Light & Engineering
Vol. 27, No. 6, pp. 106–111, 2019 *https://doi.org/10.33383/2019-065*

IRRADIATION SYSTEM FOR A CITY FARM AUTOMATED MULTI−LAYER PHYTOINSTALLATION

Vladislav G. Terekhov

IEC BL GROUP, Moscow
E-mail: terekhov@bl-g.ru

ABSTRACT

Contemporary light engineering is ready to make its contribution in the development of new, automated and (in the nearest future) fully computerised production facilities based on application of artificial irradiation for technological purposes.

It is referred to cultivation of plants using the photo-culture technology in multi-layer phytoinstallations with spectral characteristics and level of irradiation taking the species and tasks of cultivation into account. The major type of plants for these installations is lettuce cultures, consumption of which in Russia significantly lags behind the recommended values, especially during winter.

The article reviews major specifications of LED-based irradiation devices and lighting systems based on them, used for cultivation of lettuce in automated multi-layer phytoinstallations in photo-culture environment. An example of such phytonstallations is the automatic research installation developed in S.I. Vavilov VNISI, which has no parallel in Russia.

A principal distinction of the irradiation devices used in this installation is application of multi-component LED compositions based on white and colour elements allowing us to vary spectral characteristics in the PAR region within a wide range. Generally, the installation is notable for contemporary hardware and availability of computer control.

Keywords: multi-layer phytoinstallation, LED-based phytoemitter, irradiating installation, computer control, PAR, photo-culture, lettuce

1. INTRODUCTION

Appearing and dynamic development of LED-based equipment became a basis for creation of brand-new research and production facilities and installations of automated multi-layer plant cultivation which were called *City Farm*. As a matter of fact, this is about a new progressive technology of plant cultivation (mostly lettuce cultures), which solves an important problem of rational utilisation of protected ground areas which are becoming more expensive, provides high level of automation of technological process and reduces the fleet of required machinery and mechanisms as compared to a typical greenhouse technology. Application of multi-layer phytoinstallations (MPI) is possible in urban environment, which reduces transportation expenses. That is why MPIs are rather promising not only for Russian metropolises but also for a large number of small towns and settlements allowing to supply fresh and rich in vitamins vegetables for people, especially in winter[1].

MPIs for cultivation of plants using the photo-culture technology significantly differ from conventional protected ground structures (greenhouses) and deserve special consideration presented below not only for analysis of required light engineering solutions for production type MPIs but also for discussion (with consideration of the first results ob-

[1] It shall be noted that MPI had been under development in Russia in the $1980^S \div 1990^S$ [1] but these works were not completed mostly due to lack of emitters equal to contemporary LED light sources at that moment.

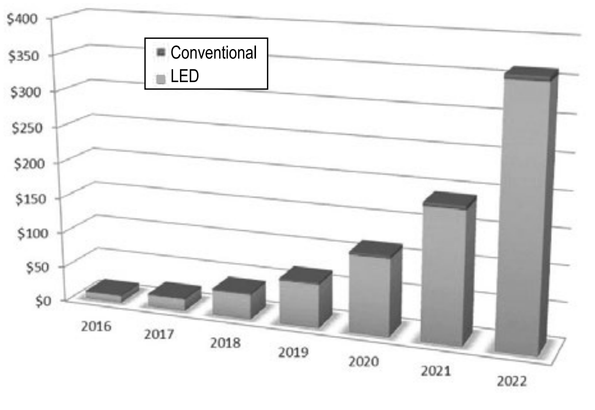


Fig.1. Development of the *City Farm* vertical multi-layer lighting systems with LED and conventional irradiation

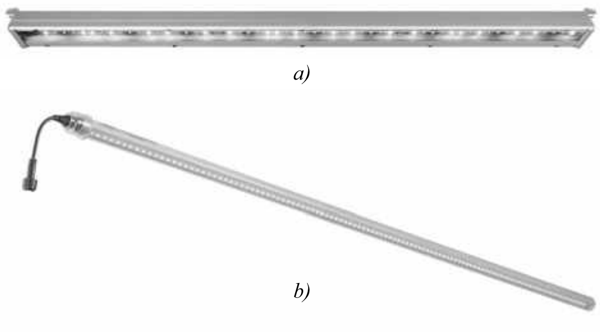


Fig.2. Examples of LED-based phytoemitters: *a*: *WAVE* series (18–105) W, *IGROX*; *b*: *L* series (14–35) W, *Valoya*

Fig. 3. Phytoemitters with GALAD Arcline Phyto LED series LEDs 30 W and 60 W designed for MPI

tained) of an opportunity to implement photobiological research programmes.

