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(54) **ARTIFICIAL SUNLIGHT LIGHTING LUMINAIRES FOR INDOOR ENVIRONMENTS**

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Sep. 24, 2023 (FI) 20237160

(51) **Int. Cl.**

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F21V 3/04	(2018.01)
F21Y 113/00	(2016.01)
F21Y 113/13	(2016.01)
F21Y 115/15	(2016.01)
H05B 45/20	(2020.01)
H05B 47/155	(2020.01)
H05B 47/19	(2020.01)

(52) **U.S. Cl.**
CPC ***F21V 9/02*** (2013.01); ***F21V 3/049*** (2013.01); ***H05B 45/20*** (2020.01); ***H05B 47/155*** (2020.01); ***H05B 47/19*** (2020.01); *F21Y 2113/00* (2013.01); *F21Y 2113/13* (2016.08); *F21Y 2115/15* (2016.08)

(58) **Field of Classification Search**
CPC F21V 9/02; F21V 3/049; H05B 47/19; H05B 47/155; H05B 45/20
USPC 362/1, 2, 231
See application file for complete search history.

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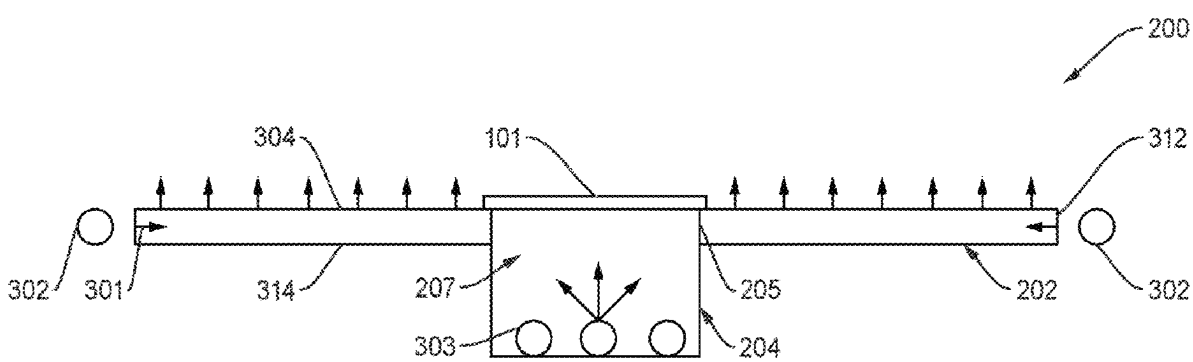
(57) **ABSTRACT**

A lighting system and luminaire replicates attributes of natural sunlight and the sky. An array of light emitters capable of emitting light closely mimicking natural sunlight. This emitted light features an adjustable correlated color temperature (CCT) that spans from 1900 K to 6500 K, faithfully reproducing the Sun's appearance across different times of the day. To ensure precision in spectral matching, the system operates within a defined wavelength range of 400 nm to 1400 nm. At least one light emitter with a wavelength within the range of 760 nm to 1400 nm is incorporated to guarantee accurate representation. A luminaire equipped with a panel interacts with the multitude of light emitters, proficiently emitting color-tunable light and simulating diverse sky scenes. To facilitate control and customization, a dedicated control system is seamlessly integrated into the luminaire, enabling precise adjustment of the correlated color temperature and spectral power distribution.

