Greenhouses covering materials: a comparative study

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Abstract: Greenhouse covering material is the most governing member of the construction which controls two major parameters, the amount of light and heat diffused from the surrounding environment into the internal space. In hot areas, balancing between optimum temperature and maximum light intensity inside the greenhouse consumes most of the energy spent in vegetable production systems. In this research, a special testing stand was fabricated to simulate the structure of a typical greenhouse provided with a 400W full spectrum light as a source of light and heat. Tests were carried out to investigate the effectiveness of different commercial covering material in light and heat diffusion. Twenty one combinations of Fiberglass, Polyethylene, Polycarbonate, Plexiglass and Agril (PP nonwoven fabric) were tested. It was concluded that Plexiglass was the highest in light transmittance of 87.4%, while the lowest was 33.03% and 34.24% for Fiberglass sheets. The enthalpy of the air moving through the testing rig was calculated according to air temperature differences between inlet and outlet openings. The highest enthalpy value was recorded for one layer of Fiberglass where it was 0.81 kJ/kg air while it was 0.2 kJ/kg air for blocked Plexiglass (60mm).

Keywords: greenhouse, enthalpy, air temperature, light transmittance, covering materials

Citation: Moustafa A. F., B. Hammad, A. H. Faisal, and O. Iwaimer. 2016. Greenhouses covering materials: a comparative study. Agric Eng Int: CIGR Journal,18(1):48-57.

1 Introduction

Sustainable utilization of natural resources is a key evaluation criterion of modern agricultural production systems. Scarcity of water and depletion of energy resources represent serious challenges facing humanity in modern history where more than 1.2 billion or almost one fifth of the world's population, live in areas of physical scarcity, and 500 million people are approaching this situation. Another 1.6 billion people, or almost one quarter of the world's population, face economic water shortage (FAO, 2012)

Protected agriculture represents the promising and the logical choice for vegetable production in modern agriculture. This proofed to be an engineering challenge especially in hot arid areas where sunlight is available more than 300 days in the year. The dilemma exists in summer season where ambient temperature exceeds 45 °C in some areas. The balance between collecting the largest amount of sunlight to increase PAR while reducing the heat accumulated inside the greenhouse is not an easy job. Thermal load inside greenhouses in such areas reduces water and energy use efficiency in vegetable production where fans should run longer hours and water is consumed in fan-pad cooling systems is dramatically wasted (Fadel et al., 2014).

Zhang et al. (1996) conducted an extensive energy and microclimatic assessment of different greenhouse covering materials where they compared single glass (CL) and three types of double polyethylene (PE) claddings. They concluded that the measured average PAR transmission during the winter months (November-March) were 0.68, 0.62, 0.65 and 0.60 for glass, anti-fog 1-year, anti-fog 3-year and anti-fog thermal claddings, respectively. In the summer months (April-October) the values were higher.

Feuilloley and Issanchou (1996) developed a method for measuring thermal transparency of materials for cladding greenhouses, using hot boxes located in the natural environment. Thus, the film is tested under natural conditions of wind, temperature, and sky radiation. In

Received date: 2015-02-19 **Accepted date:** 2015-11-30
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addition, these boxes allow comparisons to be made between the performance of a dry and a wet film resulting from condensation. On the other hand, Al-Helal and Alhamdan (2009) studied the degradation of the radiative properties of a 200 lm-polyethylene film caused by exposure to the harsh environment of Riyadh, Saudi Arabia has been investigated over a period of 13 months. Measurements of global solar radiation (GSR), photosynthetically active radiation (PAR), air temperature and relative humidity were made inside and outside two single-polyethylene-covered model structures. Results showed that exposure to the environment reduced the polyethylene film transmittance to GSR and PAR. The average summer daytime temperature inside the exposed structure was 45.7 °C, as compared to 46.9 °C inside the control structure, while the average of outside temperature was 38.2 °C. It was noticed that the examined structure had no ventilation mechanism which may explain heat accumulation.

