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Full Length Research Paper

Energy saving when lighting culture rooms for agamic propagation of plants.

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ABSTRACT: This work shows the lighting results obtained from applying anidolic lighting systems in a room for agamic propagation of plants. We evaluated the distribution of illuminance levels inside the room at three different heights and hours, with and without an added ceiling diffuser, under clear and overcast sky conditions. We estimate that it will be possible to achieve a lighting-destined energy saving from 20% to 94%. The use of an anidolic system in applications of agamic production of plants could lead to an important saving of the electrical energy that is used daily for artificial lighting systems.

Key words: Natural lighting, agamic production of plants, energy saving.

INTRODUCTION

The economic exploitation of cultures based on plants production is one of the main industrial activities of some Argentine regions. This kind of production is generally carried out by applying techniques such as propagation from live stakes, grafting, layering or by micropropagation from in vitro plant tissue culturing. When culturing industrially through agamic micropropagation, the plant tissues are grown in culture media under artificial light conditions where both the temperature and the lighting level registers are carefully monitored (Erig, A et.al., 2005) The facilities are designed by taking into account the use of fluorescent tubes since these are easily controllable light sources, despite the fact that they are also costly because of consumption levels and maintenance, and are always subject to interruptions due to service cuts or delays at the renewal of old or broken sources. Also, the use of these technologies entails a further step of an economic model mainly focused on imports to Argentina given that the materials, knowledge and resources used have a direct economic dependence to foreign products (Govil, S. et.al., 1997). On the contrary, some works carried out by Kodim (Kodym, AH. et. al. 2001) show that the use of natural lighting systems on agribusiness facilities enables us to obtain optimal results regarding quantity and quality of light, reducing this way the use of electrical energy for lighting with the consequent environmental impact that is associated to that. The utilization of natural lighting shows clear advantages when compared with artificial lighting installations, even so if considering the high demand of quality and amount of light required for agamic micropropagation techniques: Firstly, there is no energy consumption as it is a renewable energy source without any associated polluting emission. Secondly, the composition of the lighting spectrum that is obtained has all the components of photosynthetically active radiation (PAR), a fact that makes natural lighting be a more efficient resource in relation to the growth process. Thirdly, the entering of heat into the space is less per lumen than in most

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electrical lighting sources, something that could lead to a reduction of the energy that is destined to the thermal conditioning of the culture room. This work was financially supported by the PICTO 32140 UNCa-INTA Project and it details the lighting results that were obtained through the application of an anidolic system on a building used for agamic propagation of plants. It shows the data recorded at three different climatic seasons, that is winter, summer and autumn, for an experimental culture room built by GERCA, UNCa – CONICET in Catamarca province, Argentina. In order to prove the expected energy saving derived from the installation of this experimental system, we calculated the electrical consumption that was needed for putting on a same level our system and the luminous flux results thrown by a project of fluorescent tube installation.

MATERIALS AND METHODS

Experimental Culture Room and anidolic system. The culture room where the measurements were made comprises a 4x4m space. It has an only door for access which is located on the side opposite the Equator and its interior walls and ceiling have 0.79% reflectance. This experimental prototype was built in Catamarca province and is located at 28º45''S – 65º78''W. Initially, the lighting of the place was planned so as to be given by a 225 fluorescent tube installation at 36Wh consumption each and distributed in 9 shelvings of 5 shelves each. This would provide an average of 1,000lux horizontal illuminance (Eh_{med}), equivalent to an average of 18,5µmol.$m^{-2}s^{-1}$ PPF radiation over the plant media (Thimijan, RW. et. al. 1982), which are located at a distance of 0.2m from the source. For the experiment with natural light we suggested to adapt an anidolic system on the wall that faced the Equator which would redirect and concentrate the collected beams into the inner space. This system is 4m wide and 0.2m high. In figure 1 we can see the exterior aspect of the device which protrudes 0.4m out of the facade.