20 Claims, 11 Drawing Sheets



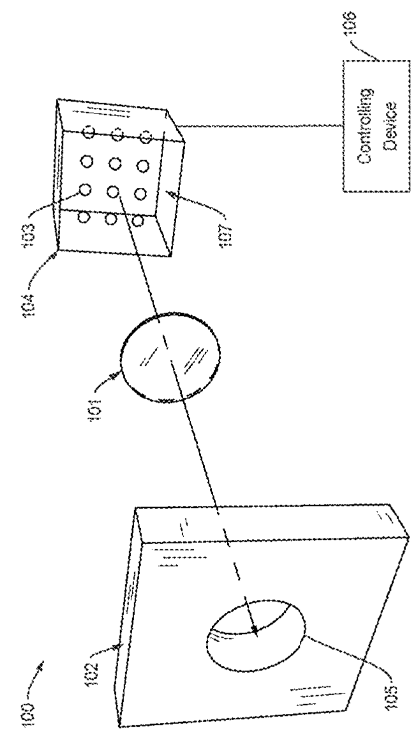


FIG. 1

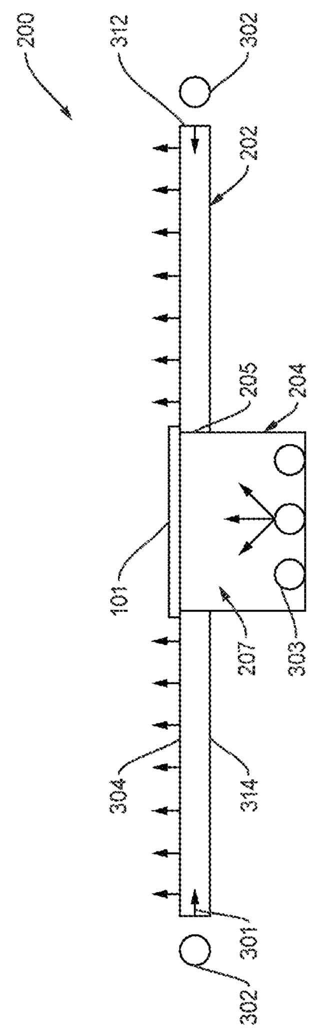


FIG. 2

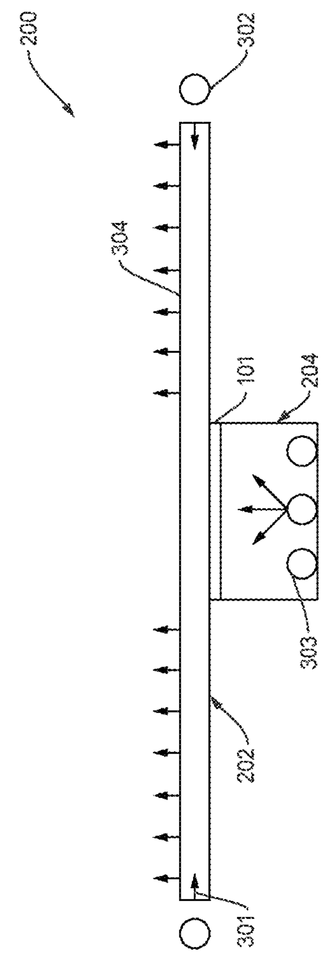


FIG. 3

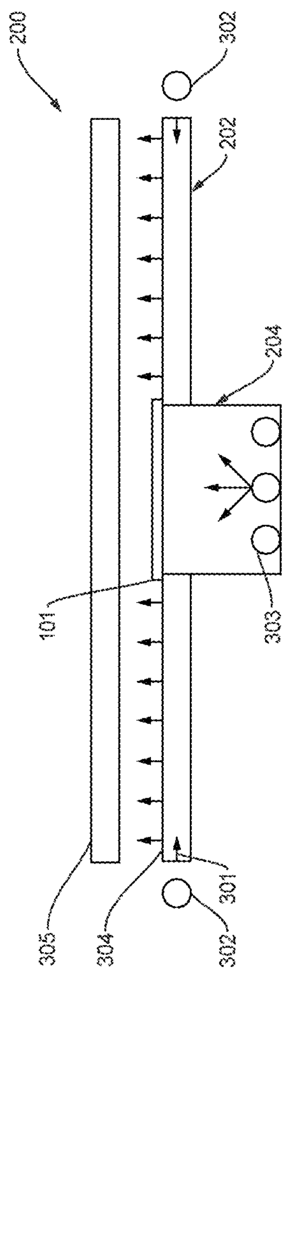


FIG. 4

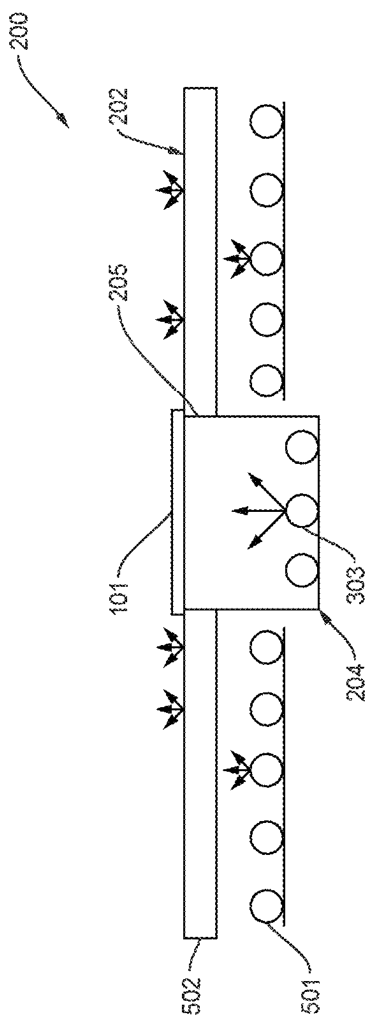


FIG. 5

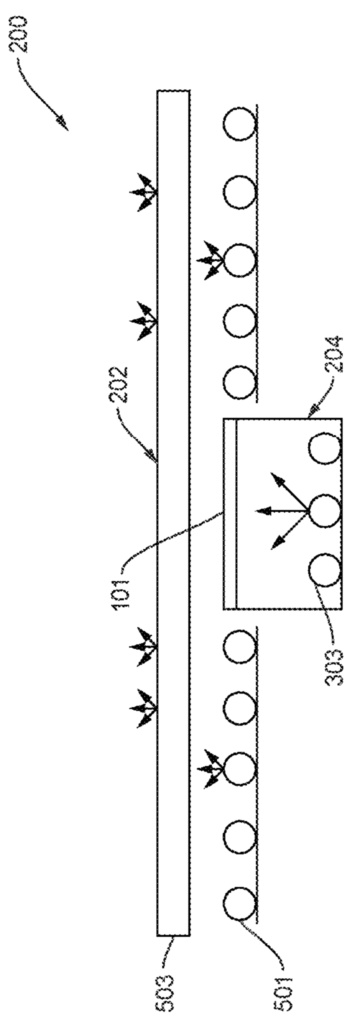


FIG. 6

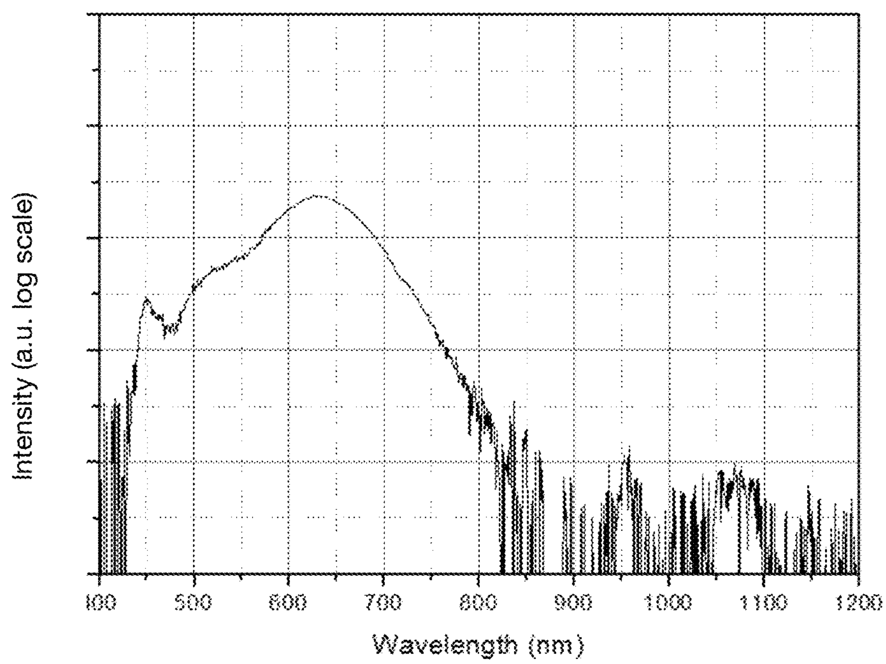

Intensity (a.u. log scale)
400
500
600
700
800
900
1000
1100
1200
Wavelength (nm)

