

AN ILLUMINATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This patent application claims priority to Singapore patent application 10202108148X, filed 26 July 2021 with the Intellectual Property Office of Singapore, the contents of it being hereby incorporated by reference in its entirety for all purposes.

TECHNICAL FIELD

[0002] The present disclosure relates to an illumination device. The present disclosure further relates to a system for illuminating a horticulture bed, and a method of manufacturing the illumination device.

BACKGROUND

[0003] The following discussion of the background is intended to facilitate an understanding of the present disclosure only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or is part of the common general knowledge of the person skilled in the art in any jurisdiction as of the priority date of the disclosure.

[0004] Indoor farms often grow their produce, e.g. plants, in vertical multi-tiered systems using artificial lighting and recirculating hydroponics systems. Light emitting diodes (LEDs) are promising artificial light sources for indoor farms, due to their high lighting efficiency as compared to other light sources such as fluorescent lamps or high-pressure sodium lamps.

[0005] Currently, LED panels which are formed by a combination of LED sources (such as individual LED lamps, LED tubes, or LEDs on one piece or several pieces of PCBs in different shapes), are available as artificial light sources for indoor farming. Due to space limitations, it is desired that a distance between the LED panel and an illumination target, e.g. plants, be as small as possible. However, it is difficult to achieve uniform light distribution using conventional LED panels at a short distance, e.g. less than 40cm. To achieve at least, some uniformity in light distribution, conventional LED panels have to be placed at least 40cm from the plants, leading to space wastage in multi-tiered systems. Furthermore, stray light may escape from the sides of the LED panels, e.g. space between the LED panel and the illumination target, and results in the loss of light intensity. This may be energy inefficient as a larger

number of LEDs have to be used to provide adequate light intensity. In addition, due to the non-uniform light distribution, farmers have to rotate the plants to allow plants located at the periphery of the horticulture bed to receive a similar amount of light as those located towards the center of the horticulture bed. In addition, non-uniform light distribution on the plants may cause competition of light and stress, which may adversely affect the growth of the plants.

[0006] Accordingly, there exists a need for an improved illumination device, that seeks to address at least one of the aforementioned issues.

SUMMARY

[0007] The disclosure was conceptualized to provide an improved illumination device, which provides uniform electromagnetic radiation distribution at a relatively short distance, for example in a range of 5cm to 40cm, or 5cm to 30cm. By shortening the distance between the illumination panel and the illumination target, e.g. horticulture bed, space wastage is minimized and the vertical multi-tiered system may include more tiers. The illumination device also reduces light loss at the periphery of the illumination panels and increases the light intensity on the plants, leading to energy savings as a smaller number of electromagnetic radiation sources, e.g. LEDs, are required. Since the illumination device provides uniform electromagnetic radiation distribution at distances within the height of the reflector, which may be the same as a distance between the illumination panel and the illumination target, the plants will be able to grow with minimum stress, and the overall health of the plants may be improved.

[0008] The illumination device of the present disclosure also reduces the manpower required, since there is no need for the farmer to rotate the plants to allow plants located at the periphery, e.g. sides of the horticulture bed to receive a similar amount of light as those located towards the center of the horticulture bed.

[0009] According to one aspect of the disclosure, there is provided an illumination device comprising: an illumination panel configured to be arranged in proximity to an illumination target, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target; a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct a portion of the at least one electromagnetic radiation incident on the reflector towards the illumination target; wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch, wherein the reflector is

spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and wherein the first pitch and the third pitch are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target.

[0010] According to another aspect of the disclosure, there is provided a system for illuminating a horticulture bed comprising: an illumination panel configured to be arranged in proximity to the horticulture bed, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target; a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct the portion of the at least one electromagnetic radiation incident on the reflector towards the horticulture bed; wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch, wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and wherein the first pitch and the third pitch are adjusted relative to each other to provide an electromagnetic radiation distribution on the horticulture bed in operation.

[0011] According to another aspect of the disclosure, there is provided a method of manufacturing an illumination device comprising: an illumination panel configured to be arranged in proximity to an illumination target, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target; a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct a portion of the at least one electromagnetic radiation incident on the reflector towards the illumination target; wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch, wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and wherein the first pitch and the third pitch are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The disclosure will be better understood with reference to the detailed description when considered in conjunction with the non-limiting examples and the accompanying drawings, in which:

- FIG. 1 shows a schematic illustration of (A) a side view of an illumination device 100, and (B) an exploded view of the illumination panel 110 of the illumination device 100, in accordance with various embodiments;
- FIG. 2 shows a schematic illustration of (A) a side view of an illumination device 200, and (B) an exploded view of the illumination panel 110 of the illumination device 200, and (C) a cross-sectional view of a lens 202, in accordance with various embodiments;
- FIG. 3 shows a method 300 for manufacturing an illumination device, in accordance with various embodiments;
- FIG. 4 shows the (A) LED arrangement on a 48cm x 48cm conventional LED panel; (B) the arrangement of red LEDs on the conventional LED panel; and a simulation of the electromagnetic radiation distribution and intensity pattern when the illumination target is (C) 15cm and (D) 40cm, away from the LED panel;
- FIG. 5 shows a simulation of the electromagnetic radiation distribution and intensity pattern of the illumination device 100, 200, (A) without and (B) with the reflector 120 in the illumination device 100;
- FIG. 6 shows a simulation of the electromagnetic radiation distribution and intensity pattern of a single beam emitted from an electromagnetic radiation source 116, (A) without and (B) with the lens 202;
- FIG. 7 shows (A) the arrangement of the illumination units 112 on a 48cm x 48cm illumination panel 110; (B) a simulation of the electromagnetic radiation distribution and intensity pattern of the blue electromagnetic radiation sources 116B; (C) a simulation of the electromagnetic radiation distribution and intensity pattern of the red electromagnetic radiation sources 116R; a graphical representation of the (D) electromagnetic radiation distribution uniformity; and (E) average electromagnetic radiation intensity in photosynthetic photon flux density (PPFD) having units of $\mu\text{mol/s/m}^2$, without and with the reflector 120 and the lens 202 in the illumination device 100, 200;
- FIG. 8 shows the simulation of the color of the electromagnetic radiation distribution when the illumination target 130, is 5cm from the illumination panel 110, with the (A)

blue 116B, or (B) red 116R, and (C) both the blue 116B and red 116R electromagnetic radiation sources 116, and without or with the reflector 120 and the lens 202 in the illumination device 100, 200;

