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Use of polymer dispersed liquid crystal (PDLC) film as a greenhouse cover material

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Abstract

As of today, we can surely say that even the smallest and the most simple greenhouses can't do without some automation, to say nothing of large enterprises. High-level automation is attained at the expense of all components available in the system, and all separate components have to smoothly perform their functions and duties. The reliable systems always have some fall-back options in cases of the failure of one or another component.

Expansion in the number of electronic components naturally leads to increase of energy consumption, and one may say that it is an important factor forming the final product price. For maintenance of competitive ability any agricultural enterprise tries to offer such production on the market, which will be competitive compared to other types of production in terms of price and quality. Therefore, the agricultural enterprise from the very beginning makes efforts to establish as much energy-saving enterprise as possible that will have a beneficial impact not only on company budget, but will provide another one big step forward aimed to preservation of natural resources.

Diminution of any energy resourse utilization means first of all their proper use and design of such greenhouse system, which uses the external climate conditions to the most benefit. The most important external climate factor for greenhouses, which generates other climate conditions is of course the sun. As we know, solar energy is the most important for plants, and in case of its deficiency the main growth processes will be inhibited, while in case of its redundancy, a plant may be damaged at all.

In greenhouses the energy is mainly used for illumination, heating and cooling, while other microclimate parameters, such as CO_2 and humidity, don't require even a third part of energy consumption. It is obvious, that the precise indices of energy consumption depend on geographic location and specific plant crop.

Based on the above-mentioned, it is necessary to use sun energy to the maximum efficiency in order to reduce energy consumption expenditures. Traditional microclimate automation systems control the mentioned factors by means of electric louvres or curtains, which provide shading

adjustment, so that a sunlight passes upper greenhouse cover and reach internal shading structure. Based on the shading structure conditions, sunlight either is reflected or partially absorbed.

The mentioned shading method has some negative aspects, first of all that its shading characteristics are permanent (unchanged), it has a fixed sun energy conductivity, permanent reflection and absorption coefficients, and it either can be used or not. Therefore, such kinds of shading methods can provide maximum efficiency only when the solar intensity exactly corresponds to parameters of the mentioned shading structure so that a plant receives exactly as much energy as is necessary for this specific plant crops and based on the specific "age" of this culture. Of course, we realize that it is virtually impossible to preserve so many parameters, since taking all the mentioned factors into account, precise natural illumination can be provided in some seasons only, and then only in some time of a day, for short period of time.

In all other cases, a plant gets more or less illumination, or else the more time is needed. During most of the time, a greenhouse microclimate automation system is forced to balance microclimate parameters deviation, with turn-on heating, light and cooling that will surely cause additional energy consumption. Apart from the fact that the mentioned classic shading method doesn't provide maximum efficiency during the most of time, it should be noted as well that a mentioned shading system is located in the inner part of the greenhouse and regardless of the material used for its manufacturing and its reflection characteristics a range of absorption coefficient is 8-15% in all cases, due to absorption of some solar energy, so the system is getting hot and further the heat will be transferred to the inner part of greenhouse, as a result a temperature parameter will change that leads to necessity of temperature decrease in the greenhouse, so a cooling system has to be turned on or outdoor air of lower temperature has to be let in that obviously will have an impact on energy consumption and microclimate.

Based on the above mentioned, it is clearly seen that currently available greenhouse microclimate automation systems, and exactly shading systems don't provide the desirable outcome, that leads to use of additional components in order to preserve the necessary microclimate. It should be also noted that deviation of one parameter, for instance temperature increase, results in change of other parameters, as well, including moisture concentration, so in order to balance a temperature, it is necessary to either let the outdoor air in or to use the cooling system. At this stage the necessary microclimate has been already disturbed, and afterwards due to entry of the outdoor air, even if this option is admissible, humidity and CO_2 concentration are disrupted, whereafter the system is forced to spent energy resources with the purpose of maintenance of desirable microclimate parameters, cooling system has to be switched on, as well and all this leads to electric energy consumption.

The presented paper offers a new method for natural illumination shading in the greenhouses, which will more precisely and effectively adjust the natural lighting; its use will also lead to less heating of the inner part of greenhouse, and the mentioned method will make it possible to perform exact and segment management of natural illumination in the greenhouses.

Properties of electron toning films as a means for an alternate shading method and its comparison with other greenhouse cover materials have been discussed in the article. It has been shown that natural illumination adjustment using electron toning technology is more precise and provides high efficiency and reduction of energy consumption. An additional information will be published in the thesis work, where the model of shading system using electron toning technology developed on the basis of this efficiency indices will be represented, the operation principles will be discussed, appropriate protocols, interfaces will be selected and operation algorithm will be developed, by means of which the single parts of the greenhouse will be elaborated and natural lighting intensities will be adjusted.

