International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 05 | May 2022 www.irjet.net p-ISSN: 2395-0072

Determining Artificial Light Requirement for Growing Plants

Abhishek Thamake[1], Akshay Ghule[2], Mayur Kate[3], Prajwal Joshi[4]

[1234]Students, Dept. of Mechanical Engineering, JSPMs Rajarshi Shahu College of Engineering, Pune, Maharashtra, India

---***---

Abstract - *Presently there is a huge impact on traditional agriculture due to climate change. Controlled growing system using artificial lighting can be used to increase the rate of production and capacity of yields. Recent development of light emitting diode (LED) technologies presents an enormous potential for improving plant growth. Photosynthetic organisms use natural light for photosynthesis, artificial light like LED can also serve this purpose. Electrical Load Estimation is critical in preliminary design level prior to any design. A reliable estimate is important to avoid any guess work. The work assesses lighting load estimation done by a scientific approach. The focus of the research paper is to solve the problems of engineers and farmers in estimating electrical lighting load requirement of a project especially a closed room or closed container.*

***Key Words*: Hydroponics, Dutch Bucket, LED, Photosynthetically Active Radiation, Photosynthetic Photon Flux, Lighting Load, High Intensity Discharge (HID) lamp.**

1. INTRODUCTION

Hydroponics is a soilless technique to grow the crops. It uses water mixed with nutrient solution which is allowed to circulate throughout the system. There are various types of hydroponics technique like Nutrient Film Technique (NFT), Media Bed, Dutch Bucket, Vertical Tower, Ebb and Flow, etc. Each technique has its own uniqueness, advantages and disadvantages and according to the type of crop, a suitable system is selected. For example, tomato plant can be grown using Dutch Bucket system.

In Dutch Bucket system, several buckets are placed on the bench and each bucket contains individual plant. A reservoir is used which holds the nutrient solution. This solution is pumped using a pump through the irrigation lines and then dropped onto the plants using the emitters. Excess of solution is returned to the reservoir using return lines. A growth medium is used to support the plant. Generally, growth medium like perlite, vermiculite, coconut is used. Plants like cucumbers, peppers, potatoes, squash and tomatoes can be grown by this system.

Figure 1: Dutch Bucket System

Crops can be grown using artificial light sources such as Light Emitting Diode (LED), High Intensity Discharge (HID) lamps. Plants perceive light in a different way than humans. For humans lumens (denoted by lm) is a measurement of total amount of light (which is visible to human eye) from lamp source. The lumen rating is directly proportional to the brightness of the lamp. The reason why lumens is not a good indicator for determining light requirements of plants, is that the light plants need most is almost out of the visible spectrum for humans.

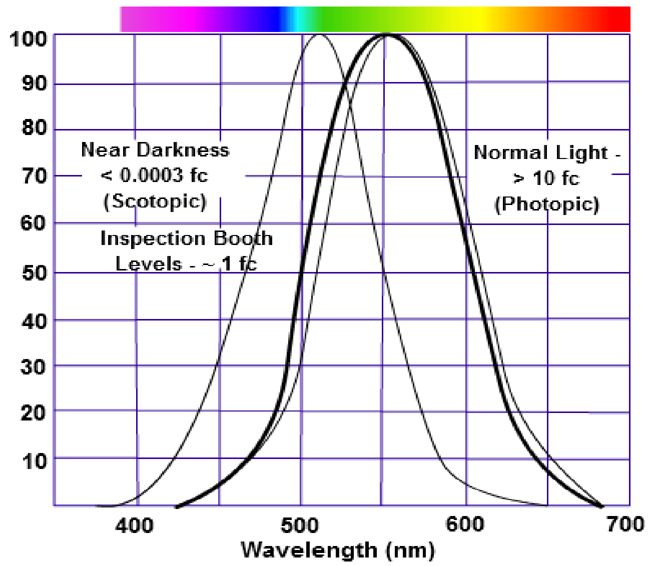

Figure 2: Response of human eye to different amounts of ambient light

The three curves in the figure 2 shows how human eye responds to different amounts of ambient light. The shift in sensitivity exists because of two types of photoreceptors, one is known as cones and the other is rods. The eye's response towards the light depends on these photoreceptors. The response of human eye under normal lighting conditions is shown by the curve on right, it is called photonic response. The cones in the human eye respond to light under these conditions. The curve peaks at 550 nm, this shows that human eye is most sensitive to yellowish-green color under normal lighting conditions.