FIG. 7

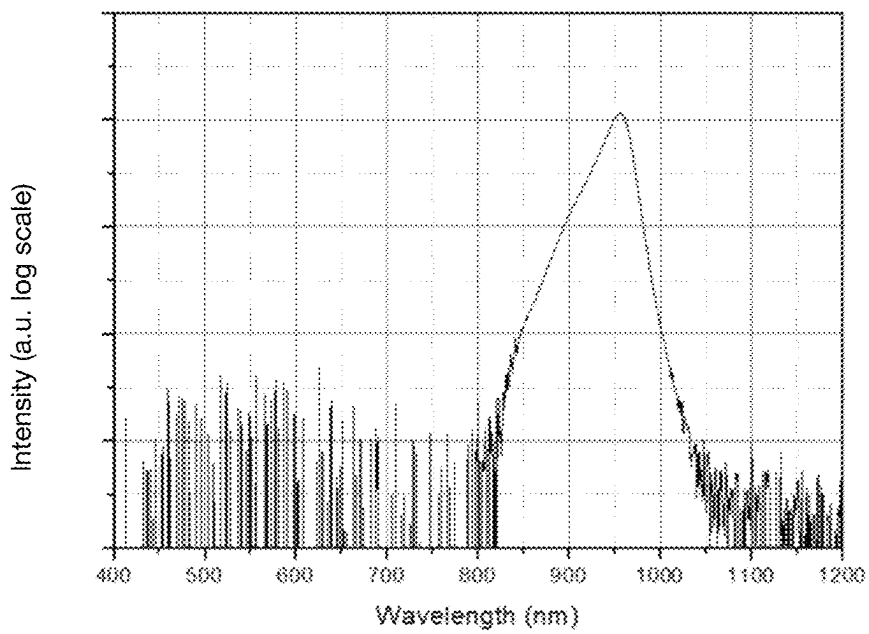

Intensity (a.u. log scale)
400
500
600
700
800
900
1000
1100
1200
Wavelength (nm)

FIG. 8

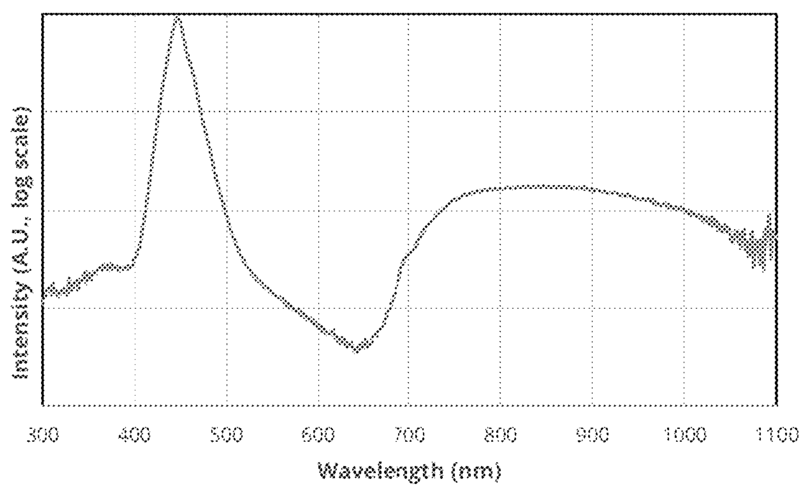

Intensity (A.U., log scale)
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)

