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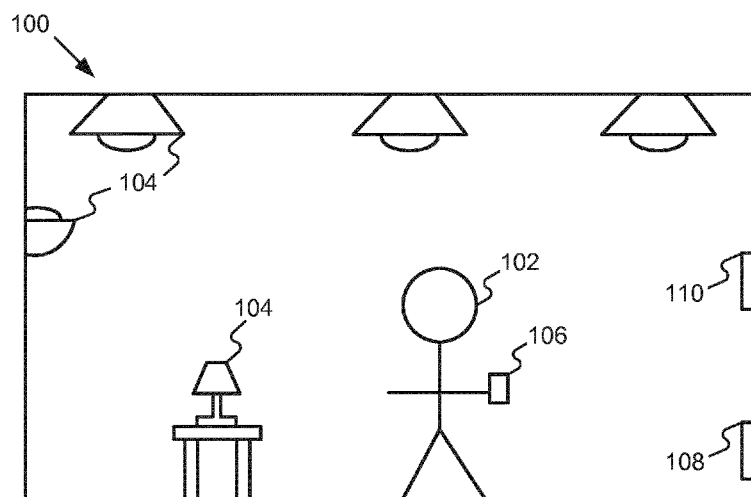


Figure 1

(57) Abstract: A method of reducing the energy consumption of a plurality of luminaires within an environment, wherein one or more of the luminaires are operable to transmit information via visible light communication, wherein the method comprises: determining a first set of luminaires that are to be used to transmit information to a user device via visible light communication; receiving an input signal to reduce the energy consumption of the plurality of luminaires; determining, for the first set of luminaires, a minimum lighting intensity required to transmit information to the user device via visible light communication; and in response to the receiving of the input signal, reducing the lighting intensity of the first set of luminaires from a current lighting intensity to an intensity equal to or greater than the minimum required lighting intensity.



Method and controller for reducing the energy consumption of a lighting system

TECHNICAL FIELD

The present disclosure relates to reducing the energy consumption of the luminaires of a lighting system.

5 BACKGROUND

Visible light communication (VLC) refers to techniques whereby information is communicated in the form of a signal embedded in the visible light emitted by a light source. VLC is sometimes also referred to as coded light or light fidelity (Li-Fi).

10 The signal is embedded by modulating a property of the visible light, typically the intensity, according to any of a variety of suitable modulation techniques. In some of the simplest cases, the signalling is implemented by modulating the intensity of the visible light from each of multiple light sources with a single periodic carrier waveform or even a single tone (sinusoid) at a constant, predetermined modulation frequency. If the light emitted by each of the multiple light sources is modulated with a different respective modulation
15 frequency that is unique amongst those light sources, then the modulation frequency can serve as an identifier (ID) of the respective light source or its light.

In more complex schemes a sequence of data symbols may be modulated into the light emitted by a given light source. The symbols are represented by modulating any suitable property of the light, e.g. amplitude, modulation frequency, or phase of the
20 modulation. For instance, data may be modulated into the light by means of amplitude keying, e.g. using high and low levels to represent bits or using a more complex modulation scheme to represent different symbols. Another example is frequency keying, whereby a given light source is operable to emit on two (or more) different modulation frequencies and to transmit data bits (or more generally symbols) by switching between the different
25 modulation frequencies. As another possibility a phase of the carrier waveform may be modulated in order to encode the data, i.e. phase shift keying.

In general the modulated property could be a property of a carrier waveform modulated into the light, such as its amplitude, frequency or phase; or alternatively a baseband modulation may be used. In the latter case there is no carrier waveform, but rather

symbols are modulated into the light as patterns of variations in the brightness of the emitted light. This may for example comprise modulating the intensity to represent different symbols, or modulating the mark:space ratio of a pulse width modulation (PWM) dimming waveform, or modulating a pulse position (so-called pulse position modulation, PPM). The modulation may involve a coding scheme to map data bits (sometimes referred to as user bits) onto such data symbols. An example is a conventional Manchester code, which is a binary code whereby a user bit of value 0 is mapped onto a data symbol in the form of a low-high pulse and a user bit of value 1 is mapped onto a data symbol in the form of a high-low pulse. Another example coding scheme is the so-called Ternary Manchester code developed by the applicant.

Based on the modulations, the information in the coded component of the light can be detected using any suitable light sensor. This can be either a dedicated photocell (point detector), or a camera comprising an array of photocells (pixels) and a lens for forming an image on the array. E.g. the camera may be a general purpose camera of a mobile user device such as a smartphone or tablet. Camera based detection of VLC is possible with either a global-shutter camera or a rolling-shutter camera. E.g. rolling-shutter readout is typical to mobile CMOS image sensors found in everyday mobile user devices such as smartphones and tablets). In a global-shutter camera the entire pixel array (entire frame) is captured at the same time, and hence a global shutter camera captures only one temporal sample of the light from a given luminaire per frame. In a rolling-shutter camera on the other hand, the frame is divided into lines in the form of horizontal rows and the frame is exposed line-by-line in a temporal sequence, each line in the sequence being exposed at a slightly later time than the last. Each line therefore captures a sample of the signal at a different moment in time. Hence while rolling-shutter cameras are generally the cheaper variety and considered inferior for purposes such as photography, for the purpose of detecting coded light they have the advantage of capturing more temporal samples per frame, and therefore a higher sample rate for a given frame rate. Nonetheless coded light detection can be achieved using either a global-shutter or rolling-shutter camera as long as the sample rate is high enough compared to the modulation frequency or data rate (i.e. high enough to detect the modulations that encode the information).

VLC is often used to embed a signal in the light emitted by an illumination source such as an everyday luminaire, e.g. room lighting or outdoor lighting, thus allowing the illumination from the luminaires to double as a carrier of information. The light thus comprises both a visible illumination contribution for illuminating a target environment such

as room (typically the primary purpose of the light), and an embedded signal for providing information into the environment (typically considered a secondary function of the light). In such cases, the modulation is typically performed at a high enough frequency so as to be beyond human perception, or at least such that any visible temporal light artefacts (e.g. flicker and/or strobe artefacts) are weak enough not to be noticeable or at least to be tolerable to humans. Thus the embedded signal does not affect the primary illumination function, i.e. so the user only perceives the overall illumination and not the effect of the data being modulated into that illumination. E.g. Manchester coding is an example of a DC free code, wherein the power spectral density goes to zero at zero Hertz, with very little spectral content at low frequencies, thus reducing visible flicker to a practically invisible level. Ternary Manchester is DC² free, meaning not only does the power spectral density go to zero at zero Hertz, but the gradient of the power spectral density also goes to zero, thus eliminating visible flicker even further.

