Effect of Using Double Layers of Polyethylene Cover with Air Gap on Control Environment inside Greenhouses

Sirelkhatim K. Abbouda, Emad A. Almuhanna, and Ali M. Al-Amri

Abstract - The effect of using double layers of polyethylene with air gap on the energy transport characteristics and most relative vegetative growth parameters and production of a tomato crop under eastern province climatic condition were studied and compared with the commonly used double layers (without air gap) covering methods. The results of this experimental work show that the greatest values of cooling effect (11.97 °C) and effectiveness of evaporative cooling system (75.05%) were achieved inside the greenhouses covered by double layers of polyethylene with 9 cm air gap (greenhouses 1), whereas, the effectiveness of cooling system (68.18%) occurred inside greenhouse covered by double layers of polyethylene without air gap (greenhouses 2). Greenhouse 1 also increased the temperature of cold air just leaving the cooling system by 3.56 °C, while greenhouse 2 increased the interior ambient air temperature by 5.06 °C. Thus, the greenhouse 1, on the average, increased the rate of vegetative growth by 13.1%, and fresh yield of tomato crop by 76.13%.

Keywords: Greenhouse, polyethylene, cover

1. Introduction

Greenhouses are required for crop production in Saudi Arabia during summer and winter periods. It can provide a suitable environment that will result in improving crop growth and production. Thus, a greenhouse is equipped with some environmental modifications such as heating, ventilating and cooling systems.

Greenhouse industry has been revolutionized by using both expensive and inexpensive transparent materials which can be supported on relatively heavy and light structures. The use of controlled environment agriculture (where the growth and development of plants is controlled by regulation of ambient conditions such as light, air temperature, air relative humidity, and soil nutrients) has been suggested for commercial crops since it could promise increased yields, better quality, and production stability of high value crop species. The required maintenance of the growth environment makes input energy costs a major consideration in the development of this agricultural technology.

During the growing season, the timing of initiation of fruiting, size and quality of the fruit, and total fresh yield depend upon the interaction between ambient weather and the grower management of greenhouse environments. The dramatic decreasing in the ambient air temperature (particularly at night) during winter season and vice versa in summer season may be considered as one of the biggest problem in Saudi Arabia's greenhouse vegetable production industry (Al-Amri, 2000).

Greenhouse ventilation is a necessary process to remove solar radiation heat, to control the level of relative humidity, and to replenish carbon dioxide that plants consume during the daylight hours in the process of photosynthesis (Al-Helal, 2007).

Greenhouses, by their inherent nature, are large energy consumers (Chiasson, 2006). As energy conservation schemes for greenhouses are implemented and greenhouse crops become more competitive with imports, profit margins should be restored, and new greenhouse construction will regain momentum. Designers will be called upon to produce new energy efficient designs compatible with energy conservation systems and changing cultural practices and crop varieties (Jones et al., 1988; Yang et al., 1995). Computer runs using long-term average solar radiation data revealed that, the greenhouse shape and cover material had an obvious effect on the effective transmissivity of the greenhouse (Lau and Staley, 1989). Greenhouses are required to allow high light transmittance, low heat consumption, sufficient ventilation efficiency, adequate structural strength and good overall mechanical behavior, low construction and operating costs (Elsner et al., 2000a).

Climate is a major factor influencing both the structural and the functional characteristics of greenhouses. The design of a greenhouse aims at exploiting the external climatic conditions for improving the indoor microclimate. For this reason, the overall greenhouse design is strongly influenced by the climate and the latitude of the location (Elsner et al., 2000b). The choice of cover material is strongly dependent upon several factors; solar radiation transmission, resistance of ultraviolet (UV) degradation, heat losses, initial purchase price, and installation cost (Heinemann and Walker, 1987; Lau and Staley, 1989). Research efforts along two paths: (a) improving the greenhouse structure to reduce energy losses, while maintaining a desirable growth environment; and (b) developing alternate energy sources such as solar, wind, reject heat from power plants, geothermal energy, and any other source to meet greenhouse heating demand (Lau and Staley, 1987; Nelson, 1990; Takakura et al., 1994).

