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(54) **DISINFECTION DEVICE AND METHOD**

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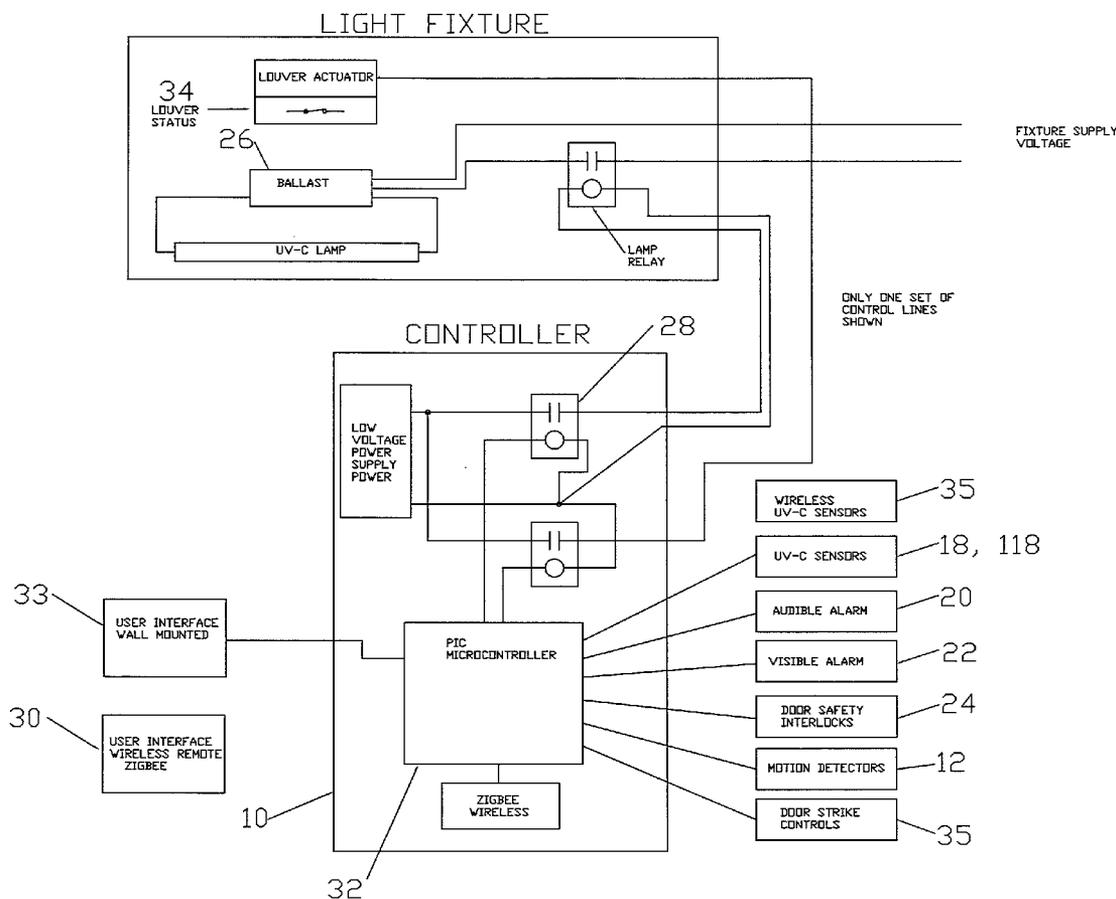
(57) **ABSTRACT**

An ultraviolet area sterilizer or disinfecter is incorporated into a building structure where concern exists regarding the presence of pathogenic bacteria on environmental surfaces. Ultraviolet C (UV-C) generators generate UV-C that is directed to architectural partitions of an enclosed area. The architectural partitions reflect UV-C to kill pathogens in the enclosed area. The device transmits a calculated dose of UV-C from a fixture mounted to an architectural partition in the enclosed area. Once an effective cumulative dose of UV-C has been reflected to radiation sensors, as measured by the sensors, the device shuts down. The device allocates power to specific UV-C emitters so as to direct UV-C radiation more uniformly throughout the area, as measured by the sensors.

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 12/361,810, filed on Jan. 29, 2009, now Pat. No. 8,067,750.

(60) Provisional application No. 61/024,373, filed on Jan. 29, 2008, provisional application No. 61/083,590, filed on Jul. 25, 2008.