Keywords:

Greenhouse, greenhouse cover material, PDLC (polymer dispersed liquid crystal) film, smart glass, smart film

As of today, three materials are mainly used as a greenhouse cover material, among them a special greenhouse cellophane 100-200 microns thick, cellular polycarbonate 4-6-8 mm thick and glasses of different thickness are the most widespread.

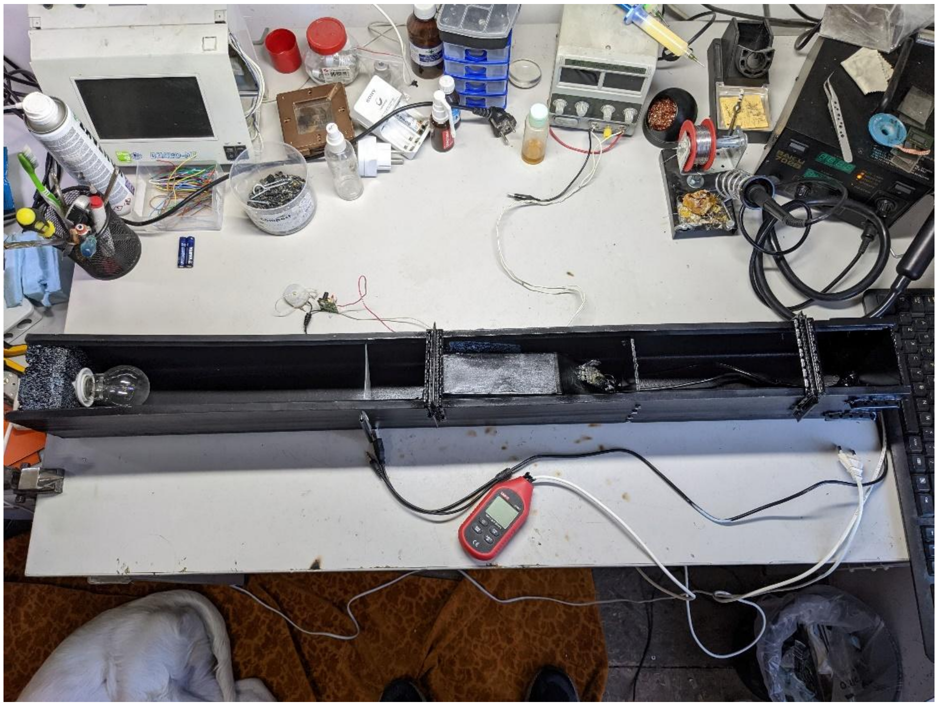
In order to discuss the use of smart-glasses as a greenhouse cover material, is necessary to compare the properties of the mentioned materials.

For these purposes a study has been conducted, during which greenhouse cellophane 150 microns thick, cellular polycarbonate 4 mm thick and PDLC film have been compared to each other.

Study has been carried out in Tbilisi, at the following location: adjacent to Tbilisi reservoir, precise location: 41.718129, 44.880107, date: 12.09.2022, time: 17:56. The study has been conducted by me: Gary Markaryan, PhD student of the Georgian Technical University.

The following equipment has been used for the experiment:

- illumination intensity measuring device – luxmeter: UNI-T UT383
- spectrometer: Theremino Spectrometer V3.1 and developed measuring unit, in which illumination diffraction grating, web-cam and a body with illumination adjustment tool (see Picture)



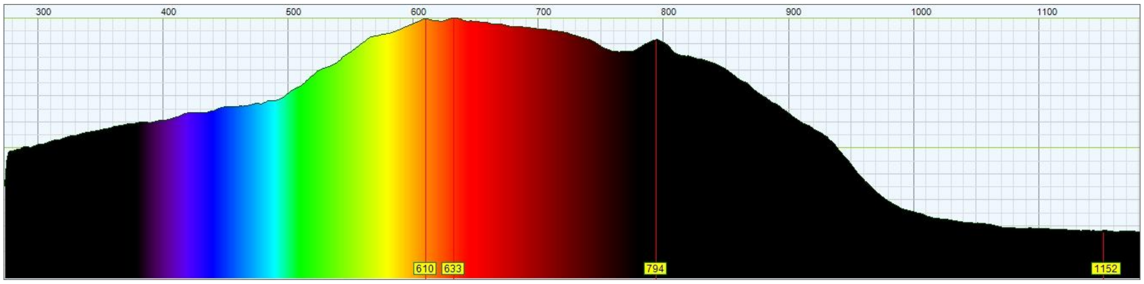
Picture

PDLC film when turned off (blurred)