Papadopoulos and Hao (1997) studied the effects of single-layered glass (glass), double inflated polyethylene film (D-poly), and rigid-twin wall acrylic panels (acrylic), as greenhouse covers on tomato (Lycopersicon esculentum Mill) growth, productivity and energy use were investigated over two spring seasons in 1993 and 1994. They concluded that, there was no significant difference in early marketable yield (harvested until April 30) between the D-poly and glass houses. Early marketable yield in the acrylic houses was similar to that in the glass houses, but higher than that in the D-poly houses in 1994. Mid-season yield in the D-poly houses was lower than in the glass houses. This reduction in fruit size shifted 6%-12% of grade # l fruit from extra-large to large. Fruit size in the glass and acrylic houses was similar. The D-poly and acrylic houses saved 30% in heating energy compared to the glass houses.

Geoola et al. (2004) carried out a comparison of transmission of the three types of films in dry and wet state, revealed that all films with no surface-active additives have a lower transmission of about 14%-19% in the wet state than in the dry state. The film with surface-active additive, in new condition had a higher transmission of about 3.5% in the wet state than in the dry state. The average loss in solar radiation transmittance of the films due to accumulation of dust and dirt, both in dry and wet states was about 8% after 3 months.

Taki et al. (2013) emphasized that energy inputs – yield relationship is a major factor in any greenhouse production system which depends mainly on greenhouse covering material performance to allow maximum useful light and optimum heat inside compared to the external climatic conditions. Hao et al. (1999) studied the effect of covering materials on plant growth and photosynthesis while Briassoulis et al. (2004) focused on the degradation of agricultural low density polyethylene films. Furthermore, Hemming et al. (2006) integrated an IR filter to the greenhouse covering materials which increased tomatoes production by 8%-12%.

The major objective of this study is to evaluate different covering materials as a greenhouse cover in laboratory; which includes a comparison between the common greenhouse covers and Plexiglass in order to conclude best combination of tested materials which fits to local environment where maximum light and optimum temperature to be maintained under very hot conditions.

2 Materials and Methods

In order to measure light and heat transmittance of covering material as major technical performance criteria, a testing model was designed and fabricated as shown in Figure 1. Where a black wooden box equipped with a ventilation fan and the cover is a 50cm × 50cm covering material under investigation where a full spectrum 400 W light source is hanged above the box as a source of light and heat as well. Each tested material/combination was shaped to fit the upper side of the box.

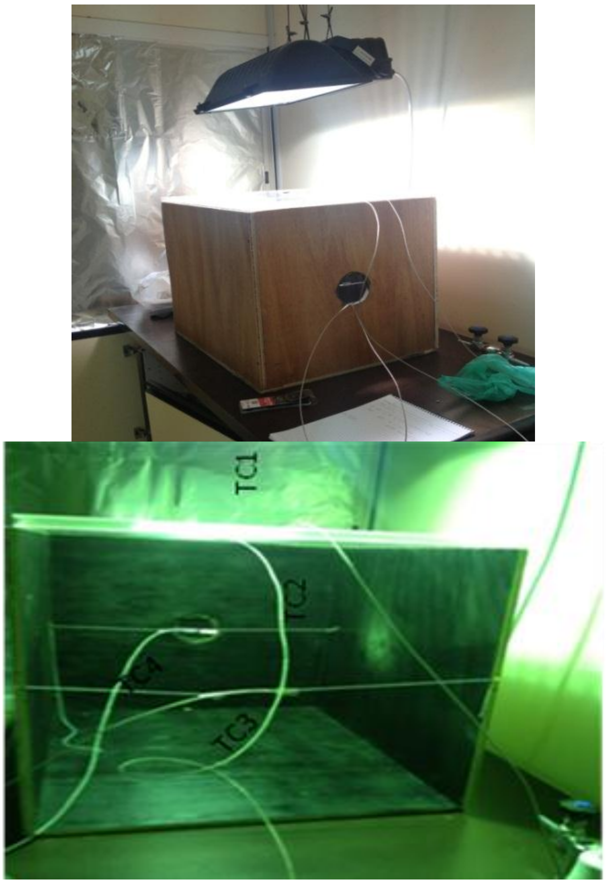

Figure 1 Testing setup showing the black box, full spectrum light and the positions of the used thermocouples

Four J type thermocouples were used to record temperature of air inside and outside the box. TC1 and TC2 recorded temperature of air directly above and below the tested panel, while TC3 and TC4 recorded air temperature in the inlet and outlet of the box. On the other hand, two light intensity sensors were used to measure light intensity above and below the tested panel. Each test started when the whole system temperature stabilized with room temperature and lasted for 30 minutes. Data capturing rate was two readings per minute using National Instruments® hardware DAQ9171 and NI express® software.