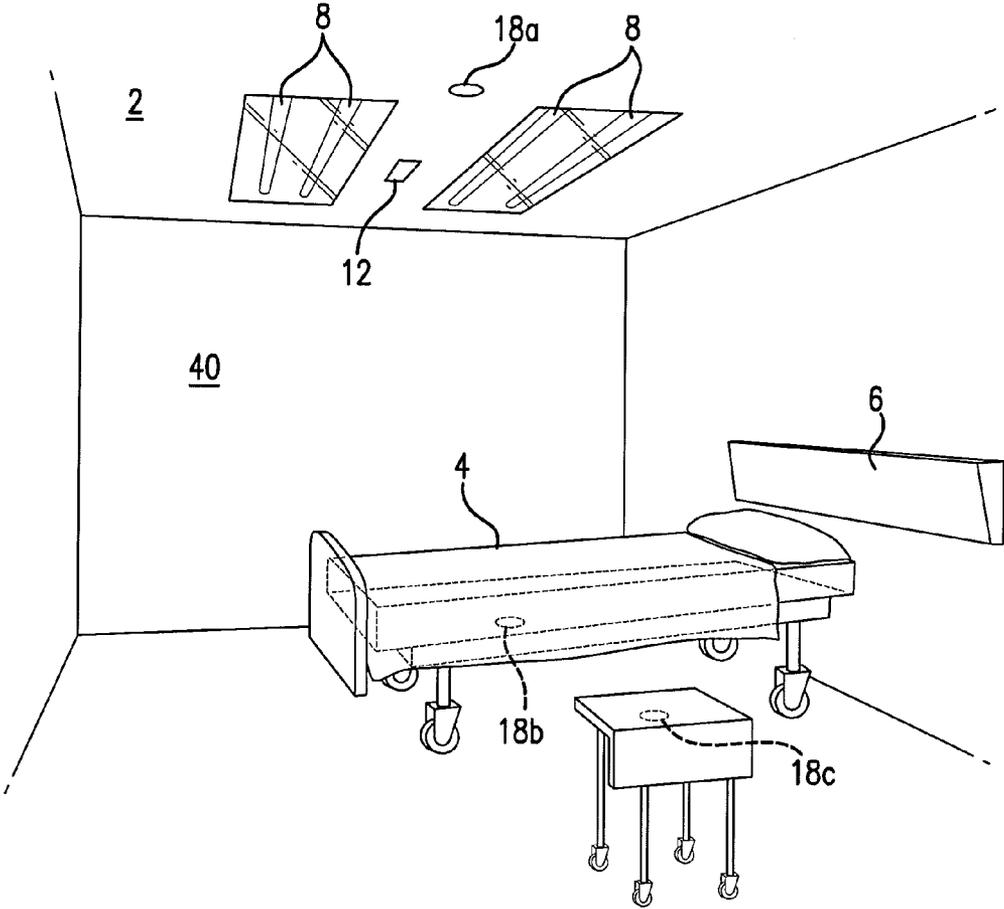


FIG. 1

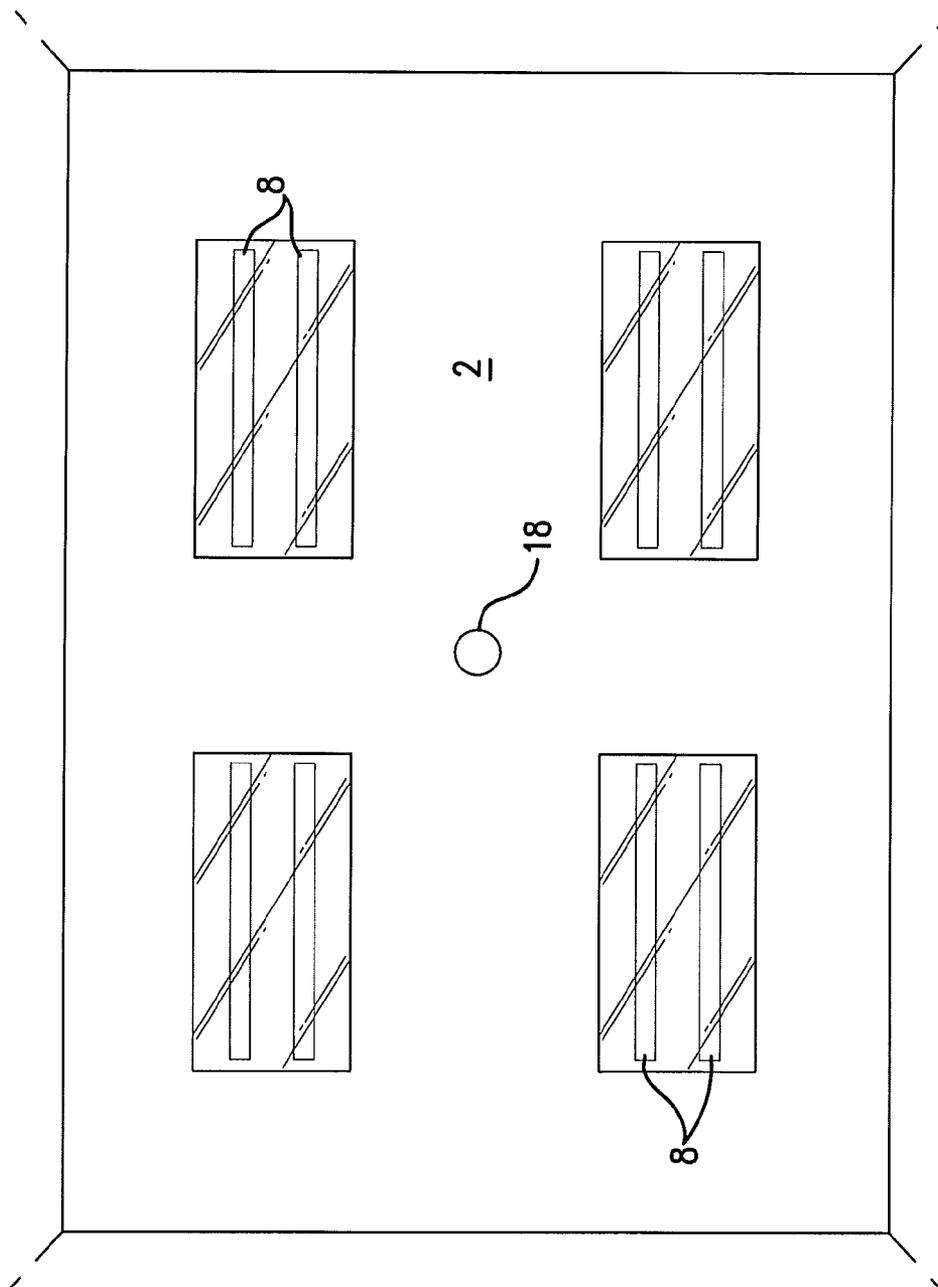


