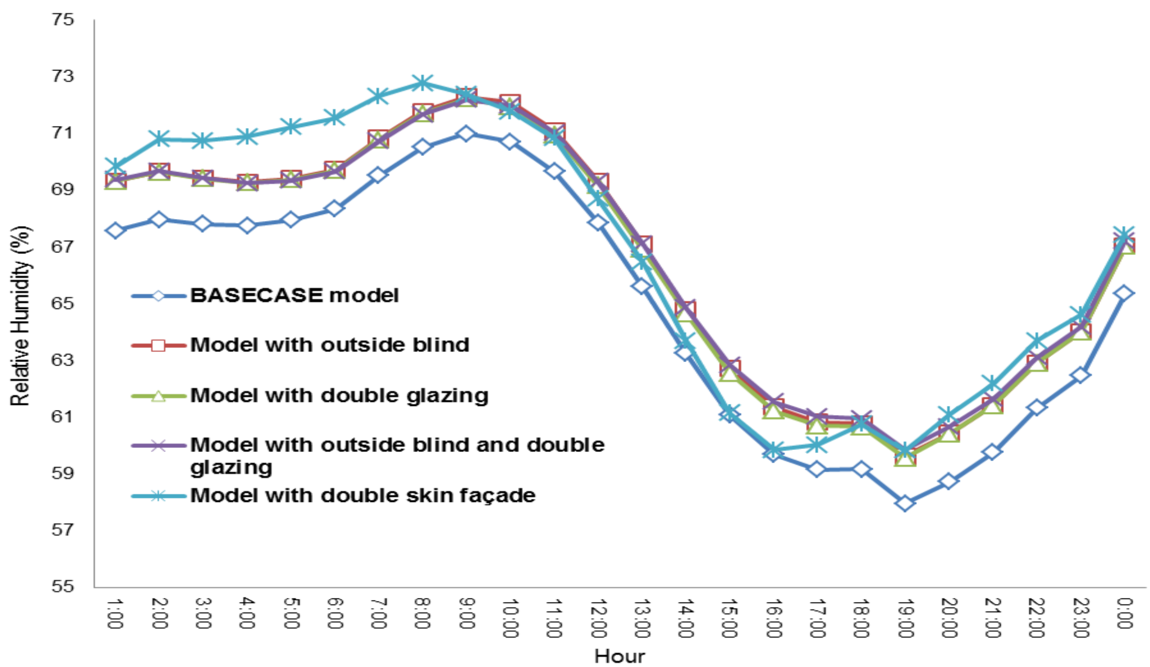

Figure 12. Hourly relative humidity of master bedrooms with different facade alternatives on 15th July.

bedroom and living room.

Cooling energy

Here, energy efficiency of each façade alternatives is presented. For clear understanding of this issue, various orientations of bungalow house and different operational schedule of blinds were included. Orientation of BASECASE model is shown in Figure 15. Study zone was marked by hatched area. West wall of master bedroom of BASECASE model was considered for