Blue range (425–450 nm) and red range (600–700 nm) are best wavelengths of visible light for photosynthesis. plants which receive a good amount of blue light will have healthy as well as strong stems and leaves. Red light is responsible for making plants flower and produce fruit. The combination of blue and red light allows a higher photosynthetic activity than that under either monochromatic light. Therefore, the light sources which are used for photosynthesis should mostly emit light in the blue and red ranges.

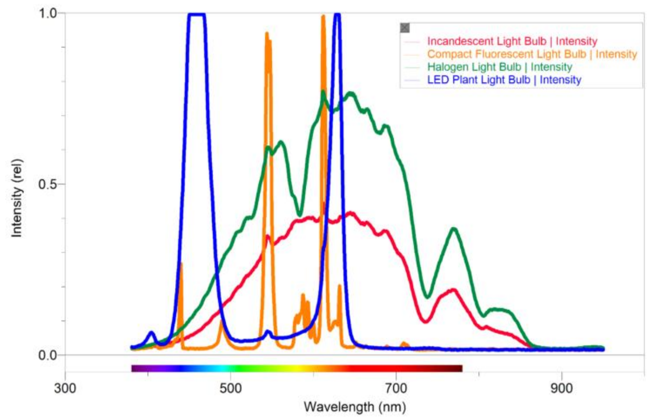

Figure 3: Relative light intensity of four light bulbs across the visible spectrum

High intensity discharge (HID) lamps, such as metal halide and high-pressure sodium lamps, have photosynthetically active radiation efficiency upto 40% and have high fluence. They are typically used in greenhouses and plant with growth rooms. Due to high operational temperatures, they cannot be placed close to canopy, their spectral distribution may vary according to input power i.e., high proportion of green–yellow region, significant ultraviolet radiation and altered red: far red ratio. LEDs have high photosynthetically active radiation efficiency (80%-100%). LEDs have high efficiency, low operating temperature and small size because of which they can be placed close to canopy. LEDs have long life expectancy, and they are easy to control. LEDs emitting blue, green, yellow, orange, red and far red are easily available in market and these can be combined to provide high fluence or special light wavelength characteristics because of their narrow-band-width light spectrum. Figure 3 shows relative light intensity of four light bulbs (Incandescent Light Bulb, Compact Fluorescent Light Bulb, Halogen Light Bulb, LED Plant Light Bulb) across visible spectrum, it is seen that LEDs have high intensity in wavelength range of 425-475 nm and 625-675 nm which is good for photosynthesis. Because of these reasons LEDs make a good choice for use in greenhouse and growth chambers all year round.

There are different terms which are related to lighting in terms for plants. These are the terms manufacturers often use for horticulture lighting. The purpose of introducing these terms is to define relation between these terms and clear some common misunderstanding. As intensity of light plays important role in lighting for farming in enclosed space, we must understand the importance and meaning of all this terms.

- **PAR:** The radiation which is available for photosynthesis is known as PAR (Photosynthetically Active Radiation). The light of wavelengths 400-700 nm and is portion of light spectrum utilized by plants for photosynthesis is photosynthesis active radiation. Human perception of brightness is green biased and measure of metrics such as luminous flux, illuminance is based on this perception. Hence these metrics do not describe the quantity of light usable for photosynthesis. Because of this reason PAR is preferred metric. PAR is not metric unit like Kg, Km, m but PAR is types of lights needed for plant growth. To measure the light intensity Quantum sensor is used.