VLC can be used in a variety of possible applications. For instance a different respective ID can be embedded into the illumination emitted by each of the luminaires in a given environment, e.g. those in a given building, such that each ID is unique at least within the environment in question. E.g. the unique ID may take the form of a unique modulation frequency or unique sequence of symbols. This in itself can then enable any one or more of a number of applications. For instance, one application is to provide information from a luminaire to a remote control unit for control purposes, e.g. to provide an ID distinguishing it amongst other such luminaires which the remote unit can control, or to provide status information on the luminaire (e.g. to report errors, warnings, temperature, operating time, etc.). For example the remote control unit may take the form of a mobile user terminal such as a smartphone, tablet, smartwatch or smart-glasses equipped with a light sensor such as a built-in camera. The user can then direct the sensor toward a particular luminaire or subgroup of luminaires so that the mobile device can detect the respective ID(s) from the emitted illumination captured by the sensor, and then use the detected ID(s) to identify the corresponding one or more luminaires in order to control it/them (e.g. via an RF back channel). This provides a user-friendly way for the user to identify which luminaire or luminaires he or she wishes to control. The detection and control may be implemented by a lighting control application or “app” running on the user terminal.

In other example applications VLC can be used to provide location dependent information (e.g. advertising, or information on museum exhibitions, etc.); or to perform localization (e.g. triangulation, trilateration or multilateration) based on VLC beacon signals

emitted from luminaires.

See documents US2014/0086590A1 and WO2010/146519A1 for considerations on keeping a modulation in VLC detectable when dimming a luminaire.

5 SUMMARY

VLC is an optical wireless communications technology that uses the visible light band, approx. 400 to 800 THz (780–375 nm), for communication. VLC is an attractive communications technology that can either complement existing wireless radio technologies like WiFi, Bluetooth, or be offered in environments where these traditional radio
10 technologies cannot be offered. In particular, VLC in indoor environments has attracted applications like indoor positioning, networked lighting and data access. In such systems, the lighting infrastructure may be used to provide both data communications and illumination. VLC may include Li-Fi. Li-Fi is as known a visible light communications system that is capable of transmitting data at high speeds over the visible light spectrum, ultraviolet and
15 infrared radiation. Hence, all aspects and/or embodiments of the invention referring to VLC may be mutatis mutandis phrased as coded light or Li-Fi.

Smart lighting systems are typically equipped with sensors, e.g. occupancy and light sensors, and use data from such sensors to offer illumination in an energy efficient manner. Energy efficiency is achieved by reducing the light output based on occupancy
20 conditions and the amount of available daylight. For instance, in areas of unoccupancy, luminaires may be dimmed or turned off. In areas where the amount of daylight is already above the required illumination level, luminaires may be dimmed or turned off, even where there is occupancy in the area.

However, dimming or turning off luminaires adversely impacts the
25 performance of VLC. For example, when one or more luminaires are dimmed (deeply) or even turned off to save energy, the resulting VLC transmit signal would have lower power, thereby adversely impacting its decoding at a receiver (e.g. smartphone).

According to a first aspect disclosed herein, there is provided a method of reducing the energy consumption of a plurality of luminaires within an environment (100),
30 wherein one or more of the luminaires are operable to transmit information via visible light communication, wherein the method comprises: determining a first set (202a) of at least one of said one or more luminaires that are to be used to transmit information to a user device in the environment via visible light communication; receiving an input signal to reduce the energy consumption of the plurality of luminaires; determining, for the first set of luminaires,

a minimum lighting intensity required to transmit information to the user device via visible light communication; and in response to the receiving of the input signal, reducing the lighting intensity of the first set of luminaires from a current lighting intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device via visible light communication; wherein said determining of the first set of luminaires (202a) comprises determining the first set of at least one of said one or more luminaires (104) to be a first set that are transmitting the same information to the user device (106) via visible light communication.

The invention thus advantageously ensures that the lighting intensity of the luminaire(s) is not dimmed so much that they are unable to perform visible light communication with the user device, whilst still enabling the overall energy consumption of the lighting system to be reduced.

Furthermore: An advantage of this is that the communication capabilities of the luminaires who are transmitting a particular message are maintained.

In embodiments, the remainder of the plurality of luminaires not in the first set may form a second set of luminaires, wherein said input signal may specify a reduced lighting intensity, and wherein the method may further comprise reducing the lighting intensity of the second set of luminaires from a current lighting intensity to an intensity equal to or less than the reduced lighting intensity specified in the received input signal. An advantage of this is that the second set of luminaires may be dimmed to a lower level than the first set of luminaires (or even switched off) in order to enact a greater reduction in energy consumption.

In examples, said first set of luminaires and the second set of luminaires may comprise the same light intensity, while still enabling the overall energy consumption of the lighting system to be reduced.

In embodiments, multiple luminaires out of the plurality of luminaires may be operable to transmit via visible light communication, and said determining of the first set of luminaires may comprise: determining at least one of the multiple luminaires operable to transmit via visible light communication that are not currently required to transmit information to the user device; and preventing the at least one luminaire that is determined to not currently be required to transmit information to the user device from transmitting information to the user device via visible light communication, such that said at least one luminaire is not included in said first set of luminaires. Said currently may be phrased as in operation, at the time of receiving the input signal to reduce energy consumption. An

advantage of this is that the luminaires that are not required for communicating with the user device can be dimmed to a greater extent or switched off to save energy.

In embodiments, said determining of the first set of luminaires may comprise determining the first set of at least one of said one or more luminaires to be a first set that are
5 within range of a visible light receiver of the user device.

In examples, the method according to the invention may further comprise receiving and/or retrieving a location of the user device. Said location may in further examples e.g. be received/retrieved in combination or together with receiving the input signal to reduce the energy consumption of the plurality of luminaires. Hence, a backend system
10 may know/be instructed with the energy consumption requirements, but also the location of a user device accordingly.

Moreover, in examples, said range may be pre-determined, such as e.g. within one or two meters from the luminaire. Moreover, in examples, said range may be determined by assessing the location of the user device, e.g. as the user device is using VLC for indoor
15 positioning and thereby also communicating its position to a backend, which may be retrieved by a controller associated with the luminaires.

In embodiments, the input signal to reduce the energy consumption of the plurality of luminaires may be received from one or more occupancy sensors and/or light sensors within the environment. For instance, the occupancy and/or light sensors may send
20 the input signal in response to a user entering or leaving the environment, and/or a lighting set-point being breached.

In embodiments, the environment may comprise at least one light sensor configured to determine an illumination level at said light sensor, and wherein the input signal to reduce the energy consumption of the plurality of luminaires may be received from
25 the least one light sensor. For example, the light sensors may measure the ambient light in the environment and determine that more than a required amount of light is present in the environment. The light sensor may therefore send the signal to reduce the energy consumption of the luminaires, e.g. by reducing the lighting intensity of the luminaires.

In embodiments, the environment may comprise at least one light sensor configured to measure an illumination level at said light sensor, wherein the at least one light
30 sensor is associated with a predetermined minimum value of the measured illumination level, wherein the predetermined minimum value of the measured illumination level may correspond to the reduced lighting intensity specified in the input signal, wherein the method may comprise: determining a minimum lighting intensity for the plurality of luminaires

corresponding to the illumination level measured by said light sensor being greater than the predetermined minimum value of the measured illumination level, wherein said reducing the lighting intensity of the first set of luminaires may comprise reducing the lighting intensity of the first set of luminaires to an intensity equal to or greater than the minimum lighting intensity for the plurality of luminaires corresponding to the illumination level measured by said light sensor being greater than the predetermined minimum value of the measured illumination level. An advantage of this is that a minimum illumination level, as measured by a light-sensor, may be maintained within the environment.

