Optimization of Cooling Load for Different Greenhouse Models in Malaysia

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Abstract- Three models of greenhouse, an internal-movable 50% shade screen mounted directly above the floor, a double envelope roof that was elevated 0.6 m from the ceiling, and an internal-movable shade screen with a double envelope roof were compared with the greenhouse designed with a modified arch roof type with a length of 6 m, width of 3 m, gutter and gable heights of 2.4 m and 0.6 m, respectively. The greenhouse located in Kuala Lumpur (latitude =3.12^o and longitude = -101.60^o). The calculations were performed using the building energy analysis program (DOE-2.1E). The comparison was made based on the reduction in thermal gains and cooling load. The results showed that the internal, movable 50% shade screen was found to be the most effective in reducing maximum cooling load requirement (at 14.89%); the double envelope roof models with and without shading reduced maximum cooling load by 10.11 % and 9.39 %, respectively.

Keywords- Greenhouse, cooling load, building energy, DOE.

1. Introduction

Numerous studies have analyzed the greenhouse energy balance. The greenhouses are considered as solar collectors by [1] and their performance is described in an analogous way. Equations for solar collectors were mainly differentiated by the absence of transpiring surfaces. José Pérez-Alonso et al. [2] used a computer program to predict the temperature and cooling parameters inside a greenhouse. Their proposed model validated the experimental observations for a typical set of parameters. Elisabeth and Andre [3] evaluated the thermal environment of workers in greenhouse construction. The impact of certain parameters on the mean air temperature evolution within the cavity was analyzed by Hashem et al. [4], these parameters included solar radiation, shading device, orientation, interior facade, and wind speed.

Keesung Kim et al. [5] investigated the impact of the types of greenhouse cover on cucumber plant growth. Perdigones et al. [6] studied the relative distribution of humidity in greenhouses using three dimensions of computational fluid dynamics. Teitel et al. [7] quantified the relationship between a number of fogging rates and cooling to regulate water consumption. Toida et al. [8] predicted the changes in temperature, CO_2 concentration, and humidity ratio in the air surrounding a greenhouse at different hours of the day. Katsoulas et al. [9] established a method to determine dry bulb temperature during the operation of the fog system. Sethi and Sharma [10] investigated the effect of an insect screen on wind-driven ventilation and examined the impact of vent configuration on greenhouse ventilation. Five of the most common greenhouse shapes were selected by [11] for comparison in a composite climate. This comparison was based on beam, diffuse, and ground reflections of solar radiation input on each shape through the walls, roof, and inclined surfaces. The present paper compares the three available models of greenhouse. The relevant criteria used to compare these models are the reduction in thermal gains and cooling load.

2. Methodology of Solar Radiation

Net radiation is used to estimate the heat load from outdoor solar radiation trapped inside the greenhouse. The total incidence of solar radiation on a surface has three components, namely, beam solar radiation, diffuse solar radiation, and reflected solar radiation from the ground and from surroundings [12]. The descriptions of these components are as follows:

2.1. Beam Radiation

The ratio of beam radiation falling on an inclined surface to that falling on a horizontal surface is referred to as the tilt factor for beam radiation and is given by

$$R_b = \cos\theta / \cos\theta_z \quad (1)$$

where θ and θz are the incidence angles on the horizontal and inclined surfaces.

2.2. Diffuse Radiation

The ratio of diffuse radiation falling on a tilted surface to that falling on a horizontal surface is called tilt for diffusion radiation and is given by:

$$R_d = (1 + \cos\beta)/2 \quad (2)$$

Where β is the inclination (slope) of the surface. The angle is considered positive for a surface sloping southward, and is considered negative for a surface sloping northward. (1+cos β)/2 is the radiation shape factor for an inclined surface with reference to the sky.

2.3. Reflected Radiation

The beam and diffuse radiation after reflection from the ground is diffused and isotropic, with the tilt factor for the reflected radiation expressed as:

$$R_d = \rho \times (1 - \cos\beta)/2 \quad (3)$$

Where ρ is the reflectivity, and (1+cos β)/2 is the radiation shape factor for the surface with respect to surroundings.

