

# Revolutionizing Agriculture: Enhancing Indoor Vertical Farming Through Smart Lighting

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Vertical farming (VF) is a groundbreaking cultivation method that utilizes vertical space for growing crops. It employs advanced techniques like soilless cultivation, hydroponics, aeroponics, and aquaponics within controlled structures. VF stands out for its resource efficiency, recycling water and nutrients to minimize waste and lower its carbon footprint. This environmentally conscious approach positively impacts sustainability by conserving natural resources, reducing pollution, and lessening waste generation. VF also brings economic benefits by cutting transportation costs and CO<sub>2</sub> emissions in the food supply chain. While not a complete replacement for traditional farming, VF complements existing methods, offering an innovative solution, particularly in urban or limited arable land settings. Integrating VF into agriculture creates a more diverse and resilient food production system, addressing 21<sup>st</sup> century challenges while respecting established practices.

## Plant eco-system

Within the plant Eco-system, Nutrients such as nitrogen, phosphorus, and potassium are needed for plant growth, acting as building blocks for critical chemicals and structures. CO<sub>2</sub> is essential to photosynthesis, the process by which plants convert light energy into chemical energy for development. Adequate CO<sub>2</sub> levels are required for efficient photosynthesis. Light, on the other hand, emerges as the most important component in plant growth, driving photosynthesis and controlling physiological processes such as photomorphogenesis. While study on light has been restricted in comparison to other growth elements, its significance is growing. Understanding the impact of light on agriculture can improve practises, particularly in controlled conditions such as vertical farming. Plants photosynthesise using the visible light spectrum (400-700 nm), which is usually supplied by artificial grow lights. LEDs have grown in popularity due to their low cost, small form, and wide range of wavelengths. Light

intensity, quality, and duration (photoperiod) are key dimensions influencing plant growth.

## Significance of Light and Spectrum

The appropriate light intensity and spectrum are critical for a good harvest since they have a direct impact on plant growth, development, and output. Plants absorb light mostly in the blue and red spectrums, which is necessary for photosynthesis. Photosynthesis is hampered if the light lacks these efficient wavelengths, leading in lower growth and production. The optimal light intensity, as measured by Photosynthetically active radiation (PAR), is crucial for a variety of outcomes:

**Low Light Intensity:** Insufficient energy for photosynthesis leads to leggy growth, small leaves, and slow development, impacting flowering and fruiting.

**Optimal Light Intensity:** Providing the right PAR range ensures maximum photosynthetic capacity, fostering vigorous growth, healthy foliage and higher yields for fruiting plants.

**Excessive Light Intensity:** Too much light can stress plants, causing photoinhibition and damage to photosynthetic machinery.

Striking a balance between spectrum and intensity is vital across various farming methods, from traditional outdoor farming to advanced systems like vertical farming, to tailor lighting conditions to crop needs, resulting in healthier, more productive plants and superior harvests.

## Optimizing Blue and Red Light in Horticulture

Only 2% of greenhouse lighting in the United States employed energy-saving LED systems in 2017, with the majority relying on less efficient high-pressure sodium (HPS) and metal halide (MH) lamps. Annual energy use for supplemental lighting in greenhouses in the United States was 588 gigatonne-hours (GWh), or 6.1 trillion British thermal units (tBtu). If the remaining 98% switched to LEDs overnight, annual consumption would fall to 416

GWh, or 4.3 tBtu of energy—an impressive 29% reduction in energy usage. This transition not only highlights the huge energy savings potential of LED lighting in horticulture, but it also results in significant cost savings of roughly \$18 million, making it both environmentally and economically beneficial for the greenhouse industry.

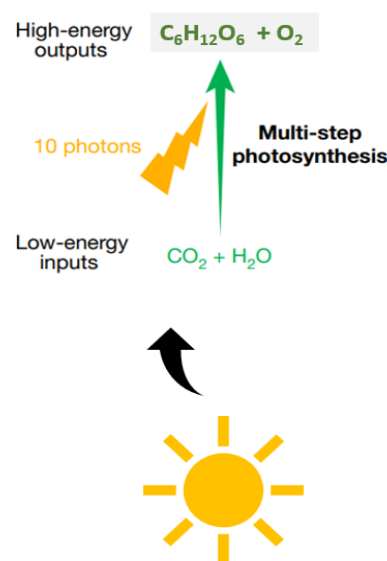
Blue light (400-500 nm) is essential in horticulture because it shortens internode length, resulting in a bushier and more compact plant structure. This promotes robust and space-efficient growth while also increasing carbon dioxide intake via leaf stomatal apparatus opening. Blue light aligns with the absorption range of chlorophyll, optimising energy production during photosynthesis. Aside from physiological benefits, blue light influences a plant's circadian rhythm, which contributes to overall health and nutrient richness.