Figure 1: Left, View of the location. Right, exterior of the façade facing the Equator

The anidolic collector we developed is a natural light passive system constructed by following the functioning principles of a compound parabolic concentrator (CPC). This was made using two parabolic symmetric specular reflectors, both facing each other so that all rays penetrating in the CPC are introduced later to the interior by at least one reflection (Courret, G., et al, 1996 and Elmualim A.A et.al. 1999). Figure 2 shows an outline of the design and cut of the installation of the culture room system.

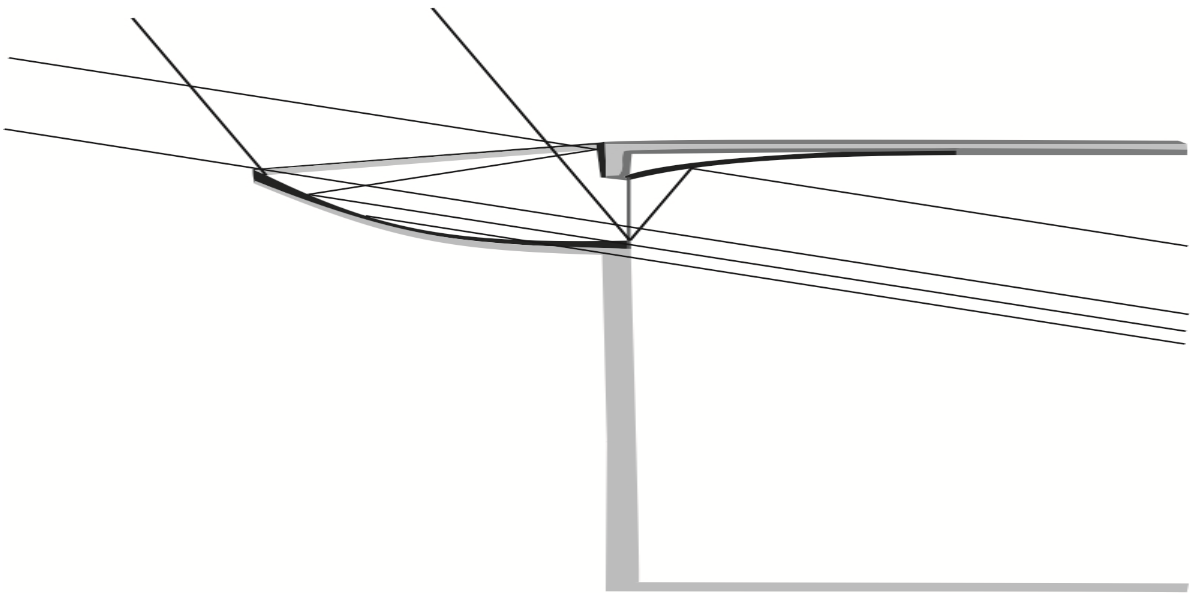


Figure 2: Left, outline of the anidolic system used. Right, path of the beams.

Room photometry

In order to assess the distribution of the room lighting we set a grid with 28 places where illuminance values would be taken at three different heights, correspondent to the approximate heights at which the sterilized media with vegetable material would be placed (1.88m, 1.44m, 0.425m). Thus, 84 points on the grid would be observed for each measurement. For the record we used a LI-COR 189 light meter and a LI-210SB photometric sensor with a 2003S leveling fixture (Figure 3). Data were taken on July 19th, 20th, 21st and December 19th, 20th and 21st of 2011. Also, on March 19th and 20th and April 4th of 2012. In all cases this was observed approximately at 10:00, 13:00 and 16:00. The lighting conditions of the sky were both clear and overcast (CIE, 2003). In order to control the measures we took the exterior illuminance values at the start and end of each measurement, verifying a maximum fluctuation of EH of +/-5%.