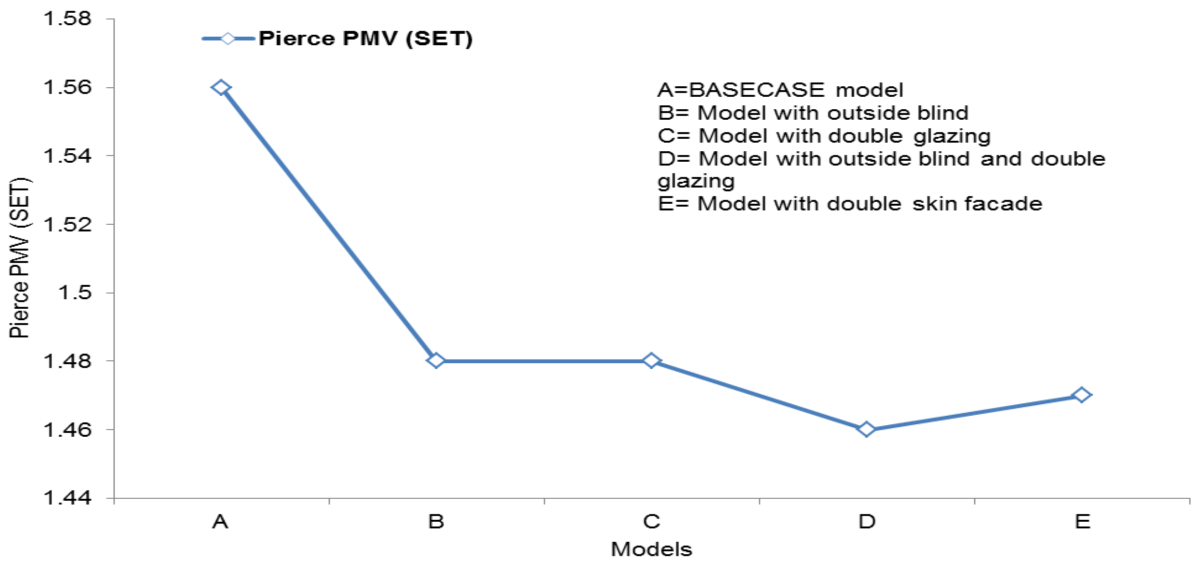

Figure 13. Annual results of Pierce PMV (SET) of master bedroom with different facades.

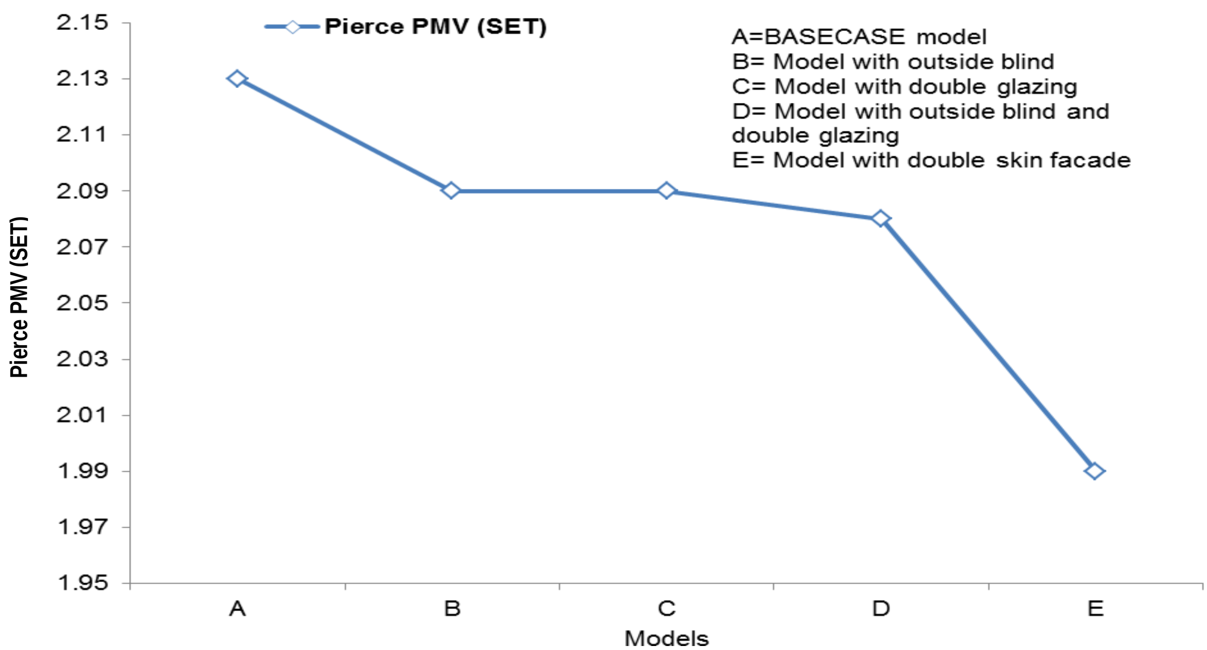

Figure 14. Annual results of Pierce PMV (SET) of living room with different facades.

replacing façade alternatives. In illustrations of simulation alternatives, this model was named west-north orientation because of its external walls. For simulation of different orientations, building was rotated for each 45°.

Annual cooling energies of BASECASE model in different orientations of external walls are shown in Figure 16. From this figure, it could be seen that east-west was most energy efficient orientation for building. Master bedroom had least energy consumption when it had west and north oriented external walls. On contrary, north-south oriented building with master bedroom walls toward south and west had the most energy consumption.