In specific combinations, Plexiglass was tested when water was forced to flow through its internal passages to examine using the cover as water heat exchanger to minimize the heat transmitted into the greenhouse; water type J thermocouples were used to measure temperature of water in and out.

The tested covering materials are:

- Type 1 Plexiglass which is 16.5mm thick and has 30mm wide channels
- Type 2 Plexiglass which is 16.5mm thick and has 60mm wide channels
- Agril sheet which is a polypropylene non-woven fabric sheet
- 6mm thick polycarbonate board
- UV treated polyethylene sheet
- 1.3mm thick corrugated fiberglass board

Different combinations of the listed covering materials were under investigation, the tested combinations are listed in Table 1 along with the abbreviations used for each of them.

Table 1 Covering material combinations and the equivalent symbols

Experimental setup	Description	Symbol
Plain Type1 Plexiglass	16.5mm thick Plexiglass with internal channels of 30mm width	PPG1
Plain Type2 Plexiglass	16.5mm thick Plexiglass with internal channels of 60mm width	PPG2
Type1 Plexiglas with Agril sheet.	A PPG1 sheet covered with Agril sheet	PGA1
Type2 Plexiglas with Agril sheet.	A PPG2 sheet covered with Agril sheet	PGA2
Type1 Plexiglas with Blocked Air	PPG1 sheet with blocked channels	PGBA1
Type2 Plexiglas with Blocked Air	PPG2 sheet with block channels	PGBA2
Type1 Plexiglas with water flow.	PPG1 sheet with water flow through channels	PGW1
Type2 Plexiglas with water flow.	PPG2 sheet with water flow through channels	PGW2
For polycarbonate, 3 combinations were investigated.		
Plain polycarbonate.	6mm thick polycarbonate board	PPC
Polycarbonate with Agril net.	PPC sample covered with Agril sheet	PCA
Polycarbonate with Polyethylene sheet.	PPC sample covered with Polyethylene sheet	PCP
For polyethylene, three combinations were investigated.		
Single layer of polyethylene.	Single layer of UV treated polyethylene sheet	PY1
Double layers of polyethylene.	Double layer of UV treated polyethylene sheet	PY2
Polyethylene with Agril net.	PY1 sample covered by an Agril sheet	PYA
For Fiber Glass, 3 combinations were tested.		
Single layer of fiberglass.	A single layer of 1.3mm thick corrugated fiberglass board	FG1
Double layer of fiberglass (parallel)	Double layers of FG1(completely parallel)	FG2a
Double layer of fiberglass (offset)	Double layers of FG1(offset and parallel)	FG2b
Fiberglass 1 with blocked air	FG2a sample while the gap in between the two layers is blocked	FG1BA
Fiberglass 2 with blocked air	FG2b sample while the gap in between the two layers is blocked	FG2BA

In order to take record temperatures in the steady state phase, the light was on for one hour before starting data logging which continue for 30 minutes with a sampling rate of two readings per minute.

3 Results and discussion

In order to evaluate the different combinations of each covering material, the collected data was displayed in a single figure for each group.

As shown in Figures 2 and 3, the recorded temperatures directly above and below the sample under investigation varied broadly with a narrow range of internal surface temperature between 18.1 °C and 21.6 °C. Furthermore, it can be noticed that flowing water in the Plexiglass sample reduced the outer surface temperature between 10 °C to 15 °C, while the inner surface had the same temperature of 20 °C. On the other hand, having water flow inside the Plexiglass reduced light transmittance dramatically from about 86% to 39%(Table 2). Plain Polycarbonate recorded almost the same light transmittance value compared to Plexiglass (about 86%) and exceeded plain Fiberglass which recorded 78.22%.