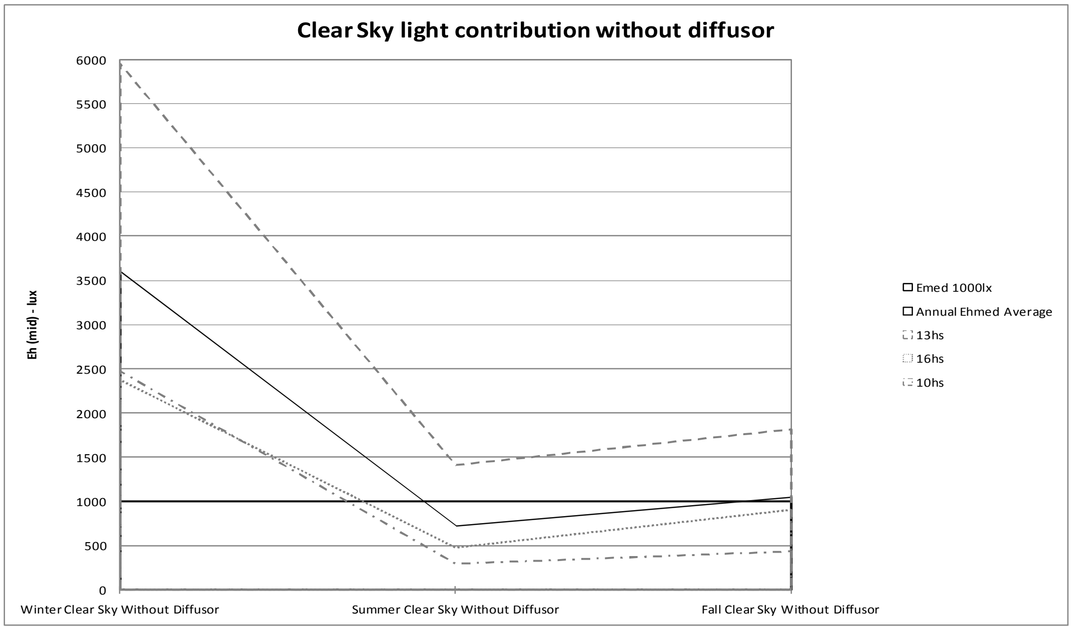
Figure 3: Equipment; Column with pre-fixed heights and LI-210 SB photometric sensor.

Measurements inside the culture room were taken in June and December 2011 and March and April 2012, comprising this way winter, summer and autumn seasons respectively. Figure 4 shows the general lighting condition of the evaluated room.

Figure 4: Situation inside the room with (left) and without (right) the ceiling diffuser.

RESULTS:

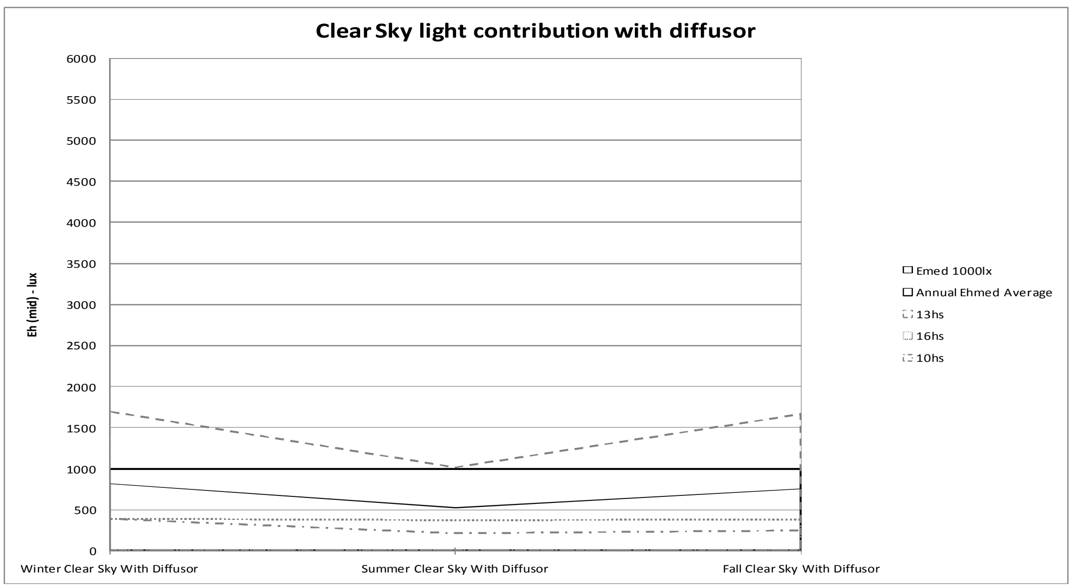
The lighting contribution inside the culture room can be seen in the series of graph 1. We show the records in lux corresponding to the three measured heights, 1.88m, 1.44m and 0.425m, to solar noon and a moment in the morning or afternoon, in winter, summer and fall seasons, under clear skies and without the ceiling diffuser.