Figure 17 shows annual cooling energy consumption of BASECASE model and model with outside blind at different orientations of Bungalow house. It could be seen that adding external blinds with high reflectivity slats at full daytime operational schedule reduced the cooling

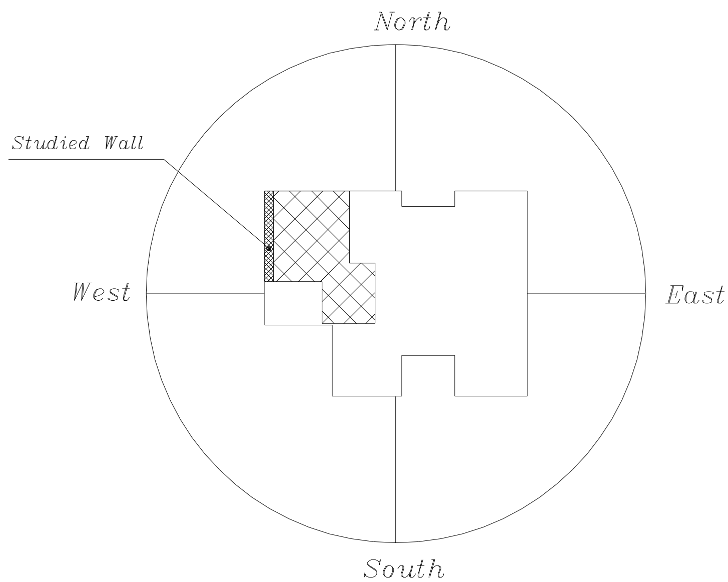

Figure 15. Orientation of bungalow house and position of surveyed zones (hatched area).

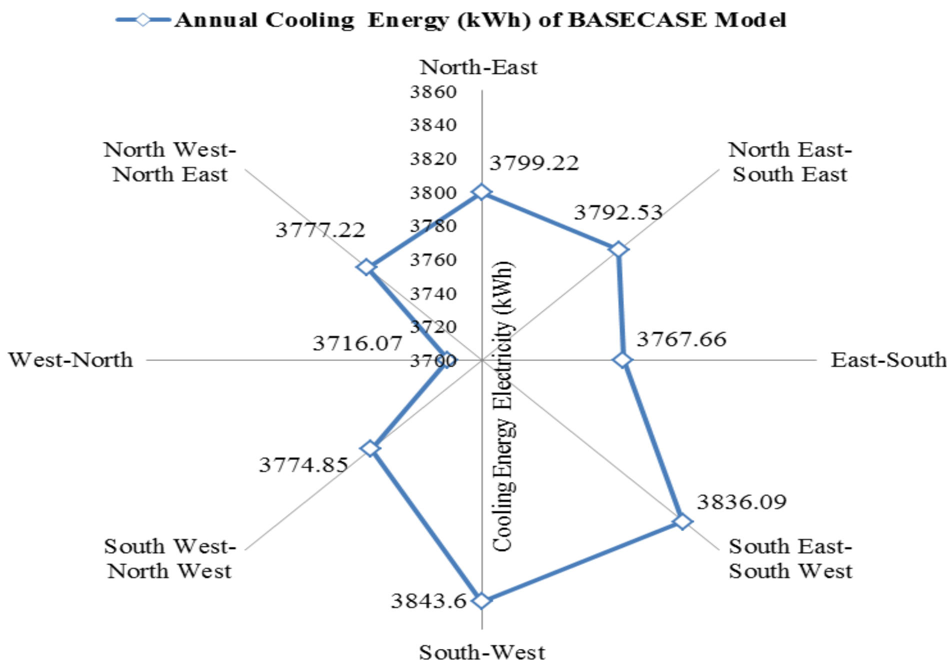

Figure 16. Annual cooling of BASECASE model in different orientations of external walls of surveyed zones.

energy consumption of the house. Most reduction of energy consumption was found to be 18.3% for west wall of east-west oriented bungalow house. While outside blind for north wall of north-south oriented house had least reduction of cooling energy with an amount of 13.6%.