2. MULTI–LAYER PHYTOINSTALLATIONS HARDWARE

LED-based phytoemitters (LEDPE) for MPIs consisting of space-saving modules (layers) have no competition. Fluorescent mercury lamps cannot be used in phytoinstallations due to environmental reasons whereas HPSLs are not applicable due to high power concentration and high temperature of a bulb.

Opportunities to create any spectrum in the PAR region (400–700) nm with high level of radiation parameters, rather simple and efficient spectrum and irradiation level adjustment led to dynamic development of the photo-culture direction in research and production programmes of the leading LED manufacturers: *CREE* (USA), *OSRAM Semiconducters* (Germany), *Lumileds* (the Netherlands), etc. as well as light engineering companies, such as *Signify* (the Netherlands), *Valoya* (Finland), MSK BL GROUP (Russia), *Current-GE* (USA), *IGROX* (Italy), etc.

Characteristically that the specialists of *Strategies Unlimited* (USA) presume in their global forecast of development of protected ground LEDPE that the volume of LEDPE irradiation in *City Farm* will increase by about 7 times by 2022 (Fig. 1) [2]. These estimations are also shared in Russia: for instance, the matters of LEDPE irradiation in MPIs were reflected in new regulations in 2017 [3].

The specifications of LEDPE by different manufacturers are rather diverse; this is mainly caused by the fact that requirements to phytoirradiation spectra for specific species of plants are currently being formed; dimensions of MPI modules are also far from unification, and actual data on stability of irradiation characteristics of LEDPE during operation is not clear enough yet.

Nevertheless, the major parameters of LEDPE for MPI may be assumed as follows:

- Electric capacity: (30 ÷ 70) W;
- Radiation spectra: Binary (*RB*: red-blue with different portion of each component) or nearly white with different portions of the green component;
- Photosynthetic photon efficiency (*EPPF*): (2.0 ÷ 2.7) μmol/J (depending on the type of spectrum), maximum value is for the binary (*RB*) type of spectrum;
- Length: ~120cm (this is caused by the most common width of MPI modules);
- Specific electric capacity (per unit of length): (0.25 ÷ 0.75) W/cm (contains indirect information on temperature of a LED crystal and its possible operational life);
- Shell protection class: *IP*54, *IP*66.

There are two designs proposed for MPI LEDPE (Fig. 2):

– In the form of a long narrow emitter with aluminium body, polycarbonate diffuser, and passive cooling;

– In the form of a narrow pipe with the diameter of (26 ÷ 28) mm made of polycarbonate as a lamp for direct replacement (retrofit) of fluorescent lamps (FL).