FIG. 9

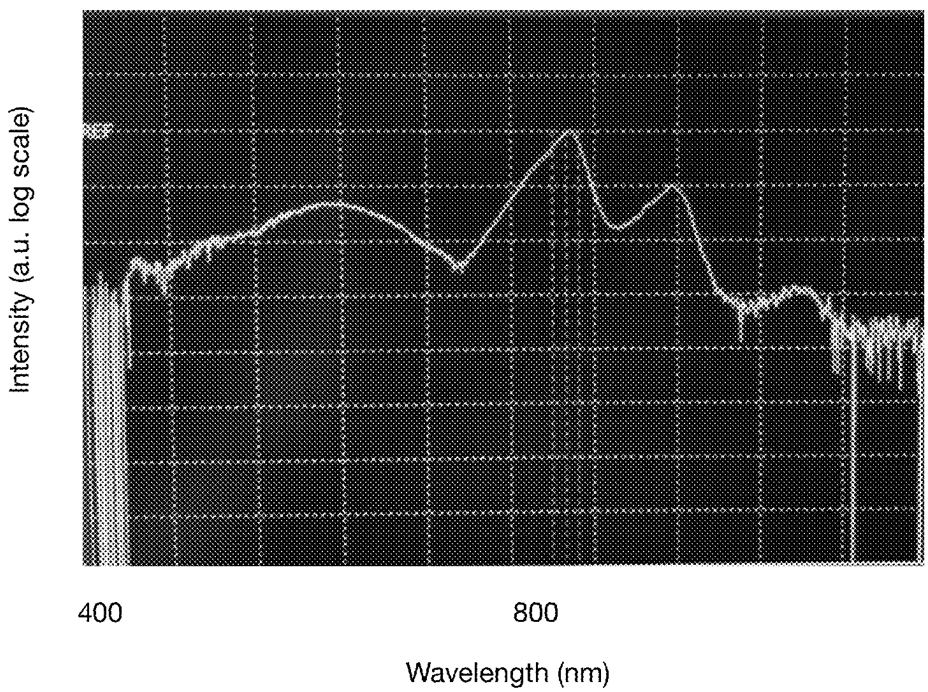


FIG. 10

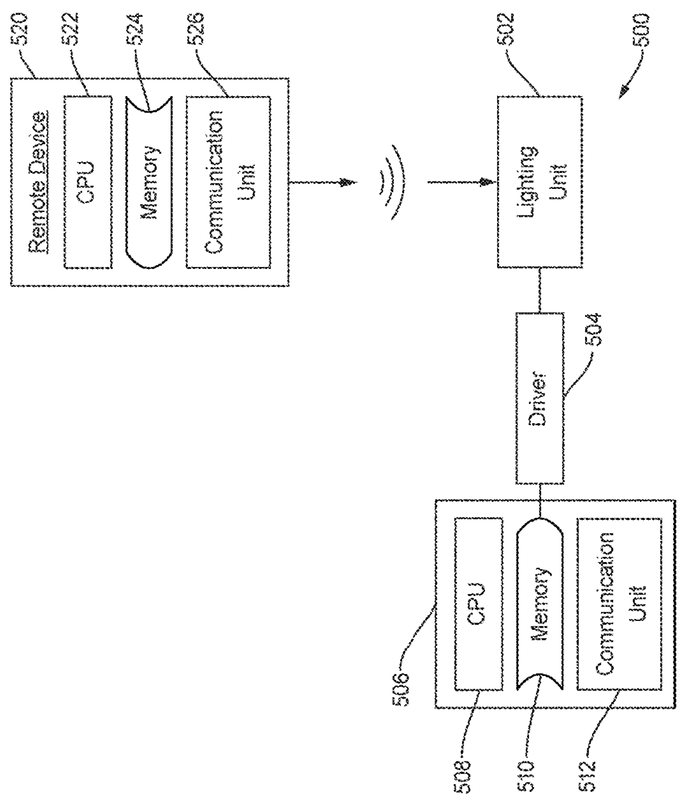

520
522
524
526
Remote Device
CPU
Memory
Communication Unit
502
500
Lighting Unit
504
Driver
506
CPU
Memory
Communication Unit
508
510
512

FIG. 11

ARTIFICIAL SUNLIGHT LIGHTING LUMINAIRES FOR INDOOR ENVIRONMENTS

FIELD OF THE INVENTION

The present invention pertains to the field of lighting luminaires designed to faithfully replicate the visual and spectral qualities of sun and the sky within indoor spaces. Specifically, the invention encompasses a lighting system and luminaire engineered to closely mimic the appearance and spectral characteristics of the Sun and Sky throughout the day.

BACKGROUND TO THE INVENTION

Contemporary indoor environments often lack access to natural sunlight and the dynamic visual and spectral experiences it provides. This deficiency can have adverse effects on human health and well-being, leading to a demand for lighting systems capable of reproducing the Sun's and Sky's visual and non-visual effects.

PURPOSE OF THE INVENTION

The present invention addresses this need by introducing a lighting system and luminaire designed to simulate the visual and spectral qualities of the Sun and Sky, enhancing the indoor environment's health benefits.

DESCRIPTION OF THE INVENTION

This innovation utilizes a multitude of light emitters arranged to emit light closely resembling natural sunlight. The emitted light has an adjustable correlated color temperature (CCT) spanning from 1900 K to 6500 K, replicating the Sun's appearance at different times of the day.

To achieve accuracy in spectral matching, the lighting system operates within a limited wavelength range of 400 nm to 1400 nm, emulating the Sun's spectral output. Furthermore, at least one light emitter with a wavelength falling within the range of 760 nm to 1400 nm is integrated into the system to ensure faithful representation.

The invention also includes a luminaire equipped with a panel that interacts with the plurality of light emitters. This panel is adept at emitting color-tunable light and simulating a variety of sky scenes, effectively expanding the lighting system's capabilities to encompass the Sky's appearance.

To facilitate control and customization, a dedicated control system is integrated into the luminaire, enabling precise adjustment of the correlated color temperature and spectral power distribution. This control system provides the capability to replicate the appearance and spectrum of the Sun and Sky throughout the day.

Additionally, to cater to user preferences and specific indoor environments, the luminaire is equipped with a user interface for adjusting its settings. This user-friendly interface ensures that the lighting experience can be tailored to meet individual needs.

BRIEF DESCRIPTION OF THE FIGURES

Further aspects and embodiments of the invention are detailed in the accompanying drawings and subsequent description. These aspects and embodiments are illustrative and not limiting, representing various potential applications of the invention.

FIG. **1** depicts a schematic representation of a exemplary lighting system as described in the disclosed embodiments.

FIG. **2** provides a cross-sectional perspective of a lighting system, as per the disclosed embodiments, wherein an edge-lit panel serves as the color-tunable light emitting panel.

FIG. **3** presents a cross-sectional perspective of an alternative embodiment of the lighting system shown in FIG. **2**.

FIG. **4** showcases another alternative embodiment of the lighting system as described in the disclosed embodiments.

FIG. **5** presents a cross-sectional view of a lighting system in accordance with another alternative embodiment, featuring a back-lit-type color-tunable light-emitting panel.

FIG. **6** depicts a cross-sectional view of an alternative embodiment of the lighting system shown in FIG. **5**.

FIG. **7** shows a plot representing an example spectral profile for a tunable white-light light emitting diode (LED) light source.

FIG. **8** presents a plot depicting an example spectral profile for an infrared light-emitting diode (LED).

FIG. **9** displays a plot illustrating the typical normalized power versus wavelength for a broadband infrared emitter.