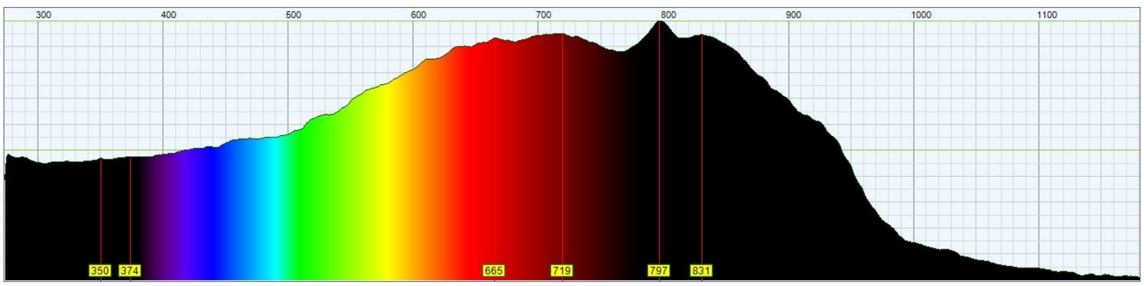
PDLC fil when turned on (transparent)

The study was designed that way that sunlight illumination and spectra were measured by the mentioned device first, then the different covers: greenhouse cellophane, polycarbonate and PDLC film were installed, and the mentioned parameters were registered.

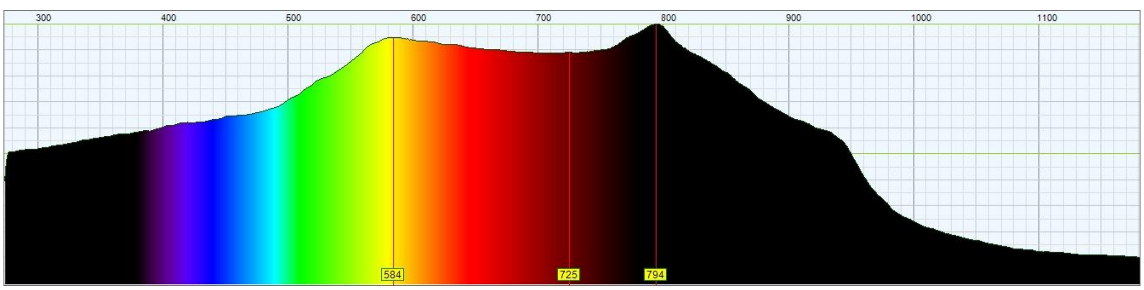
Indicator 1: without cover (direct sun light) - 48260 lux



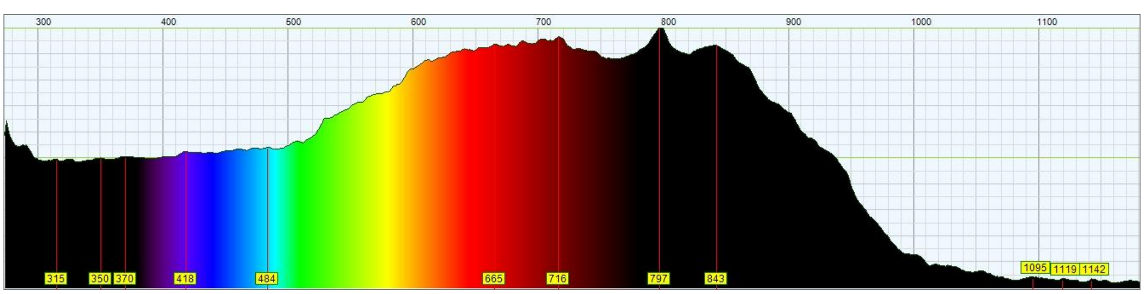
Indicator 2: PDLC film, turned-off state (blurred) - 11430 lux



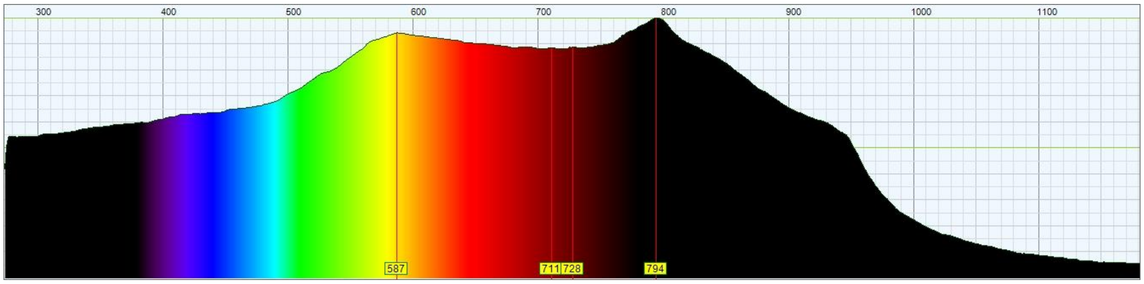
Indicator 3: PDLC film, turned-on state (transparent) - 37200 lux