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Polyethylene as a greenhouse covering material is low in cost, light weight, easy to apply. Unfortunately, it also has a high light transmittance and thermal conductivity. A polyethylene film is one of the most common greenhouse covering materials in Saudi Arabia. However, polyethylene films as greenhouse covering materials with its transparent characteristics that transmits visible light (400–700 nm), which is the main source of energy for photosynthesis. Furthermore, it is susceptible to mechanical failure due to harsh conditions of high temperature, solar radiation, and wind (Alhamdan, and Al-Helal. 2009).

The radiation transmission through a covering material is affected by several factors including: type of covering material, dirtiness, dust deposition, and changes in color caused by aging, location, and incident angle of the radiation. Another factor which determines the transmittance of a greenhouse covering is the presence of condensate on the interior surface of the materials. Temperature of the greenhouse cover is an essential parameter needed for any analysis of energy transfer in the greenhouse. Measuring the correct value of is difficult due to the transparency of the covering materials and the effects of solar and thermal radiation and air movement on the cover surface. (Abdel-Ghany et al. 2006)

Polyethylene films have been used extensively as greenhouse covering materials in Saudi Arabia. They have high light transmittance, and are transparent to thermal radiation. Also, they are flexible and the least expensive cover material. A serious problem with the greenhouse polyethylene cover is the short lifetime, especially in harsh weather conditions such as high temperature, high solar intensity, and dust, all of which are common in arid regions as occurs in central region, Saudi Arabia. The daily maximum temperature reaches as high as 45 °C, and the amount of solar radiation exceeds 1000 W/m² (Alhamdan and Al-Helal, 2009).

Therefore, the main goal of this study is to investigate the effect of covering methods on thermal performance and energy transport characteristics in greenhouses under local climatic conditions, and their effect on the most relative vegetative growth parameters. Specific objectives are to: (a) compare the traditional covering method (double layers of polyethylene) vs. (double layers – separated with air gap - of polyethylene), (b) study the effect of covering method on the thermal performance and energy transport characteristics for each case, and (c) study the effect of covering method on the most relative vegetative growth parameters and productivity.

2. Materials and Methods

Two identical gable-even-span greenhouses at the Agricultural and Veterinary Research Station of King Faisal University were utilized to grow and produce tomato during the summer months of 2010. Each one had gross dimensions of 8.00 m long, 4.00 m wide, and 3.16 m height, with a net surface area of 32.00 m² (Fig. 1). Water galvanized pipes (38.1 mm diameter) were used to form the structural frame of the two experimental greenhouses. To reduce both the side effects of wind blowing over the roof of the greenhouse and the intensity of solar radiation flux incident inside the greenhouse during the hot summer season, the rafters were sloped at 30° of the horizontal plane. Each gable roof had gross dimensions of 2.310 m long (rafter) and 1.16 m height. The height of each side wall was 2.00 m. The straight-side wall pipes were strongly connected to the concrete foundations in order to transfer gravity, uplift and overturning loads such as those from the crop, suspended equipment, and wind loads safely to the ground.

Both greenhouses were covered by double layers of 200 µm thick, 5.5% UV polyethylene sheet with the following criteria:

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato Crop</td>
<td>283780</td>
<td>3374</td>
<td>271691</td>
<td>3184</td>
<td>225236</td>
<td>2295</td>
</tr>
<tr>
<td>Cucumber Crop</td>
<td>247629</td>
<td>3272</td>
<td>227889</td>
<td>2859</td>
<td>196645</td>
<td>2134</td>
</tr>
<tr>
<td>Marrow Crop</td>
<td>11751</td>
<td>132</td>
<td>12510</td>
<td>139</td>
<td>9515</td>
<td>105</td>
</tr>
<tr>
<td>Other Vegetable</td>
<td>76118</td>
<td>935</td>
<td>70378</td>
<td>842</td>
<td>56217</td>
<td>616</td>
</tr>
</tbody>
</table>

Area in hectare and production in ton  Source: Ministry of Agriculture, KSA
The first greenhouse was covered by double layers - a gap of 9 cm air gap - of polyethylene.
- The second greenhouse was covered by double layers - stick to each other - of polyethylene.