- FIG. 9 shows a simulation of the electromagnetic radiation distribution and intensity patterns with the (A) 116B blue or (B) red 116R electromagnetic radiation sources 116, without or with a reflector of 15cm in height and the lens 202 in the illumination device 100, 200; and
- FIG. 10 shows a simulation of the electromagnetic radiation distribution and intensity pattern for a 2 x 2 array of illumination units 112 comprising the (A) blue 116B or (B) red 116R electromagnetic radiation source 116; a 3 x 3 array of illumination units 112 comprising the (C) blue 116B or (D) red 116R electromagnetic radiation source 116; a 5 x 5 array of illumination units 112 comprising the (E) blue 116B or (F) red 116R electromagnetic radiation source 116, without or with the reflector 120 and lens 202 arranged on a 48cm x 48cm illumination panel 110, and at varying distances between the illumination panel 110 and the illumination target 130. FIG. 10(G) shows the corresponding graphical representation of the uniformity of the electromagnetic radiation distribution, based on FIG. 10(A) to (F).

DETAILED DESCRIPTION

[0013] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the disclosure may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the disclosure. Other embodiments may be utilized and structural, and logical changes may be made without departing from the scope of the disclosure. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0014] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0015] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0016] While terms such as “first”, “second” etc., may be used to describe various directions, such directions are not limited to the above terms. The above terms are used only to distinguish one direction from another, and do not define an order and/or significance of the elements. Without departing a scope of rights of the specification, a first direction may be referred to as a second direction, and similarly, the second direction may be referred to as the first direction.

[0017] Throughout the description, the term “electromagnetic radiation”, as used herein, may refer to light quanta or rays which propagate through space. In some embodiments, electromagnetic radiation may refer to light ranging from UV, visible light, to infrared lighting having a wavelength in the range of 200 to 2000 nm, and may be within the range of 300 to 750 nm. Accordingly, the term “electromagnetic radiation distribution”, may refer to the distribution of the light rays on an illumination target, owing to the diffusion, absorption and/or scattering of the electromagnetic radiation from an electromagnetic radiation source to the illumination target. The illumination target may include a single object and an area comprising multiple objects.

[0018] Throughout the description, the term “pitch”, as used herein, may refer to a distance from the center of one illumination unit to the center of a neighboring illumination unit.

[0019] Throughout the description, the term “uniform”, as used herein, may refer to an equal, constant or similar amount of light being distributed at various points of an illumination target. Accordingly, the term “uniform electromagnetic radiation distribution” may be defined as an equal or constant amount of illumination, i.e. light distribution at various points of the illumination target. In various embodiments, electromagnetic radiation uniformity may be calculated as the ratio of minimum to average electromagnetic radiation intensity. For optimal plant growth, the uniformity may have a value ranging from 0.5 to 1.0, preferably having a value of at least 0.7.

[0020] Throughout the description, the term “horticulture bed”, as used herein, may include a receptacle, e.g. planter box containing various arrangements of plants. The plants may be of the same genus and/or species, or may include two or more, such as a variety of plant geneses

and/or species. The horticulture bed may further include system(s) for providing nutrients to support plant growth.

[0021] FIG. 1 shows a schematic illustration of (A) a side view of an illumination device 100, and (B) an exploded view of the illumination panel 110 of the illumination device 100, in accordance with various embodiments. The illumination device 100 includes an illumination panel 110 configured to be arranged in proximity to an illumination target 130, the illumination panel 110 including a plurality of illumination units 112. Each illumination unit 112 is configured to emit at least one electromagnetic radiation 114 directed toward the illumination target 130. For example, the illumination panel 110 and the illumination target 130 may be spaced apart at a distance that allows the illumination target 130 to receive a desired level of electromagnetic radiation 114 emitted from the plurality of illumination units 112 arranged on the illumination panel.

[0022] The illumination device 100 also includes a reflector 120 extending from at least a part of a perimeter of the illumination panel 110, towards the illumination target 130. For example, depending on the shape of the illumination panel 110, the reflector 120 may extend from the sides of, or circumference of the illumination panel 100. In some embodiments, the reflector 120 may extend along an entire perimeter, e.g. along all the sides of, or the entire circumference of, the illumination panel 110. The reflector 120 may extend from the illumination panel 110 in a third direction D3, e.g. vertical direction or z-axis, which may be perpendicular to the illumination panel 110, as shown in FIG. 1(A). In various embodiments, a height of the reflector 120 may be equal to or less than a vertical distance between the illumination panel 110 and the illumination target 130. In some embodiments, a distance between the illumination panel 110 and the illumination target 130 may range from 5cm to 40cm, preferably between 5cm to 30cm, and the reflector 120 may have a height equal to or less than said distance. In an embodiment, the height of the reflector 120 is equal to said distance.