FIG. 2

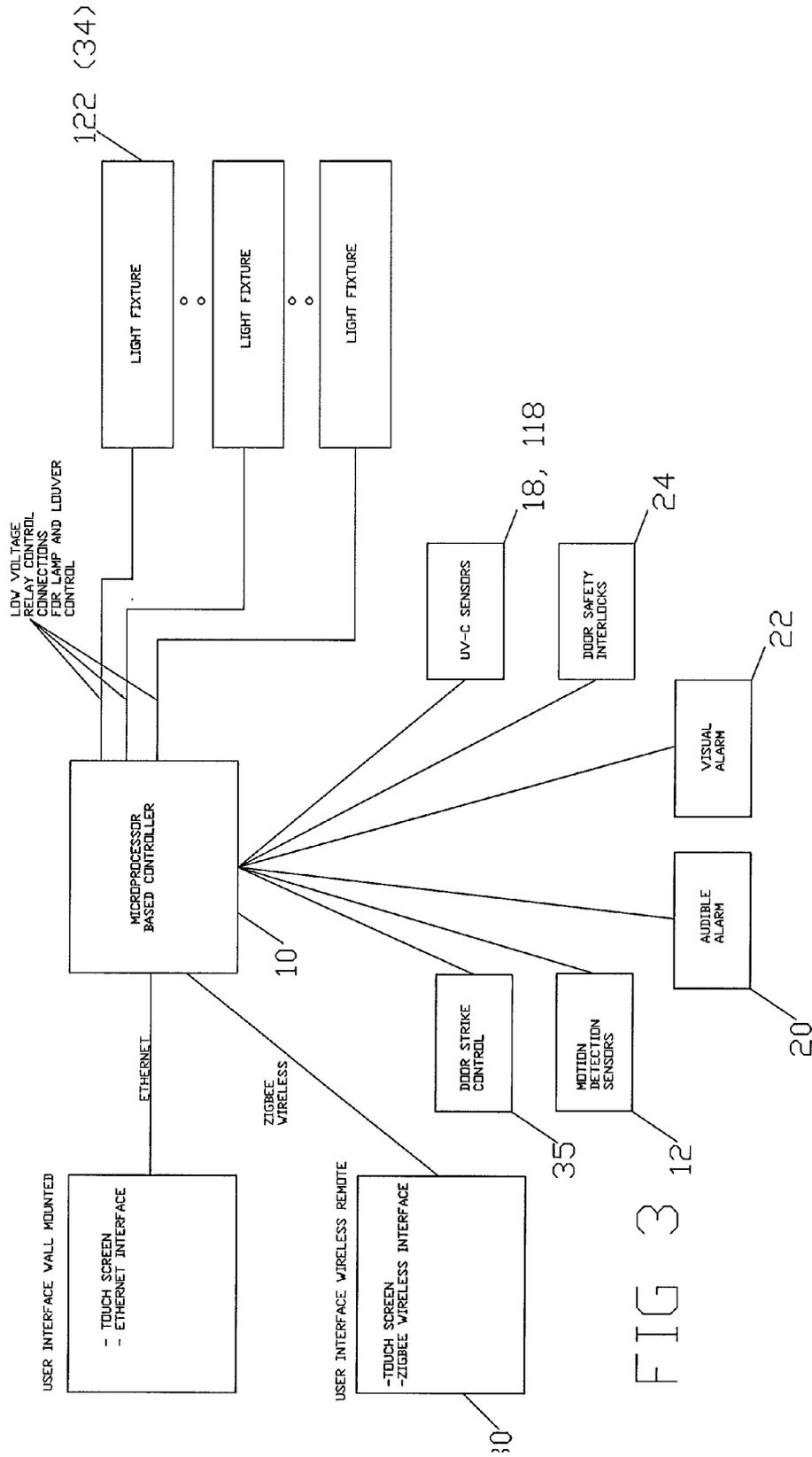
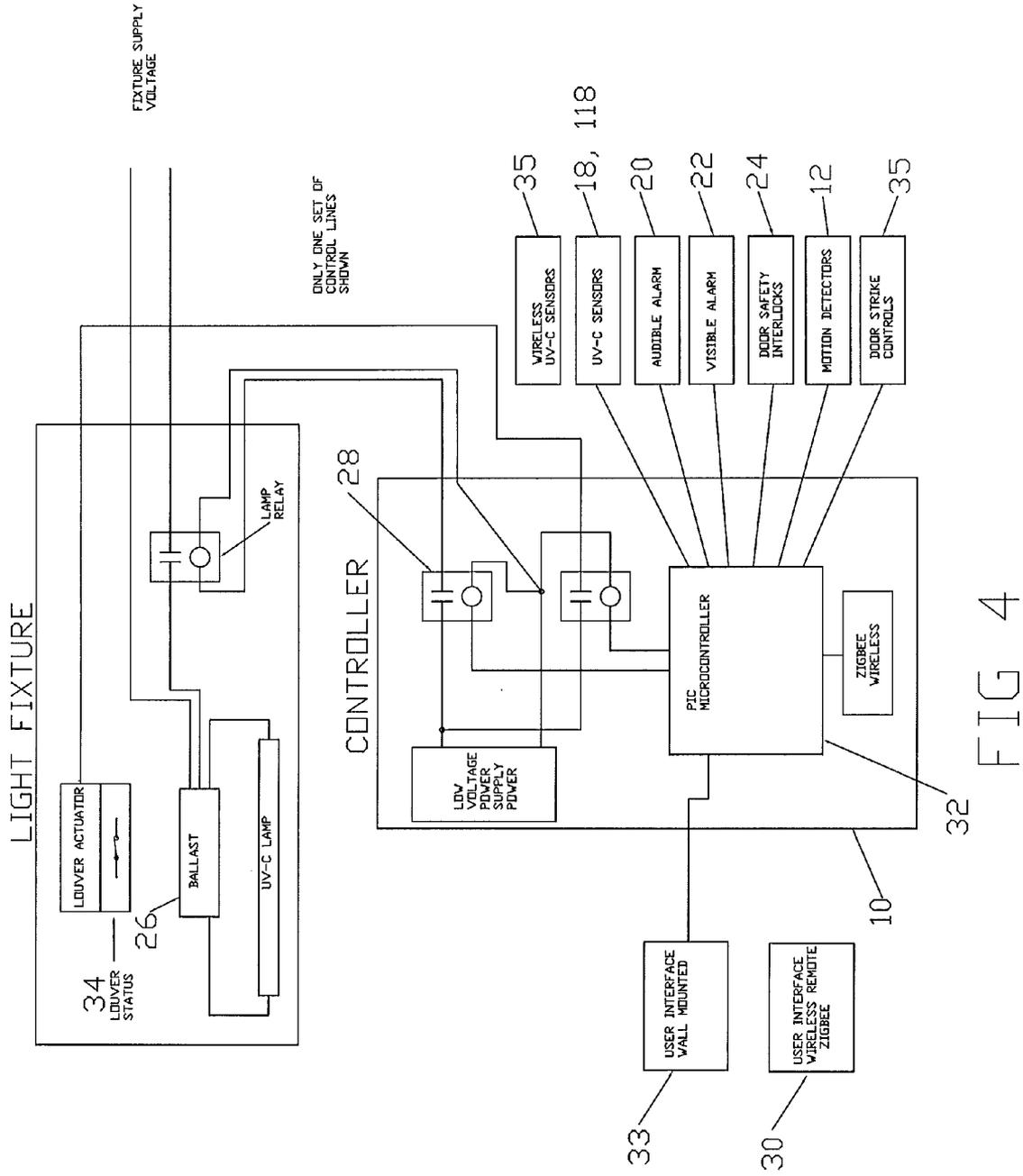