To increase and maintain the durability of structural frame and polyethylene cover, twenty tensile galvanized wires (2.0 mm diameter) are tied and fixed throughout the rafters and vertical pipes in each side. The experimental greenhouses are orientated in East-West direction.

2.1. Design of Evaporative Cooling System:

The evaporative cooling system is mainly based on the process of heat absorption during the evaporation of water. It mainly consists of cooling pads and extracting fans. A crossfluted cellulose pad was mounted in a vertical fashion at the end of the greenhouse. A PVC pipe (0.5 inch diameter) was suspended immediately above the cooling pads. Holes were drilled each 10 cm long throughout the length of PVC pipe, and the end of this pipe was capped. To spread the water uniformly before it drops onto the cooling pads, a baffle was placed below the water pipe. A water sump was mounted under the pads to collect the water and return it into the water tank (600 liters), from which it could be recycled to the cellulose pads by means of the water pump. In order to bring the cold air onto the plants throughout the growth period, the cooling pads were located 20 cm above the ground surface of the greenhouse. Two extracting fans (single speed, direct driven, 50 cm diameter, and 3630 m³/hr discharge) were located on the leeward side of the greenhouse and the pads on the side toward the prevailing wind (opposite side of the extracting fans). The extracting fans were automatically operated using a differential thermostat. They switched "ON" when the ambient air temperature inside the greenhouse was equal or greater than 25°C, and switched "OFF" when the interior ambient air temperature was lower than 25°C. In order to prevent the accumulation of salt on the cellulose pads (mean reason of pad damage), potable water was usually used in the evaporative cooling system.

2.2. Design of Irrigation System:

A drip irrigation system was employed throughout the experimental work. It mainly consisted of five components: main water supply tank, fertilizer tank, pipes, water pump, and drippers. In order to mix chemical fertilizers with irrigation water before it passes through the drippers, an eighty liter fertilizer tank (cylindrical form) was placed in the line of the watering system. To distribute the irrigation water uniformly for the two greenhouses, a polyvinyl chloride (PVC) pipe (1.0 inch diameter) was employed as a main. Twenty drippers (0.375 inch diameter) were uniformly distributed alternatively (with 50 cm dripper spacing) throughout each row of plants using lateral rubber pipe (0.5 inch diameter, and 3.785 l/h discharge). The watering system was pumped and run only thirty minutes a day throughout the experimental work, in order to conserve the irrigation water.

2.3. Instrumentation

Temperature and relative humidity inside greenhouses were measured using a HOBO® U12 Logger (Onset Computer, Bourne, MA) with a manufacturer stated accuracy of ±0.35°C; ambient temperature and relative humidity were recorded for the length of study. Data were collected at each 10 s by a data logger (HOBO data logger- U30 - NRC) and averaged over a time of 1 hr. Air temperature
and relative humidity outside greenhouses were measured using 12-bit Temperature/RH Smart Sensor (S-THB-M002). The temperature and relative humidity sensors were placed in multi-plate radiation shields (Hobo-RS3 Solar Radiation Shield) to protect them from error-producing solar radiation and precipitation. These shields rely on a combination of plate geometry, material and natural ventilation to provide effective shielding. The solar radiation (W/m²) flux incident on a horizontal surface was measured using Hobo Silicon Pyranometer, with a measurement range of 0 to 1280 W/m² over a spectral range of 300 to 1100 nm. Data were collected at each 10 s by a data logger (HOBO data logger- U30 - NRC) and averaged over a time of 1 hr. Plant leaf surface temperature were measured using Fluke 568 Infrared and Contact Thermometers, Fluke Corporation, 6920 Seaway Blvd. Everett, WA USA 98203, USA.

2.4. Effect on Tomato Production:

Environmental parameters are generally recognized to have a major impact on the production of protected cropping. These parameters have been included ambient air temperature, air relative humidity, light, air movement, solar radiation intensity as well as number of plants per unit area. For the duration of the experimental work (2 years - 4 seasons), the leaves number of tomato plant, the stem length, and the total fresh yield of tomato crop will monitored and compared between the treatments. Statistical analysis will be used in order to compare the treatments and to clarify the effect of different treatments on the tomato crop. Tomato seeds (ALZAIN F1, Ergon seed, Ergon International N.V., Holland ) will be planted in the nursery. The tomato seedlings will be raised in 100 mm and will be vegetated out at the four leaves stage.