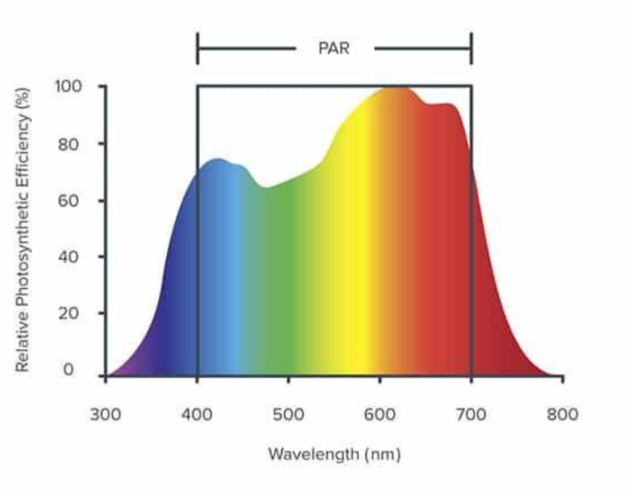

Figure 4: Photosynthetically Active Radiation (PAR)

- **PPF:** PPF stands for photosynthetic photon flux. PPF is the measurement of the total amount of PAR produced by the lighting system each second (μmol/s). PPF shows how efficient a lighting system is to produce PAR.

- **PPFD:** Photosynthetic photon flux density measures how much light is actually received by the plants or "the number of photosynthetically active photons which fall on a surface each second". The measurement is expressed as µmol/m²/s. Since the lights are brightest at the center and decreases at the edges of the leaves, to calculate he actual PPFD the manufacturer should mention: measurement distance from light source (vertical and horizontal).

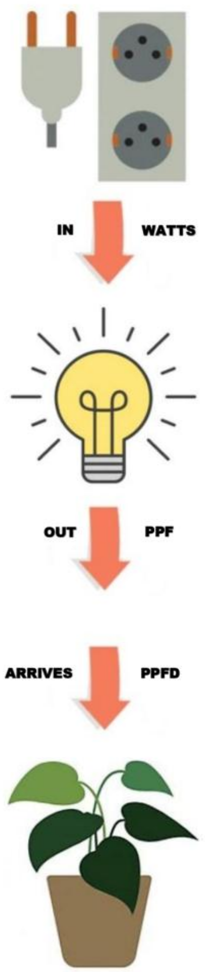

Figure 5: Flow of Energy

- **DLI:** The measurement of amount of Photosynthetically Active Radiation (PAR) which is delivered over a 24 - hours period is called as Daily Light Integral (DLI). It is also an important factor which influences the growth of plant over a period of time. It is expressed as mol/m²/day. A lighting system with higher PPF at less photoperiod will deliver same amount of DLI as compared to system with lower PPF and longer photoperiod. By knowing DLI of plants the preferred lighting system can be installed.

- **Watt (Wattage):** It is the unit of power. The amount of energy consumed by lighting fixture depends its efficiency. Higher the efficiency means more PPFD.

- **Coefficient of Utilization (CU):** It tells the amount of light falling on the growth area from the light source. Alternatively, it is the quantity of Photosynthetic Photon Flux (PPF) that the light has produced is making its way towards the plant. CU can be found as:

$$CU = \frac{Actual\ angle\ utilized}{Total\ angle}$$

For example, if actual angle utilized is 90° from total angle of 360°, then CU will be 0.25.

- **PPF/Watt:** This term depends on the type of artificial light and also on the manufacturer. Generally, for LED it is between 2 to 2.5 PPF/W. More the value of PPF/W more is the efficient light source for growing the plant.

Placement of light source: If the growth area is 4 m2, then the light is placed at 2 m from the surface of growth area. This is because light intensity degrades as we move away from the light. And if we move towards the plant its growth area reduces. Here, Inverse Square Law rule becomes applicable. It explains that if we double the distance the intensity is reduced to 1/4th of total intensity.

For example, if the value of PPFD (intensity) is 1000 µmol/m²/s at the distance of 1 m then intensity at 2 m will be 250 µmol/m²/s.