FIG 3 12



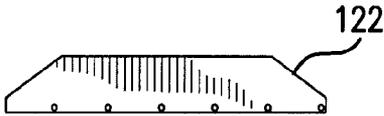


FIG. 5A

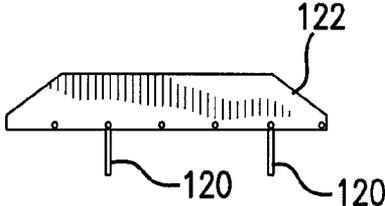


FIG. 5B

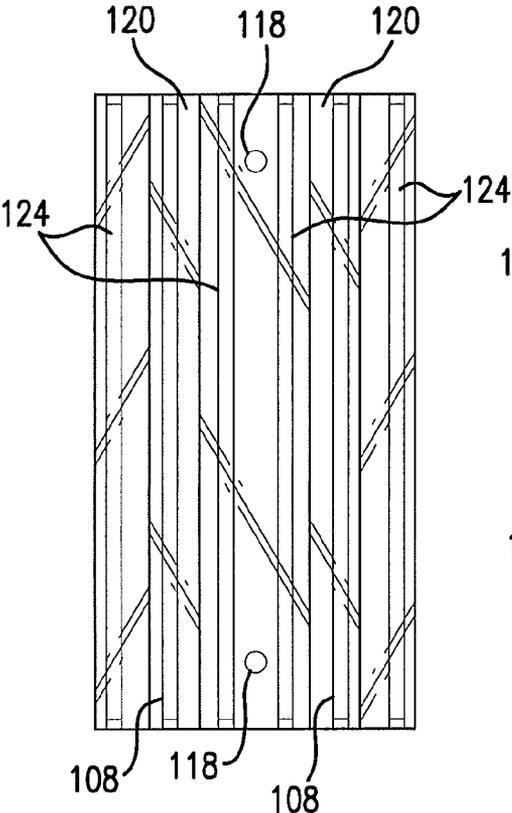


FIG. 6A

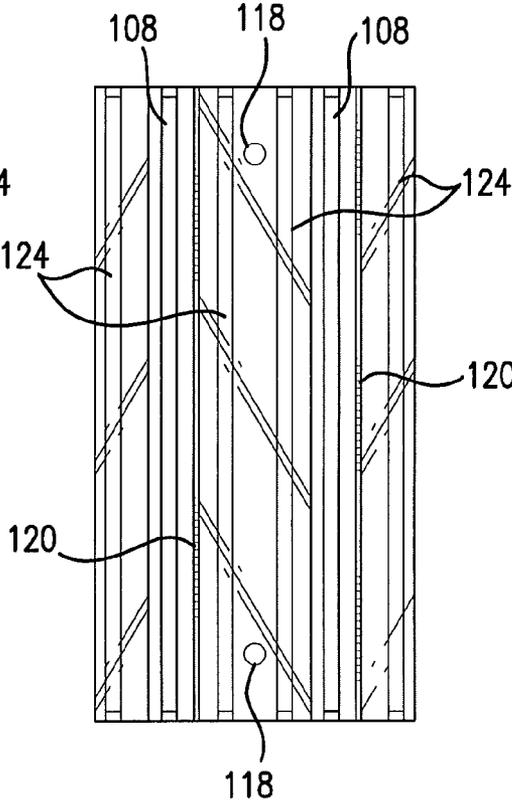


FIG. 6B

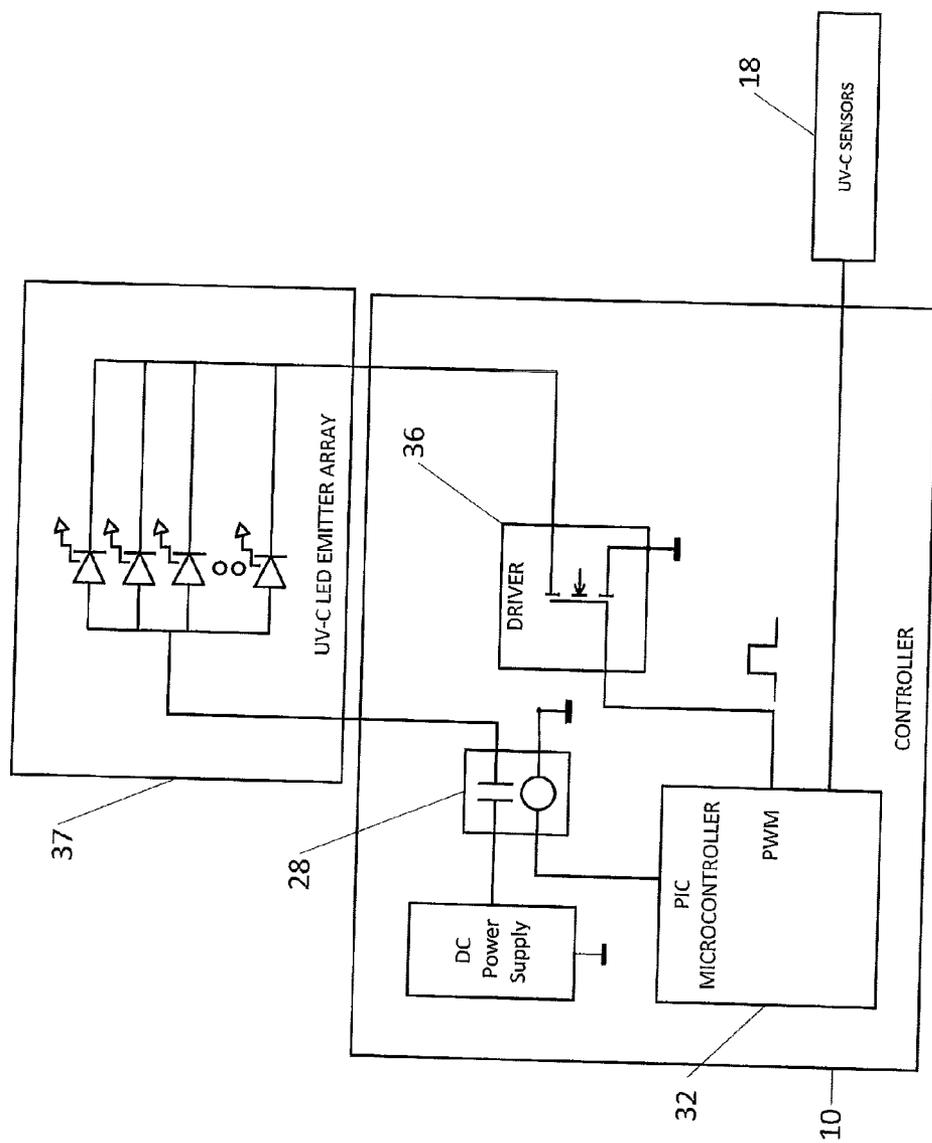


FIG. 7

## DISINFECTION DEVICE AND METHOD

**[0001]** This application is a continuation in part of application Ser. No. 12/361,810 filed Jan. 29, 2009, which claims priority from provisional application Ser. No. 61/024,373, filed Jan. 29, 2008; and provisional application Ser. No. 61/083,590, filed Jul. 25, 2008, and in which Applicant claims priority.

### FIELD OF THE INVENTION

**[0002]** This invention relates to methods and devices for bacterial, fungal and/or viral sterilization and disinfection, and is more particularly directed to a method and device for disinfecting rooms and similar enclosed areas.

### BACKGROUND OF THE INVENTION

**[0003]** Nosocomial, or hospital acquired, infections are common, costly, and sometimes lethal. A recent review of such infections in the cardiac surgery unit of a major hospital revealed a nosocomial infection rate of 27.3% that more than doubled the mortality rate for afflicted patients. The nature of bacteria acquired in the hospital setting differs significantly from bacteria found in a community setting primarily in their resistance to antibiotic therapy.

**[0004]** “Historically, staphylococci, pseudomonads, and *Escherichia coli* have been the nosocomial infection troika; nosocomial pneumonia, surgical wound infections, and vascular access-related bacteremia have caused the most illness and death in hospitalized patients; and intensive care units have been the epicenters of antibiotic resistance. Acquired antimicrobial resistance is the major problem, and vancomycin-resistant *Staphylococcus aureus* is the pathogen of greatest concern. The shift to outpatient care is leaving the most vulnerable patients in hospitals. Aging of our population and increasingly aggressive medical and surgical interventions, including implanted foreign bodies, organ transplantations, and xenotransplantation, create a cohort of particularly susceptible persons. Renovation of aging hospitals increases risk of airborne fungal and other infections.

**[0005]** Significant morbidity, mortality, and costs are associated with these infections. Many factors contribute to these dangerous infections. Most notably is the overuse of antibiotics and poor personal hygiene such as hand washing. Abundant evidence exists, however, that the hospital environment itself contributes to the problem by harboring virulent strains of bacteria, fungi, and viruses, and that many methods commonly used are ineffective and may actually spread contaminants.

**[0006]** Attempts to eradicate surface contaminants from the hospital setting have varied greatly in strategy and success. These have ranged from antiseptic soaps to fumigation with formaldehyde gas. Topical antiseptics are problematic for several reasons. First, they have recently been shown to actually induce antibiotic resistances and thus may be adding to the problem. Secondly, many surfaces such as keyboards, television sets, and monitoring controls are difficult if not impossible to decontaminate with liquid disinfectants without harming the electronics. Gas disinfection, while effective, is time consuming, hazardous to workers, and environmentally unwise.