In the hot climate of the Eastern Province of the Kingdom of Saudi Arabia, evaporative cooling systems have been commonly employed to reduce the interior ambient air temperature of greenhouses. Evaporative cooling system efficiency (n) is normally defined as (ASHRAE, 1983):

\[ \eta = \frac{T_{odb} - T_{adb}}{T_{odb} - T_{owb}} \times 100 \]  

or

\[ \eta = \frac{T_{dd}}{T_{wd}} \times 100 \]  

(2)

where:-

\( T_{odb} \) = dry-bulb temperature of outside air, °C
\( T_{idb} \) = dry-bulb temperature of inside air, °C
\( T_{owb} \) = wet-bulb temperature of outside air, °C
\( T_{dd} \) = cooling effect (\( T_{odb}-T_{idb} \)), °C
\( T_{wd} \) = wet-bulb depression (\( T_{odb}-T_{owb} \)), °C

3. Results and Discussion

The experimental work was carried out during five months of 2010 (Jun to Aug, 90 days were recorded during this period). Data obtained from this research work are summarized in Table 2.

It clearly shows that substantial decrease of ambient air temperature inside the greenhouses occurred when the air relative humidity outside the greenhouses was less than 20% and outside air temperature near 40 °C.

Under these conditions, the evaporative cooling system provided a cooling effect (air temperature difference between outside and inside the greenhouse) of 10 °C or more.

The cooling effect and, consequently, the effectiveness of the evaporative cooling system were strongly affected by the wet-bulb depression (difference between dry and wet-bulb temperatures of outside air) that was affected mainly by air relative humidity. Therefore, all the data collected throughout the experimental work were examined to approach mathematical models (Fig. 2).
The best fit equations relating the cooling effect ($T_{dd}$) to the wetbulb depression ($T_{wd}$) for the three greenhouses were:

- For Greenhouse 1: $T_{dd} = 2.2235 + 0.6329 \times T_{wd}$ \[r = 0.975\]
- For Greenhouse 2: $T_{dd} = 0.5475 + 0.6559 \times T_{wd}$ \[r = 0.987\]

The greatest values of cooling effect (11.97 °C) and effectiveness of evaporative cooling system (75.05%) were achieved inside greenhouse 1 at the greatest value of wet-bulb depression (15.95 °C) and lowest value of air relative humidity (24.2%); while, the lowest value of cooling effect (8.25 °C) and effectiveness of cooling system (68.18%) occurred inside greenhouse 2 at the lowest value of wet-bulb depression (12.10 °C) and greatest value of air relative humidity (38.40%). For the duration of the experimental work, the wetbulb depression was found to be directly related to the exterior ambient air temperature, air relative humidity and saturation pressure of the air. As the exterior ambient air temperature is increased and the air relative humidity is decreased, the saturation pressure is thus increased making the cooling system more efficient.

To examine the relationship between the interior ambient air temperatures ($T_{ai}$) for both greenhouses and the exterior ambient air temperature ($T_{ao}$), air relative humidity (R.H.) and wet-bulb depression ($T_{wd}$), multiple regression analysis was used. The ambient air temperature for greenhouses 1 and 2 was plotted against wet-bulb depression (Fig. 3). Regression analysis revealed a highly significant linear relationship between these parameters for green-

### Table 2. Daily Average, Ambient Air Temperatures outside ($T_{odb}$) and Inside ($T_{idb}$) the Greenhouses, Wet-bulb ($T_{owb}$), Wet-bulb depression ($T_{wd}$), Cooling effect ($T_{dd}$), Air relative humidity outside the greenhouses (R.H.) and Effectiveness of evaporative cooling system ($\eta$).