Graph 1: Illuminance distribution, clear sky without diffuser, 1.88m, 1.44m and 0.425m; higher height 13:00, lower height 15:00. Scale 0 – 5,000 lux.

Graph 1 shows that the levels of exterior illuminance in winter season were 59,710 lux at 10:00 and 65,590 lux at 13:00. The average of horizontal illuminance recorded inside the culture room during the morning was Eh_{med}=601lux, with a minimum value of 157lux and a maximum one of 3,812lux. The average efficiency of the anidolic system under those sky conditions was 1.4%. In the case of the records for solar noon, the average level of illuminance was Eh_{med}=2008lux, with a minimum of 266lux, and a maximum of 16,000lux. If we take the average of the room illuminance as the parameter, the actual use of the exterior illuminance was 3.14%. Next, the graph shows the luminous winter season situation inside the culture room, with exterior illuminance level at a range going from 76,900lux in the morning hours up to 121,300lux at solar noon time. The average level reached at the highest solar altitude moment was 1,407lux, with a minimum record of 427lux and a maximum of 4,987lux. In terms of efficiency, the average level of illuminance reached represents 1.15% of the exterior illuminance. On the other hand, in the afternoon observation, under a Eh_{ext} of 92,790lux, the average room levels reached 473lux, with a maximum of 1,485lux, a minimum of 170lux, with an average percentage of use of exterior illuminance of 0.5%. The morning of that same day reached a value of Eh_{ext}: 79,465lux and had a Eh_{med} of 291lux inside the room with a maximum value of 828lux and a minimum of 132lux, what represented 0.36% of efficiency of the system. Finally, graph 1 shows the lighting situation inside the culture room for measurements carried out in the autumn season. The exterior illuminance was Eh_{ext}=105,830lux at the solar noon and Eh_{ext}=74,165 in the afternoon. The values of the illuminance inside the room reached at the highest solar altitude moment an average value of 1,814lux, with a minimum record of 427lux and a maximum of 9,302lux. In terms of efficiency, the average level of illuminance reached represents 1.72% of the exterior illuminance. In the afternoon, the levels inside the room reached an average of 902lux, with uniformity being U=0.22. This means there was an average percentage of exterior illuminance use of 1.21%. The records for illuminance in the morning were taken under an exterior illuminance of Eh_{ext}=41790. We observed that the levels inside the room reached Eh_{med}: 432lux. This represents an average of 1.03% of exterior illuminance use.

The lighting results obtained in the culture room under clear skies and with the ceiling diffuser can be seen in the series of graph 2.