**[0007]** Ultraviolet (UV) light has been long used for disinfection and sterilization. Ultraviolet light may be produced

artificially by electric-arc lamps. Recently, the widespread availability of low to medium pressure mercury bulbs has led to the development of devices which use UV-C to decontaminate water supplies. UV-C is a high frequency wavelength of light within the ultraviolet band and has been shown to be the most bactericidal type of ultraviolet light. UV-C has wavelengths of about 2800 Å to 150 Å. To date, there are no published efforts to use UV-C to decontaminate or disinfect larger areas such as operating rooms. The only recent availability of the appropriate bulbs as well as significant safety concerns regarding worker exposure to UV-C likely contribute to the lack of efforts to use UV-C outside of self-contained water purification systems.

### SUMMARY OF THE INVENTION

**[0008]** An ultraviolet area sterilizer or disinfecter for use [pl]where concern exists regarding the presence of pathogens on environmental surfaces. Ultraviolet C (UV-C) generators generate UV-C radiation that is directed into an enclosed area. The direct and reflected UV-C radiation kills pathogens in the enclosed area. The device transmits a calculated dose of UV-C radiation in the enclosed area. Once an effective cumulative dose of UV-C radiation has been reflected to radiation sensors, as measured by the sensors, the device shuts down. The device allocates power to specific UV-C emitters so as to direct UV-C radiation more uniformly throughout the area, as measured by the sensors.

### DESCRIPTION OF THE DRAWINGS

**[0009]** FIG. 1 is a perspective view of a medical facility room incorporating the invention.

**[0010]** FIG. 2 is a plan view of an array of bulbs.

**[0011]** FIG. 3 is a schematic of the device.

**[0012]** FIG. 4 is a schematic of the controls of the device.

**[0013]** FIG. 5A is an elevation of a lighting fixture that incorporates UV-C bulbs.

**[0014]** FIG. 5B shows the fixture of FIG. 5A with louvers in an open position for actuation of the bulbs.

**[0015]** FIG. 6A is a bottom plan view of a lighting fixture that incorporates UV-C bulbs

**[0016]** FIG. 6B shows the fixture of FIG. 6A with louvers in an open position for actuation of the bulbs

**[0017]** FIG. 7 is a schematic of a pulse width modulation control of a light emitting diode (LED) UV-C bulb.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

**[0018]** The examples given in the discussion of preferred embodiments are fixtures to buildings or rooms to buildings. However, the elements of the device as described herein may also be incorporated in a mobile device that is portable. A portable device is described in Deal, U.S. Pat. No. 6,656,424. The power allocation devices and methods as described herein are useful with fixed and portable devices and methods of ultraviolet-C (UVC) disinfection.

**[0019]** Referring now to the drawing figures, banks of UV-C emitting bulbs **8** are positioned in an architectural partition, which could be a wall, but may be a ceiling **2** of the enclosed area. The enclosed area may be a room located in a building. FIG. 1.

**[0020]** In one embodiment, four (4) pairs of medium pressure mercury bulbs may be present in a fixture that is located in a ceiling of a room. FIG. 2. The bulbs may be 48-inch long,

115-Watt UV-C generating lamps or bulbs that produce 300 microwatts of ultraviolet radiation at 1 meter. Other effective UV-C generators or bulbs may be used. As will be understood by one skilled in the art, the UV-C generators or bulbs may be one or more arrays of light emitting diodes (LEDs) that emit UV-C radiation. Each pair of bulbs is preferred to be positioned to provide coverage of specific portions of the entire room. The lamps or bulbs may be positioned between ceiling tiles that are commonly used in commercial buildings, including hospitals and medical clinics. The lamps or bulbs may be positioned in a similar manner to fluorescent bulb arrays that are used as lighting in buildings.

**[0021]** One advantage of using the bulbs in multiple fixtures, with the fixtures affixed to walls and/or ceilings of real property is that broad coverage of the room may be achieved, with the UV-C radiation emanating from multiple locations that are remote from each other and over a relatively large area. Optimal positioning of the bulbs according the requirements of the particular room may be achieved. If a portable unit is used, the dissemination of UV-C radiation is limited to a radius around the machine.

**[0022]** A base, such as a lighting fixture, is provided for the lamps or bulbs. The base or fixture may be positioned in the ceiling between ceiling tiles and/or HVAC outlets. The lamps or bulbs are positioned to direct UV-C radiation from overhead toward the room structure, and toward furniture 4, fixtures 6 and equipment within the room. The UV-C radiation is reflected from surfaces in the room, and particularly, the flat and preferably light colored wall surfaces, so that the UV-C radiation is received both directly and indirectly, by reflection, to substantially all surfaces in the room. Surfaces that are not in a direct, unobstructed line with the UV-C emitters will receive UV-C radiation in a dosage that is effective to achieve adequate disinfection of the room due to reflection from other surfaces in the room as measured by the UV-C sensors.

**[0023]** UV-C sensors, such as sensor 18a, may be mounted in the ceiling, such as in ceiling tiles, and positioned so as to receive reflected radiation that is reflected from objects in the room or the walls and floors of the room, without receiving material levels of UV-C radiation directly from the UV-C lamps. That is, one or more of the sensors may be mounted in the same flat, planar architectural partition as the UV-C bulbs or emitters so that the sensors do not receive direct radiation, but rather, they receive reflected radiation that is reflected from surfaces in the room. The bulbs 8 are preferred to be recessed within a fixture, and the sensor may also be recessed within a ceiling or similar plane, so that the sensor does not receive direct radiation from the bulbs.

**[0024]** Sensors may be mounted on fixtures or objects located in the room. Multiple sensors may be positioned in the room. These sensors may be connected to controls by wire, or by wireless communication. None of the sensors shown in FIG. 1 receive a material dose of UV-C radiation directly from the UV-C bulbs. Sensors 18b and 18c are shown as being positioned under objects in the room, such as beds, tables or other furniture 4, equipment or fixtures. These sensors are positioned so that they do not receive direct radiation from the UV-C bulbs 8. Similarly, sensor 18a, by being positioned in the ceiling, does not receive direct radiation from the UV-C bulbs, but only such UV-C radiation as is reflected to it.

**[0025]** In another embodiment, the bulbs 8 are mounted below the ceiling, but just below the ceiling. The bulbs should be at least two (2) meters above the floor, and it is preferred that the highest bulb is mounted not more than 15 centimeters

from the ceiling. In one embodiment, the bulbs are mounted in one or more corners of the enclosed area or room, and are positioned for maximum reflectivity toward the darkest corner of the room. In an embodiment, the bulbs are mounted in a room in a corner and just below the ceiling, with the bulbs direct to a diagonally opposite corner of the room that is the darkest corner of the room. The darkest corner of the room is the corner that is measured to receive the lowest level of reflected radiation. If the run time of the bulbs, as determined by the cumulative dosage received by the sensors, exceeds a pre-set time limit, then an additional bulb or bulbs, spaced apart from other arrays of bulbs, should be added.