<table>
<thead>
<tr>
<th>Month</th>
<th>Greenhouse</th>
<th>$T_{odb}$, °C</th>
<th>$T_{idb}$, °C</th>
<th>$T_{owb}$, °C</th>
<th>$T_{wd}$, °C</th>
<th>$T_{dd}$, °C</th>
<th>R.H., %</th>
<th>$\eta$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun, 2010</td>
<td>G1</td>
<td>36.08</td>
<td>24.37</td>
<td>20.32</td>
<td>15.76</td>
<td>11.71</td>
<td>22.90</td>
<td>74.30</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>24.93</td>
<td>15.95</td>
<td>11.15</td>
<td></td>
<td></td>
<td></td>
<td>70.75</td>
</tr>
<tr>
<td>Jul, 2010</td>
<td>G1</td>
<td>37.72</td>
<td>25.75</td>
<td>21.77</td>
<td>15.95</td>
<td>11.97</td>
<td>24.20</td>
<td>75.05</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>26.67</td>
<td>11.05</td>
<td>11.05</td>
<td></td>
<td></td>
<td></td>
<td>69.28</td>
</tr>
<tr>
<td>Aug, 2010</td>
<td>G1</td>
<td>37.04</td>
<td>28.29</td>
<td>24.94</td>
<td>12.10</td>
<td>8.75</td>
<td>38.40</td>
<td>72.31</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>28.79</td>
<td>8.25</td>
<td>8.25</td>
<td></td>
<td></td>
<td></td>
<td>68.18</td>
</tr>
<tr>
<td>Mean</td>
<td>G1</td>
<td>36.95</td>
<td>26.14</td>
<td>22.34</td>
<td>14.60</td>
<td>10.81</td>
<td>28.50</td>
<td>73.89</td>
</tr>
<tr>
<td></td>
<td>G2</td>
<td>26.80</td>
<td>10.15</td>
<td>10.15</td>
<td></td>
<td></td>
<td></td>
<td>69.40</td>
</tr>
</tbody>
</table>

![Figure 2 Cooling effect (Tdd) versus wetbulb depression (Twd).](image-url)
houses 1 and 2. It also showed that, the differences between the intercepts and the slopes were highly significant (P < 0.001). The regression equations obtained for the greenhouses were:

\[ T_a(\text{Greenhouse 1}) = 0.4785(T_{wd}) + 18.056 \quad [r = 0.893] \]

\[ T_a(\text{Greenhouse 2}) = 0.4555(T_{wd}) + 19.732 \quad [r = 0.895] \]

![Figure 3](image)

**Figure 3** Interior air temperature \((T_a)\) versus wet-bulb depression \((T_{wd})\).

The effectiveness of evaporative cooling system varied from time to time, day to day and from greenhouse to another throughout the experimental work according to the intensity of solar radiation flux incident, the air relative humidity, the stage of plant growth, the intensity of cucumber plants per square meter of ground, and the type of greenhouse cover. Although cold air just leaving the evaporative cooling system for the two greenhouses was at the same level of temperature, the ambient air temperatures inside the greenhouses were varied from one greenhouse to another throughout the air stream. Greenhouse 1 increased the temperature of cold air just leaving the cooling system by 3.56 °C, while greenhouse 2 increased the interior ambient air temperature by 5.06 °C. This difference (1.5 °C) was due to the variation in intensity of solar radiation flux incident inside the two greenhouses, which was converted into thermal energy. As the exterior air relative humidity is decreased and outside dry-bulb temperature exceeded 40 °C, the wet-bulb depression and the saturation pressure increased and the vapor pressure thus decreased making the evaporative cooling system more efficient and vice versa.

Wet-bulb depression was plotted against air relative humidity (Fig. 4). Regression analysis revealed a highly significant linear relationship (P < 0.001) between these parameters. The best fit equation relating the wet-bulb depression \((T_{wd})\) to the outside air relative humidity (R.H.) was:

\[ T_{wd} = 27.887 - 0.4523 (\text{R.H.}) \quad [r=0.993] \]

![Figure 4](image)

**Figure 4** Wet-bulb depression \((T_{wd})\) versus air relative humidity (R.H.).

As the number of plants per square meter of greenhouse ground surface area is increased, the consumption rate of light energy in photosynthesis process and shading area inside the greenhouse are thus increased making the rate of heat exchange between the ground bare area and interior ambient air decrease. To assess the most important parameters affecting effectiveness of evaporative cooling system, the exterior ambient air temperature and wet-bulb depression were employed. Multiple regression analysis revealed a highly significant linear relationship (\(R = 0.989; \ P < 0.001\)) between the exterior ambient air temperature and effectiveness of evaporative cooling system.