2.4. Total Radiation

The total radiation flux falling on an inclined surface at any instant is expressed as:

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (4)$$

2.5. Total solar radiation on the greenhouse

The sum of solar radiation falling on different sections (each wall and roof) of the greenhouse is expressed using the following equation by [13]:

$$S_t = \sum_{i=1}^{i=m} I_{Ti} A_i \quad (5)$$

Where i is the number of sections in the greenhouse, and A_i is the area of section i.

Solar radiation transmitted through the surfaces is received by the floor and the plants inside the greenhouse. Radiation absorbed by the floor is either lost to the ground or convects to the air room, whereas radiation absorbed by plants evaporates into the air room.

3. Cooling Requirement

When the greenhouse is maintained at set-point conditions, cooling requirement is estimated by subtracting the greenhouse heat lost to the environment from incoming solar radiation, wherein the net solar radiation is larger than the greenhouse heat loss. The cooling requirement is estimated by Wee [14] as:

$$Cooling_{reurment} = S_t - Q_l \quad (6)$$

Where Q_l is the total heat lost to the environment.

Various software applications, such as Transient Systems Simulation Program (TRANSYS), Department of Energy Program (DOE-2.1E), and DESIGN BUILDER, have been used to calculate the cooling load in buildings [15]. In the present study, the Department of Energy Program (DOE-2.1E) was used to calculate the thermal load, cooling requirement, and types of radiation in the structure. The DOE-2 code can simulate various energy conservation measures in buildings, and it has been widely tested for accuracy. Weather data, considered as Typical Metrological Year for Kuala Lumpur, was used in the simulation. The average monthly dry bulb and wet bulb temperatures for different months are shown in Fig.1.

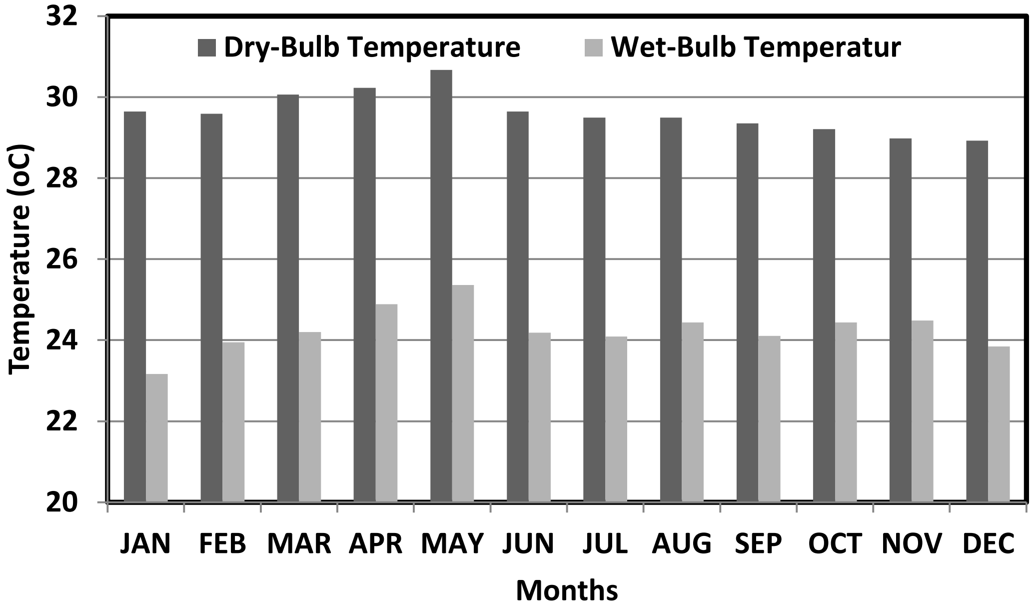

Fig. 1. Plot of monthly average Dry and Wet -Bulb temperature for different months of the year in Malaysia.

4. Greenhouse Information (Base case)

The greenhouse was conducted at the Green Technology Innovation Park in University Kebangsaan Malaysia (latitude=3.12o and longitude=-101.60o). A photograph of the greenhouse used in this research is presented in Fig. 2. Its roof type is a modified arch with an effective area of 20 m2. A door (1 m × 2 m) with mechanisms for opening and closing the system was placed at the center of the north wall. The dimensions of the greenhouse, as shown in Fig. 3, are 6 m (length) by 3 m (width), with gutter and gable heights of 2.4 m and 0.6 m, respectively. The roof and walls were built using a single layer of visible plastic with a thickness of 6 mm, U of 5.182 W/m2ºC, SC of 0.95, visible transmission of 0.881, and solar heat gain coefficient total solar transmission (SHGC) of 0.815. The greenhouse was equipped with two 40-watt exhaust fans for ventilation.