FIG. **10** showcases a plot depicting the typical normalized power versus wavelength for an artificial sunlight luminaire.

FIG. **11** presents a schematic diagram of an LED luminaire in accordance with the disclosed embodiments.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to specific embodiments of the present invention. Examples of these embodiments are illustrated in the accompanying drawings. Numerous specific details are set forth to provide a thorough understanding of the present invention. While the embodiments will be described in conjunction with the drawings, it will be understood that the following description is not intended to limit the present invention to any one embodiment. On the contrary, the following description is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the appended claims.

The disclosed embodiments provide lighting systems to provide simulated natural sunlight in rooms, offices, and other indoor locations. As natural sunlight is essential for human beings and provides important benefits to human physical and mental health, indoor lighting systems according to the disclosed embodiments are crucial for those who do not go outdoors much due to their work or lifestyle, or those who live in regions where the day is shorter or the climate does not provide enough sunlight. According to the disclosed embodiment, the color temperature and intensity of the lighting system's light may vary based on the time of day or year and the geographic locations according to settings selected by users. For example, a user may program the lighting system to function like natural sunlight in a tropical place, even if they actually live at a high-latitude location.

In addition, the lighting systems and luminaires according to the disclosed embodiments are capable of reproducing natural light without emitting harmful ultraviolet radiation. They can simulate a sunny sky scene throughout the day, encompassing both visual and non-visual effects. This capability allows users to perceive sunny sky scenes indoors, fostering a sense of connection to nature, happiness, and overall well-being.

FIG. **1** presents an exemplary lighting system aligned with the disclosed embodiments. Within FIG. **1**, the lighting system denoted as **100** encompasses a color-tunable light-emitting panel, numbered **102**, designed to emulate a sky, a tunable white light engine, designated as **104**, simulating a sun, and a control device denoted as **106**, which oversees the regulation of both the light engine **104** and the light-emitting panel **102**. The color-tunable light-emitting panel **102** may take the form of either an edge-lit or back-lit panel, or even an Organic Light Emitting Diodes (OLEDs) panel. Within the light engine **104**, there is a minimum of one light source **103**, consisting of an array of light-emitting diodes (LEDs) thoughtfully arranged within an optical cavity **107** contained within the light engine **104**.

Additionally, the lighting system **100** includes an optical element **101**, strategically positioned in front of the light engine **104**. The color-tunable light-emitting panel **102**, whether edge-lit or back-lit, features an aperture **105**. The tunable white light engine **104** can be attached to or inserted into this aperture **105**.

The control device **106** serves as the central coordinator for the light emitters, ensuring the creation of the desired color, intensity, and pattern to effectively replicate the characteristics of sunlight at any given time of day or year.

As depicted in FIG. **1**, the light emitting panel **102**, light engine **104**, optical element **101**, and controlling device **106** are presented as distinct components. However, it's important to note that the disclosed embodiments are not confined to this specific configuration. For instance, the light engine **104** could be positioned inside the aperture **105** of the light emitting panel **102** or mounted around it. It's also possible for the light engine **104** and controlling device **106** to be integrated into a single unit. Furthermore, a single diffuser, such as optical element **101**, might be incorporated directly on the top surface of the light emitting panel **102**.

Moreover, the controlling device **106** can be a separate entity, capable of wireless and remote connectivity with both the light engine **104** and light emitting panel **102**, without being an integral part of the lighting system **100**. Essentially, any combination of these elements that forms a lighting system and luminaire with the ability to replicate natural light and simulate sunny sky scenes throughout the day, encompassing both visual and non-visual effects, falls under the purview of the disclosed embodiments.

FIG. **2** presents a cross-sectional view of lighting system **200**, as outlined in the disclosed embodiments. In this configuration, color-tunable light emitting panel **202** is designed as an edge-lit panel. Within FIG. **2**, the tunable white light engine **204** is equipped with a tunable white light source **303**, offering adjustable Correlated Color Temperature (CCT) to effectively replicate direct sunlight throughout the day.

The tunable light source is engineered using multiple controllable channels of white LEDs to precisely regulate the color temperature of the white light output within a range spanning from 1900 K to 6500 K. These channels in a tunable white light source may all emit white light but with varying color temperatures, or in combination with one channel of amber LEDs. The tunable light source **303** can be constructed from various combinations of multi-channel colored LEDs.

In one embodiment, a 2-channel white LED array is employed within light engine **204**. Such a two-color LED array comprises numerous LEDs of a first color temperature (warm white) and multiple LEDs of a second color temperature (cool white). The white LEDs in the first channel emit white light with a color temperature of approximately 2700K, remaining within five MacAdams ellipses of the Black Body Curve. In the second channel, the white LEDs emit white light with a color temperature of approximately 6500K, also within five MacAdams ellipses of the Black Body Curve.

In another embodiment, a 3-channel (three-color LED array) configuration is used. This includes an array of greenish-white LEDs with a peak wavelength around 550 nm (which may vary from about 505 nm to about 550 nm), several cool white LEDs featuring a color temperature of approximately 6500K within five MacAdams ellipses of the Black Body Curve, and a third group of amber LEDs with a peak wavelength of about 625 nm added to the mix, thus expanding the gamut sufficiently to encompass the Black Body Curve over the desired range.

Tunable white light engine **204** is integrated into aperture **205** from the rear side of light emitting panel **202**, while optical element **101** is affixed to the front surface of light engine **204**, serving as the light-emitting surface. Within the light engine **204**'s optical cavity **207**, multiple controllable channels of white LEDs from tunable white light source **303** are positioned to emit light towards the light-emitting surface **101**.

Given that the color-tunable light emitting panel **202** is designed in an edge-lit style, it incorporates a multitude of LEDs **302** positioned along the edges of a light guide **301**. These LEDs **302** function as light sources for the color-tunable light emitting panel **202**. Additionally, the color-tunable light emitting panel **202** includes a light output window, denoted as light out-coupling structures **304**, on its front (or top) side, a light input window **312** adjacent to the LEDs **302**, and a reflective surface or reflector **314** on its rear (or bottom) side.