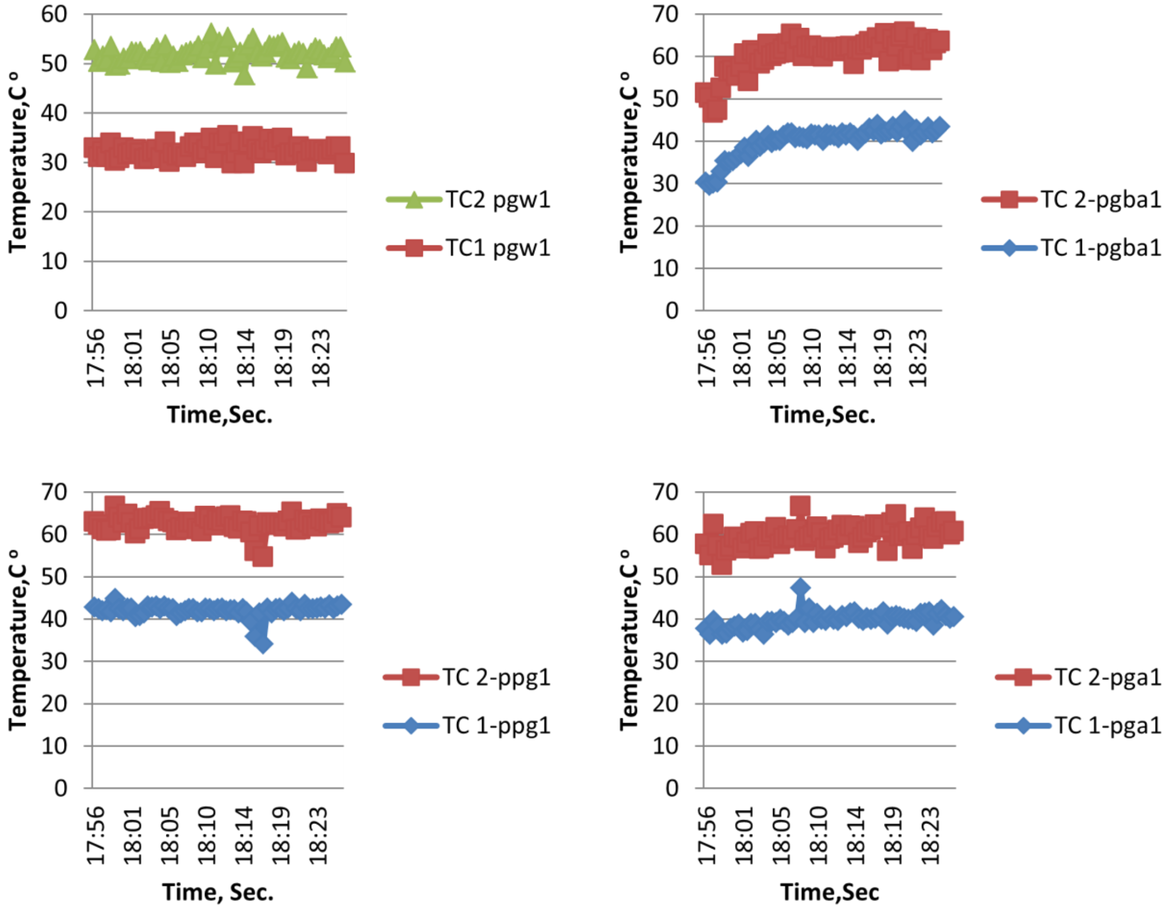

Figure 2 Type 1 Plexiglass testing results

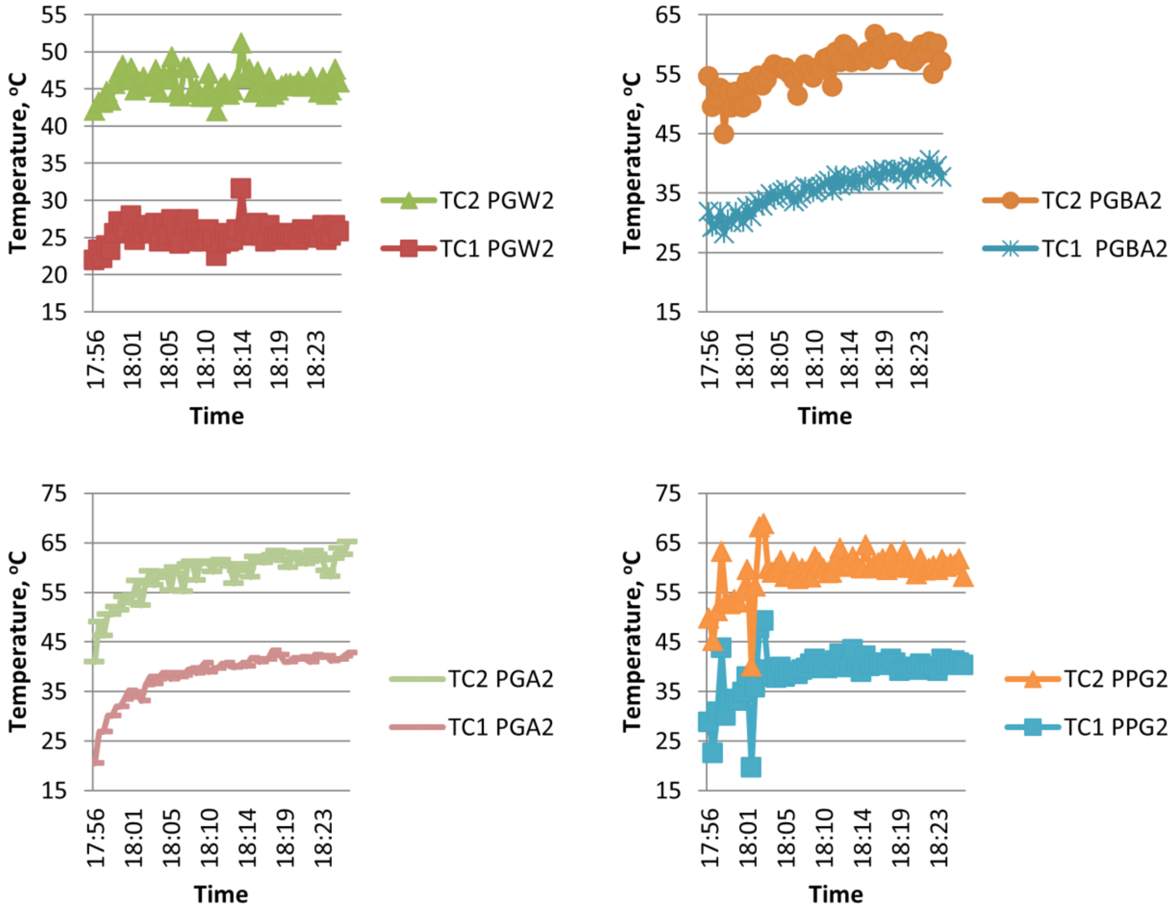

Figure 3 Type 2 Plexiglass testing results

Table 2 Light transmittance measured for the tested sample combinations

	Light intensity above the sample, Lux	Light intensity below sample, Lux	Transmittance,%
PPG1	1444.8	1244.2	86.12
PPG2	1541.2	1346.6	87.37
PGA1	1528.7	1127.2	73.74
PGA2	1524.4	1162.2	76.24
PGBA1	1517.3	1302.6	85.85
PGBA2	1534.2	1336.5	87.11
PGW1	1478.9	584.13	39.50
PGW2	1450.7	814.8	56.17
PPC	1478.5	1283.9	86.84
PCA	1533.1	1114.1	72.67
PCP	1512.6	1043.4	68.98
PY1	1508.5	1166.1	77.30
PY2(double)	1530.2	1082.2	70.72
PYA	1511.7	1117.1	73.90
FG1	1525.9	1193.6	78.22
FG2a(2 layers)	1470.5	642.4	43.69
FG2b(2 layers)	1453.5	648.6	44.62
FG1BA	1420.4	486.4	34.24
FG2BA	1474.3	486.9	33.03

Although the highest temperature reduction was recorded in case of the plain Plexiglass sample in both types, pumping water into the inner channels of both types of Plexiglass reduced the upper temperature by 5%-33% compared to the recorded data in other samples, while the average temperature beneath the sample was 32.3 °C which was the lowest among the examined Type 1 Plexiglass. On the other hand, average temperature just below the tested sample was 20.1°C -20.4 °C in all tested combinations of Type 2 Plexiglass. Results shown in Figures 4 and 5 show that temperature of water flew through Type 1 Plexiglass was increased by 1.1 °C while the rise was 1.3 °C in case of Type 2 Plexiglass.