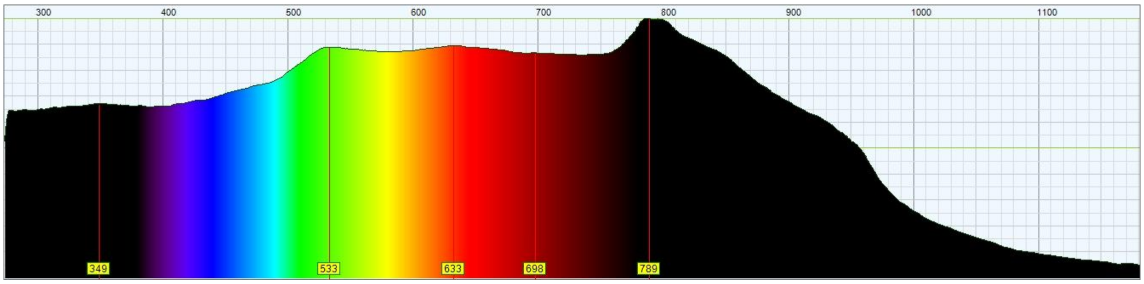
Indicator 4: two PDLC films, turned-off state (blurred) - 7000 lux



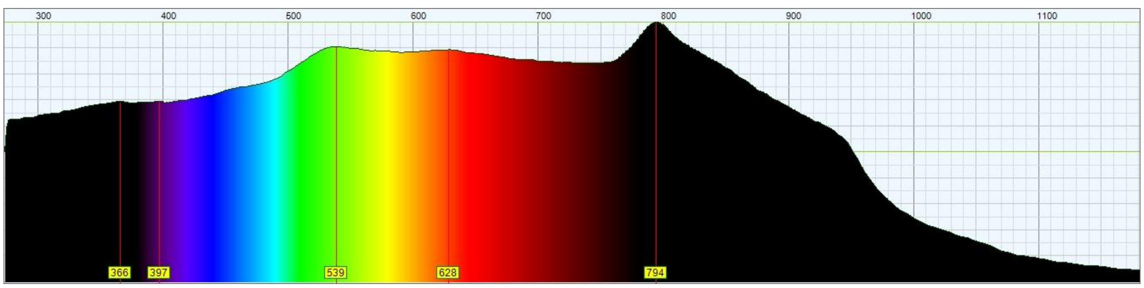
Indicator 5: two PDLC films, turned-on state (transparent) - 28500 lux



Indicator 6: hot-house cellophane - 27860 lux



Indicator 7: cellular polycarbonate 4 mm - 21210 lux



Data distribution according to the best indices:

Position	Cover	Lux
1	sunlight without cover	48260
	Glass	38608-44399
2	PDLC film, turned-on state (transparent)	37200
3	two PDLC films, turned-on state (transparent)	28500
4	hothouse cellophane	27860
5	cellular polycarbonate 4 mm	21210
6	PDLC film, turned-off state (blurred)	11430
7	two PDLC films, turned-off state (blurred)	7000

It is seen from the mentioned Table that PDLC film in turned-on state (transparent) has better indices compared to cellophane and polycarbonate.

As for comparison of spectrograms, it has to be compared with the first index, where sunlight spectra ratio is shown.

While comparing indices 1 (sun), 6 (cellophane) and 7 (polycarbonate), one can see that in pictures 6 and 7 takes place a slight decrease of 560-700 nm spectra, while the rest of spectral range reduces in proportional intensity only.

By comparison of index 1 (sun), 3 (PDLC film, turned-on state (transparent) and 5 (two PDLC films, turned-on state (transparent)) one can see that a change took place in more narrow range, approximately 630-700 nm and the intensity of the rest of spectra has smaller difference compared to cellophane and polycarbonate.

As for indices 2 and 4, where the PDLC film in turned-off state (blurred) is used, one can see that in the mentioned picture the whole spectral range is shifted to ultrared spectra, since dispersion of rays occurs in blurred state.

All this enables us to say for sure that the mentioned material (PDLC) may be used as a greenhouse cover material.