[0023] The reflector 120 is configured to direct a portion of at least one electromagnetic radiation 114a incident on the reflector 120 towards the illumination target 130. As shown in FIG. 1(A), the reflector 120 may receive a portion of the at least one electromagnetic radiation 114a incident on it, and may direct said portion of the at least one electromagnetic radiation 114b towards the illumination target 130. In other words, the reflectors 120 may prevent or minimize the loss of a portion of the at least one electromagnetic radiation 114a that may escape

from the sides of the illumination panel 110, and/or the space between the illumination panel 110 and the illumination target 130, and may reflect the portion of the at least electromagnetic radiation 114b towards the illumination target 130.

[0024] Referring to FIG. 1(B), each illumination unit 112 is spaced apart from a neighboring illumination unit 112 in a first direction D1 by a first pitch P1, and each illumination unit 112 may be spaced apart from another neighboring illumination unit 112 in a second direction D2 by a second pitch P2. The first direction D1 may be along the x-axis or lateral axis, and the second direction D2 may be along the y-axis or longitudinal axis of the illumination panel 110. In various embodiments, the reflector 120 is spaced apart from an adjacent illumination unit 112 proximate to the first direction D1 by a third pitch P3, and the reflector 120 is spaced apart from an adjacent illumination unit 112 proximate to the second direction D2 by a fourth pitch P4. That is, the reflector 120 and an illumination unit 112 immediately adjacent to the reflector 120 may be separated by the third pitch P3 in the first direction D1 and by the fourth pitch P4 in the second direction D2.

[0025] In the illumination device 100, the first pitch to fourth pitch P1 to P4 are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target 130. For example, dependent on the application of the illumination device 100, a user may determine an electromagnetic radiation distribution by adjusting the first pitch P1, second pitch P2, third pitch P3 and fourth pitch P4 of the illumination units 112, and the reflector 120. This allows the user to suitably customize a desired electromagnetic radiation distribution for an illumination target 130 to achieve an intended objective, such as to facilitate plant growth.

[0026] The adjustments of the first pitch P1, second pitch P2, third pitch P3 and fourth pitch P4 may determine the uniformity of the electromagnetic radiation distribution on an illumination target 130, and in various embodiments, in the first direction D1, the third pitch P3 may be adjusted to be less than the first pitch P1, e.g. $P3 < P1$, and in the second direction D2, the fourth pitch P4 may be adjusted to be less than the second pitch P2, e.g., $P4 < P2$, to provide at least, some uniformity in the electromagnetic radiation distribution on the illumination target 130. In some embodiments, the first pitch P1 may be equal to the second pitch P2, and the third pitch P3 may be equal to the fourth pitch P4. In some embodiments, at least one of the third pitch P3 may be adjusted to be half of the first pitch P1, e.g. $P3 = 0.5P1$ (in the first direction D1), or the fourth pitch P4 may be adjusted to be half of the second pitch

P2, e.g. $P4 = 0.5P2$ (in the second direction D2) to provide a uniform electromagnetic radiation distribution on an illumination target 130. In an embodiment, the third pitch P3 may be half of the first pitch P1, e.g. $P3 = 0.5P1$, and the fourth pitch P4 may be half of the second pitch P2, e.g. $P4 = 0.5P2$.

[0027] In an embodiment, the illumination target 130 may be a horticulture bed including a variety of plants 132 arranged thereon. The illumination device 100 having the third pitch P3 adjusted to be half of the first pitch P1 (in the first direction D1) and fourth pitch P4 adjusted to be half of the second pitch P2 (in the second direction D2) may provide a uniform electromagnetic radiation distribution, e.g. uniformity of at least 0.7, on the horticulture bed 130 within a distance ranging from 5cm to 40cm, preferably 5cm to 30cm. As such, plants 132 arranged at various parts, e.g. periphery vs center of the horticulture bed may receive the same or similar amounts of electromagnetic radiation. In indoor farming, this minimizes space wastage in the third direction D3 and the vertical multi-tiered system may include more tiers. Furthermore, manpower resource requirements may be reduced as farmers do not have to move or rotate the plants 132 to ensure that plants 132 located at the periphery receive the same amount of electromagnetic radiation for optimal growth. In addition, the reflector 120 prevents or minimizes loss of electromagnetic radiation which may escape from the sides of the illumination panel 110, and increases the intensity of electromagnetic radiation on the illumination target 130. As such, a smaller quantity of LEDs may be required, and the illumination device 100 may have improved energy efficiency.

[0028] As shown in FIG. 1(B), at least one illumination unit 112 includes a plurality of electromagnetic radiation sources 116, each electromagnetic radiation source 116 being configured to emit an electromagnetic radiation 114 which is directed towards the illumination target 130. In various embodiments, the at least one electromagnetic radiation source 116 may be an LED, for example, a high-powered LED which emits an electromagnetic radiation of approximately 1W to 3W per LED. High-powered LEDs have higher photosynthetic photon efficacy as compared to low-, e.g. 0.05W to 0.1W per LED or mid-, e.g. 0.25W to 0.5W, powered LED. Since high-powered LEDs may be used, the number of electromagnetic radiation sources 116 for each illumination unit 112 may be reduced. In some embodiments, each illumination unit 112 may include 2 to 10, preferably 5 to 7 electromagnetic radiation sources 116.

[0029] In various embodiments, the at least one electromagnetic radiation source 116 may be configured to emit electromagnetic radiation of a different wavelength relative to the emitted electromagnetic radiation wavelength of another electromagnetic radiation source 116 within the illumination unit 112. In some embodiments, at least one electromagnetic radiation source 116 may have a wavelength ranging between 400nm to 500nm, e.g. blue light; and a wavelength ranging between 620nm to 750nm, e.g. red light. It is contemplated that the electromagnetic radiation sources 116 may be of various other wavelengths within the visible light spectrum, the infra-red spectrum or the ultra-violet spectrum. The illumination unit 112 may therefore include a combination of electromagnetic radiation sources 116 with different wavelengths, and a user may tune the optical spectrum of each illumination unit 112 by selecting and combining the wavelengths of different electromagnetic radiation sources 116, for improved photosynthetically active electromagnetic radiation, i.e. amount of light available for plant 132 photosynthesis. Different wavelength combinations may affect the growth speed, morphology, and taste of crops. In addition, optimizing the conditions of each illumination unit 112 within the illumination panel 110, avoids the unnecessary over-supply of electromagnetic radiation, reduces the number of electromagnetic radiation sources 116 required and heat generated by each electromagnetic radiation source 116. This may lead to energy savings of up to 40% in vertical multi-tiered systems for indoor farming.