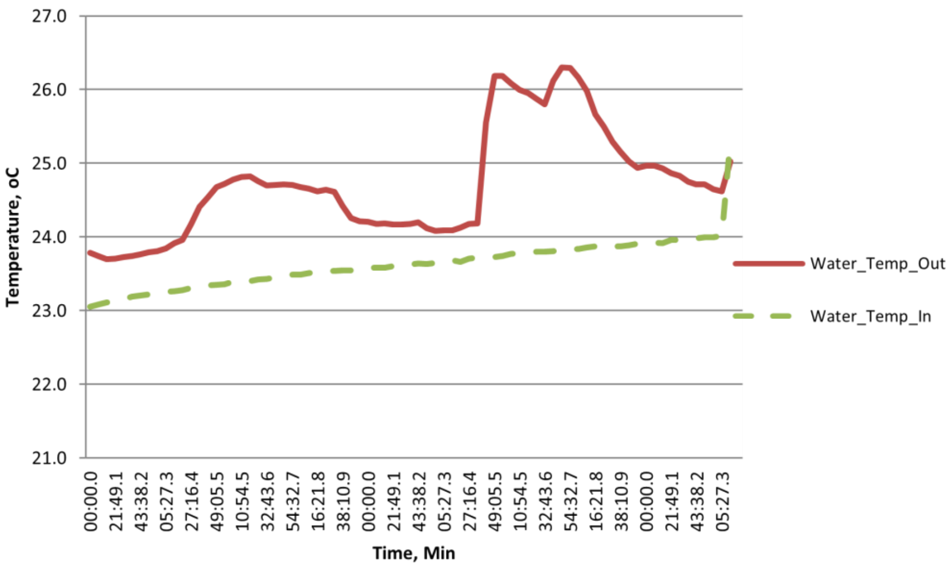

Figure 4 Type 1 Plexiglass water in/out temperature

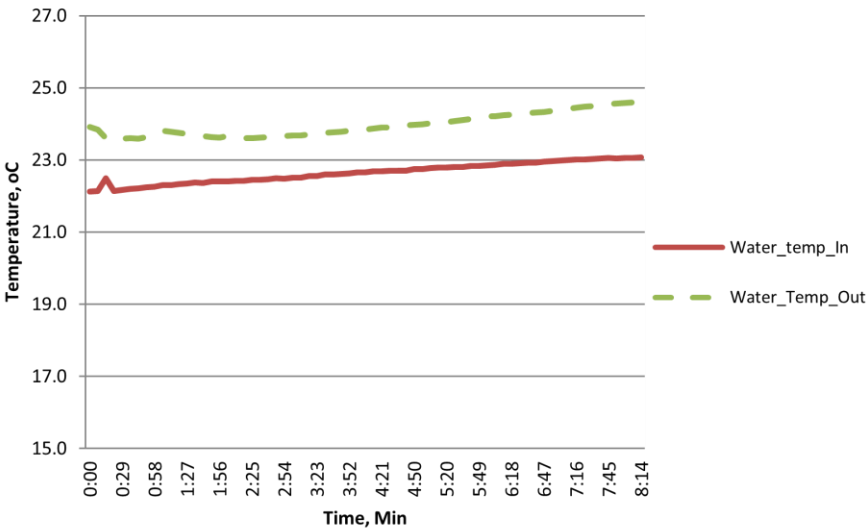

Figure 5 Type 2 Plexiglass water in/out temperature

The maximum temperature reduction was recorded in case of both air blocked samples of two fiberglass layers with a decrease of about 47.5% between temperature directly above and below the tested sample (Figure 6). On the other hand, Figure 7 shows that all Polycarbonate combinations reduced the inner temperature with about 50% which equals the resulted data of the double layer polyethylene sheet as shown in Figure 8.