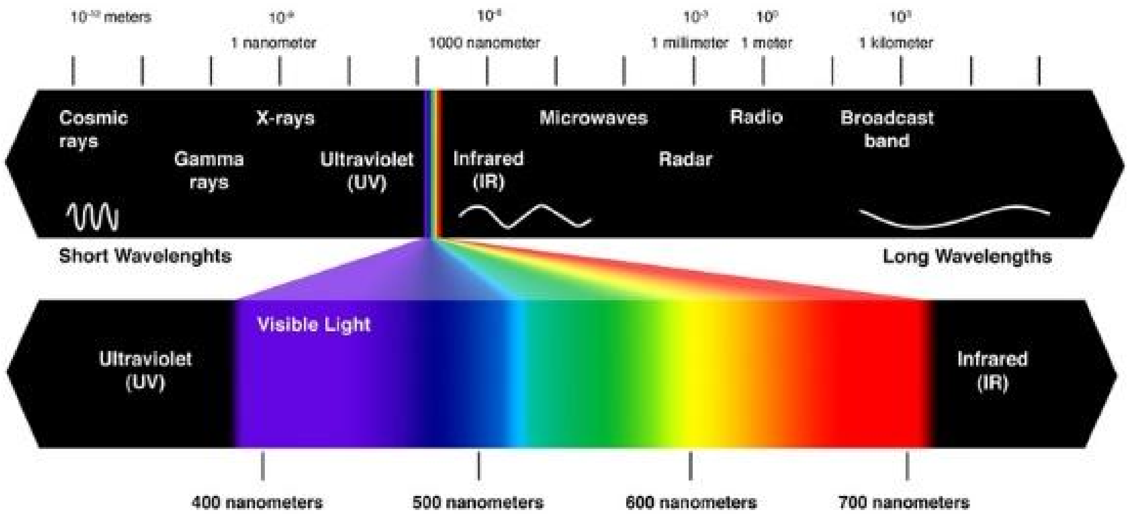
It is seen from the table, where the lighting power values in blurred state are shown that one film is able to adjust (control) the illumination range 37200-11430 lux that means that it can adjust up to 70% of sunlight hit into the cover.

When we have used two films, we were able to manage the range of 28500-7000 lux, and the regulation range is 75%. Since the value 28500 lux is obtained using this method, which exceeds the index 3 (or 27860, where cellophane is used), the use of double film remains relevant, though it is questionable so far as is practicable to use double quantity of films for receipt of 5% difference only.

Unfortunately, during the study I forgot to measure the glass characteristics, though lots of studies have been already conducted to this date, according to which we can state with confidence that the light conductivity of glass exceeds all the above-mentioned materials and it approximately equals to 80-92% that means that in case of glass use in our study we would get the index 38608 – 44399 lux.

Based on the above-mentioned data it is seen that the mentioned method for PDLC film application may be used as a shading method.

The importance of illumination spectra for plants. As is known, solar irradiation consists of waves of definite length spectral composition (see Figure).



Figure

It should be noted that eye visible spectral range includes waves with lengths from 400 to 700 nm. Different wave lengths have different power. The shorter a wave is, the more energy it contains. Everyone knows that photosynthesis is an essential process for plants growth and development, since the mentioned process promotes generation of organic substances, which feed a plant. Photosynthesis requires energy, water and carbon dioxide, and plants get energy from illumination.

- red (600-720 nm) and orange (595-620 nm) are the most important portions in light spectrum. The mentioned spectra not only lay the foundation for photosynthesis but also have an effect on ongoing processes of plant development. For instance, red spectrum dosing enables control of blossoming process and promotes root system development, as well.
- blue and violet light spectra (490-380 nm) also take direct participation in photosynthesis process. In addition, they perform functions of protein formation and plant growth rate adjustment.
- blue spectrum rays are responsible for leaf development, plant growth etc. Shortage of rays of the mentioned spectrum causes plant grows in height. In order to receive the more amount of blue spectrum, a pigment, which is responsible for plant orientation, is also sensitive to dark blue spectrum.
- radiation in the 315-380 nm range doesn’t provide plant elongation in height and is responsible for the synthesis of some vitamins. Ultraviolet rays improve plant resistance to cold, as well.
- as for the waves of the 565-490 nm range, plant usually absorbs and uses them when experiences a deficit of other main spectra.

Thus, a definite range of lighting takes responsibility for certain processes, that is why our spectral analysis of PDLC film was so important to establish how acceptable its use is.

Resulting from the spectral analysis we obtained data which clearly show that PDLC film doesn't perform light spectra absorption and transformation to other spectra, so we can state with confidence that the mentioned method is applicable in the greenhouse business.

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