Double glazing declined cooling energy demand (Figure 18). In east-west oriented bungalow house, the use of double glazing for windows of west wall of master bedroom saved 18.3% of cooling energy. While, saving for east wall of same orientation was obtained as 17.6%. Lowest amount of saving was obtained as 13.8% for

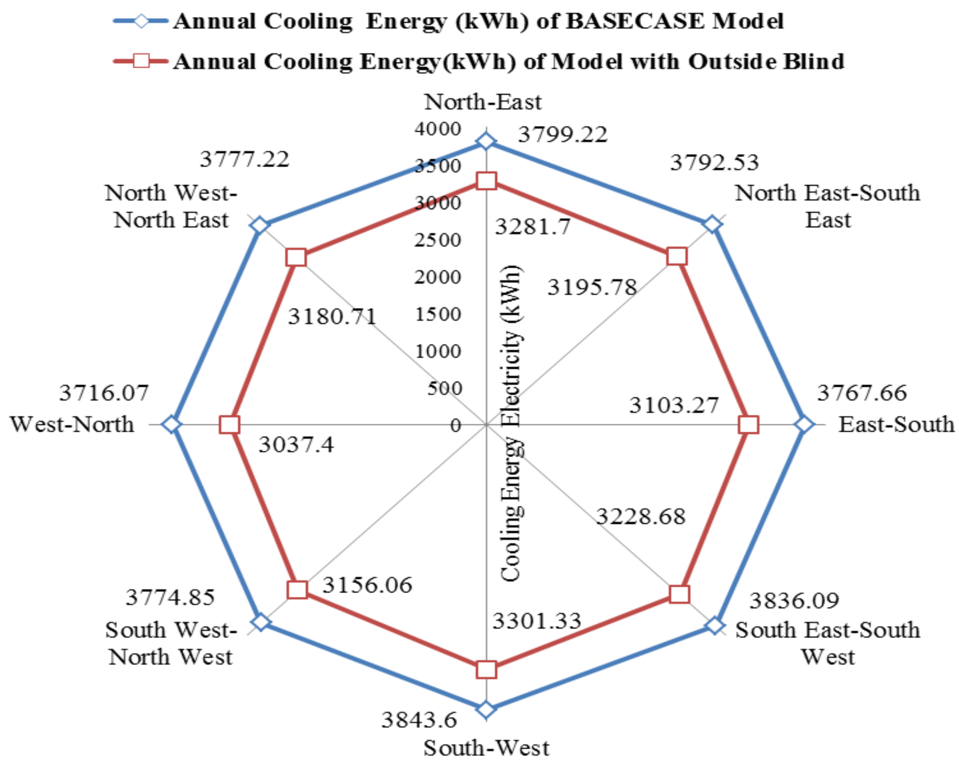

Figure 17. Comparison of annual cooling energy of BASECASE model with annual cooling of model with outside blind (high reflectivity slats).