In embodiments, given the reduced lighting intensity of the second set of luminaires, the method may comprise determining a minimum lighting intensity for the first set of luminaires corresponding to the illumination level measured by said light sensor being greater than the predetermined minimum value of the measured illumination level; wherein said reducing the lighting intensity of the first set of luminaires may comprise reducing the lighting intensity of the first set of luminaires to an intensity equal to or greater than the minimum lighting intensity for the first set of luminaires corresponding to the illumination level measured by said light sensor being greater than the predetermined minimum value of the measured illumination level. That is, an illumination level of the first set of luminaires that is required, in addition to the known illumination level of the second set of luminaires, to meet the predetermined minimum value of the measured illumination level may be determined.

In embodiments, the method may comprise determining a minimum lighting intensity for the first set of luminaires that corresponds to a determined error rate of the transmission of information to the user device via visible light communication being less than a predetermined maximum error rate, wherein said reducing the lighting intensity of the first set of luminaires may comprise reducing the lighting intensity of the first set of luminaires from the current intensity to an intensity equal to or greater than the minimum lighting intensity for the first set of luminaires that corresponds to a determined error rate of the transmission of information to the user device via visible light communication being less than a predetermined maximum error rate. An advantage of this is that not only is visible light communication between the first set and the user device maintained, it is maintained with an acceptable error rate.

In embodiments, the method may comprise determining a respective distance between the user device and each of the luminaires in the first set of luminaires, wherein the error rate used in said determination of the minimum lighting intensity for the first set of

luminaires is a function of the determined respective distances between the user device and each of the luminaires in the first set of luminaires. An advantage of this is that the determined error rate of the visible light communication can be calculated more accurately based on (real-time) luminaire-device distances.

5 In embodiments, the method may comprise determining an optimized lighting intensity, wherein the optimized lighting intensity is equal to the greater of: (i) the minimum lighting intensity for the plurality of luminaires that would ensure the sensed illumination level of the at least one light sensor is at the level greater than the predetermined minimum value of the measured illumination level, and (ii) the minimum lighting intensity for the first
10 set of luminaires that would ensure the error rate of the transmission of information to the user device via visible light communication is at the rate less than the predetermined maximum error rate; and wherein said reducing the lighting intensity of the first set of luminaires comprises reducing the lighting intensity of the first set of luminaires from the current intensity to the optimized lighting intensity. That is, a control problem may be solved
15 to optimize the reduction in energy consumption whilst ensuring acceptable visible light communication.

In embodiments, the method may comprise: controlling one or more of the luminaires that are not transmitting the same information to the user device and/or that are not visible by the receiver of the user device to stop transmitting information to the user
20 device via visible light communication; and/or controlling one or more of the luminaires that are visible to the user device that are not transmitting the same information to the user device, to transmit the same information to the user device as the luminaires that are in the first set of luminaires and currently transmitting the same information to the user device. An advantage of this is that the signal-to-noise ratio of the desired information is increased.

25 Moreover, as partly mentioned, the invention may advantageously ensure that the lighting intensity of the luminaire(s) is not dimmed so much that they are unable to perform visible light communication with the user device, whilst enabling a desired illumination condition to be achieved, e.g. a light scene or illumination uniformity provided by the luminaires, such as e.g. whenever a lighting system compensates for incident daylight
30 so as to reduce energy consumption. The second set of luminaires may for example, in aspects, provide illumination to achieve, together with the first set, a light sensor set-point and/or other objectives such as illumination/dimming uniformity.

According to a second aspect disclosed herein, there is provided a controller for reducing the energy consumption of a plurality of luminaires within an environment,

wherein one or more of the luminaires are operable to transmit information via visible light communication, wherein the controller is configured to determine a first set of at least one of said one or more luminaires that are to be used to transmit information to a user device in the environment via visible light communication and that are transmitting the same information to the user device (106) via visible light communication; wherein the controller comprises an interface configured to receive an input signal to reduce the energy consumption of the plurality of luminaires; and wherein the controller is configured to: determine, for the first set of luminaires, a minimum lighting intensity required to transmit information to the user device via visible light communication; and in response to receiving the input signal, control the first set of luminaires to reduce the lighting intensity of the first set of luminaires from a current intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device via visible light communication.

In embodiments, the controller may be configured to perform any of the methods disclosed herein.

According to a third aspect disclosed herein, there is provided computer program comprising instructions embodied on computer-readable storage and configured so as when the computer program is executed on a computing device, the computing device is arranged to carry out a method according to any of the methods disclosed herein.

According to a fourth aspect disclosed herein, there is provided a system comprising: a plurality of luminaires, wherein one or more of the luminaires comprise a lighting driver configured to cause the one or more luminaires to transmit information via visible light communication; and a controller, wherein the controller is implemented in hardware or software a central device or across one or more of the plurality of luminaires, the controller being configured to determine a first set of at least one of said one or more luminaires that are to be used to transmit information to a user device in the environment via visible light communication; wherein the controller comprises an interface configured to receive an input signal to reduce the energy consumption of the plurality of luminaires; and wherein the controller is configured to: determine, for the first set of luminaires, a minimum lighting intensity required to transmit information to the user device via visible light communication; and in response to receiving the input signal, control the first set of luminaires to reduce the lighting intensity of the first set of luminaires from a current intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device via visible light communication.

BRIEF DESCRIPTION OF THE DRAWINGS

To assist understanding of the present disclosure and to show how embodiments may be put into effect, reference is made by way of example to the accompanying drawings in which:

5 Figure 1 shows schematically an example environment comprising a lighting system,

 Figure 2 shows schematically an example of a plurality of luminaires divided into sets,

 Figure 3 shows schematically an example system for reducing the energy
10 consumption of a plurality of luminaires, and

 Figure 4 shows schematically an example control diagram for reducing the energy consumption of a plurality of luminaires.

DETAILED DESCRIPTION

15 Dimming the lighting intensity of a luminaire may negatively affect that luminaire's performance of visible light communication since a greater lighting intensity renders better VLC reception. However, a greater lighting intensity also incurs a greater energy consumption. Embodiments of the invention enable the energy consumption of a plurality of luminaires to be reduced, whilst ensuring that the luminaire(s) lighting intensity is
20 not reduced to the point that VLC cannot be performed.

 Figure 1 illustrates an example environment 100 in which embodiments disclosed herein may be employed. The environment 100 is a space which may be occupied by one or more users 102. The environment 100 may take the form of an indoor space such as one or more rooms of a home, office or other building; an outdoor space such as a garden
25 or park; a partially covered space such as a gazebo; or a combination of such spaces such as a campus or stadium or other public place that has both indoor and outdoor spaces.