Fig. 2. Photograph of greenhouse.

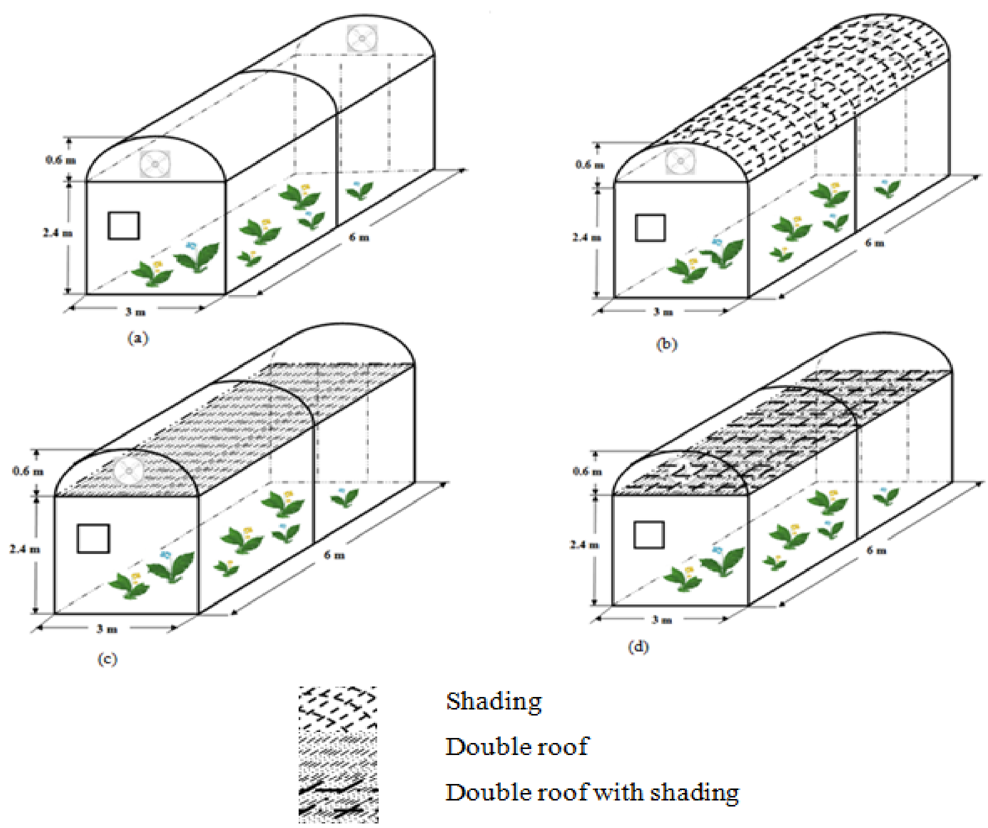

Fig. 3. Greenhouse models using in DOE-2.1E software :(a) Single roof(base case) (b) Single roof with internal shading (c)double roof (d) Double roof with internal shading.

5. Results and Discussion

5.1. Original Greenhouse (Base Case)

Cooling load calculations are dependent on the indoor design temperature, as well as on the location, orientation, and construction of the greenhouse. In this paper, three greenhouse models were used to estimate the cooling load using the department of energy DOE-2.1 E software and ultimately reduce the cooling load requirement. The original greenhouse, as shown in Figure 3a, served as basis for comparing the reduced cooling load among the models.

Figure 4 shows the maximum cooling load for each month, indicating that the load peaks in August (2562.1KWh), and is lowest in November (1968.7 KWh). As shown in Fig. 5, the maximum cooling load was calculated at 12.89 KW.