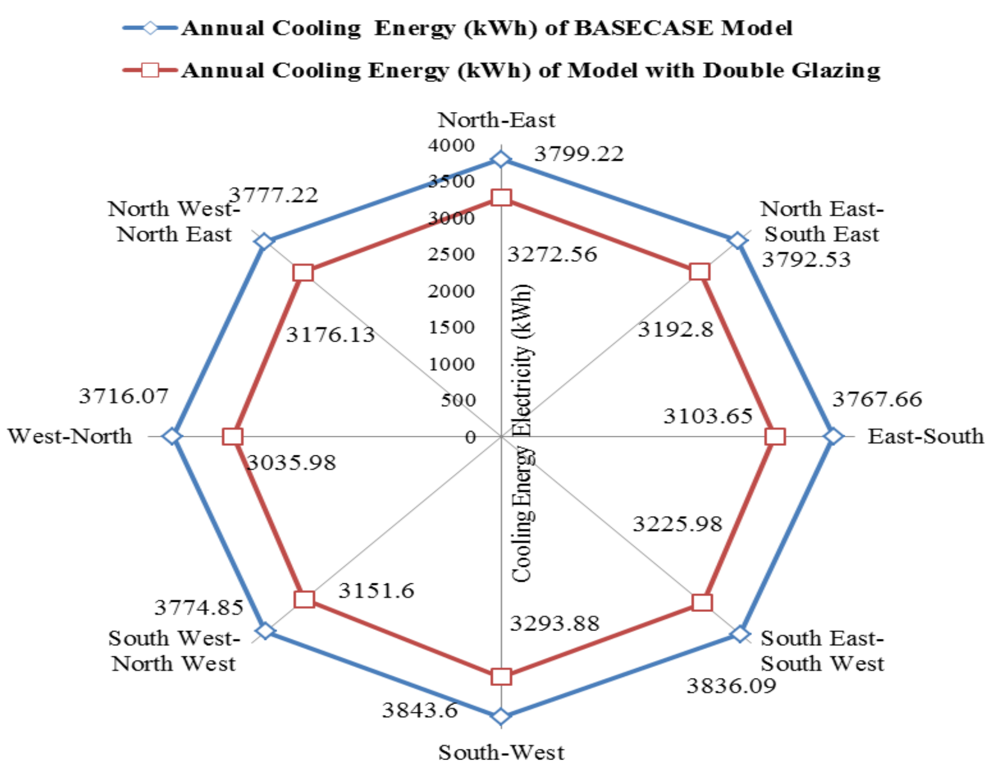

Figure 18. Comparison of annual cooling energy of BASECASE model with annual cooling energy of model with double glazing.

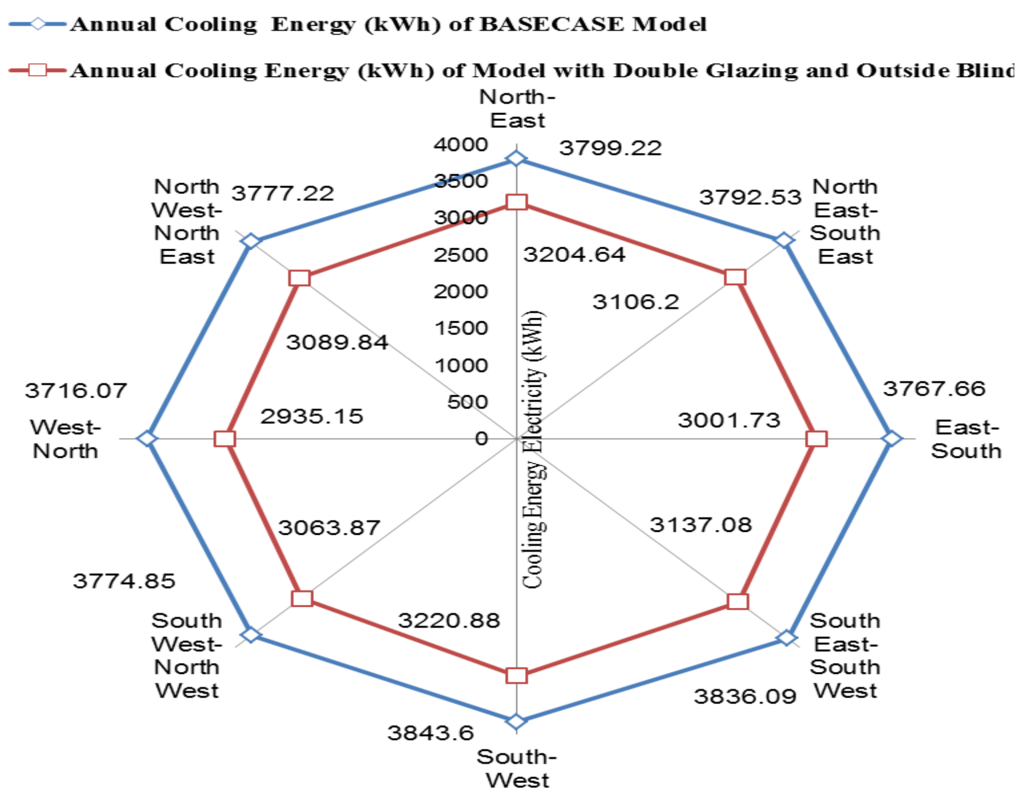

Figure 19. Comparison of annual cooling energy of BASECASE model with annual cooling energy of model with integrated outside blind and double glazing.

north wall of north-south orientated building. It could be realized that double glazing had approximately equal energy saving with full daytime operated outside blind for master bedroom (Figure 21).

Figure 19 shows annual cooling energy of BASECASE model and model with integrated outside blind and double glazing at different orientations of bungalow house. Integration of double glazing and outside blind saved 21 and 20.3% of cooling energy consumption for west and east walls of east – west oriented bungalow house respectively. North-south oriented building with double glazed window and outside blind in its north wall saved 15.6% of cooling energy. It indicated that application of full daytime operated outside blind together with double glazing increased energy saving by 1.8 to 2.7% in comparison with master bedroom with double glazing. Comparison of energy use of various facades for west wall could be seen in Table 5.