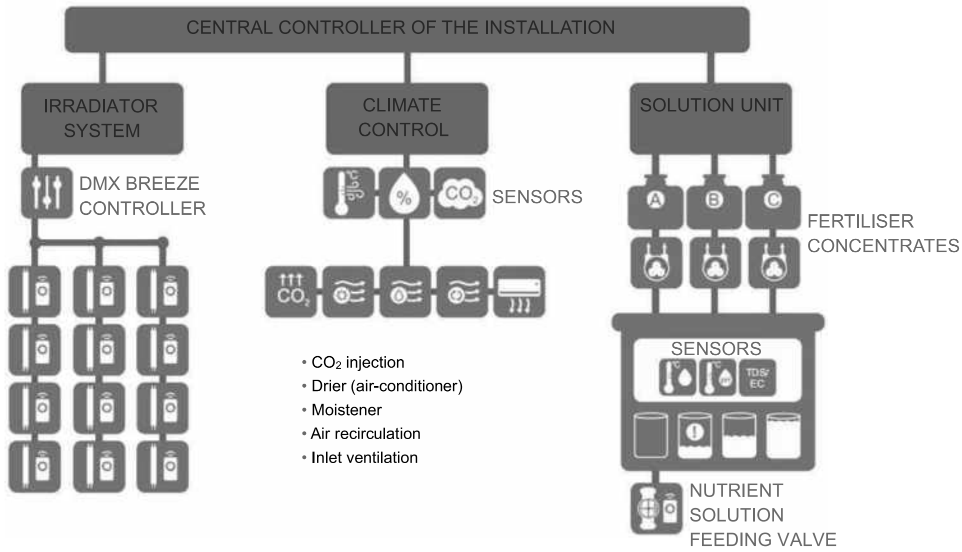


Fig.4. MPI block diagram

Recently, the second variant is getting widespread use.

In 2018, S.I. Vavilov VNISI together with KETZ developed a series of LEDPE GALAD Arcline Phyto LED30 W and 60 W (Fig. 3) with two spectral variants: with *EPPF* of 2.1µmol/J for the white radiation design (T_{cc}= 3700K) and of 2.5µmol/J for the *RB* spectrum design. Dimensions of LEDPE: (1201×115×67) mm, *IP65* class of protection.

It is worth noting that, unlike conventional lighting installations (LI) for greenhouses, LIs for MPI have a number of distinctions which are, in particular, related to the fact that the distance between PE and the planting plane does not exceed 60 cm and the distance between lettuce cultures may be equal to (10–20) cm in the end of the vegetation period. That is why it is very important that the PE surface temperature shall not exceed 80 °C and the heating component of the PE balance shall not cause overheating of the root area of the next (upper) layer of MPI. Light distribution of LEDPE shall provide uniform distribution of irradiance over the technological area.

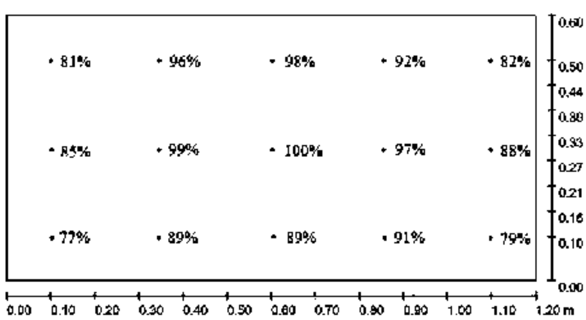


Fig.5. Level of technological area irradiation uniformity

The levels of irradiation and spectral characteristics of MPI are necessary to be selected on the basis of the results of photobiological studies (in our case, on the basis of [4, 5]). Sometimes, if the plants significantly differ from the studied ones, it is necessary to conduct additional experiments for elaboration of a "light engineering recipe" of efficient cultivation of specific plants[2].

Like in the case of greenhouses with a photoculture, the share of technological irradiation in the general energy consumption of MPI exceeds 90 %, therefore, the energy-saving factor of irradiation may be considered one of the most important ones.

Designing of a LEDPE starts with correct selection of parameters of the applied LEDs. In particular, this relates to the maximum possible luminous efficacy (lm/W) for quasi-monochromatic LEDs determining the level of *EPPFD* of LED.

As a universal indicator of energy efficiency of a LI for PI (including MPI), the ratio $EPPFD_{LI} = PPFD_{av} / P_1$ [µmol/J], where $PPFD_{av}$ is average *PPFD* on the studied surface, [µmol / (s·m^2)], P_1 is specific installed electric capacity of LI [W/m^2], may be assumed [6].

The matter of availability of the far-red (700–780) nm range in the PE spectrum, i.e. beyond the PAR region, is worth considering particularly. This radiation is not used for photosynthe-

[2] Wherein, the light engineering parameters of PE and LI shall be specified in photosynthetic photon units in accordance with GOST R57671–2017 "LED irradiators for greenhouses: General specifications".