**[0026]** In one embodiment, a sensor is mounted in the same corner of a room or enclosed area as an array of bulbs. The sensor is positioned so as to not receive direct radiation. The sensor is positioned within and surrounded by a surround which acts to shield to shield the receiver sensor from direct radiation, but allows reflected radiation to be received.

**[0027]** This may be accomplished in one embodiment by placing the sensor in a tube, with an opening in the end of the tube allowing the sensor to receive reflected radiation.

**[0028]** FIGS. 5A, 5B, 6A, and 6B show an embodiment of UV-C emitting bulbs 108 positioned in a light fixture. The light fixture 122 may be mounted in a ceiling, such as a light fixture that is positioned between ceiling tiles. In this embodiment, fluorescent light bulbs 124 of a type that are generally in use are also present in the fixture. Bulbs 124 provide visible light for lighting the room and may be operated by a wall switch.

**[0029]** UV-C sensors 118 are present in the fixture 122. The sensors are preferred to be spaced apart from the UV-C emitting bulbs and mounted in the fixture so that they receive UV-C radiation that is reflected from surfaces in the room, and particularly surfaces that are below the bulbs 108, and the sensors do not receive material levels of direct UV-C radiation from the bulbs.

**[0030]** The embodiment of the light fixture shown in FIG. 5 and FIG. 6 uses louvers 120 as a safety device to prevent inadvertent discharge of UV-C radiation when people are in the room, motion is detected, or if objects are in the room that should not be present. The louvers also protect the UV-C bulbs, and help discourage service or replacement by unauthorized persons.

**[0031]** The covers or louvers 120 may be formed of an opaque material that prevents visible light and UV-C radiation from passing through. Alternatively, the covers or louvers may be formed of a material that is substantially transparent or translucent to visible light, but prevents or filters UV-C radiation from passing through the cover.

**[0032]** In one embodiment, the covers or louvers are movable and are movable in response to commands from the control system. Upon actuation of the device, the louvers are moved by actuators from the position (closed) shown in FIGS. 5A and 6A to the position (open) shown in FIGS. 5B and 6B to reveal the bulbs and permit treatment of the room. Upon completion, the actuators move the louvers to the closed position. The actuators may be driven by electric motors which rotate a drive train to rotate the louvers from the closed position into the open position and back to the closed position. Solenoids may also be used to move the louvers. A feedback device may be employed to provide open or closed louver status. A louver interlock mechanism may be included to prevent accidental activation of the lamps.

**[0033]** If coverage of the room cannot be accomplished by arrays of lamps positioned in the walls, the lamps or bulbs may be supplemented with lamps or bulbs positioned within the ceiling. It is preferred that the UV-C emitters are positioned overhead, so that the lamps are not easily reached by persons in the room. Further, positioning the lamps overhead gives the best chance of unobstructed emission of the UV-C radiation and reflection of the radiation, and particularly reflection from wall surfaces. The lamps or bulbs are spaced apart as necessary to achieve UV-C coverage that effectively kills pathogens in the room and within a reasonable time, such as less than about twenty (20) minutes for an operating suite. Portable lamps or bulbs may also be used, with the portable lamps positioned as required within the room. The position of the portable lamps may be dictated by the position of furniture or equipment that is located, or relocated, within the room.

**[0034]** In one embodiment, a control box **10** contains a controller. The controller is preferred to comprise components such as a microcontroller **32** and redundant control relays **28**. Motion detectors **12**, door interlocks **24** or door strike controls **35**, louver status **34**, and audible **20** and visible alarms **22** are preferred to be employed for safety. An embodiment of a control structure using a microcontroller is herein-after described.

**[0035]** Referring now to FIG. **4**, door interlocks **24** are shown. These interlocks are activated by the doors of the room in which the device is operating. The door interlocks are switches which disable the device if any one of the switches is opened, such as by opening the door. Door strike controls **35** would not allow the door to be opened while the device is activated. Optional motion detectors **12** are immediately monitored upon activation of the device and prior to powering of the ballasts **26** and the bulbs, by means of a relay **28**. If the motion detectors sense motion at any time during the operation of the device, power to the ballasts and the bulbs is immediately disabled.

**[0036]** The device may be controlled by a programmable microcontroller. The controller may be a PIC Microcontroller **32** (PIC). The PIC may be contained in control box **10**. PICO Microcontrollers, available from Microchip Technology, Inc of Chandler, Ariz., may be used.

**[0037]** The PIC Microcontroller continuously receives a voltage input from sensors, such as sensors **18**, **118**, which receive reflected UV-C radiation, although sensors receiving direct radiation may also be monitored. Upon initiation of the device, the sensors continuously sense and measure the level of UV-C radiation which is reflected back to the device. It is preferred that the cumulative UV-C radiation emission is measured from initiation of the emission to termination for each of the sensors. Ideally, reflections from substantially all points in the room will be measured. Placement of the sensor and the number of sensors to be used will be determined by the size, architecture and contents of the room. For example, eight or more sensors that are strategically positioned may be used. Wireless remote UV-C sensors **35** may also be employed to monitor a specific area of concern.

**[0038]** If the device is ceiling mounted according to a preferred embodiment of the device, at least one sensor will typically be positioned in the ceiling to receive reflected radiation from the bulbs that are directed away from the ceiling. A sensor or sensors may be positioned in the lighting fixture, but is preferred that the sensor or sensor be positioned so as to receive reflected radiation without receiving UV-C radiation directly from the UV-C bulbs.

**[0039]** Each sensor converts the measurement of the level of radiation to a voltage output, which is transmitted to the microcontroller, such as the PIC. The PIC samples the voltage received at intervals and adds the cumulative total of the voltage received. When the PIC determines that the reflected UV-C radiation received by each and every sensor has reached the predetermined minimum cumulative total, the PIC causes the device to shut down, and a signal is given to the operator that the process has been completed. The PIC is programmable to measure voltage inputs as required by the particular application.

**[0040]** The PIC receives commands from a control, which may be a wireless remote control **30**, or it may be hardwired to the other operating components **33**. The control may be mounted on a wall, but should be mounted outside of the enclosed area or room to be treated so that the control can be operated without exposing the operator to UV-C radiation.

**[0041]** A switch activates the remote control. Entry of a security code allows the operator to begin sending commands to the PIC. Commands include Activate, Shutdown, enter Sterilization Mode, or enter Sanitize Mode. The remote is in two-way communication with the device and displays data from the sensor array, time left to sterilize or sanitize the room, and in case of bulb failure, the status of all numbered bank of bulbs. If two-way communication with the remote is lost, the device shuts down.

**[0042]** The PIC monitors the motion detectors at least one minute prior to activation of the UV-C bulbs and continues to monitor the detectors during the cycle. The PIC performs calculations regarding bactericidal doses, stores cumulative dosing data, adjusts or causes allocation of UV-C emitter power levels and/or emissions as required, and conducts system checks to alert the operator of bulb failure. This is needed since an operator should not look at the bulbs to check for burned out bulbs or damaged banks. The PIC can be reprogrammed by attaching a personal computer via a data bus connection, thus allowing alteration to the algorithms to accommodate special circumstances.