Figure 20 shows annual cooling energy of BASECASE model and model with shaft box type DSF at different orientations of bungalow house. It is seen that in east-west oriented building, DSF in east wall of master bedroom saved 15.3% of cooling energy while it saved 15.4% of cooling energy when it was used in west wall. In north-south oriented building, DSF in south wall of master bedroom saved minimum amount of cooling electricity (9.3%).

In Figure 21, energy consumption of all façade alternatives were compared with BASECASE model. It would be seen that difference between DSF and double glazing façade performance decreased in east and north east orientation. Good performance of DSF could be realized in these orientations. It was also in congruence with weather data of Kuala Lumpur which indicated dominant winds blow in west and south west directions. Figure 21 also shows that east-west orientation is appropriate orientation and north-south orientation is the worst. It has been shown that north east with south west orientations for different facades had slightly better energy conservation conditions than northwest with south east orientations.

Figure 22 shows that daytime operation of blinds would be more energy efficient than its full daytime schedule. Outside blind operated at daytime (8 A.M. to 6 P.M.) saved 19.6% of cooling energy of BASECASE model. This amount of saving was 1.4% more than outside blind installed all hours of a day. Façade with double glazing and outside blind with daytime (8 A.M. to 6 P.M.) operation declined by 23.6% of cooling electricity demand. It had 2.6% more energy saving than the same façade with full daytime schedule. Façade with DSF and operational schedule of its internal blind at daytime (8 A.M. to 6 P.M.) saved 17.4% of cooling energy. This amount was 2% more than DSF with full daytime internal

Table 5. Comparison of cooling energy consumption of different facades with respect to operational schedule of blinds.

Model	Operational schedule of blinds	Energy saving ratio (%)	Electricity consumption (kWh)
BASECASE model	-	-	3716.1
Model with double glazing	-	18.3	3036
Model with outside blind	Full daytime	18.2	3037.4
	8 A.M. – 6 P.M.	19.6	2985.3
Model with double glazing and outside blind	Full daytime	21	2935.1
	8 A.M. – 6 P.M.	23.6	2839.1
Model with double skin facade	Full daytime	15.4	3144.6
	8 A.M. – 6 P.M.	17.4	3068.1