[0030] FIG. 2 shows a schematic illustration of (A) a side view of an illumination device 200, and (B) an exploded view of the illumination panel 110 of the illumination device 200, and (C) a cross-sectional view of a lens 202, in accordance with various embodiments. Illumination device 200 may be based on illumination device 100 described with reference to FIG. 1(A) and (B) and repeated descriptions will be omitted. Illumination device 200 may further include a lens 202 arranged on at least one electromagnetic radiation source 116 of the plurality of electromagnetic radiation sources 116 within the illumination unit 112. In some embodiments, the lens 202 may be arranged on all the electromagnetic radiation sources 116 within the illumination unit 112.

[0031] Referring to FIG. 2(C), the lens 202 may be a hemispherical lens, e.g. dome-shaped lens, configured to modify the electromagnetic radiation 114 emitted by the electromagnetic radiation source 116 to form a modified electromagnetic radiation 212. The lens 202 may include an outer hemisphere 204 comprising a transparent material, e.g. glass or plastic, and an inner semi-ellipsoidal cavity 206. In some embodiment, the radius of the outer hemisphere 204

may be 5mm, and the semi-ellipsoidal cavity 206 may have a depth of 4mm and a radius of 3mm. The hemispherical lens 202 may be a convex lens, e.g. plano-convex lens, configured to widen the electromagnetic radiation 114 beam, and may have a refractive index of ranging from 1.3 to 1.8, preferably 1.51. In some embodiments, the modified electromagnetic radiation 212 may have a modified beam angle equal to or greater than 90°, preferably greater than 120°, and may have increased uniformity. Alternatively, the modified beam angle may be less than 90°. The lens 202 may be easily manufactured and produced in batches since the lens 202 may be molded as an optical component using plastic sheet panels.

[0032] Referring to FIG. 2(A), the reflector 120 may be configured to receive a portion of the electromagnetic radiation 114a, and a portion of the modified electromagnetic radiation 212a, and may direct the portion of electromagnetic radiation 114b and the portion of modified electromagnetic radiation 212b towards the illumination target 130. In some embodiments, the reflector 120 may direct a portion of the modified electromagnetic radiation 212a incident on it towards the illumination target 130. The illumination device 200 including the lens 202 arranged on at least one electromagnetic source 116 may improve the uniformity of the electromagnetic radiation distribution on the illumination target 130, at a distance ranging between 5cm to 40cm, preferably 5cm to 30cm, or within the height of the reflector 120.

[0033] While the illumination target 130 as described above may be a horticulture bed. In some embodiments, the illumination target 130 may be any target that requires uniform electromagnetic radiation distribution.

[0034] According to another aspect of the disclosure, there is provided a system for illuminating a horticulture bed comprising an illumination panel configured to be arranged in proximity to the horticulture bed, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target; a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct the portion of the at least one electromagnetic radiation incident on the reflector towards the horticulture bed; wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch, wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and wherein the first pitch and the third pitch are adjusted relative to each other to provide an electromagnetic radiation distribution on the horticulture bed in operation. The system may be based on the illumination device 100, 200

described with reference to FIG. 1(A) to 2(C), e.g. having the illumination panel 110, reflector 120, and illumination target 130 which may be a horticulture bed, and repeated descriptions will be omitted.

[0035] In various embodiments, each illumination unit may be spaced apart from another neighboring illumination unit in a second direction by a second pitch, and the reflector may be spaced apart from another adjacent illumination unit proximate to the reflector in the second direction by a fourth pitch. The second direction may be perpendicular to the first direction. The first pitch P1, second pitch P2, third pitch P3 and the fourth pitch P4 of the illumination panel of the system may be adjustable relative to each other to provide a uniform electromagnetic radiation distribution. In various embodiments, in the first direction D1, the third pitch may be adjusted to be less than the first pitch, e.g. $P3 < P1$ and in some embodiments, may be half of the first pitch, e.g. $P3 = 0.5P1$. In the second direction D2, the fourth pitch may be adjusted to be less than the second pitch, e.g. $P4 < P2$ and in some embodiments, may be half of the first pitch, e.g. $P4 = 0.5P2$. Thus, uniform electromagnetic radiation distribution on the horticulture bed may be provided at all distances within the height of the reflector.

[0036] FIG. 3 shows a method 300 for manufacturing an illumination device, in accordance with yet another aspect of the disclosure. Method 300 includes: providing an illumination panel configured to be arranged in proximity to an illumination target, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target (step 302); and arranging a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct a portion of the at least one electromagnetic radiation incident on the reflector towards the illumination target; wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch, wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and wherein the first pitch and the third pitch are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target (step 304). The method 300 of manufacture of the illumination device may refer to the illumination device 100, 200 described with reference to FIG. 1(A) to 2(C), and repeated descriptions will be omitted.

EXAMPLES

[0037] The illumination device 100, 200, system for illumination a horticulture bed, and method 300, herein disclosed are further illustrated in the following examples, which are provided by way of illustration and are not intended to be limiting the scope of the present disclosure.

[0038] In the Examples, an exemplary conventional LED panel with tunable LED light sources, e.g. Osram PHYTOFY® RL LED panel, e.g. Example 1, was used to determine the electromagnetic radiation distribution on an illumination target, for comparison to the illumination device 100, 200 of the present disclosure. Currently, conventional LED panels may be employed in the vertical multi-tiered systems for indoor farming.