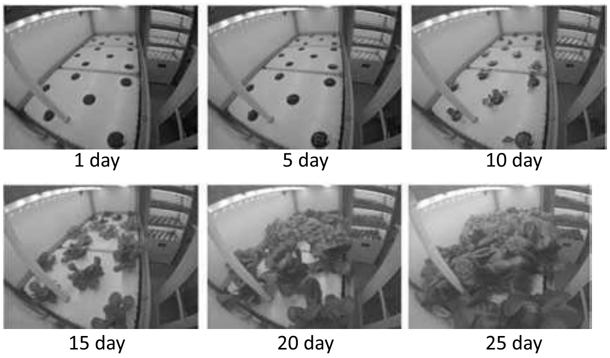


Fig.6. Vegetation stages of lettuce plants

sis and does not cause energy impact on a plant; however, by actuating the active form of the phytochrome F_{730} plant pigment, it adjusts photo morphogenesis of a plant. The impact of this spectral rangeтon growth and development of plants is currently being studied, which makes it desirable that it would be available in the radiation spectrum of PEs for research programmes.

3. LI FOR A VERTICAL MPI IN VNISI

In S.A. Vavilov VNISI, the automated vertical MPI was designed, manufactured, and commissioned for conducting of photobiological studies with application of state-of-the-art LED emitters and methods of adjustment of plant irradiation modes. The research MPI is also designed for assistance in development of requirements to major light engineering parameters of PE and LI with a plant photo-culture.

Fig. 4 shows that the MPI contains three light-isolated units (modules) with four sections with area of 0.72 m^2 ((1.2·0.6) m) each[3] located above each other allowing us to cultivate up to 264 plants simultaneously. Two six-channel controlled PEs based on GALAD Arcline Phyto-72 which allow creating almost unlimited number of combinations of radiation spectra are installed in each section. The specifications of LED of each channel are presented in Table. Capacity of each PE may vary between 12.5 and 50.0 W. Maximum power of the whole LI is 1200 W and corresponding specific electric power of LI is 140 W/m^2. Maximum *PPFD* over the technological area of LI is up to 320 µmol/(s·m^2). High uniformity of irradiation was reached (Fig. 5).

[3] The total technological area of the MPI is 8.64 m^2.

Fig.7. Lettuce cultivation in the MPI in S.A. Vavilov VNISI

Spectral characteristics of LI and irradiation level were measured using the devices by *Li-COR* (USA) and *UPRtek* (Taiwan).

Before each vegetation LI is adjusted by regulating spectral and irradiating characteristics of PE via *DMX512* protocol using a special control scheme consisting of a personal computer with a *USB – DMX 512 RDM* adapter and *RDM Controller 2.0* software. Based on the results of the spectrum selection procedure, the table of channel level values is input in the BRIZ-*DMX* controller operating in conjunction with the real-time timer BRIZ-RV.

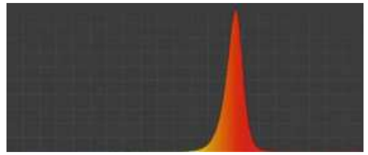
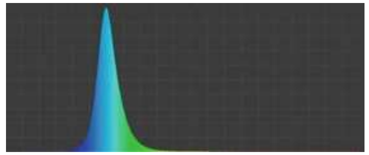
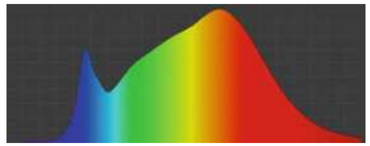
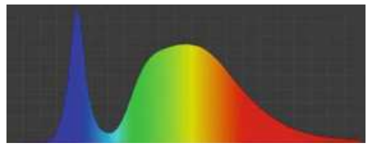
Opportunities to set different spectral combinations are practically not limited in the MPI. The methodology and procedure of their selection were evaluated by us during studies of different PAR ranges on different installations in a phytotron [5].

MPI is fully automated with permanent control of parameters of the key cultivation systems: climatic installation, solution unit and LI. The remote monitoring and control system allow us to monitor the process of vegetation and to adjust parameters and cultivation modes, if necessary, using any device (PC, smart-phone or tablet) via a *web* interface in real time.