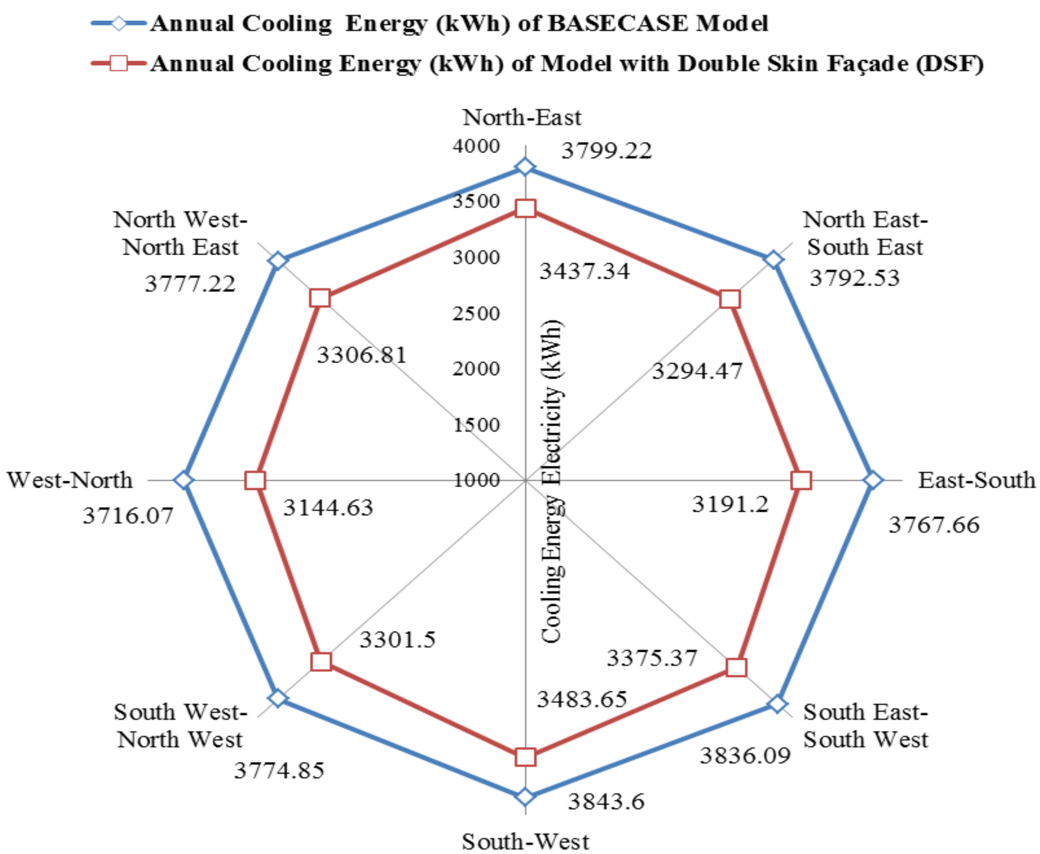

Figure 20. Comparison of annual cooling energy of BASECASE model with annual cooling of model with shaft box type DSF (inner clear, outer double glazing with blind inside of DSF).

blind. Therefore, DSF could be seen as near to energy efficiency of double glazing. The comparison of energy performance of various facades with regard to operational schedule of blinds has been presented in Table 5. These results proved that operation of blinds at daytime (8 A.M. to 6 P.M.) was more appropriate than full daytime operated blinds.

Conclusion

Results of this study could be indicated as some guidelines;

1. Integration of double glazing (outer: Reflective pane with metal colored painting; inner: Clear pane) and

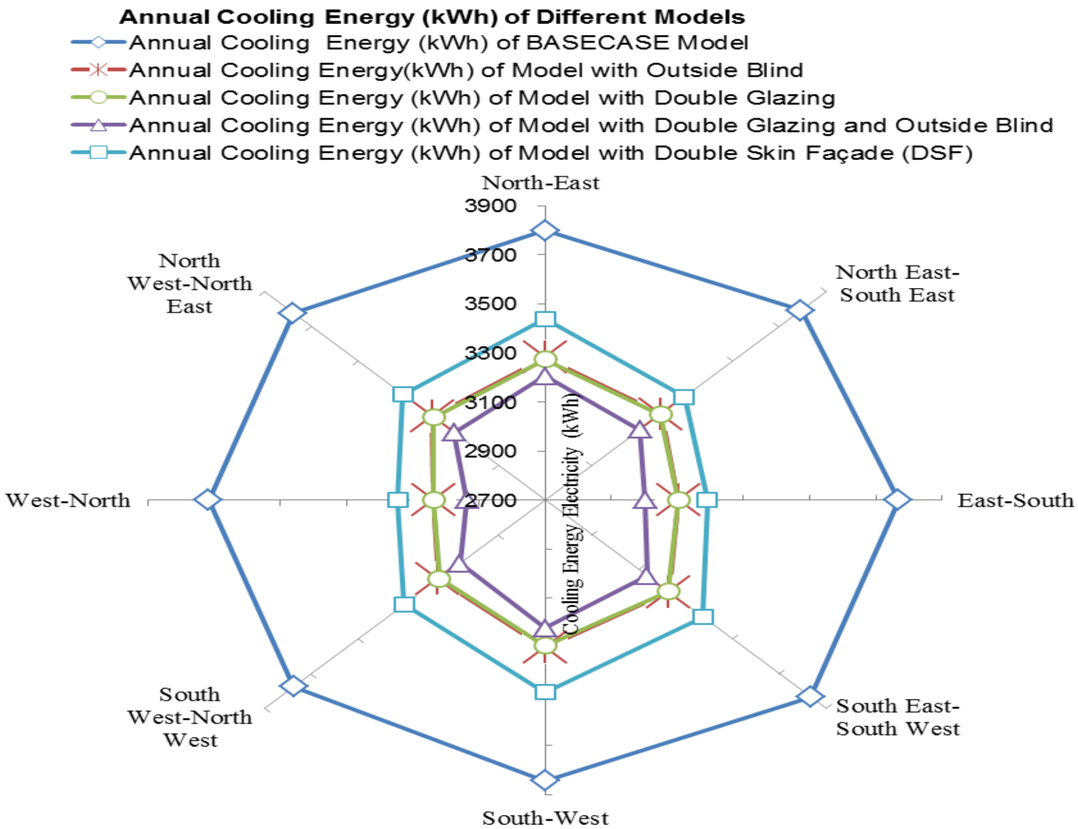

Figure 21. Comparison of annual cooling energy of different facade alternatives.