[0039] In the Examples below, the illumination target 130 may be a horticulture bed comprising a various arrangement of plants. In FIG. 5(A) to 10(G), the term “with our solution”, as used herein, may refer to the illumination device 100, 200 having a reflector 120 extending from at least a part of the perimeter of the illumination panel 110 and/or the lens 202 arranged on at least one electromagnetic radiation source 116 within the illumination unit 112. The term “without our solution”, as used herein, may refer to conventional illumination panels, e.g. LED panels, which do not include the reflector and/or the lens, as shown in Example 1.

Example 1. Electromagnetic radiation distribution in conventional illumination panels

[0040] FIG. 4 shows the (A) LED arrangement on a 48cm x 48cm conventional LED panel; (B) the arrangement of red LEDs on the conventional LED panel; and a simulation of the electromagnetic radiation distribution and intensity pattern when the illumination target is (C) 15cm and (D) 40cm, away from the LED panel. The LEDs are Osram GH CSSRM4.24 red LEDs, and are modelled with a 120° beam angle, and uniformities are calculated by the ratio of minimum to average light intensity in the analyzed area of the illumination target.

[0041] Conventional LED panels may include 77 LEDs comprising 16 red LEDs, 19 white LEDs, 10 infrared LEDs, 16 blue LEDs and 16 green LEDs arranged on the panel (see FIG. 4(A)). The LEDs are of different wavelengths and are arranged on the panel randomly. By ray tracing simulations, at a distance of 15cm between the LED plane and the illumination target, the uniformity of the electromagnetic radiation distribution is 0.35 (see FIG. 4(C)); while at a distance of 40cm, the uniformity of the electromagnetic radiation distribution is 0.59 (see FIG. 4(D)). This may not be optimal for plant growth which requires a uniformity of at least 0.7. To achieve a uniformity of at least 0.7, the LED panel must be arranged at a distance of more than

40cm from the illumination target, which may not be suitable for high-density indoor farming, as it leads to space wastage.

Example 2. Electromagnetic radiation distribution and intensity pattern without or with the reflector on 2 x 2 array of illumination units

[0042] FIG. 5 shows a simulation of the electromagnetic radiation distribution and intensity pattern of the illumination device 100, 200, (A) without and (B) with the reflector 120 in the illumination device 100. The 2 x 2 array of illumination units 112, each including one electromagnetic radiation source 116 are arranged on a 24cm x 24cm illumination panel 110, as shown on the right-hand side of FIG. 5(A) and (B). The illumination panel 110 may be placed 15cm away from the illumination target 130, and the electromagnetic radiation sources 116 may be the Luminus deep red LED SST-10-DR with a beam angle of 120°. The first pitch P1 in the first direction D1 and the second pitch P2 in second direction D2 between an electromagnetic radiation source 116 and a neighbouring electromagnetic radiation source 116 may be 12cm, and the third pitch P3 and the fourth pitch P4 between the reflector 120 and an adjacent electromagnetic radiation source 116 may be 6cm, e.g. $P3 = 0.5P1$, $P4 = 0.5 P2$.

[0043] Referring to FIG. 5(A) and (B), there may be loss of electromagnetic radiation at the corner of the illumination panel 110 and the space between the illumination panel 110 and the illumination target 130, and the uniformity of the electromagnetic radiation distribution may be 0.50 (FIG. 5(A)). By arranging the reflector 120 such that it extends along the entire perimeter of the illumination panel 110, the uniformity of the electromagnetic radiation distribution may be increased to 0.89, and the average intensity on the illumination target 130 of 24cm x 24cm may also be increased by 3.44 times (FIG. 5(B)).

Example 3. Electromagnetic radiation distribution of a beam without or with the lens

[0044] FIG. 6 shows a simulation of the electromagnetic radiation distribution and intensity pattern of a single beam emitted from an electromagnetic radiation source 116, (A) without and (B) with the lens 202. The lens 202 may refer to the hemispherical lens as described with reference to FIG. 2(C), which is configured to modify the beam profile of electromagnetic radiation 114 emitted by the electromagnetic radiation source 116. The electromagnetic radiation source 116 may be the Luminus deep red LED SST-10-DR with a beam angle of 120°.

[0045] Referring to FIG. 6(A) and (B), the lens 202 may widen, e.g. expands the electromagnetic radiation 114 beam and as a result, increase the uniformity of electromagnetic radiation distribution of a single beam from 0.32 (FIG. 6(A)) to 0.50 (FIG. 6(B)), on a 12cm x 12cm illumination target 130, located 10cm away from electromagnetic radiation source 116.

Example 4. Electromagnetic radiation distribution and intensity pattern without or with the reflector and lens on a 4 x 4 array of illumination units

[0046] FIG. 7 shows (A) the arrangement of the illumination units 112 on a 48cm x 48cm illumination panel 110; (B) a simulation of the electromagnetic radiation distribution and intensity pattern of the blue electromagnetic radiation sources 116B; (C) a simulation of the electromagnetic radiation distribution and intensity pattern of the red electromagnetic radiation sources 116R; a graphical representation of the (D) electromagnetic radiation distribution uniformity; and (E) average electromagnetic radiation intensity in photosynthetic photon flux density (PPFD) having units of $\mu\text{mol/s/m}^2$, without and with the reflector 120 and the lens 202 in the illumination device 100, 200. Electromagnetic radiation uniformity and intensity patterns were simulated at distances of 3cm, 4cm, 5cm, 10cm and 15cm between the illumination panel 110 and the illumination target 130.