 The environment 100 is equipped with one or more luminaires 104 installed or otherwise disposed at different locations throughout the environment 100. A luminaire 104 may refer to any kind of illumination device for illuminating an environment or part of the
30 environment occupied by a user 102, whether providing, for example, ambient lighting or specific task lighting. Each of the luminaires 104 may take any of a variety of possible forms, such as a ceiling or wall mounted luminaire, a free-standing floor or table luminaire, or a less traditional form such as a luminaire 104 embedded in a surface or an item of furniture. The different luminaires 104 in the environment 100 need not take the same form as one another.

Whatever form it takes, each luminaire 104 comprises at least one lamp (illumination element) and any associated housing, socket and/or support. Examples of suitable lamps include LED-based lamps, or traditional filament bulbs or gas discharge lamps.

The environment 100 is also equipped with one or more user devices 106. The user device 106 may be, for example, a mobile device including mobile or cell phones (including so-called “smart phones”), personal digital assistants, pagers, tablet and laptop computers and wearable communication devices (including so-called “smart watches”).

The environment 100 may also be equipped with one or more occupancy sensors 108. The occupancy sensor(s) 108 are configured to detect the presence of an occupant within the environment 100 (or at least within a zone or location within the environment 100). The occupancy sensors 108 may comprise, for example, infrared sensors such as PIR sensors that detect differences in heat. Inside the PIR sensor is a pyroelectric sensor which can detect the sudden presence of objects (such as humans) who radiate a temperature different from the temperature of the background, such as the room temperature of a wall. An occupancy sensor 108 may be an environmental sensor such as, for example, a temperature, humidity, and/or carbon dioxide sensors, which detect the change in the environment 100 due to the presence of a human. An occupancy sensor 108 may also be an ultrasonic or microwave sensor that sends high frequency sound or micro waves into the environment 100 and checks for their reflected patterns. If the reflected pattern is changing continuously then it assumes that there is occupancy, whereas if the reflected pattern is the same for a preset time then the sensor assumes there is no occupancy. An occupancy sensor 108 may instead be a keycard slots that assumes occupancy when a key card is inserted into the keycard slot (e.g. a room key inserted into a hotel room keycard slot). Other examples include a door operated switch and an audio sensor. An occupancy sensor 108 may be any device that can detect an occupancy within the environment 100. For example, an occupancy sensor 108 may be a camera that captures images of the environment. The camera may be installed within the environment, e.g. a CCTV camera or other camera monitoring the environment. The occupancy may be a microphone that detects sounds within the environment. The sensor data (e.g. images, sounds, etc.) may be passed to the controller (or a different smart system) which may determine, from that data, whether a user 102 is present in the environment 100.

The environment 100 may also be equipped with one or more light sensors 110. A light sensor 110 (e.g. an ambient light sensor) is a device that is configured to measure the amount of light (e.g. ambient light) incident on the light sensor 110, i.e. to

determine an illumination level at the sensor. The light sensor 110 may be, for example, a photodetector. Photodetectors may generate electricity when illuminated (such as photo-voltaic detectors) or (photo-emissive detectors) or they may change their electrical properties when illuminated (such as photo-resistors or photo-conductors). A light sensor 110 may also
5 be a light dependent resistor (LDR), a photodiode, a photoresistor, etc.

Figure 3 illustrates an example of a lighting system 300. The user device 106 may optionally comprise a user interface 302 arranged to receive an input from the user 102 and operatively coupled to a controller 304. The user interface 302 may comprise a display in the form of a screen and some arrangement for receiving inputs from the user 102. For
10 example, the user interface 302 may comprise a touch screen, or a point-and-click user interface comprising a mouse, track pad, or tracker ball or the like. Alternatively or additionally, the user interface 302 may comprise a dedicated actuator or control panel for controlling the luminaires 104 within the environment 100. For example, the user device 106 may be in the form of a dedicated control unit (wired or wireless) which can be operated by
15 the user, e.g. by using one or more buttons, sliders, switches and/or dials of the dedicated control panel.

In embodiments the controller 304 of the user device is implemented in the form of software stored on a memory of the transmitter and arranged for execution on a processing apparatus of the transmitter (the memory on which the software is stored
20 comprising one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processing apparatus on which the software is run comprising one or more processing units). Alternatively it is not excluded that some or all of the controller 304 could be implemented in dedicated hardware circuitry, or configurable or reconfigurable hardware circuitry such as a PGA or FPGA.

The controller 304 of the user device 106 may be coupled to the luminaire 104
25 discussed in relation to Figure 1 via a wireless transceiver 306. The controller 304 may thereby control the luminaire 104 based on commands input by the user 102. The user device 106 and luminaire 104 may each comprise a respective wireless transmitter and receiver (or transceiver 306, 308) for communicating via any suitable wireless medium, e.g. a radio
30 transceiver for communicating via a radio channel (though other forms are not excluded, e.g. an ultrasound or infrared transceiver). The wireless transceivers 308, 310 may comprise, for example, a ZigBee, Bluetooth, Wi-Fi, Thread, JupiterMesh, Wi-SUN, 6LoWPAN, etc. interface for communicating with the luminaire 104 or user device, respectively, and with the central bridge or server 310. For instance the radio channel may be based on the same radio

access technology used by the wireless transceiver (e.g. ZigBee, Bluetooth, Wi-Fi, Thread, JupiterMesh, Wi-SUN, 6LoWPAN, etc.). The radio channel can be used by the user device 106 to control the luminaires 104.

Alternatively, the wireless transceiver 306 may communicate with the illumination sources 104 via a central bridge or a server 310, for example, over a local area network such as a WLAN or a wide area network, such as the internet. Communication may be via the wireless transceivers 306, 308. Alternatively, the luminaires 104 may each comprise a wired connection, e.g. to communicate with a central bridge 310. In some examples, the wireless transceiver 308 may communicate with other luminaires 104 via a wireless network and/or via the central lighting bridge 310, for example, over a local area network or a wide area network such as the internet. It is also not excluded that a wired connection could alternately, or additionally, be provided between the luminaires 104 themselves, or between a central lighting bridge 310 and the luminaires 104 for control purposes, e.g. an Ethernet or DMX connection.

One or more of the luminaires 104 may each be configured to transmit coded light messages via coded light communication. A luminaire may comprises a light source 312 and a driver (not shown) connected to the light source 312. The luminaire 104 may also comprise a controller 314 coupled to an input of the driver, for controlling the light source 312 to be driven via the driver. Particularly, the controller may be configured to control the light source 312, via the driver, to modulate the illumination it emits in order to embed a cyclically repeated coded light (VLOC) message. Any suitable known modulation technique may be used to do this. In embodiments the controller 314 of a luminaire is implemented in the form of software stored on a memory of the luminaire and arranged for execution on a processing apparatus of the luminaire (the memory on which the software is stored comprising one or more memory units employing one or more storage media, e.g. EEPROM or a magnetic drive, and the processing apparatus on which the software is run comprising one or more processing units). Alternatively it is not excluded that some or all of the controller 314 could be implemented in dedicated hardware circuitry, or configurable or reconfigurable hardware circuitry such as a PGA or FPGA.