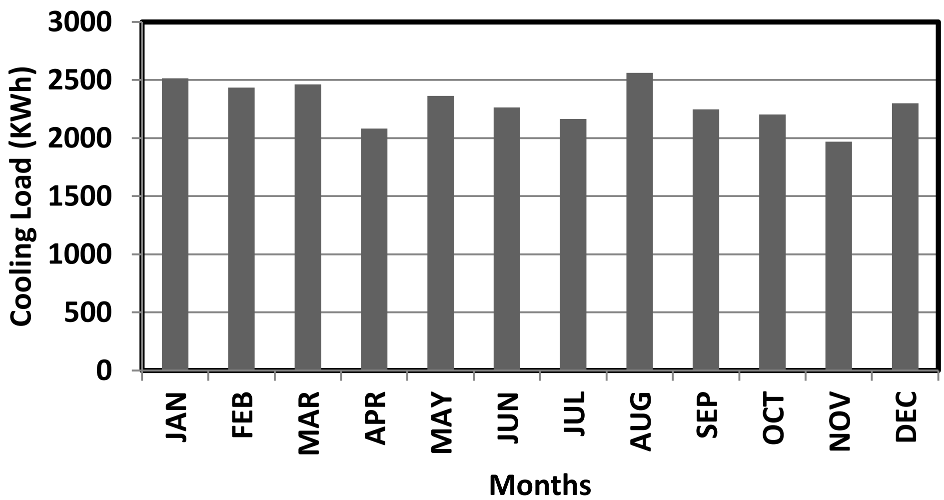

Fig. 4. Monthly cooling load profile (original greenhouse).

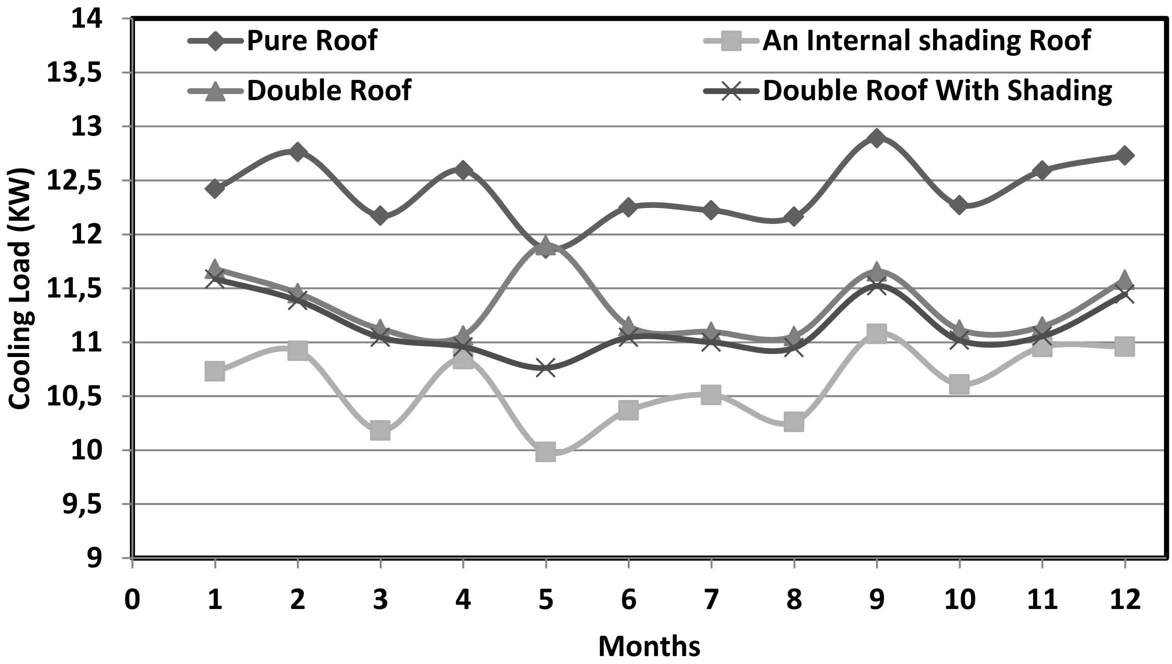

Fig. 5. Maximum cooling load profile for different models.

5.2. Model 1: Shading roof

Reducing incoming solar radiation through internal shade cloths or whitewashing on the roof has been known to effectively reduce greenhouse air temperature, including the energy gain and the cooling load. As shown in Fig. 5, the maximum cooling load decreased from 12.89 KW to 10.97 KW, representing a 14.89% drop. Figure 6 illustrates the simulation results wherein the maximum cooling load peaked in August at approximately 2091.98 KWh and minimum cooling occurred in November at approximately 1482.3KWh.