[0047] Referring to FIG. 7(A), a 4 x 4 array of illumination units 112 (16 illumination units 112) is shown. Each illumination unit 112 may include 2 electromagnetic radiation sources 116 – a blue 116B and a red, 116R electromagnetic radiation source 116. The first pitch P1 and the second pitch P2 between an illumination unit 112, and a neighbouring illumination unit 112 may be 12cm, e.g. distance between centre of an illumination unit 112 to a centre of the neighbouring illumination unit 112 may be equal, and the third pitch P3 and the fourth pitch P4 between the reflector 120 and an adjacent radiation source 116 may be 6cm, e.g. $P1 = P2$, $P3 = P4$, $P3 = 0.5P1$, $P4 = 0.5P2$. In Example 4, the blue electromagnetic radiation source 116B may be located at an ideal position for optimal reflection of a portion of electromagnetic radiation from the reflectors 120. The red electromagnetic radiation source 116R may be spaced apart by 10mm from the blue electromagnetic radiation source 116B. Based on the spacing of 10mm between each electromagnetic radiation source 116, each illumination unit 112 may include up to 9, preferably up to 7 electromagnetic radiation sources 116.

[0048] In Example 4, the blue electromagnetic radiation source 116B may be the Luminus SST-10-B blue LED having a peak wavelength at 450nm and a power of 1W (equivalent to

3.76 $\mu\text{mol/s}$ photosynthetic photon flux (PPF) at 450nm) when driven by a 0.6A current; and the red electromagnetic radiation source 116R may be the Osram GH CSSRM4.24 red LED having a peak wavelength at 646-666nm and a power of 1W (equivalent to 5.52 $\mu\text{mol/s}$ PPF at 660nm) when driven by 0.7A current. Both LEDs have a beam angle of 120° (before modifying by lens 202). Based on the illumination panel 110 as shown in FIG. 7(A), 60.27 $\mu\text{mol/s}$ blue of light and 88.3 $\mu\text{mol/s}$ of red light may be generated, and for an illumination target 130 having an area of 48cm x 48cm (same area as illumination panel 110), the average PPFD for blue and red LEDs will be 261.1 $\mu\text{mol/s/m}^2$ and 383.2 $\mu\text{mol/s/m}^2$, respectively, which is sufficient and optimal for plant growth when the illumination target 130 is a horticulture bed.

[0049] FIG. 7(B) and (C) thus demonstrates that without the reflector 120 and lens 202 in the illumination device 100, 200, the electromagnetic radiation uniformity at a distance of 15cm away from the illumination target 130, may not be sufficient for plant growth. Increasing the distance between the illumination panel 110 and the illumination target 130, increases the uniformity of the electromagnetic radiation distribution, but leads to space wastage in vertical multi-tiered systems. The inclusion of the reflector 120 and the lens 202 increases the uniformity of the electromagnetic radiation distribution, when the illumination panel 110 is at least, 5cm away from the illumination target 130. FIG. 7(B) and (C) further show that at a distance of 4cm between the illumination panel 110 and illumination target 130, blue electromagnetic radiation sources 116B provide better electromagnetic radiation distribution uniformity, as compared to red electromagnetic radiation sources 116R.

[0050] Referring to FIG. 7(B) to (D), for the blue electromagnetic radiation sources 116B, the uniformity of electromagnetic radiation distribution on an illumination target 130, at 3cm, 4cm, 5cm, 10cm, and 15cm distances from the illumination panel 110, are respectively 2.8, 4.5, 3.3, 2.1 and 2.0 times of those without the reflector 120 and lens 202 reflector 120 in the illumination device 100, 200. For the red electromagnetic radiation sources 116R, the uniformity of electromagnetic radiation distribution on an illumination target 130, at 3cm, 4cm, 5cm, 10cm, and 15cm distances from the illumination panel 110, are respectively 1.6, 2.9, 3.7, 2.2 and 2.2 times of those without the reflector 120 and the lens 202 in the illumination device 100, 200. Since the red electromagnetic radiation sources 116R are positioned approximately 10mm from the optimal electromagnetic radiation source 116 position, e.g. position of blue electromagnetic radiation source 116B, within the illumination unit 112, the uniformities for

the red electromagnetic radiation sources 116R may be lower than those of blue electromagnetic radiation sources 116B.

[0051] As shown in FIG. 7(E), it may be seen that without the reflector 120 and the lens 202 in the illumination device 100, 200, the intensity of the electromagnetic radiation distribution (both for blue and red electromagnetic radiation sources 116B, 116R) decreases as the distance between the illumination panel 110 and illumination target 130 increases. This is because the electromagnetic radiation intensity decreases with increasing distances, since there is loss of a portion of electromagnetic radiation from the sides of the illumination panel 110, or the space between the illumination panel 110 and illumination target 130. The addition of reflectors 120 “traps” the portion of electromagnetic radiation and reflects it towards the illumination target 130, such that electromagnetic radiation intensity on the illumination target 130 may not decrease as much when the illumination panel 110 is positioned at increasing distances from the illumination target 130. It may be seen that the electromagnetic radiation intensities on the illumination target 130 at distances of 5cm, 10cm and 15cm are approximately equal, and accordingly, plants arranged on the horticulture bed, e.g. illumination target 130, may grow in an environment with uniform electromagnetic radiation distribution at all distances within the height of the reflector 120. As such, the plants do not need to compete for electromagnetic radiation or lean towards locations where the electromagnetic radiation is stronger, causing plant shape deformation. The plants may therefore have minimal stress.