By means of special compact video cameras *HIKVISION DS-2CD1031* and *GoPro Session5* installed in the modules, the state and development of the plants were constantly remotely monitored. It is possible to conduct phenological monitoring of plants at different stages of vegetation (Fig. 6); their results may be further taken into account for adjustment of the LI radiation spectrum in the course of ontogenesis.

Table

Nominal Parameters of LEDs Used in the MPI in S.I. Vavilov VNISI*

Channel number	LED type (manufactured by *CREE*)	Dominant wavelength, nm	Current, mA	Voltage, V	Radiation parameters		Spectrum
1	XPE BGR-L1-0000-00F01	620–630	350	2.2	*PPF*, µmol/s	1.1	
2	XPE BRD-L1-0000-00801	650–670	350	2.2		1.92	
3	XPEEPR-L1-0000-00C01	720–740	350	2.2		2.34	
4	XPEBBL-L1-0000-00Z01	465–485	350	3.2	Φ_v, lm	35.2	
5	XPG DWT-U1-0000-00FE5	400–700 (4,000K)	350	3.2		120	
6	XPGDWT-B1-0000-00LE3	400–700 (5,000K)	350	3.2		150	

*According to the manufacturer's data presented on www.cree.com.

To sum up, we would like to note that the created automated installation for cultivation of plants in controlled environment provides brand new opportunities for conducting of photobiological studies: it reduces the experiment periods, expenditures for their conducting and minimises the routine maintenance part directly involving people.

CONCLUSION

Since April, 2019, the MPI in the S.I. Vavilov VNISI has been operating in the testing mode with variation of spectral characteristics and irradiation level. Currently, several vegetations of different varieties of lettuce and greengrocers have passed. The obtained crop capacity results are (30–40)% higher than those in lettuce lines of industrial greenhouses with the photo-culture technology, which directly confirms high efficiency of the light engineering decisions and other microclimate parameters taken in the MPI (Fig. 7).

ACKNOWLEDGMENT

Research was funded by the Ministry of Science and Higher Education of the Russian Federation (project “Comprehensive studies in the plant photo-culture and creation of high-effective LED phytoirradiators for increase of energy efficiency of industrial greenhouses”). Contract on granting subsidy #14.576.21.0099 dated 9/26/2017. Contract ID0000000007417PD20002. Project ID RFMEFI57617X0099.

REFERENCES

1. Tikhomirov A.A., Sharupich V.P., Lisovsky G.M. Plant Photoculture: Biophysical and Biotechnological Basics [Svetokultura rasteniy: biofizicheskiye i biotekhnologicheskiye osnovy], Novosibirsk: Siberian department of RAS, 2000, 213 p.

2. Philip Smallwood. Tracking the Horticultural SSL Market and Technology // Horticultural Lighting Conference, USA, 2017, Denver, Colorado.

3. Boos G.V., Prikupets L.B., Rozovsky E.I., Stolyarevskaya R.I. Standardisation of Light Engineering Devices and Installations for Greenhouses [Standartizatsyya svetotekhnicheskikh priborov i ustanovok dlya teplits] // Svetotekhnika, 2017, # 6, pp. 69–74. // Light & Engineering Journal, 2018, Vol. 26. #1, pp.18–24.

4. Prikupets L.B., Boos G.V., Terekhov V.G., Tarakanov I.G. Studying of the Affects of Radiation in Different Ranges of PAR Region on Capacity and Biochemical Composition of Biomass of Lettuce and Leaf Vegetables [Issledovaniye vliyaniya izlucheniya v razlichnykh diapazonah oblasti FAR na produktivnost i biokhimicheskiy sostav salatno-zelennykh kultur] // Svetotekhnika, 2018, № . 5, pp. 6–12 // Light & Engineering, 2018, Vol. 26, # 4, pp.38–47.