The user device 106 comprises a camera 316 (or any other suitable light sensor) and a decoder (not shown) coupled to an input from the camera 316 in order to receive images captured by the camera 316. The decoder is configured to extract the information transmitted in the visible light via visible light communication, e.g. from the one or more luminaires 104. The decoder need not necessarily be implemented in the same

physical unit as the camera 316. In embodiments the decoder may be incorporated into the same unit, e.g. incorporated together into a mobile user terminal such as a smartphone, tablet, smartwatch or pair of smart-glasses (for instance being implemented in the form of an application or “app” installed on the user terminal). Alternatively, the decoder could be implemented on an external terminal. For instance the camera 316 may be implemented in a first user device such as a dedicated camera unit or mobile user terminal like a smartphone, tablet, smartwatch or pair of smart glasses; whilst the decoder may be implemented on a second terminal such as a laptop, desktop computer or server connected to the camera 316 on the first terminal via any suitable connection or network, e.g. a one-to-one connection such as a serial cable or USB cable, or via any one or more suitable networks such as the Internet, or a local wireless network like a Wi-Fi or Bluetooth network, or a wired network like an Ethernet or DMX network.

Embodiments of the invention may be performed by controller 304 and/or controller 314 (or a lighting driver comprising the controller 314). Furthermore, embodiments of the invention may also be performed by a controller of the central bridge 310 or a master luminaire. The environment 100 comprises a plurality of luminaires 104 of which one or more are operable to (or configured to) transmit information via visible light communication (coded light, Li-Fi, etc.). Techniques for transmitting information via VLC have been discussed above. The controller 304 is configured to determine a first set of the one or more luminaires 104 that are to be used to transmit information to a user device 106 via VLC. The first set of luminaires 202a comprises a minimum of one luminaire that is to be used to transmit information to the user device 106 via VLC. Those luminaires that are determined as not being used to transmit information to the user device 106 via VLC form a second set. For example, Figure 2 illustrates an example showing a plurality of luminaires within the environment 100 split into two sets. A first set of luminaires 202a is formed of those luminaires determined to be used for VLC with the user device 106, with the second set of luminaires 202a formed of the remaining luminaires.

The controller 304 may determine which luminaires form the first set of luminaires 202a by determining which luminaires are actively transmitting information via VLC. For example, the controller 304 may receive an input indicating which luminaires are transmitting information (e.g. broadcasting information). The controller 304 may poll each luminaire 104 and/or groups of luminaires to determine if the luminaire(s) are engaged in VLC. In this example, the luminaires that are not actively transmitting information via VLC form the second set of luminaires.

As another example, the controller 304 may determine which luminaires form the first set of luminaires 202a by determining which luminaires are transmitting (or are to be used to transmit) the same information to the user device 106 via VLC. That is, controller 304 may determine which luminaires are transmitting the same message, command, identifier, etc., to the user device 106. For example, the first set of luminaires 202a may be determined as those luminaires transmitting message A, whilst the second set of luminaires may be those luminaires transmitting messages B, C, and D. If more than one group of luminaires is transmitting a respective same message (e.g. two luminaires are transmitting message A and three luminaires are transmitting message B), the first set may be determined as the group of luminaires that are, for example, transmitting the highest priority message, contain the highest number of luminaires, contain the smallest number of luminaires, transmitting the largest content (i.e. the most amount of information), etc.

Furthermore, the controller 304 may determine which luminaires form the first set of luminaires 202a by determining which luminaires are visible to the user device 106. For example, the first set of luminaires 202a may be determined as those luminaires in view of the user device 106, with the second set of luminaires formed of those luminaires that are not in view of the user device 106. Whether the luminaires are in view of the user device 106 may be determined based on feedback from the user device 106. For example, the user device 106 may determine which of the luminaires are captured in an image taken by the user device 106 and transmit this information to the controller 304. The user device 106 may instead transmit the image to the controller 304 for the controller 304 to determine which luminaires are visible in the image. As another example, each luminaire 104 may transmit a respective identifier as part of the information transmitted via VLC. The identifiers detected by the user device 106 may be used to determine which luminaires are visible to the user device 106.

In some examples, the controller 304 may determine which luminaires form the first set of luminaires 202a by determining which of the luminaires the user device 106 is receiving information via VLC. In this example, the first set of luminaires 202a will comprise at least some of the luminaires that are transmitting information. A luminaire 104 need not necessarily be visible to the user device 106 for the user device 106 to receive information from that luminaire. For example, Li-Fi enables visible light communication to be received by a user device 106 after e.g. reflection of coded light from a surface within the environment 100.

As another example, the controller 304 may determine which luminaires form the first set of luminaires 202a by determining which of the luminaires are within a given

range of the user device 106. For example, the first set of luminaires may be those luminaires that are within a predetermined range (or distance, radius, etc.) of the user device 106, with the second set formed of those luminaires that are not within (or outside of) the predetermined range. The controller 304 may determine the distance between the user device 106 and a respective luminaire 104 based on, for example, the analysis of images captured of a respective luminaire 104 by the user device 106. As another example, the luminaire 104 and/or user device 106 may transmit a signal via a wireless communication technology such as, for example, Wi-Fi, Bluetooth, infrared, etc. The received signal strength of a signal received at the luminaire 104 and/or user device 106 from the user and/or luminaire, respectively, may be used to determine the distance between the user device 106 and luminaire. Additionally or alternatively, the controller 304 may determine the location of the user device 106. The controller 304 may determine the distance between the user device 106 and a respective luminaire 104 based on the user device's determined location. The location of the user device 106 may be determined based on, for example, indoor positioning systems, global positioning systems (GPS), received signal strength indications (RSSI) of wireless signals (e.g. triangulation or trilateration of wireless signals). Another technique that may be used to determine the location of the user device 106 is "fingerprinting", which relies on mapping a received signal strength from multiple devices at each of a plurality of locations throughout the environment 100 in a preliminary commissioning phase. When signals are later received from the user device 106 in day-to-day operation, the RSSI measurement can be compared to the "mapped" measurements.

The controller 304 may determine which luminaires form the first set of luminaires 202a by determining which of the luminaires that are configured to transmit via VLC but are not (currently) required to transmit information to the user device 106. For example, two or more luminaires may be transmitting the same information, e.g. message, to the user device 106. The controller 304 may determine that only one of those luminaires is required to transmit the message, e.g. the other luminaires are superfluous. As another example, the controller 304 may determine that one or more of the luminaires are not visible to and/or are out of reliable VLC range from the user device 106. The controller 304 may control the luminaires that are not required to transmit information to the user device 106 to not transmit information via VLC. That is, one or more of the luminaires 104 may be prevented from transmitting information to the user device 106 via VLC. Therefore the first set of luminaires 202a determined by the controller 304 would not, in these examples, include the luminaires that are not required to transmit information to the user device 106.

In embodiments, the first set of luminaires is a set of those luminaires that provide VLC and illumination of the environment. In some embodiments, the second set of luminaires may only provide illumination in a way, together with the first set, to achieve the light sensor set-points and/or other objectives such as illumination or dimming uniformity.