Red light (630-660 nm) is essential for stem growth, leaf expansion, and the regulation of key plant processes such as flowering and dormancy. It is well-known for promoting rapid growth, allowing for tall and vigorous plant development in a short period of time. Growers can manipulate flowering timing, manage dormancy, and stimulate seed germination by using red light to control growth stages. Red light is a valuable resource for achieving specific cultivation goals and schedules, making it an important component of horticultural lighting strategies for desired plant characteristics and yields.

### Plant Energy Conversion Mechanism

Photosynthesis, which is essential for plant growth, consists of approximately 23 intricate steps that convert low-energy inputs into high-energy carbohydrates. In the visible light spectrum, the efficiency metric, which measures the number of photons required to fix one CO<sub>2</sub> molecule, is around ten. Individual steps operate at approximately 95% efficiency, with a theoretical maximum efficiency of 30%. Overall efficiency is limited to 30% due to cumulative effects and limiting factors such as environmental conditions. Photosynthesis converts a fraction of the incoming light energy into essential carbohydrates, despite its intricate efficiency at each step. Understanding these complexities is essential for

improving plant productivity as well as addressing global food and energy challenges.



### Photo Morphology: Light's Influence on Plant Shape and Colour

Light has both direct and indirect effects on plants, according to a 2018 study by Pattison and colleagues using the Red Salad Bowl lettuce cultivar. Their findings revealed that light intensity has a significant impact on plant responses, particularly the synthesis of anthocyanin pigments, which provide a protective red colour to the leaves. Insufficient light triggered anthocyanin synthesis when the photosynthetic photon flux density (PPFD) was low (equivalent to 10% of full sunlight). Increasing the PPFD to 25% resulted in anthocyanin synthesis, demonstrating the plant's response to changing light intensity under potentially stressful conditions.

Leaf expansion is influenced by the wavelength or colour of light. Leaf expansion decreases as the proportion of blue light increases, as seen in transitions from warm to neutral to cool white light. This suggests that different light wavelengths have an effect on plant growth and morphology. The intensity and wavelength of light have an impact on plant responses and growth patterns.

### IoT-Enabled Smart Lighting Control Strategy

The integration of Internet of Things (IoT) technology in greenhouse or indoor farming settings to optimise and control the use of artificial lighting is referred to as an IoT-Enabled Smart Lighting Control Strategy. This novel approach makes use of real-time

data, predictive models, and intelligent algorithms to manage the supplemental lighting provided to plants.

The following are possible key components of IoT-enabled smart lighting control strategies:

**1. Probabilistic Models:** Using advanced models to forecast natural sunlight availability, such as Markov-based sunlight prediction models. These models aid in anticipating periods of low natural light, allowing for intelligent supplemental lighting adjustment.

**2. Plant-Specific Requirements:** Consider the specific light requirements of the plants being grown. Light intensity, duration, and spectrum requirements vary by crop. IoT technology enables customization based on these specific needs, optimising plant growth and energy consumption.

**3. Variable Electricity Pricing Profiles:** Considering fluctuating electricity pricing profiles. The strategy aims to reduce overall energy costs by aligning lighting schedules with times of lower electricity costs.

**4. Real-Time Monitoring:** Continuously monitoring environmental conditions within the greenhouse using sensors and IoT devices. This includes things like lighting, temperature, and humidity. Real-time data allows for dynamic lighting strategy adjustments based on current conditions.

**5. Energy Efficiency:** Improving energy efficiency is the primary goal of an IoT-enabled smart lighting control strategy. It reduces overall energy consumption and associated costs by intelligently coordinating artificial lighting with natural sunlight conditions and adapting to the specific needs of the plants.

**6. Experimental Studies:** To validate the effectiveness of these strategies in real-world conditions,

researchers frequently conduct experimental studies. In these studies, IoT-enabled lighting controls are implemented in controlled environments and the impact on plant growth, energy consumption, and cost savings is measured.

Overall, IoT-enabled smart lighting control strategies represent a forward-thinking approach to environmentally friendly and financially viable greenhouse operations. Growers can improve energy efficiency, lower operational costs, and contribute to more environmentally conscious and productive agricultural practises by leveraging the power of IoT technology.

### Conclusion

Vertical farming (VF) uses hydroponics, aeroponics, and aquaponics to revolutionise crop cultivation in three dimensions. VF conserves resources, promotes sustainability, and supplements traditional farming methods. It excels at lighting control, which is essential for photosynthesis, flowering, and fruiting. With LEDs, lighting technology advanced from chemical-fuel to efficient electric discharge lamps. LEDs, which are small and energy-efficient, have tripled their efficacy in the last decade, making indoor farming more sustainable. Blue light promotes growth and nutrient uptake, whereas red light controls flowering and dormancy. The amount of light, as measured by PPFD, influences pigment synthesis and leaf expansion. Greenhouse lighting is optimised using advanced technologies and IoT sensors, saving energy. In the face of evolving challenges, smart lighting in VF promises a sustainable agriculture future by conserving energy and ensuring productivity.

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