[0052] FIG. 8 shows the simulation of the color of the electromagnetic radiation distribution when the illumination target 130, is 5cm from the illumination panel 110, with the (A) blue 116B, or (B) red 116R, and (C) both the blue 116B and red 116R electromagnetic radiation sources 116, and without or with the reflector 120 and the lens 202 in the illumination device 100, 200. The arrangement of electromagnetic radiation sources 116 within the illumination unit 112 of the illumination panel 110 is shown in FIG. 7(A). Referring to FIG. 8(A) to 8(C), the color of the electromagnetic radiation distribution on the illumination target 130, e.g. horticulture bed, may be uniform, with the blue 116B or the red 116R electromagnetic radiation sources 116, and with both the blue 116B and ref 116R electromagnetic radiation sources 116, when the illumination device 100, 200 includes the reflector 120 and the lens 202. Conversely, without the reflector 120 and the lens 202, the electromagnetic radiation distribution is concentrated at central area under each individual electromagnetic radiation sources 116R,

116B (see top row in each of FIG. 8(A) to 8(C)), and the color of the electromagnetic radiation distribution may not be uniform.

[0053] FIG. 9 shows a simulation of the electromagnetic radiation distribution and intensity patterns with the (A) 116B blue or (B) red 116R electromagnetic radiation sources 116, without or with a reflector of 15cm in height and the lens 202 in the illumination device 100, 200. The distance between the illumination target 130 and the illumination panel 110 may be 20cm, i.e. the reflector may be 5cm shorter than said distance. The arrangement of illumination units 112, each comprising 2 electromagnetic radiation sources 116 on the illumination panel 110 is as shown in FIG. 7(A).

[0054] FIG. 9(A) and 9(B) shows that a difference of 5cm between the distance of the illumination panel 110 and illumination target 130, e.g. horticulture bed, and the height of the reflector results in loss of electromagnetic radiation, since not all of the electromagnetic radiation emitted from the electromagnetic radiation sources 116R, 116B can be trapped under the illumination area for the plants. Because electromagnetic radiation may escape from the bottom of reflectors 120, e.g. the 5cm difference between reflector 120 height and said distance, the plants located at the periphery of the horticulture bed may not receive the reflected light. This results in the reduction in the uniformity of the electromagnetic radiation distribution, since the periphery, e.g. corners of the horticulture bed does not receive the reflected light. Although the average intensity on the horticulture bed may be increased by 48% and 37% respectively for blue 116B (FIG. 9(A)) and red 116R (FIG. 9(B)) electromagnetic radiation sources 116 (with the reflector 120 and lens 202), the uniformity of the electromagnetic radiation distribution may be reduced. In particular, electromagnetic radiation distribution uniformity may be less than 0.7 at the periphery of the horticulture bed, and may only achieve uniformity of 0.77 at the central area of the horticulture bed (see dashed boxes in FIG. 9(A) and 9(B)). This suggests that the height of the reflector 120 may suitably be the same as the distance between the illumination panel 110 and the illumination target 130. For example, the distance between the illumination panel 110 and illumination target 130 may be 15cm when a reflector of 15cm in height is used; and the distance between the illumination panel 110 and illumination target 130 may be 20cm when a reflector of 20cm in height is used.

Example 5. Electromagnetic radiation distribution and intensity pattern without or with the reflector and lens on various arrays of illumination units

[0055] FIG. 10 shows a simulation of the electromagnetic radiation distribution and intensity pattern for a 2 x 2 array of illumination units 112 comprising the (A) blue 116B or (B) red 116R electromagnetic radiation source 116; a 3 x 3 array of illumination units 112 comprising the (C) blue 116B or (D) red 116R electromagnetic radiation source 116; a 5 x 5 array of illumination units 112 comprising the (E) blue 116B or (F) red 116R electromagnetic radiation source 116, with or without the reflector 120 and lens 202 arranged on a 48cm x 48cm illumination panel 110, and at varying distances between the illumination panel 110 and the illumination target 130. FIG. 10(G) shows the corresponding graphical representation of the uniformity of the electromagnetic radiation distribution, based on FIG. 10(A) to (F). Each illumination unit 112 may include either the blue 116B or the red 116R electromagnetic radiation source 116B. The blue electromagnetic radiation source 116B may be the Luminus SST-10-B blue LED, and the red electromagnetic radiation source 116R may be the Osram GH CSSRM4.24 red LED. Both LEDs have a beam angle of 120° (before modifying by lens 202). The first pitch P1 and the second pitch P2 between each illumination unit 112 on the 2 x 2 array may be 24cm; the 3 x 3 array may be 16cm; the 4 x 4 array may be 12cm (FIG. 7(A)); and the 5 x 5 array may be 9.6cm. The third pitch P3 and fourth pitch P4 may be half of the first pitch P1 and second pitch P2, respectively, e.g. $P3 = 0.5P1$, $P4 = 0.5P2$.

[0056] Referring to FIG. 10(A) to (G), it may be seen that an increase in the number of illumination units 112, each having the blue 116B or red 116R electromagnetic radiation source 116, on the illumination panel 110, and a greater distance between the illumination target 130 and the illumination panel 110, may lead to an increase in the uniformity of electromagnetic radiation distribution on the illumination target 130. Without the reflector 120 and lens 202, even at a distance of 15cm between the illumination panel 110 and illumination target 130, the electromagnetic radiation distribution uniformity is less than 0.5.

[0057] With the inclusion of the reflector 120 and lens 202 on the illumination device 100, 200, the illumination panel 110 including the 4 x 4 (FIG. 7(B) and (C)) and 5 x 5 arrays (FIG. 10(E) and (F)) of illumination unit 112 may be as close as 5cm to the illumination target 130 and may also achieve a uniform electromagnetic radiation distribution of at least 0.7. The distance between the illumination target 130 and illumination panel 110 may preferably be at least 10cm to achieve uniform electromagnetic radiation distribution of at least 0.7, in the 2 x 2 (FIG. 10(A) and (B)) and 3 x 3 (FIG. 10(C) and (D)) arrays of illumination units 112.