The light guide receives light emitted by the plurality of LEDs **302** via the light input window **312**, and this light propagates in guided mode within the guide **301**. The plurality of LEDs **302** may consist of, for example, a linear stripe of color-tunable RGB or RGBA or RGBW LEDs. These LEDs **302** can be individually adjusted in output to create the desired color, intensity, and pattern. The light guide can be constructed from light-transmitting materials such as glass, silicone, or polycarbonate (PC).

The out-coupling structure, also known as the light output window **304**, may have a rough surface or can be formed by applying diffusely reflective paint onto the surface of the light guide **301**. This allows for the uniform distribution of light received from the light guide **301** along the surface of the light output window **304**. In an alternative configuration, the surface of the light output window **304** may be adorned with surface microstructures, such as dot patterns, designed to diffuse the light emitted from the light guide **301**.

In another alternative embodiment, the out-coupling structure **304**, combined with the reflector **314**, can be implemented on the rear surface of the light guide **301**. In this scenario, the lighting system **200** includes an additional diffusing film attached to the front surface of the color-tunable light emitting panel **202**.

In yet another alternative embodiment, a linear stripe of color-tunable RGB or RGBA or RGBW LEDs may be positioned adjacent to the tunable white light engine **204**, affixed to an inner edge of the light guide **301**.

Furthermore, the color-tunable light emitting panel **202** may be constructed using OLED (organic LED) technology. An OLED panel has the capability to generate diffused light with controlled color, intensity, and pattern.

FIGS. **3-4** depict alternative configurations of lighting system **200** as presented in FIG. **2**, featuring an edge-lit color-tunable light emitting panel **202**. In FIG. **2**, the tunable white light engine **204** is inserted into the aperture **205** on the rear surface of the color-tunable light emitting panel **202**. However, in FIG. **3**, the tunable white light engine **204**, accompanied by an optical element **101**, is positioned behind the light guide **301**. In this arrangement, a smooth surface region on the rear side of the light guide **303** faces the tunable white light source **303**.

FIG. **4** presents an alternative embodiment of lighting system **200**. According to the disclosed embodiments, a single diffuser **305** is positioned adjacent to the front surface of the color-tunable light emitting panel **202**. This diffuser **305** serves both the light engine **204** and the light emitting panel **202** by diffusing the light emitted from the light source **302** of the light emitting panel **202** and the light emitted from the light source **303** of the light engine **204**. It's worth noting that the use of optical element **101** may be optional in this alternative embodiment.

Diffuser **305** can take the form of a volumetric element, or its surface may be textured or coated with a diffusely reflective paint to scatter the light, achieving a diffuse illumination effect. The surface corresponding to the light guide **301** may also feature surface microstructures, such as dot patterns, to scatter the light received from the light guide **301**.

Additionally, diffuser **305** can also function as an optical element **101**. Consequently, the surface of diffuser **305** that corresponds to the light engine **204** may incorporate similar microstructures as those found in optical element **101**, as illustrated in FIG. **2**, effectively simulating natural sunlight.

The specific structure of diffuser **305** outlined above is provided for illustrative purposes and is not limited to those details. Any combinations of microstructures and materials capable of achieving the light-diffusing functions described in the disclosed embodiments fall within the scope of the present invention.

FIG. **5** presents a cross-sectional view of lighting system **200**, demonstrating alternative embodiments. In this illustration, color-tunable light emitting panel **202** adopts a back-lit style configuration. Positioned behind it are multiple LEDs **501**, which may include RGB, RGBA, or RGBW LEDs. These LEDs are arranged in conjunction with a diffuser **502**, which serves as the light emitting surface. Unlike edge-lit panels, the back-lit style eliminates the need for a light guide within the light emitting panel.

Tunable white light engine **204**, featuring optical element **101** on its front side, is inserted into aperture **205**. The tunable white light engine **204** and optical element **101** share the same functions and structures as those depicted in FIG. **2**. Therefore, detailed descriptions of these elements are omitted for brevity.

The purpose of diffuser **502** is twofold: it facilitates uniform light emission and prevents the visibility of hot spots to viewers. While the attributes of diffuser **502** have been mentioned earlier, a detailed description is omitted here for conciseness.

Moving to FIG. **6**, lighting system **200** bears resemblance to that of FIG. **5**. However, it introduces a single diffuser **503** that caters to both the color-tunable light emitting panel **202** and the tunable white light engine **204**. The characteristics of this single diffuser **503** mirror those of diffuser **305** in FIG. **4**. Thus, a comprehensive description of diffuser **503** is omitted in the interest of brevity.

As depicted in FIG. **7**, offering an illustrative spectral profile of a white-light light emitting diode (LED), scientific findings underline the advantageous effects of sunlight on human productivity, well-being, and overall health. Consequently, achieving a spectral output encompassing the wavelength range from 400 nm to 1400 nm is highly desirable. Such a broad wavelength coverage not only replicates the health-promoting attributes of natural sunlight but also eliminates harmful UV radiation, thus safeguarding user well-being."

A representative spectral profile of an infrared (IR) light emitting diode (LED) operating at a central wavelength of approximately 940 nanometers (nm) is presented in FIG. **8**. This spectral illustration serves to depict the emission characteristics of the IR LED within the near-infrared spectrum, which is utilized to simulate a portion of the sunlight spectrum. Notably, the profile showcases a prominent emission curve centered around the 940 nm wavelength, signifying the LED's ability to emit radiant energy with peak intensity in this specific wavelength range. This emission profile underscores the IR LED's suitability for generating precise IR wavelengths, thereby contributing to the faithful replication of a selected segment of the sunlight spectrum. Such capabilities are instrumental in applications where the emulation of sunlight spectral components is vital, including those related to indoor lighting systems designed to mimic natural light.