5. Prikupets L.B., Boos G.V., Terekhov V.G., Tarakanov I.G. Optimisation of Light Engineering Parameters of Lettuce and Leaf Vegetables Photo-culture Using LED Emitters [Optimizatsiya svetotekhnicheskikh parametrov pri svetokulture salatno-zelennykh rasteniy s ispolzovaniyem svetodiodnykh izluchateley] // Svetotekhnika, 2019, № . 4, pp. 6–13//Light & Engineering, 2019, Vol. 27, #5, pp.43–54.

6. Prikupets L.B. Process Illumination in the Russian Agriculture [Tekhnologicheskoye Osveshcheniye v agropromyshlennom komplekse Rossii] // Svetotekhnika, 2017, # 6, pp. 6–14. Prikupets L.B. Technological Lighting for Agro-Industrial Installation in Russia // Light & Engineering, 2018, Vol. 26, No. 4, pp. 7–17.

Vladislav G. Terekhov,
engineer. He graduated with honors from Moscow State University of Economics, Statistics and Informatics with a degree in Applied Informatics in Economics, and at present, he is a Head of the Department for the Promotion of LLC International Lighting Corporation BL GROUP and researcher in VNISI of S.I. Vavilov.
He is a member of the Organizing Committee of the All-Russian Conference “Gallium, Indium and Aluminum Nitrides. Structures and devices” and an expert on energysaving technologies in the lighting of the Russian Union of Builders

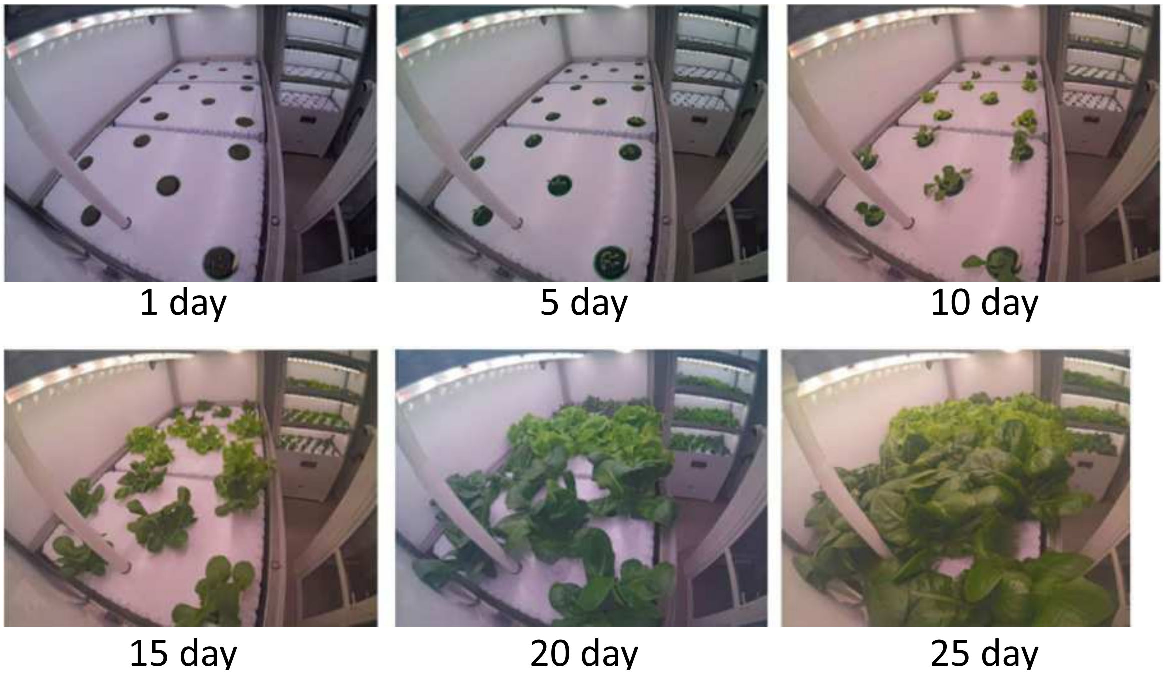


Fig.6. Vegetation stages of lettuce plants

Fig.7. Lettuce cultivation in the MPI in S.A. Vavilov VNISI