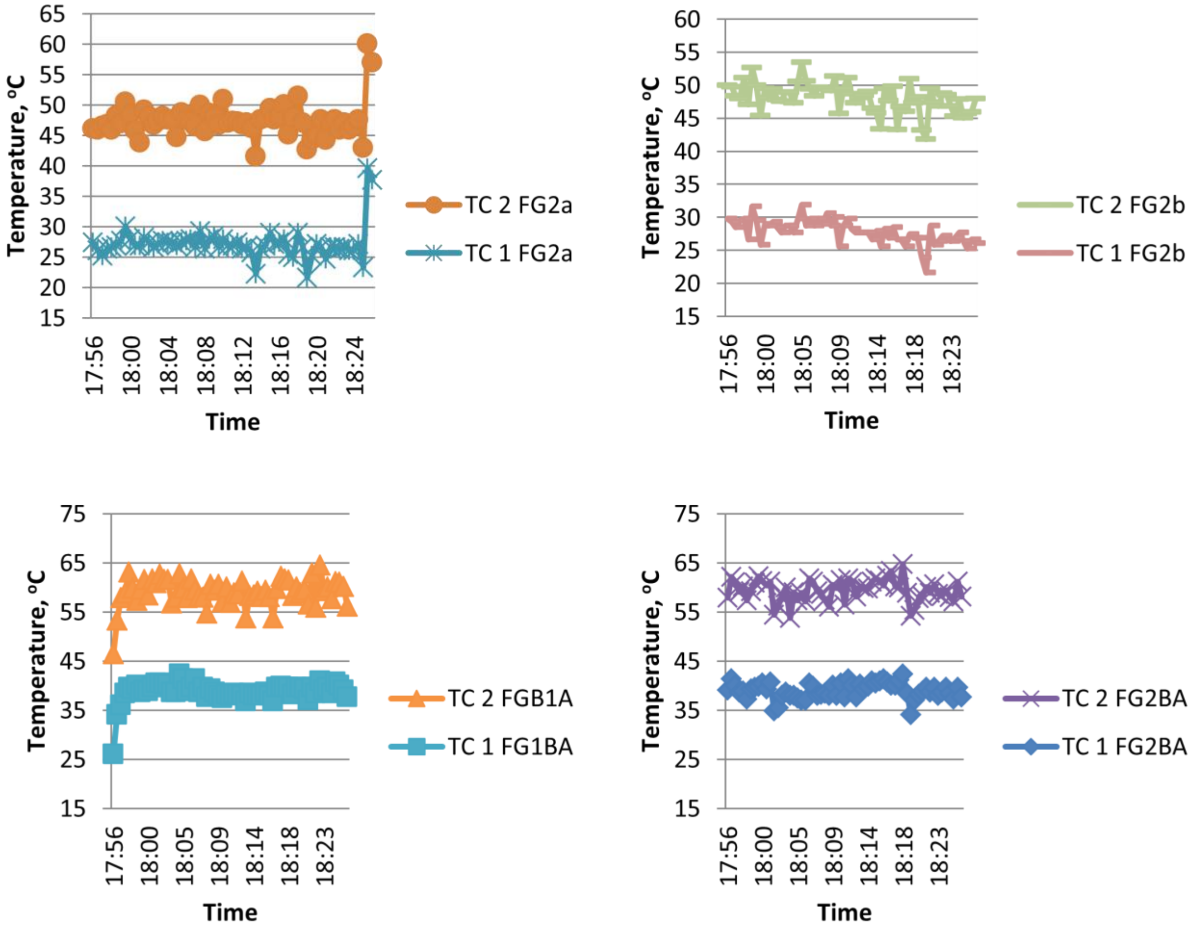

Figure 6 Fiberglass combinations testing results

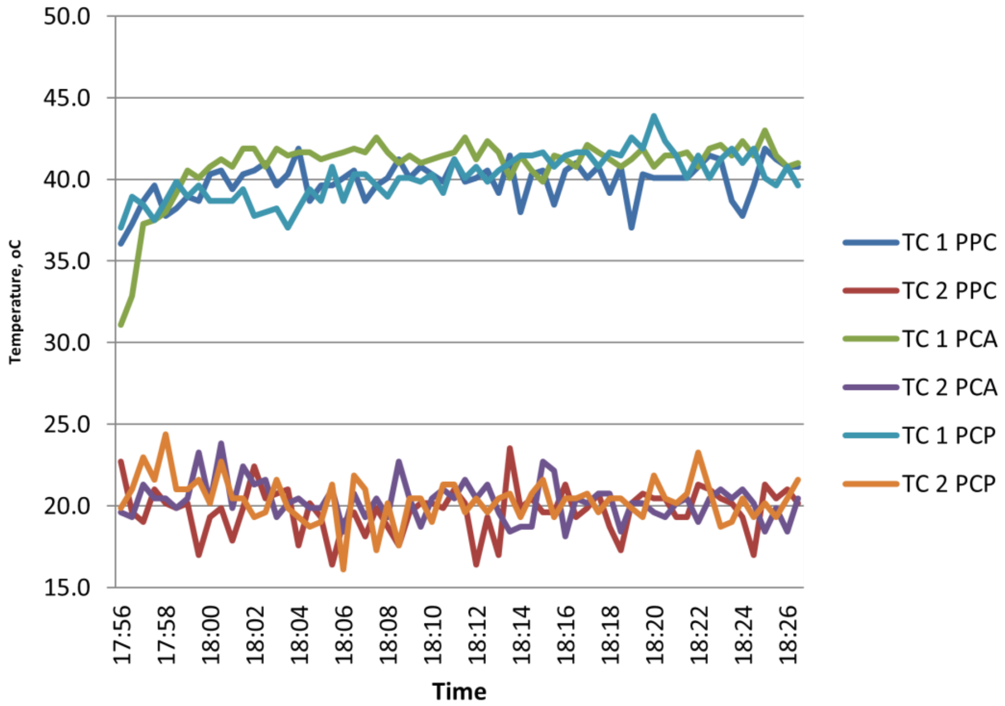

Figure 7 Polycarbonate combinations testing results

Figure 8 Polyethylene combinations testing results

3.1 Light transmission through the tested samples:

It is clear from the data tabulated in Table 2 that light transmittance of both Type 1 and Type 2 Plexiglass are very similar to Polycarbonate sheets, while other combinations reduce the light transmittance especially with the fiberglass where it did not exceed 35%. On the other hand, flowing water in the Plexiglass reduced light transmittance by more than 50% compared to plain Plexiglass. Light transmission through virgin Polyethylene sheets was comparable to what was reported by Picuno and Sica (2004) where it was 80% while it was 70% for the recycled 80 μm Polyethylene.

3.2 Enthalpy

Using the recorded temperature of air in and out of the experimental setup, the enthalpy was calculated to determine the energy used to increase the temperature of the air passing through the system in kJ/kg. According to Figure 9, Type 2 Plexiglass which has a 60 mm passage width allowed the air flowing through the system to accumulate the minimum energy levels while it was the maximum in case of the plain Plexiglass.

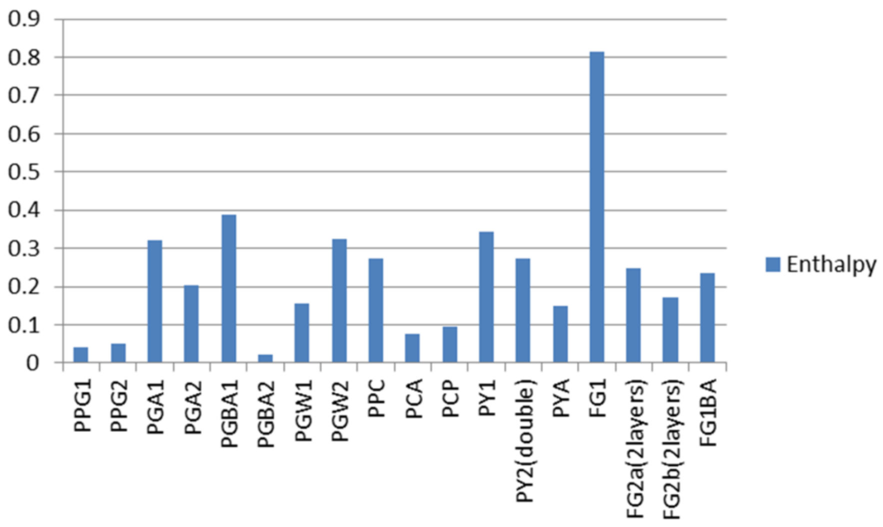

Figure 9 Enthalpy value of the air passed through testing device, kJ/kg air

4 Conclusions

According to this specific investigation, typically used covering materials such as Polyethylene and Fiberglass were compared to Plexiglass in a laboratory test according to its heat and transmittance. Findings of this research showed that Plexiglass performance in both heat and light transmittance are achievable by other materials as well such as Polycarbonate which gave a comparable readings with Plexiglass and better readings than Fiberglass. It is also concluded that pumping water through Plexiglass inner passages reduced light transmittance which may be needed in hot areas especially in summer. It is recommended to carry out more research and field studies to collect field data to help greenhouse designers to select the optimum cover materials. Moreover it is highly recommended to study light quality parameters of each of the tested materials and combinations in order to have a better understanding of the potential effect of using such material as greenhouse cover under various production systems taking in consideration the aging effect especially in harsh environments with high ambient temperature, sandy storms and high UV. Furthermore, aging effect should be examined in order to estimate life expectancy of each of them, hence the feasibility of investment in modern covering materials to be learnt.

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