An exemplary spectral profile, as depicted in FIG. **9**, delineates the outstanding features of a continuous broadband infrared (IR) emitter. This profile underscores its impressive capabilities in delivering a seamless spectrum of IR emissions, extending from 650 to 1100 nanometers (nm), while maintaining exceptional light output characteristics. Across this expansive wavelength range, the emitter consistently and efficiently emits radiant energy, showcasing its proficiency in generating IR radiation with noteworthy intensity and precision. This spectral profile serves as compelling evidence of the broadband IR emitter's adeptness in faithfully reproducing a significant segment of the sunlight spectrum. Encompassing critical IR wavelengths essential for replicating specific spectral elements inherent to natural sunlight, this broad emission range is of paramount significance. Consequently, this emitter assumes substantial importance in applications where the faithful recreation of sunlight's spectral attributes is imperative, particularly in advanced indoor lighting systems designed to mimic the nuanced qualities of natural light.

The heart of the innovative lighting system, as illustrated in FIG. **10**, lies in its spectral profile, a key aspect of the technology presented herein. This meticulously engineered system is designed with the utmost care to faithfully replicate the entire spectrum of natural sunlight, spanning from 400 nm to 1100 nm. At its core, this system features a continuous white LED light source emitting within the range of 400 nm to 700 nm, effectively encompassing the complete visible spectrum and faithfully reproducing the radiant qualities of natural sunlight. In addition to this, the system seamlessly integrates three strategically positioned infrared LEDs, operating within the spectral range of 650 nm to 1100 nm. These constituent elements work harmoniously to generate a broadband emission characterized by superior light output attributes. Within this extensive wavelength range, the lighting system consistently and efficiently emits radiant energy, delivering unrivaled intensity and precision. This exemplary spectral profile serves as compelling evidence of the system's exceptional ability to faithfully replicate a substantial portion of the sunlight spectrum. Its adaptability and precision render it an indispensable asset across a multitude of applications where the faithful recreation of natural light's spectral characteristics is of paramount importance. Whether deployed in indoor environments or advanced lighting systems, this innovation excels in emulating the nuanced attributes of natural light, thereby reshaping the quality of illuminated spaces.

FIG. **11** presents a schematic diagram of an LED luminaire **500**, a central component of the disclosed embodiments. This innovative LED luminaire boasts the capability of establishing wireless communications with remote devices, exemplified here by remote device **520**.

In accordance with the disclosed embodiments, LED luminaire **500** encompasses a lighting unit **502**, which comprises LED-based light-emitting elements, including variations such as lighting systems **200** or light engines **204** as elucidated in FIGS. **2-6**. Augmenting this core is an LED driver **504**, responsible for energizing light engine **204** to dispense light and connect to a branch circuit (not depicted). A pivotal element is the controlling device **506**, encompassing a CPU **508**, which could be a microprocessor or microcontroller. It also incorporates a memory **510**, adept at housing data and software that the CPU **508** executes. This software assumes the critical role of regulating the operations of light unit **502**. The configuration is further fortified with a communication unit **512**, engineered to both emit and capture signals, forging connections with remote devices like remote device **520**.

Controlling device **506** itself can take the form of an embedded computing device, augmented with intrinsic wired or wireless communications capabilities. This embedded computing device manifests in various incarnations, potentially serving as a dedicated computer or processor. Its primary function entails assimilating input from a wired or wireless module and then issuing control signals to other modules and the driver.

Conversely, remote device **520** emerges as a versatile counterpart, spanning personal computers, smartphones, and similar entities. This device is endowed with a CPU **522** and a memory **524**, where executable software resides, facilitating the regulation of remote device **520**'s operations. Additionally, a communication unit **526** stands ready, facilitating seamless interaction with the communication unit **512** of controlling device **506**. This bidirectional communication empowers remote device **520** to issue commands to controlling device **506**. These commands range from the elementary, such as turning LED luminaire **500** on or off, to the sophisticated, such as altering the time zone or regions represented by LED luminaire **500**. Remote device **520** can also harness these communications to acquire various shades of natural sunlight, each characterized by distinct colors and temperatures, in line with user preferences and specific requirements.

As appreciated by those skilled in the art, the present invention can manifest in multiple embodiments, including a system, method, or computer program product. These embodiments encompass entirely hardware-based configurations, entirely software-based implementations (comprising firmware, resident software, microcode, etc.), or hybrid embodiments that amalgamate software and hardware elements, generically referred to as a "circuit," "module," or "system" herein. Furthermore, this innovation can exist as a computer program product, residing in any tangible medium of expression possessing computer-usable program code.

In practice, various computer-usable or computer-readable media may find application, including electronic, magnetic, optical, electromagnetic, infrared, or semiconductor systems, devices, apparatuses, or propagation mediums. Exemplary media comprise electrical connections with one or more wires, portable computer diskettes, hard disks, random access memory (RAM), read-only memory (ROM), erasable programmable read-only memory (EPROM or Flash memory), optical fibers, portable compact disc read-only memory (CD-ROM), optical storage devices, transmission media supporting the Internet or an intranet, or magnetic storage devices. Notably, the computer-usable or computer-readable medium might even include paper or another suitable substrate onto which the program is printed. These tangible forms facilitate the electronic capture of the program, for instance through optical scanning, and subsequent compilation, interpretation, or processing, as needed, followed by storage in a computer memory.

Computer program code tasked with executing the operations of the present invention can be composed in a variety of programming languages. This span encompasses object-oriented languages such as Java, Smalltalk, C++, or similar choices and conventional procedural languages like the "C" programming language and its analogs. The program code can execute exclusively on a user's computer, partially on a user's computer, serve as a stand-alone software package, partially run on the user's computer and partially on a remote computer, or operate entirely on a remote computer or server. In this latter scenario, the remote computer may connect with the user's computer via various networks, encompassing local area networks (LANs) or wide area networks (WANs), or through external computers, such as via the Internet facilitated by an Internet Service Provider.