5 The controller 304 comprises an interface configured to receive an input signal to reduce the energy consumption of the plurality of luminaires. The input signal may be triggered by a user command from the user. For example, the user may input a command via the user device 106 to reduce the energy consumption of the luminaires.

10 Alternatively, the input signal may be received as part of an automated process. For example, the input signal may be triggered in response to the plurality of luminaires consuming more than a predetermined total amount of energy (e.g. within a set period of time such as, for example, an hour, a day, etc.) and/or exceeding a predetermined energy consumption rate. For instance, the controller 304 may determine that a reduction in the energy consumption of the plurality of luminaires is required in order to meet a target
15 energy consumption rate.

 The input signal to reduce the energy consumption of the plurality of luminaires may be an input to reduce the energy consumption of the plurality by reducing the lighting intensity of the plurality of luminaires. For example, the input signal to reduce the energy consumption of the plurality of luminaires may be received from one or more of the
20 occupancy sensors 108 within the environment 100. The occupancy sensors 108 may detect that the user (or users) is not in the environment 100 and therefore the lighting intensity of the luminaries may be reduced. The occupancy sensor 108 may send the signal directly to the controller 304. Alternatively, the occupancy sensor 108 may communicate with, for example, a smart (or intelligent) system. The occupancy sensor 108 may transmit sensor data
25 to the smart system which then sends the input signal (if required) to the controller 304.

 As another example, the input signal to reduce the energy consumption of the plurality of luminaires may be received from the least one light sensor 110. For instance, the light sensor 110 may determine that a predetermined maximum (or desired) illumination level is being achieved within the environment 100 (or at least at that light sensor 110). For
30 example, the daylight in the environment 100 may be sufficient to illuminate the environment 100 without the need for much (or indeed any) artificial light from the luminaires. The light sensor 110 may then provide the input signal to the controller 304 informing the controller 304 that the lighting intensity of the plurality of luminaires may be reduced in order to reduce the energy consumption of the luminaires.

The controller 304 is configured to determine, for the first set of luminaires 202a, a minimum lighting intensity required to transmit information from those luminaires to the user device 106 via VLC. The minimum lighting intensity (or luminance, brightness, etc.) may be a minimum lighting intensity that achieves reliable VLC with the user device 106.

- 5 The controller 304 may determine the minimum lighting intensity for the first set of luminaire 104 before or after the input signal is received. The controller 304 may determine the minimum lighting intensity required for each of the individual luminaires in the first set to transmit information to the user device 106 via VLC. Alternatively, the controller 304 may determine the minimum lighting intensity required for the first set as a whole to transmit
10 information to the user device 106 via VLC. For example, if more than one luminaire 104 are transmitting the same message to the user device 106, the minimum lighting intensity for those luminaires may be less than the minimum lighting intensity required for a single luminaire 104 to transmit a message to the user device 106.

- In response to receiving the input signal to reduce the energy consumption
15 (e.g. by reducing the lighting intensity of the luminaires), the controller 304 is configured to control the first set of luminaires 202a to reduce the lighting intensity of the first set of luminaires 202a from a current intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device 106 via visible light communication. That is, the first set of luminaires 202a will initially be illuminating the
20 environment 100 with a current lighting intensity. The controller 304 will reduce the lighting intensity of the first set of luminaires 202a such that the updated lighting intensity is not less than the determined minimum lighting intensity. An advantage of this is that VLC between the first set of luminaires 202a and the user device 106 is maintained whilst a reduction in energy consumption reduction is achieved.

- 25 The lighting intensity of the first set of luminaires 202a may be reduced to the minimum lighting intensity that is determined to be required for the first set of luminaires 202a to transmit information via VLC to the user device 106. That is, the lighting intensity of those luminaires is reduced by an amount equal to the difference between the current lighting intensity and the minimum lighting intensity. Alternatively, the lighting intensity of the first
30 set of luminaires 202a may be reduced by less than the difference between the current lighting intensity and the minimum lighting intensity such that the updated lighting intensity is greater than the minimum lighting intensity.

The input signal may specify a reduced lighting intensity for the plurality of luminaires. For example, the input signal may specify a reduced lighting intensity for the

luminaires that is required to achieve a desired reduction in energy consumption. The input signal may indicate a reduction in terms of a delta from the current lighting intensity of the luminaires. The input signal may instead indicate an absolute target lighting intensity to reduce the current lighting intensity to that level. The controller 304 may be configured to
5 reduce the lighting intensity of the second set of luminaires from a current lighting intensity to the reduced lighting intensity. In some examples, the controller 304 may reduce the lighting intensity of the second set of luminaires from a current lighting intensity to a lighting intensity less than the reduced lighting intensity. The controller 304 may reduce the lighting intensity of the luminaires in the second set to zero. That is, the second set of luminaires may
10 be switched off (or de-powered).

The controller 304 may be configured to reduce the lighting intensity of the second set of luminaires (i.e. those that are not to be used for VLC) by more than the lighting intensity of the first set of luminaires 202a (i.e. those that are being used for VLC) in order to enact a greater energy reduction overall. That is, the larger reduction in lighting intensity of
15 the second set of luminaires compensates for the smaller reduction in lighting intensity of the first set of luminaires 202a.

When reducing the lighting intensity of the first set of luminaires 202a, the controller 304 may ensure that a minimum illumination level within the environment 100 is maintained. For instance, due to the time of day (e.g. evening or night time), the environment
20 100 (e.g. a room within a house) may require a minimum level of illumination. As another example, the environment 100 may be an office environment 100 which requires permanent illumination. When the environment 100 has one or more light sensors 110 configured to determine (i.e. measure, sense, detect, etc.) a respective illumination level (or value of the illumination level) of the environment 100 at that sensor, each of those light sensors 110 may
25 be associated with a predetermined minimum illumination level (or a predetermined minimum value of the measured illumination level). The predetermined minimum illumination level may be set by a user to maintain a minimum desired illumination level within the environment 100. Each light sensor 110 may have the same predetermined minimum illumination level. Alternatively, one, some or all of the light sensors 110 may
30 have a different predetermined minimum illumination level. The input signal to reduce the energy consumption of the plurality of luminaires may specify a reduced lighting intensity of the luminaires that corresponds to the predetermined minimum illumination level. That is, the reduced lighting intensity may specify a lighting intensity of the luminaires that would result

in the illumination level measured at the light sensor(s) 110 being equal to the predetermined minimum illumination level.

The controller 304 may be configured to determine a minimum lighting intensity for the plurality of luminaires that would ensure that the determined illumination level at the light sensor(s) 110 is at a level greater than the predetermined minimum illumination level. The controller 304 may then control the first set of luminaires 202a to reduce the lighting intensity of those luminaries to an intensity equal to or greater than the minimum lighting intensity that would ensure the determined illumination level by the light sensor(s) 110 is above (i.e. greater than) the predetermined minimum illumination level. In this embodiment, the controller 304 is configured to reduce the lighting intensity of the first set of luminaires 202a to a lighting intensity that is both (i) an intensity that ensures the determined illumination level by the light sensor(s) 110 is greater than the predetermined minimum illumination level, and (ii) equal to or greater than the minimum lighting intensity required to transmit information to the user device 106 via visible light communication. This ensures that VLC is maintained, the environment 100 is adequately illuminated and a reduction in energy consumption is achieved.