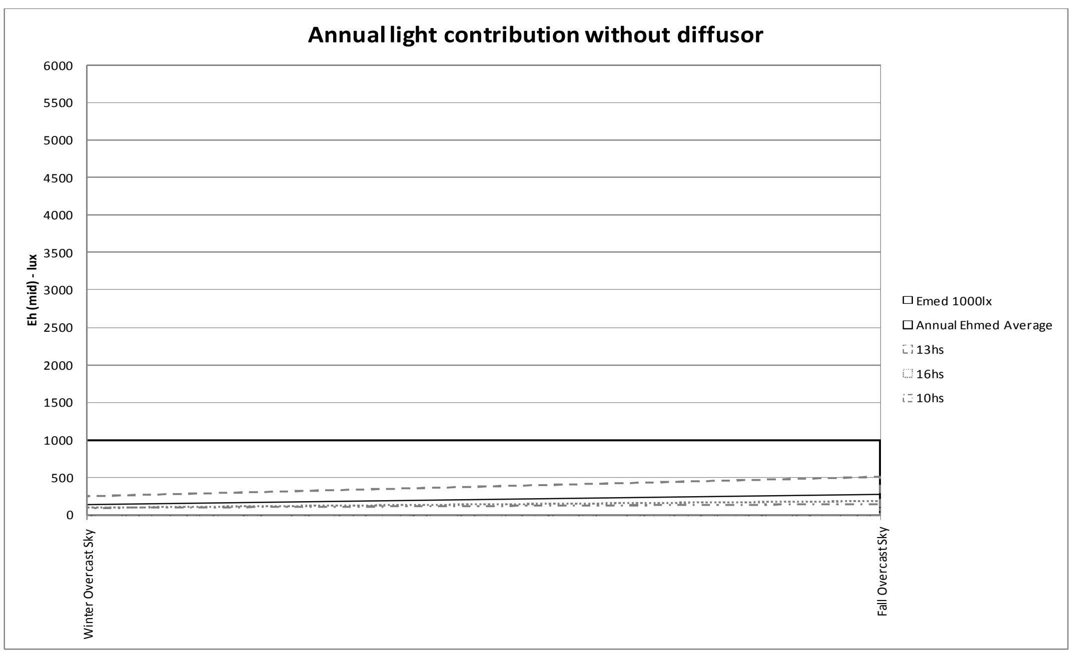
Graph 2: Illuminance distribution, clear sky with diffuser, 1.88m, 1.44m and 0.425m; higher height 13:00, central height 10:00, lower height 12:00. Scale 0 – 5,000 lux.

In graph 2, the values show the distribution of illuminance in the room after using the alveolar polycarbonate ceiling diffuser. The winter measurements were made at 10:00 and 12:00 with 27,300lux and 63,400lux of exterior illuminance levels respectively. At 12:00 the Eh_{med} of the room illuminance was 1,691lux, with a minimum of 382lux and a maximum of 8,892lux. The average level of the room represents 2.66% of the exterior illuminance level. On the other hand, the records for 10:00 show a Eh_{med} of 386lux, with extreme values of 138lux and 1,325lux, and an average efficiency of 1.4%.

In the summer season, the average Eh_{ext} was 76,525lux at 09:30, 120,070lux at 13:00 and 90,705lux at 16:00. At the solar noon the average record of illuminance inside the room was Eh_{med}=1,012lux, with a minimum record of 352lux and a maximum of 3,276lux. The system's average efficiency under this sky conditions was 0.84%. In the afternoon, the levels reached an average level of illuminance of Eh_{med}=369lux, with a minimum of 129lux and a maximum of 1,618lux. The actual use of the exterior illuminance was 0.4%, if we take the average of illuminances recorded as the parameter.

Finally, we can see the lighting situation inside the culture room for the measurements taken in the fall season. The exterior illuminance records went from an average of 96,845lux at the solar noon, to 14,192lux in the morning (09:00), to 41,305lux in the afternoon (17:00).The values of illuminance inside the room reached at the moment of the highest solar altitude an average of 1,659lux, with a minimum record of 232lux and a maximum of 9,270lux. The efficiency, taking into account the average illuminance level reached, was 1.71% of the exterior illuminance. In the afternoon the levels inside the room reached an average of 377lux. That is, an average percentage of actual illuminance use of 0.91%.The morning illuminance records reached an average of 250lux, with uniformity being U=0.20 and efficiency 1.76%.