It is vital to underscore that the terms "comprises" and "comprising," when employed in this context, specify the presence of declared features, integers, steps, operations, elements, and/or components, but do not preclude the inclusion or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. In summary, embodiments might materialize as a computer process, a computing system, or an article of manufacture, such as a computer program product on computer-readable media. This computer program product could be a computer storage medium, readable by a computing system, and encoding program instructions for executing a computer process. Once accessed, these instructions instruct a processor to facilitate the functionalities disclosed herein.

Finally, it should be understood that the structure, materials, acts, and equivalents of all elements referred to as "means" or "steps" in the claims below encompass any structure, material, or act to perform the specified function, either in conjunction with other claimed elements or as stand-alone entities. This description, while comprehensive, is intended for illustrative and explanatory purposes and does not exhaustively detail all possible modifications or variations. Modifications and variations apparent to those of ordinary skill in the art, without straying from the essence and scope of the invention, are deemed to fall within the appended claims.

Without further elaboration, it is believed that one skilled in the art can, using the preceding description, utilize the present invention to its fullest extent. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever.

In the foregoing and in the examples, all temperatures are set forth uncorrected in degrees Celsius and, all parts and percentages are by weight, unless otherwise indicated.

The entire disclosures of all applications, patents and publications, cited herein and of corresponding Finnish application No. 20237160, filed Sep. 24, 2023, are incorporated by reference herein.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.

What is claimed is:

1. A lighting luminaire, comprising:

a plurality of channels of a white visible light emitter array (**303**) configured to mimic sunlight, wherein each channel has a distinct correlated color temperature, and wherein a white light output of each channel has a spectral range between 400 nm and 750 nm;

one channel of a plurality of infrared light emitters (**103**) configured to mimic infrared light emission of sunlight; and

a controller (**506**) configured to coordinate a light output of a tunable white light engine and the infrared light emitters to emulate a spectrum and an intensity of natural sunlight throughout a day.

2. The lighting luminaire of claim **1**, wherein a diffuser (**101**) is disposed in front of the white visible light emitter array.

3. The lighting luminaire of claim **1**, wherein one channel of the plurality of infrared light emitters is at least one continuous broadband light emitter with wavelengths ranging from 650 nm to 1100 nm.

4. The lighting luminaire of claim **1**, wherein the controller is configured to receive user input via a remote device (**520**).

5. The lighting luminaire of claim **1**, wherein the controller is a separate element that can be wirelessly and remotely connected with the lighting luminaire.

6. The lighting luminaire of claim **1**, further comprising a wireless communication module for connecting the lighting luminaire to a network and enabling remote control via a mobile device or computer.

7. The lighting luminaire of claim **1**, further comprising a color-tunable light emitting panel (**202**), integrally coupled to the luminaire, configured to emit light with a selected color and pattern.

8. The lighting system of claim **7**, wherein the color-tunable light emitting panel is an edge-lit type.

9. The lighting system of claim **7**, wherein the color-tunable light emitting panel is a back-lit type.

10. The lighting system of claim **7**, wherein the color-tunable light emitting panel is an organic light emitting diode panel.

11. The lighting system of claim **7**, further comprising a controller configured to coordinate a light output of a tunable white light and infrared light engine and a color-tunable light emitting panel to emulate sunny sky scenes throughout the day.

12. The lighting system of claim **7**, further comprising a communication interface for receiving external commands to adjust the white light output of the light engines and the color tunable light emitting panel.

13. A method of manufacturing a lighting luminaire, comprising the following steps:

providing a white visible light engine comprising a plurality of channels of a white visible light emitter array (**303**), wherein each channel having a distinct correlated color temperature and a spectral range between 400 nm and 760 nm, configured to emulate part of a spectrum and an intensity of natural sunlight such that the correlated color temperature of a resulting white light output is within a range from 1900K to 6500K;

integrating one channel of a plurality of infrared light emitters (**103**) configured to mimic infrared light emission of sunlight; and

installing a controller (**506**) configured to control the lighting luminaire to emulate a spectral power density and intensity of natural sunlight according to a predetermined schedule or a user input.

14. The method of claim **13**, further comprising providing a remote device (**520**) operably connected to the controller and configured to allow a user to adjust settings of the luminaire according to user preferences.

15. The method of claim **13**, further comprising integrally coupling a color tunable light emitting panel (**202**) to the light engine and configuring it to emulate diverse sky scenes.

16. A lighting luminaire comprising:

one channel of a tunable white light source (**303**) that emits visible light with a correlated color temperature adjustable within a range from 1900 K to about 6500 K to mimic spectral output of natural sunlight;

one channel of at least one infrared light emitter configured to emit infrared light with an emission spectrum in a range of 650 nm to 1400 nm; and

a controller (**506**) configured to coordinate light output of the tunable white light source and the at least one infrared emitter to simulate spectral power distribution and intensity of natural sunlight throughout a day.

17. The lighting luminaire of claim **16**, wherein the tunable white light source comprises a plurality of channels, each channel comprising at least one white visible light emitter, and wherein each channel emits the visible light at a distinct correlated color temperature.

18. The lighting luminaire of claim **16**, wherein the controller (**506**) is further configured to modulate the light output of the tunable white light source and the at least one infrared light emitter to simulate the spectral power density and intensity of natural sunlight over time, based on either a predetermined schedule or in response to a user input.

19. The lighting luminaire of claim **16**, further comprising a wireless communication module configured to connect the lighting luminaire to a network.

20. The lighting luminaire of claim **16**, further comprising a color-tunable light emitting panel (**202**) integrally coupled to the luminaire, wherein the panel is configured to emit light having a selected color or pattern.

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