[0058] Various embodiments of the disclosure thus provide an improved illumination device, which provides uniform light distribution at a short distance, e.g. 5cm to 40cm, preferably 5cm to 30cm. By shortening the distance between the illumination panel and the illumination target, e.g. horticulture bed, space wastage is minimized and the vertical multi-tiered system may include more tiers for high-density indoor farming. The illumination device also reduces light loss at the periphery of the illumination panels and increases the light intensity on the produce, leading to energy savings as a smaller number of electromagnetic radiation sources, e.g. LEDs are required. Since the illumination device provides uniform electromagnetic distribution at distances within the height of the reflector, which may be the same as a distance between the illumination panel and the illumination target, the plants will be able to grow with minimum stress, and the overall health of the plants may be improved.

[0059] While the disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the disclosure as defined by the appended claims. The scope of the disclosure is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

CLAIMS

1. An illumination device comprising
an illumination panel configured to be arranged in proximity to an illumination target, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target;
a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct a portion of the at least one electromagnetic radiation incident on the reflector towards the illumination target;
wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch,
wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and
wherein the first pitch and the third pitch are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target.
2. The illumination device of claim 1, wherein each illumination unit is spaced apart from another neighboring illumination unit in a second direction by a second pitch,
wherein the reflector is spaced apart from another adjacent illumination unit proximate to the reflector in the second direction by a fourth pitch, the second direction being perpendicular to the first direction, and
wherein the second pitch and the fourth pitch are adjustable relative to each other to provide the electromagnetic radiation distribution based on the type of illumination target.
3. The illumination device of claim 1 or claim 2, wherein the first pitch and the third pitch, and the second pitch and the fourth pitch are adjustable relative to each other to provide a uniform electromagnetic radiation distribution.
4. The illumination device of claim 2 or claim 3, wherein the reflector extends perpendicular to the illumination panel, in a third direction perpendicular to the first direction and the second direction, and towards the illumination target.

5. The illumination device of any one of claims 1 to 4, wherein the reflector extends along an entire perimeter of the illumination panel.
6. The illumination device of any one of claims 2 to 5, wherein the third pitch is adjusted to be less than the first pitch, and the fourth pitch is adjusted to be less than the second pitch.
7. The illumination device of any one of claims 2 to 6,
wherein the first pitch is equal to the second pitch, and
wherein the third pitch is adjusted to be half of the first pitch, and the fourth pitch is adjusted to be a half of the second pitch.
8. The illumination device of any one of claims 1 to 7, wherein at least one illumination unit comprises a plurality of electromagnetic radiation sources, each electromagnetic radiation source configured to emit an electromagnetic radiation which is directed toward the illumination target.
9. The illumination device of claim 8, wherein at least one electromagnetic radiation source is configured to emit the electromagnetic radiation of different wavelength relative to the emitted electromagnetic radiation wavelength of another electromagnetic radiation source within the illumination unit.
10. The illumination device of claim 8 or claim 9, further comprising a lens arranged on the at least one electromagnetic radiation source of the plurality of electromagnetic radiation sources within the illumination unit.
11. The illumination device of claim 10, wherein the lens comprises a hemispherical lens configured to modify the electromagnetic radiation emitted by the electromagnetic radiation source, to form a modified electromagnetic radiation, which forms at least another part of the portion of the at least one electromagnetic radiation.

12. The illumination device of claim 11, wherein the modified electromagnetic radiation has a modified beam angle.

13. The illumination device of any one of claims 8 to 12, wherein the at least one electromagnetic radiation source is a high-power light emitting diode.

14. The illumination device of any one of claims 4 to 13, wherein a height of the reflector is equal to or less than a distance between the illumination panel and the illumination target, in the third direction, and

wherein the distance between the illumination panel and the illumination target, ranges from 5 to 40 cm, preferably 10 to 30 cm.

15. The illumination device of any one of claims 1 to 14, wherein the illumination target is a horticulture bed.

16. A system for illuminating a horticulture bed comprising

an illumination panel configured to be arranged in proximity to the horticulture bed, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target;

a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct the portion of the at least one electromagnetic radiation incident on the reflector towards the horticulture bed;

wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch,

wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and

wherein the first pitch and the third pitch, are adjustable relative to each other to provide an electromagnetic radiation distribution on the horticulture bed in operation.

17. The system of claim 16, wherein each illumination unit is spaced apart from another neighboring illumination unit in a second direction by a second pitch,

wherein the reflector is spaced apart from another adjacent illumination unit proximate to the reflector in the second direction by a fourth pitch, the second direction being perpendicular to the first direction, and

wherein the second pitch and the fourth pitch are adjustable relative to each other to provide the electromagnetic radiation distribution on the horticulture bed in operation.

18. The system of claim 17, wherein the first pitch and the third pitch, and the second pitch and the fourth pitch, are adjustable relative to each other to provide a uniform electromagnetic radiation distribution.

19. The system of claim 17 or claim 18, wherein the third pitch is adjusted to be less than the first pitch, and the fourth pitch is adjusted to be less than the second pitch, preferably the third pitch is adjusted to be half of the first pitch and the fourth pitch is adjusted to be half of the second pitch.

20. A method of manufacturing an illumination device comprising
providing an illumination panel configured to be arranged in proximity to an illumination target, the illumination panel comprising a plurality of illumination units, each illumination unit configured to emit at least one electromagnetic radiation directed towards the illumination target;

arranging a reflector extending from at least a part of a perimeter of the illumination panel, the reflector configured to direct a portion of the at least one electromagnetic radiation incident on the reflector towards the illumination target;

wherein each illumination unit is spaced apart from a neighboring illumination unit in a first direction by a first pitch,

wherein the reflector is spaced apart from an adjacent illumination unit proximate to the reflector in the first direction by a third pitch, and

wherein the first pitch and the third pitch are adjustable relative to each other to provide an electromagnetic radiation distribution based on the type of illumination target.