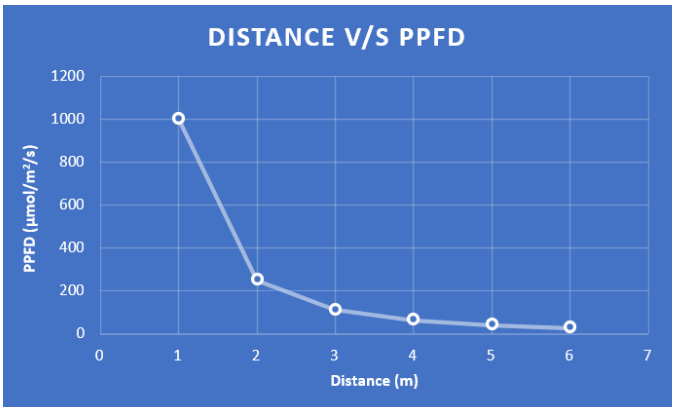

Figure 6: Distance v/s PPFD

2. ESTIMATES OF CALCULATIONS

To grow plants hydroponically by providing required lighting system we have performed the calculation based on plant requirements. We have chosen a tomato plant which is grown hydroponically through Dutch Bucket system which has a growth area of 0.743 m^2. Plants are grown in Dutch Bucket system which is placed in enclosed space. We have used the light emitting diode (LED) for the lighting system as LEDs have advantages like little heat production and low power consumption.

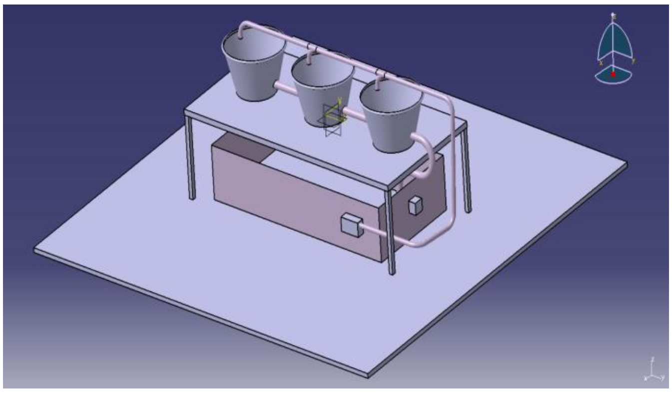

Figure 7: CAD of Dutch Bucket System

3. CALCULATONS

Here, we are calculating lighting load for growing tomato plant.

We have,

- Daily Light Integral (DLI)=15 $mol/m^2/day$.
- Duration (t) = 50400 sec (14 hours).
- Growth Area (A) = 0.743 m^2 (from CAD).
- Coefficient of Utilization (CU) = $\frac{180}{360}$ = 0.5
- PPF/Watt = 2.1 μmol/J.

1. Calculating required Photosynthetic Photon Flux Density (PPFD):

$$PPFD = \frac{DLI}{Duration}$$

$$= \frac{15}{50400}$$

PPFD = 297.619 $\mu mol/m^2/s$.

2. Calculating Photosynthetic Photon Flux (PPF):

$$PPF = PPFD \times Area$$

$$= 297.619 \times 0.743$$

PPF = 221.13 μmol/s

3. Calculating Power:

$$Power = \frac{PPF}{CU \times \frac{PPF}{Watt}}$$

$$= \frac{221.13}{0.5 \times 2.1}$$

Power = 210.6 W

∴ For 0.743 m^2 area 210.6 W is required.

The average time for which lights are kept ON is 14 hours each day.

∴ Throughout year the time will be,
Total Duration = 14 × 365= 5110 hours.

∴ Units consumed throughout the year is

= Power × Total Duration

=210.6 × 5110

=1076166 Wh.

∴ Total Units consumed are 1,076.166 kWh annually.

Parameters	Unit	Value
Daily Light Integral (DLI	mol/m^2 /day	15
Duration	sec	50400
Growth Area	m^2	0.743
Coefficient of Utilization (CU)	multiple (0 to 1)	0.5
PF/Watt	μmol/J	2.1
PPFD	$\mu mol/m^2$ /s	297.619
PPF	μmol/s	221.13
Power	W	210.6
Units	kWh	1076.166

Table 1: Summary

4. CONCLUSION

For estimation of calculation of the lighting load we have considered tomato plant (Solanum lycopersicum) and amongst various hydroponic systems we have used Dutch Bucket system as it is suitable for tomato plant to grow. LEDs consume around 60% less energy than a conventional lighting system to deliver the same light and they have been popular as a new artificial lighting source for photosynthesis and to regulate photomorphogenesis and also to enhance nutritional quality of crops. Hence, due to its several advantages we have considered LEDs as our primary lighting source. The purpose of this calculation is to get an idea of how the lighting system must be provided to grow a plant in its required environment. The various parameters that we found through these calculations are PPFD = 297.619 $\mu mol/m^2/s$, PPF = 221.13 μmol/s, Total Units consumed are 1,076.166 kWh annually for area 0.743 m^2. Through above calculated results we can conclude that the parameters found in this are sufficient to design a lighting system.