As described above, the input signal to reduce the energy consumption of the luminaries may specify a reduced lighting intensity. The controller 304 may reduce the lighting intensity of the second set of luminaires to the specified reduced lighting intensity. The controller 304 may also determine a minimum lighting intensity for the first set of luminaires 202a that would ensure that the determined illumination level of the at least one light sensor 110 is at a level greater than the predetermined minimum illumination level. That is, the second set of luminaires may have already been set to the reduced lighting intensity, and the controller 304 then determines a lighting intensity of the first set of luminaires 202a that would meet the predetermined minimum illumination level requirements of the light sensor(s) 110. Alternatively, the controller 304 may receive the input signal specifying the reduced lighting intensity and determine the minimum lighting intensity of the first set of luminaires 202a before reducing the lighting intensity of the first set and second set of luminaires. The specified reduced lighting intensity may be a lower intensity than (i.e. less than) the determined minimum lighting intensity of the first set of luminaires 202a.

The controller 304 may then control the first set of luminaires 202a to reduce the lighting intensity of those luminaries to an intensity equal to or greater than the minimum lighting intensity that would ensure the determined illumination level by the light sensor(s) 110 is above (i.e. greater than) the predetermined minimum illumination level. In this

embodiment, the controller 304 is configured to reduce the lighting intensity of the first set of luminaires 202a to a lighting intensity that is both (i) an intensity that ensures the determined illumination level by the light sensor(s) 110 is greater than the predetermined minimum illumination level, and (ii) equal to or greater than the minimum lighting intensity required to transmit information to the user device 106 via visible light communication. The second set of luminaires may be switched off (i.e. powered down) completely and therefore the illumination level at the light sensor(s) 110 may be achieved solely by the first set of luminaires 202a.

The controller 304 may determine appropriate lighting intensity levels (i.e. dimming levels) for the luminaires such that the light sensor measurements are above the predetermined illumination levels (i.e. sensor set-points) using the following equation:

$$\sum_{m=1}^M I_{i,m} d_m + s_i \geq t_i$$

Here, $I_{i,m}$ is the illuminance seen at light sensor i due to contribution of luminaire m being at dimming level d_m , s_i is the daylight contribution at light sensor i , and t_i is the sensor set-point.

The controller 304 may, as a feature of determining a minimum lighting intensity required to transmit information to the user device 106 via VLC, determine a minimum lighting intensity for the first set of luminaires 202a that would ensure that the VLC is conducted reliably. That is, a minimum lighting intensity such that the VLC has an error rate of transmission of information to the user device 106 that is less than a predetermined maximum allowable error rate. The predetermined maximum allowable error rate may be set by the user. The error rate determined for a particular lighting intensity may be determined based on, for example, feedback from the user device 106, “known” error rates for a given lighting intensity, estimated error rates for a given lighting intensity, etc. The determined error rate may also be determined based on a determined distance between the user device 106 and respective luminaires. The controller 304 may determine an error rate for one, some or each of the luminaires in the first set.

The controller 304 may determine appropriate lighting intensity levels (i.e. dimming levels) for the luminaires such that the error rate η_k at user device k is no more than an expected maximum tolerable limit, $\eta_{\{max,k\}}$ using the following equation:

$$\eta_k(\{d_n, r_{nk}\}_{n \in N_k \subseteq S_k}) \leq \eta_{\{max, k\}}$$

Here, the set of luminaires seen by user device k is denoted by S_k . Based on user device locations (and luminaire 104 locations), the VLC transmitter-receiver distances may be computed, denoted by r_{ik} . That is, the error rate used in the determination of the minimum lighting intensity for the first set of luminaires 202a may be a function of the determined respective distances between the user device and each of the luminaires in the first set of luminaires 202a.

The controller 304 may then control the first set of luminaires 202a to reduce the lighting intensity of those luminaries to an intensity equal to or greater than the minimum lighting intensity that would ensure the determined error rate of the transmission of information to the user device 106 via VLC is at a rate less than the predetermined maximum error rate.

The controller 304 may seek to reduce energy consumption of the luminaires by optimizing a control problem. The controller 304 may determine an optimized lighting intensity for the luminaires that seeks to minimize the energy consumption of the plurality of luminaires but such that (i) the minimum lighting intensity for the plurality of luminaires ensures the sensed illumination level of the light sensor(s) 110 is greater than the predetermined minimum illumination level, and (ii) the minimum lighting intensity for the first set of luminaires 202a ensures the error rate of the transmission of information to the user device 106 via VLC less than the predetermined maximum error rate. The optimized lighting intensity for the first set of luminaires 202a may be the greater of the two determined minimum lighting intensities. The controller 304 may reduce the lighting intensity of the first set of luminaires 202a from the current lighting intensity to the optimized lighting intensity. An advantage of this is that the greatest reduction in energy consumption can be achieved that still enables error-free (or at least allowable erroneous) VLC between the luminaires and user device 106.

The controller 304 may seek to minimize the energy consumption E_m for the first and/or second set of luminaires, wherein the energy consumption is a function of the dimming level (lighting intensity) of each luminaries in those sets, using the following equation:

$$\min_{\{d_i, \{N_m\}\}} \sum_{m=1}^M E_m(d_m)$$

such that the constraints C1 and C2 are met:

$$\text{C1:} \quad \sum_{m=1}^M I_{i,m} d_m + s_i \geq t_i$$

$$5 \quad \text{C2:} \quad \eta_k(\{d_n, r_{nk}\}_{\{n \in N_k \subseteq S_k\}}) \leq \eta_{\{max, k\}}$$

That is, the dimming levels that achieve the greatest energy reduction whilst both maintaining set illumination levels within the environment 100 and ensuring reliable VLC are enacted.

As an optional feature, the controller 304 may be configured to control one or more of the luminaires that are not transmitting the same information to the user device 106 to stop transmitting information to the user device 106 via VLC. That is, if two luminaires are transmitting message A via VLC and one luminaire 104 is transmitting message B via VLC, the controller 304 may control the luminaries transmitting message B to stop transmitting (any information) via VLC. Similarly, the controller 304 may be configured to control one or more of the luminaires that are not visible by the receiver of the user device 106 to stop transmitting information to the user device 106. An advantage of this is that the signal-to-noise ratio of the message can be increased to allow for better reception of the message. The controller 304 may instead control all of the luminaires that are not transmitting a desired message to stop transmitting via VLC, even if only one luminaire 104 is transmitting the desired message.

As another optional feature, the controller 304 may be configured to control one or more of the luminaires that are visible to the receiver of the user device 106 and that are not transmitting the same information to the user device 106, to transmit the same information to the user device 106 as the luminaires that are in the first set of luminaires 202a and currently transmitting the same information to the user device 106. That is, if the first set of luminaries are transmitting message C via VLC and a luminaire 104 is transmitting message D via VLC (or not transmitting any message), the controller 304 may control the luminaire 104 that was transmitting message D to instead transmit message C. This therefore increases the signal-to-noise ratio of the desired message.