**[0043]** An example of a protocol for using an embodiment of the device is described. An operator checks the room for occupants, then leaves the room. After securing the room, the operator enters into the control a security code or password, whereupon the operator is prompted to press an "on" switch on the control, activating the device. The audible voice alarms and the motion detectors activate and are preferred to stay on until the entire cycle has been complete. Should the device detect motion, the device automatically deactivates itself until the operator re-enters the room to clear the room, thus preventing the operator from re-activating the device and harming an occupant present in the room.

**[0044]** One or more motion detectors are monitored for a preset time, such as one minute, prior to opening the louvers and powering the UV-C bulbs, and then stay active until the cycle is complete, the bulbs are powered down and the louvers closed. The array of bulbs according to the embodiment shown in the drawings emits UV-C radiation downwardly to at a preferred minimum angle of 150 degrees, and more preferably, at substantially 180 degrees, from the array of bulbs, so that working and occupied surfaces that are below the array of bulbs and are within the enclosed area are exposed to UV-C radiation. As seen in FIG. **1**, all furniture, fixtures and objects that are in a direct line with the bulbs **8** will receive direct radiation.

**[0045]** Sensors are positioned so as to not receive direct output from the germicidal lamps, thus measuring the dose of UV-C reflected back to the sensors. This data is fed into the microcontroller where it is integrated to compute cumulative exposure of UV-C reflected back from each sensor in the array.

**[0046]** In one embodiment, reflecting from the least reflective surface or direction the microcontroller calculates the time the device stays activated to allow an effective dose of UV-C to be emitted within the enclosed area. Several thousand measurements or “snapshots” may be taken for computation of the cumulative dosage.

**[0047]** Once sufficient time for a lethal dose of UV-C to be reflected back to the sensors has elapsed, and the minimum cumulative dosage corresponding to each sensor is received by the corresponding sensor, the device may power down the bulbs and sound an “all clear” alert to the operator. If the device uses louvers or similar movable covers for the fixture, then the louvers may move to a closed position that covers the UV-C emitters or bulbs.

**[0048]** Upon completion of the cycle, the device is preferred to have disinfected all the exposed surfaces within the room, including the primary shadows such as the back or wall side of rails, cabinets which are not against the wall, and tables. Surfaces not directly exposed to the UV-C radiation may be sterilized by UV-C radiation reflected from the walls and ceilings.

**[0049]** In most environments, there is a presence of what microbiology labs label as “wild spore forms” of bacteria. These bacteria are not known to cause human disease, and yet, are resistant to low doses of UV-C. The dual programming modes of one embodiment of the device allow treatment as required. One mode (Sanitize) kills all known pathogens and requires a lower exposure and thus shorter time. The other mode (Sterilize) kills all species of bacteria and requires greater cumulative doses and therefore more time.

**[0050]** Without adequate safety features, daily use of intense UV-C is dangerous and impractical. The device may have motion detectors which assure the room is vacant of personnel prior to activation. Once activated, the device shuts down instantly when motion occurs anywhere in the room being disinfected. If the device loses two-way communication with the control panel it also shuts down. In daily use, safety protocols commonly used in hospitals such as those in use for laser and x-ray devices may be implemented.

**[0051]** The device is able to sanitize or sterilize exposed surfaces in a room. It is able to do so safely, leave no residual toxins or radiation, and generates no adverse environmental side products. In addition, the device is able to notify the operator of the time required to perform this task and automatically shuts down upon completion of sterilization. The inventor has performed tests to prove the efficacy of the device, all of which have been successful. Reflectivity of some paints and other surfaces which absorb rather than reflect UV-C, requiring prolonged exposures of twenty minutes or greater. Specially-reflective paints are preferred to be included in the system of area sterilization presented by this invention.

**[0052]** The estimated reflection from the wall in a typical hospital room was only 3%. Reflection below three percent is not desirable, since the increased exposure time required to achieve an effective dose may result in degradation of articles which are present in the room and which are exposed to direct UV-C radiation. A minimum of five (5%) percent reflectivity

is desired. Through the use of paint or coating that produces a painted wall reflecting 50-85% of the UV-C, the efficiency of the device is increased, allowing for greatly decreased exposure times.

**[0053]** It is preferred to have the walls of the room, and other painted surfaces in the room, covered with paint or a similar coating. The paint or coating should have UV-C reflectivity enhancing materials, which may be pigments, in the paint **40**. The reflective particles or pigments may be colorants. In one embodiment, the coating includes particles of barium sulfate that will reflect the UV-C radiation. This coating may be transparent to the naked eye, and used to cover painted surfaces such as painted walls or cabinets. In another embodiment, aluminum oxide is used as a pigment that will enhance reflectivity of the UV-C radiation. It is preferred that the paint or coating not have titanium dioxide in a form that absorbs ultraviolet radiation. The paint or coating should be free of materials that are added to the paint or coating for the purpose of absorbing ultraviolet radiation.

**[0054]** In one embodiment of the device, which may be fixed to a building or which may be portable, each sensor of the plurality of sensors is associated with a bank of UV-C radiation emitting bulbs, and each bank of bulbs is powered by a variable output ballast. Each of the sensors converts the measurement of the level of reflected UV-C radiation to a voltage output, which is transmitted to the controller, which may be a PIC. The PIC samples the voltage received at intervals and adds the cumulative total of the voltage received from each sensor. When the PIC determines that the reflected radiation received by a particular sensor (originated from the associated bulb or bulbs) is lower on average than the other sensors, the power from the variable ballast to the bulb or bulbs associated with the sensor is increased, thereby increasing UV-C emission from the bulb or bulbs. At the same time, power from the ballast to a bulb or bulbs whose associated sensor is receiving higher than average reflected UV-C radiation is reduced in proportion, thereby reducing the UV-C emission. This protocol may be repeated, and may be repeated on a continuous sampling basis during the operational cycle of the device. In a preferred embodiment, each sensor receives the required or predetermined cumulative dosage at approximately the same time, while maintaining substantially constant total ballast input power and substantially a total emission output from the sum of the emitters. This embodiment provides an optimum sterilization rate for a given input power, and prevents repeated over dosing of some areas resulting from bringing the minimally exposed area or areas to a minimum effective cumulative dosage.