5.3. Model 2: Double envelope roof

The absolute effects of a double envelop roof on cooling load are minimal compared with those of the shading roof. Increasing the number of roof layers barely affects thermal energy. Figure 7 reveals that the maximum cooling load occurred in January at approximately 3456.1 KWh, whereas minimum cooling occurred in May at approximately 2249.5 KWh. As shown in Fig. 5, the use of a double roof significantly reduces cooling load by 9.39 %.

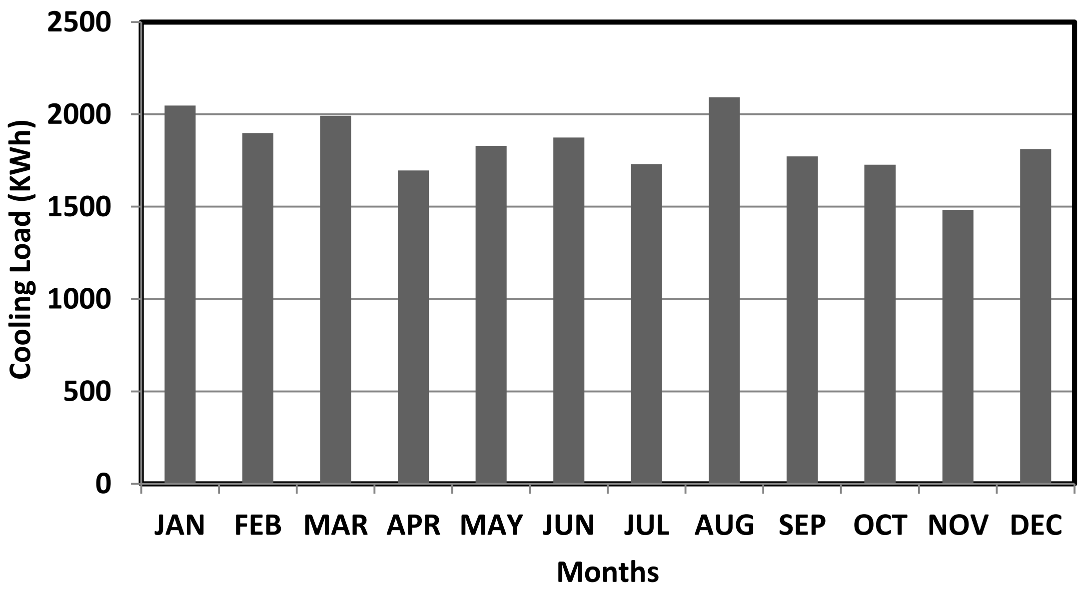

Fig. 6. Monthly cooling load profile (model 1).