Graph 3 shows the lighting contribution inside the culture room at the solar noon and a time in the morning or afternoon, on overcast skies without ceiling diffuser.



Graph 3: Illuminance distribution, overcast sky without diffuser, 1.88m, 1.44m and 0.425m, higher height 13:00, lower height 17:00. Scale 0 – 5,000 lux.

We can observe the lighting results for fully overcast sky, reaching an exterior illuminance level (Eh_{ext}) of 19,250lux at 13:00 and 7,200lux at 17:00. The values inside the room reached at the moment of maximum solar altitude an average of 249.5lux, with a minimum of 83lux and a maximum of 750lux. In terms of efficiency, the average level of illuminance represents 1.29% of the exterior illuminance. On the other hand, the afternoon levels reached an average of 95.8 lux, and an average percentage of exterior illuminance use of 1.33%. It is important to mention the fact that because the anidolic concentrator orientates towards the Equator, we considered that the levels recorded in the morning could be taken as symmetrical.

Next, the values shows an average Eh_{med} were 14,792lux at 09:30, 3,5570lux at 14:00 and 15,763lux at 17:00. At the solar noon the average illuminance recorded inside the room was Eh_{med}=505lux with a minimum value of 144lux and a maximum value of 2,230lux. The average efficiency of the anidolic system under these sky conditions was 1.35%. As for the records in the morning and afternoon, the average levels of illuminance were Eh_{med}=147 for the former and 182lux for the latter, with minimum values of 45lux and 55lux and maximum values of 480lux. If we take the average lighting demand of 1,000lux or 18,5µmol.$m^{-2}s^{-1}$ that plant tissues need in every medium, we can observe that the average level of natural light entering the room in different moments of the year are 502lux, 1,743lux and 601lux in the morning, 3,354lux, 1,586lux and 398lux at solar noon and 121lux, 191lux and 213lux in the afternoon. Each of these abovementioned values depend on the conditions being clear sky without diffuser, clear sky with diffuser or overcast sky without diffuser respectively. This represents a potential daily saving from 20% to 95% of the energy used for the luminous stimulation of the plants. Following these data, in order to predict with a higher degree of accuracy which would be the real income of solar light during a whole year, we need to know the sunshine hours of the place where the culture room is located. For instance, the city of Mendoza is located at 32°52'41''S and 68°52''W and the average of clear sky conditions every year is 84% (Grossi Gallegos, H., 2007). Assuming that the levels of exterior illuminance are similar to those registered in Catamarca province, this amount of sunshine could meet between 70% and 95% of the light demand required for the plants to grow through the use of an anidolic system and the room's configuration without attaching any ceiling diffuser.

DISCUSSION

We gathered the data of the levels of horizontal illuminance delivered by an anidolic system at three different heights inside a culture room for the propagation of agamic plants. We took seasonal measurements that comprised a whole year and could observe that the optimal functioning of the collector was reached at the moments close to the solar noon under clear sky conditions and without any added ceiling diffuser, getting average lighting levels of 994lux. On the other hand, in the case of measurements carried out using an alveolar polycarbonate ceiling diffuser, we observed that the income of natural light inside the room decreased to an average of 706lux. This represents a loss of 29% efficiency rates compared to the same situation without the diffuser. Therefore, we can state that the lighting system for the culture room attains an optimal level under direct incident solar light conditions and without diffusion of beams into the room. The results obtained show that the design and installation of natural light passive systems, conceived for being used on plant culture rooms with agamic propagation, can mean an important lighting income that enables us to save the energy that is needed by the artificial lighting systems. However, even though the existing correlation between the data we obtained and the sunshine levels over the culture room location could make up a methodology for the annual prediction of the behavior of the natural light system, it would be desirable to continue studying the efficiency of anidolic systems during longer periods, to try to isolate the lighting income of the system in terms of flux and to carry out in vitro culture experiences under this kind of lighting, analyzing the efficacy of this system by taking into account the growth physiology of vegetable tissues from different species

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