**[0055]** In an embodiment that is similar to the one described immediately above, the plurality of emitters are UV-C emitting light emitting diode (LED) arrays that receive direct current from a pulse width modulated power supply. FIG. 7. A driver **36** modulates (such as a rapid on-off) the direct current supplied to an array of LEDs **37**. The frequency and duty-cycle of the pulse width modulation (PWM) may be independently varied by the controller, which may be a PIC, so that the level of UV-C emission over a given period of time may be varied. There may be a plurality, or array, of drivers and a plurality of arrays of LEDs. When the PIC determines that the reflected UV-C radiation received by the sensors **18** is not in balance, such as some being below an average for the entirety of sensors and some being above the average, pulse width modulated radiation emissions are adjusted to achieve a more uniform reflected dose. The controller may vary pulse

width modulation to causes LED arrays associated with sensors that are receiving below average reflected radiation to increase UV-C radiation emissions, while reducing the UV-C radiation emissions from LED arrays associated with sensors that are receiving above average reflected radiation. This protocol may be repeated, and may be repeated on a continuous sampling basis during the operational cycle of the device. In a preferred embodiment, each sensor receives the required or predetermined cumulative dosage at approximately the same time, while maintaining substantially a constant total input power and substantially a total emission output from the sum of the emitters. This embodiment provides the optimum sterilization rate for a given input power and prevents repeated over dosing of areas. As with the other embodiments, when the predetermined level of radiation is achieved, power is terminated, and a signal may be provided to indicate that treatment is concluded.

What is claimed is:

- 1. A device for disinfecting an enclosed area by use of ultraviolet radiation, comprising:
  - a plurality of ultraviolet-C radiation emitters; and
  - a plurality of radiation sensors that are each positioned to receive reflected ultraviolet-C radiation;
  - a controller, wherein each of the plurality of radiation sensors is connected to the controller and each of the plurality of radiation sensors communicates a dosage of ultraviolet-C radiation received to the controller, and wherein the controller reduces an ultraviolet-C radiation emission level of a first ultraviolet-C radiation emitter of the plurality of ultraviolet-C radiation emitters and increases an ultraviolet-C radiation emission level of a second ultraviolet-C radiation emitter of the plurality of ultraviolet-C radiation emitters in response to the dosage of ultraviolet-C radiation received from the plurality of radiation sensors.
- 2. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein the controller controls the ultraviolet-C radiation emission level of the first ultraviolet-C radiation and the ultraviolet-C radiation emission level of the second ultraviolet-C radiation so that a predetermined cumulative dosage received by a radiation sensor that receives ultraviolet-C radiation from the first emitter and a predetermined cumulative dosage received by a radiation sensor that receives ultraviolet-C radiation from the second emitter are achieved at substantially the same time.
- 3. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein the controller controls the ultraviolet-C radiation emission level of the first ultraviolet-C radiation and the ultraviolet-C radiation emission level of the second ultraviolet-C radiation so that a predetermined cumulative dosage received by a radiation sensor that receives ultraviolet-C radiation from the first emitter and a predetermined cumulative dosage received by a radiation sensor that receives ultraviolet-C radiation from the second emitter are achieved at substantially the same time, and upon the radiation sensor that receives ultraviolet-C radiation from the first emitter receiving the predetermined cumulative dosage and the radiation sensor that receives ultraviolet-C radiation from the second emitter receiving the predetermined cumulative dosage, the controller causes ultraviolet-C radiation emission from the first emitter and ultraviolet-C radiation emission from the second emitter to terminate.

- 4. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein the plurality of radiation sensors is arranged to measure ultraviolet-C radiation reflected from substantially all of an enclosed area.
- 5. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein the plurality of ultraviolet-C radiation emitters are light emitting diodes.
- 6. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a variable output ballast that is connected to the controller, and the variable output ballast is connected to the ultraviolet-C radiation emitters, wherein the controller signals the variable output ballast to increase power to the first ultraviolet radiation emitter and to decrease power to the second ultraviolet radiation emitter.
- 7. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller determines an average level of reflected radiation received by the plurality of sensors, and increases power to each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and decreases power to each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.
- 8. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller determines an average level of reflected radiation received by the plurality of sensors, and increases power at each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation to achieve the average level of reflected radiation and decreases power to each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation to achieve the average level of reflected radiation.
- 9. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a variable output ballast that is connected to the controller, and the variable output ballast is connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller determines an average level of reflected radiation received by the plurality of sensors, and the controller signals the variable output ballast to increase power to each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and the controller signals the variable output ballast to decrease power to each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.
- 10. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a variable output ballast that is connected to the controller, and the variable output ballast is connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller determines an average level of reflected radiation received by the plurality of sensors, and the

controller signals the variable output ballast to increase power to each emitter of the plurality of sensors that is associated with a sensor that is lower than the average level of reflected radiation to achieve the average level of reflected radiation and the controller signals the variable output ballast to decrease power to each emitter of the plurality of sensors that is associated with a sensor that is higher than the average level of reflected radiation to achieve substantially the average level of reflected radiation measured at each sensor.

11. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a pulse width modulator that is connected to the controller, the pulse width modulator connected to the ultraviolet-C radiation emitters, wherein the controller signals the pulse width modulator to modulate power to the first ultraviolet radiation emitter to increase ultraviolet-C emission as a function of time and to modulate power to the second ultraviolet radiation emitter to decrease ultraviolet-C emission as a function of time.

12. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a pulse width modulator that is connected to the controller, the pulse width modulator connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller determines an average level of reflected radiation received by the plurality of sensors, and the controller signals the pulse width modulator to modulate and increase ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and the controller signals the pulse width modulator to modulate and decrease ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.

13. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a pulse width modulator that is connected to the controller, and wherein each of the ultraviolet-C radiation emitters is an array of light emitting diodes, the pulse width modulator connected to each of the ultraviolet-C radiation emitters, wherein the controller signals the pulse width modulator to modulate power to the first ultraviolet radiation emitter to increase ultraviolet-C emission as a function of time and to modulate power to the second ultraviolet radiation emitter to decrease ultraviolet-C emission as a function of time.

14. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a pulse width modulator that is connected to the controller, and wherein each of the ultraviolet-C radiation emitters is an array of light emitting diodes, and the pulse width modulator is connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated

with one of the arrays of light emitting diodes, and the controller determines an average level of reflected radiation received by the plurality of sensors, and the controller signals the pulse width modulator to modulate and increase ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and the controller signals the pulse width modulator to modulate and decrease ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.

15. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a variable output ballast that is connected to the controller, and the variable output ballast is connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller continuously determines an average level of reflected radiation received by the plurality of sensors during operation, and the controller continuously signals the variable output ballast during operation to increase power to each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and the controller signals the variable output ballast to decrease power to each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.

16. A device for disinfecting an enclosed area by use of ultraviolet radiation as described in claim 1, further comprising a pulse width modulator that is connected to the controller, the pulse width modulator connected to the ultraviolet-C radiation emitters, wherein each sensor of the plurality of sensors is associated with an emitter of the plurality of emitters, and the controller continuously determines an average level of reflected radiation received by the plurality of sensors during operation, and the controller continuously signals the pulse width modulator during operation to modulate and increase ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving less than the average level of reflected radiation and the controller signals the pulse width modulator to modulate and decrease ultraviolet-C radiation emission as a function of time by each emitter of the plurality of sensors that is associated with a sensor that is receiving more than the average level of reflected radiation.

17. A device for disinfecting an enclosed area by use of ultraviolet radiation, as described in claim 1, wherein the ultraviolet-C radiation sensors cause the ultraviolet-C radiation emission of the ultraviolet-C radiation emitters to vary in proportion to the ultraviolet-C radiation received by the ultraviolet-C radiation sensors.

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