Thus, the double layers – separated with air gap of polyethylene cover mainly increased the effectiveness of cooling process. The relationship between ambient air temperatures inside and outside the two greenhouses was plotted in Fig. 6.
Figure 5 Relationship between ambient air temperature inside and outside the greenhouses.

Relationship between solar radiation inside and outside the greenhouses pelted in Figure 6. Using 50% shading cover for both greenhouses resulted in reduction of solar radiation inside both houses with 71.2% and 74.2% for greenhouse 1, and 2 respectively.

Figure 6 Relationship between solar radiation inside (using 50% shading cover) and outside the greenhouses.

The difference in stem length of tomato plants (Fig. 7) varied from one week to another throughout the growing season. It also indicates that the greater stem length was obtained from greenhouse 1 because the ambient air temperature inside the greenhouse 1 was around the optimum temperature (25 °C), particularly at the critical period (from 10 am to 3 pm) during daylight (Fig. 5).

Figure 7: Relationship between height of tomato plants and growing season

Therefore, the weekly average rates of vegetative growth (stem length of plant) for the two greenhouses were 15.4 cm/plant/week and 13.8 cm/plant/week, respectively (Fig. 7). Thus, greenhouse 1 increased the average rate of vegetative growth by 13.1% (compared with greenhouse 2).

This difference may be explained by the fact that the optimum ambient air temperature surrounding the tomato plants enhances and increases the absorption rate of nutrient elements, photosynthesis process, and building of carbohydrates.

As the green areas of leaves increased due to increase of vegetative growth rate, the biochemical processes increased, making the process of photosynthesis more efficient. The ambient air temperature surrounding the tomato plants played a vital role not only for vegetative growth, but also in influencing the vitality of seed insemination and, consequently, the number of fruit set per plant. As the ambient air temperature inside the greenhouse is increased over 30 °C, the death rate of seed insemination is increased, and the fruit set is thus decreased making the crop fruitful at a minimum level. Also, excess temperatures of greenhouse ambient air commonly caused loss in stem strength, and area of leaves, delay in flowering, loss of fruit size, and increase in pathogenic organisms. Due to all reasons discussed above, the total fresh yield of tomato crop for greenhouse 1, and 2 was 464.2 kg (5.8 kg/plant), and 263.55 kg (3.29 kg/plant), respectively (Fig. 8). Consequently, the greenhouses covered by double layers of polyethylene with 9 cm air gap (greenhouses 1) more productive than the greenhouse covered with polyethylene sheet stick to each other (greenhouse 2). Although greenhouse 1 and 2 were covered with the same cover, greenhouse 1 was found to be more productive because its cooling system had greater cooling effectiveness than the cooling system of greenhouse 2. This temperature of ambient air was mainly enhanced and increased the absorption rate of nutrients elements which influenced the increasing of fruit set rate throughout the experimental work.

The differences between mean fresh yield of tomato crop were highly significant with a probability of 0.99. Analysis of variance for tomato fresh yield revealed that, the F ratio were significant (P < 0.001).

This clearly means that, the cooling ambient air inside the greenhouse particularly at daylight during hot summer season affecting significantly and positively the fresh yield of tomato crop.
4. Conclusions

The effect of using double layers of polyethylene with air gap on the energy transport characteristics and most relative vegetative growth parameters and production of a tomato crop under eastern province climatic condition were studied and compared with the commonly used double layers (without air gap) covering methods. The results of this experimental work show that the greatest values of cooling effect (11.97 °C) and effectiveness of evaporative cooling system (75.05%) were achieved inside the greenhouses covered by double layers of polyethylene with 9 cm air gap (greenhouses 1), whereas, the effectiveness of cooling system (68.18%) occurred inside greenhouse covered by double layers of polyethylene without air gap (greenhouses 2). Greenhouse 1 increased the temperature of cold air just leaving the cooling system by 3.56 °C, while greenhouse 2 increased the interior ambient air temperature by 5.06 °C. Thus, the greenhouse 1, on the average, increased the rate of vegetative growth by 13.1%, and fresh yield of tomato crop by 76.13%.

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