REFERENCES

[1] Nisha Sharma, Somen Acharya, Kaushal Kumar, Narendra Singh and O.P. Chaurasia (2018). Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation 17(4): 364-371. DOI: 10.5958/2455-7145.2018.00056.5

[2] Guilherme Lages Barbosa, Francisca Daiane Almeida Gadelha, Natalya Kublik, Alan Proctor, Lucas Reichelm, Emily Weissinger, Gregory M. Wohlleb and Rolf U. Halden (2015). Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods. Int. J. Environ. Res. Public Health, 12(6), 6879-6891. DOI:10.3390/ijerph120606879

[3] Robinson, S. J. and Schmidt, J. T. (1984). Fluorescent Penetrant Sensitivity and Removability – What the Eye Can See, a Fluorometer Can Measure, Materials Evaluation, Vol. 42, No. 8, pp. 1029-1034

[4] Eva Darko, Parisa Heydarizadeh, Benoıˆt Schoefs and Mohammad R. Sabzalian (2014). Photosynthesis under artificial light: the shift in primary and secondary metabolism. Phil. Trans. R. Soc. B 369: 20130243. Available online: http://dx.doi.org/10.1098/rstb.2013.0243

[5] Yeh N, Chung JP (2009). High-brightness LEDs: energy efficient lighting sources and their potential in indoor plant cultivation. Renew. Sustain. Energy Rev. 13, 2175–2180. Available online: https://doi.org/10.1016/j.rser.2009.01.027

[6] Muzammal Rehman, Sana Ullah, Yaning Bao, Bo Wang, Dingxiang Peng Lijun Liu (2017). Light-emitting diodes: whether an efficient source of light for indoor plants? Environ Sci Pollut Res (2017) 24:24743–24752. DOI: 10.1007/s11356-017-0333-3

[7] S. Dutta Gupta and A. Agarwal (2017). Artificial Lighting System for Plant Growth and Development: Chronological Advancement, Working Principles, and Comparative Assessment. Springer, Singapore. Available online: https://doi.org/10.1007/978-981-10-5807-3_1

[8] Luechai Promratrak (2017). The effect of using LED lighting in the growth of crops hydroponics. International Journal of Smart Grid and Clean Energy, vol. 6, no. 2.

[9] Jacob A. Nelson, Bruce Bugbee (2014). Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures. PLOS ONE, Volume 9, Issue 6, e99010.

[10] Flávio Barcellos Cardoso, Herminia Emilia Prieto Martinez, Derly José Henriques da Silva, Carla do Carmo Milagres, José Geraldo Barbosa (2018). Yield and quality of tomato grown in a hydroponic system, with different planting densities and number of bunches per plant. Pesquisa Agropecuária Tropical [Agricultural Research in the Tropics], Goiânia, v. 48, n. 4, p. 340–349.

[11] Dietmar Schwarz, Andrew J. Thompson and Hans-Peter Kläring (2014). Guidelines to use tomato in experiments with a controlled environment. Frontiers in Plant Science Crop Science and Horticulture, Volume 5, Article 625. DOI: 10.3389/fpls.2014.00625

[12] Dr. Martine Dorais (2003). The use of supplemental lighting for vegetable crop production: Light intensity, crop response, nutrition, crop management, cultural practices. Canadian greenhouse conference.

[13] Onofrio Davide Palmitessa , Marco Antonio Pantaleo and Pietro Santamaria (2021). Applications and Development of LEDs as Supplementary Lighting for Tomato at Different Latitudes. Agronomy. Available online: https://doi.org/10.3390/agronomy11050835

[14] Gioia D. Massa, Hyeon-Hye Kim, Raymond M. Wheeler, Cary A. Mitchell (2008). Plant Productivity in Response to LED Lighting. HORTSCIENCE VOL. 43(7).