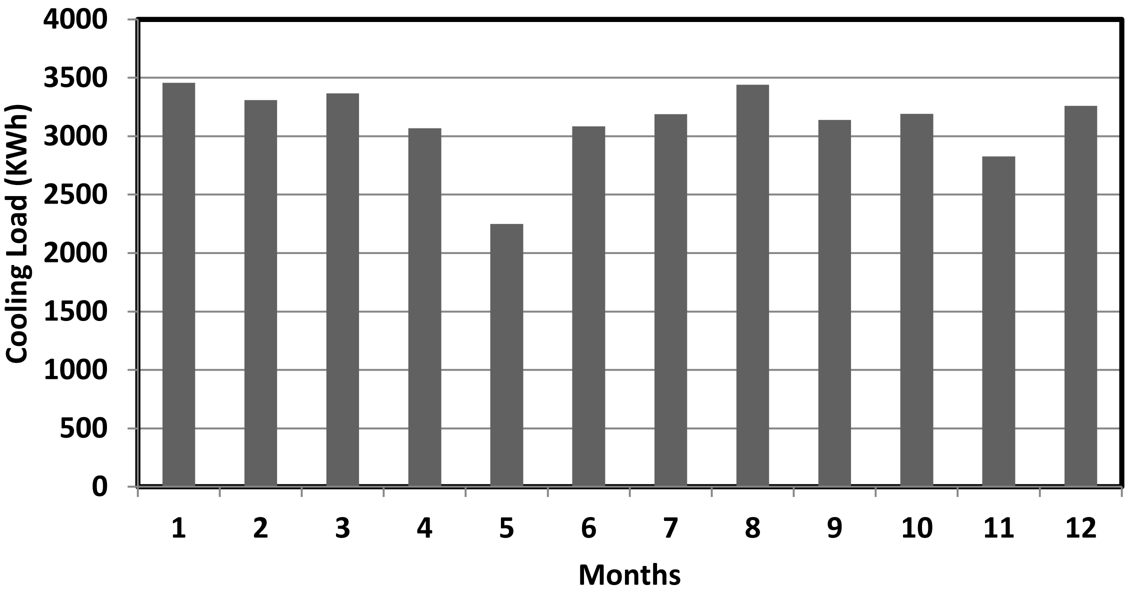

Fig. 7. Monthly cooling load profile (model 2).

5.4. Model 3: Double envelope roof with shading

A double envelope roof with shading more effectively reduces the cooling load compared with a similar roof type with no shading. Figure 8 shows that the maximum cooling load occurred in January at around 3337.3 KWh, whereas the minimum cooling occurred in November at around 2678.2 KWh. According to Fig. 5, a 10.11% reduction in the cooling load can be achieved using double roof with shading.

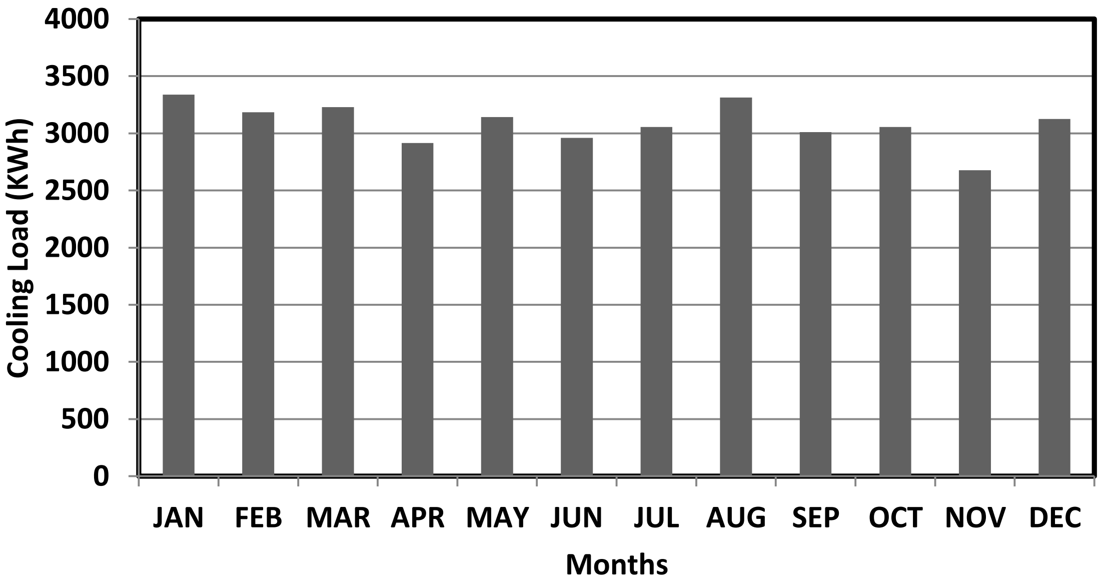

Fig. 8. Monthly cooling load profile (model 3).

6. Conclusion

Three models of greenhouse have been compared in the building energy analysis program (DOE-2.1E). The reduction in thermal gains and cooling load has been calculated for this comparison. From the simulation results the following conclusions can be drawn.

1. The maximum cooling load of the original greenhouse is 12.89 KW.
2. An internal, movable 50% shade screen reduces the cooling load by 14.97%. Additionally, this decreases the air conditioning system's cooling load capacity to 10.97 KW, as compared with the 12.89 KW reductions in the original greenhouse design.

3. A double envelope roof with shading and a double envelope roof without shading reduces cooling load by 10.11% and 9.39%, respectively.
4. The modification in the roof of greenhouse from single roof to double roof with shading can cause 6.5-9.7 ^{o}C change in the inside temperature of the greenhouse.

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