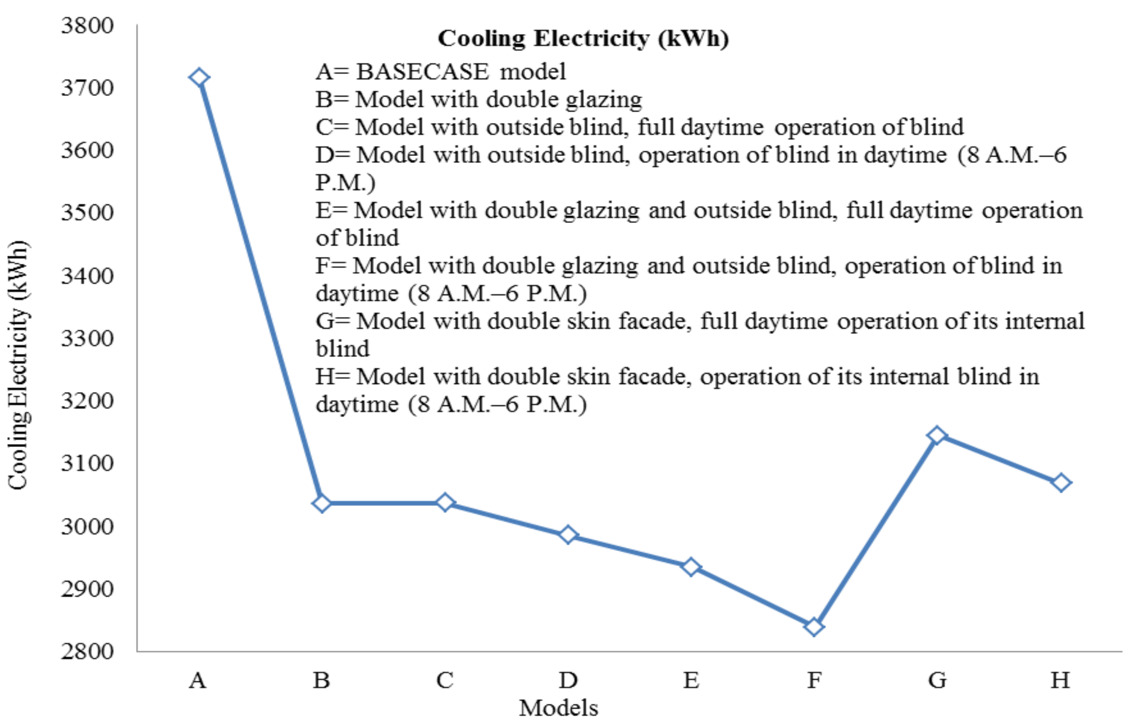

Figure 22. Comparison of cooling energy consumption of different facades with respect to operational schedule of blinds.

outside blind with high reflectivity slats (with daytime schedule of blind) caused most energy saving.

2. In east-west oriented building, most energy efficiency of model was in west wall with external blind and double glazing with 18.3% energy saving. High solar radiation to this wall would be the reason for more efficiency of these strategies in this orientation.

3. Integration of double glazing and external blind has not only saved more energy, but also it increased annual thermal comfort condition of master bedroom (space with cooling system).

4. DSF, clear inner skin, double glazing outer skin (outer: reflective , inner clear) with internal blind and night time ventilation reduced energy consumption of BASECASE model however reduction amount was less than other examined façade alternatives.

5. The use of outside blind at daytime saved more cooling energy than those used at full daytime.

6. Outside blind with high reflectivity and daytime operated slats would be more energy efficient than façade with double glazing (inner clear, outer reflective pane).

7. DSF with daytime scheduled internal blind would decrease energy consumption as its difference with double glazing would be less than 1%.

8. In living room (without cooling system), DSF lowered air temperatures and ameliorated thermal comfort condition. It presented best annual Pierce PMV (SET), Fanger PMV and Kansas TSV values in comparison to other alternatives. It could increase natural ventilation and air change. In master bedroom (with cooling system), integration of double glazing and outside blind would be suitable with respect to annual thermal comfort condition and energy consumption.

These results could be helpful for architects and designers to have proper viewpoint in design of façade elements and their position. It is suggested that in future studies, subjective survey and local desires would give priorities to achieve thermal comfort. Thereafter, relationship between people behavior and cooling energy consumption of houses could be explored.

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