Figure 4 illustrates an example control diagram 400 for reducing the energy consumption of a plurality of luminaires 104. The controller 304 may receive inputs indicating light sensor set-points 402 determined using occupancy status information from occupancy sensors 108, illumination level measurements from light sensors 110, active VLC

links 404, and user device locations 406. The active user VLC links may be in the form of luminaire identifiers that are in the range of the user device 106. The user device 106 locations and active VLC links are used to determine quality of service constraints 408 (e.g. the allowable error rate). The controller may use the inputs to determine the dimming levels for the luminaires and VLC mapping information 410 (e.g. which luminaires are required or are to be used for VLC). The illumination from the luminaires 104 and other light sources 412 (e.g. daylight and artificial light sources) are monitored (e.g. periodically or continuously) by the light sensors 110, which feed an updated measurement back to the controller 304. The dimming levels for the luminaires 104 may be adapted (e.g. periodically or continuously) in response to the updated measurements.

CLAIMS:

1. A method of reducing energy consumption of a plurality of luminaires (104) within an environment (100), wherein one or more of the luminaires (104) are operable to transmit information via visible light communication, wherein the method comprises:

determining a first set (202a) of at least one of said one or more luminaires (104) that are to be used to transmit information to a user device (106) in the environment (100) via visible light communication;

receiving an input signal to reduce the energy consumption of the plurality of luminaires (104);

determining, for the first set of luminaires (202a), a minimum lighting intensity required to transmit information to the user device (106) via visible light communication; and

in response to the receiving of the input signal, reducing the lighting intensity of the first set of luminaires (202a) from a current lighting intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device (106) via visible light communication;

wherein said determining of the first set of luminaires (202a) comprises determining the first set of at least one of said one or more luminaires (104) to be a first set that are transmitting the same information to the user device (106) via visible light communication.

2. A method according to claim 1, wherein the remainder of the plurality of luminaires (104) not in the first set form a second set of luminaires (202b), wherein said input signal specifies a reduced lighting intensity, and wherein the method further comprises reducing the lighting intensity of the second set of luminaires (202b) from a current lighting intensity to an intensity equal to or less than the reduced lighting intensity specified in the received input signal.

3. A method according to claim 1 or claim 2, wherein multiple luminaires out of the plurality of luminaires (104) are operable to transmit via visible light communication, and

said determining of the first set of luminaires (202a) comprises:

determining at least one of the multiple luminaires (104) operable to transmit via visible light communication that are not currently required to transmit information to the user device (106); and

5 preventing the at least one luminaire that is determined to not currently be required to transmit information to the user device (106) from transmitting information to the user device (106) via visible light communication, such that said at least one luminaire is not included in said first set of luminaires (202a).

10 4. A method according to any of claims 1 to 3, wherein said determining of the first set of luminaires (202a) comprises determining the first set of at least one of said one or more luminaires (104) to be a first set that are within range of a visible light receiver of the user device (106).

15 5. A method according to any of claims 1 to 4, wherein the input signal to reduce the energy consumption of the plurality of luminaires (104) is received from one or more occupancy sensors and/or light sensors within the environment (100).

20 6. A method according to any of claims 1 to 5, wherein the environment (100) comprises at least one light sensor (110) configured to determine an illumination level at said light sensor (110), and wherein the input signal to reduce the energy consumption of the plurality of luminaires (104) is received from the least one light sensor (110).

25 7. A method according to any preceding claim when dependent on claim 2, wherein the environment (100) comprises at least one light sensor (110) configured to measure an illumination level at the at least one light sensor (110), wherein the at least one light sensor (110) is associated with a predetermined minimum value of the measured illumination level, wherein the predetermined minimum value of the measured illumination level corresponds to the reduced lighting intensity specified in the input signal, wherein the
30 method comprises:

determining a minimum lighting intensity for the plurality of luminaires (104), corresponding to the illumination level measured by said light sensor (110) being greater than the predetermined minimum value of the measured illumination level,

wherein said reducing the lighting intensity of the first set of luminaires (202a)

comprises reducing the lighting intensity of the first set of luminaires (202a) to an intensity equal to or greater than the minimum lighting intensity for the plurality of luminaires (104) corresponding to the illumination level measured by said light sensor (110) being greater than the predetermined minimum value of the measured illumination level.

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8. A method according to claim 6 when dependent on claim 2, comprising:
given the reduced lighting intensity of the second set of luminaires (202b),
determining a minimum lighting intensity for the first set of luminaires (202a) corresponding
to the illumination level measured by said light sensor (110) being greater than the
predetermined minimum value of the measured illumination level; and wherein said reducing
the lighting intensity of the first set of luminaires (202a) comprises reducing the lighting
intensity of the first set of luminaires (202a) to an intensity equal to or greater than the
minimum lighting intensity for the first set of luminaires (202a) corresponding to the
illumination level measured by said light sensor (110) being greater than the predetermined
minimum value of the measured illumination level.

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9. A method according to any of claims 1 to 7, comprising determining a
minimum lighting intensity for the first set of luminaires (202a) that corresponds to a
determined error rate of the transmission of information to the user device (106) via visible
light communication being less than a predetermined maximum error rate,
wherein said reducing the lighting intensity of the first set of luminaires (202a)
comprises reducing the lighting intensity of the first set of luminaires from the current
intensity to an intensity equal to or greater than the minimum lighting intensity for the first
set of luminaires (202a) that corresponds to a determined error rate of the transmission of
information to the user device (106) via visible light communication being less than the
predetermined maximum error rate.

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10. A method according to claim 9, comprising determining a respective distance
between the user device (106) and each of the luminaires in the first set of luminaires (202a),
wherein the error rate used in said determination of the minimum lighting intensity for the
first set of luminaires is a function of the determined respective distances between the user
device (106) and each of the luminaires in the first set of luminaires.

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11. A method according to claim 9 when dependent on claim 7 or claim 8, comprising:

determining an optimized lighting intensity, wherein the optimized lighting intensity is equal to the greater of: (i) the minimum lighting intensity for the plurality of luminaires (104) corresponding to the illumination level measured by said light sensor (110) being greater than the predetermined minimum value of the measured illumination level, and (ii) the minimum lighting intensity for the first set of luminaires (202a) that corresponds to a determined error rate of the transmission of information to the user device (106) via visible light communication being less than the predetermined maximum error rate; and

wherein said reducing the lighting intensity of the first set of luminaires (202a) comprises reducing the lighting intensity of the first set of luminaires from the current intensity to the optimized lighting intensity.

12. A method according to claim 4, comprising:

controlling one or more of the luminaires (104) that are not transmitting the same information to the user device (106) and/or that are not visible by the receiver of the user device (106) to stop transmitting information to the user device (106) via visible light communication; and/or

controlling one or more of the luminaires (104) that are visible to the user device (106) that are not transmitting the same information to the user device (106), to transmit the same information to the user device (106) as the luminaires that are in the first set of luminaires (202a) and currently transmitting the same information to the user device (106).

13. A controller (304) for reducing energy consumption of a plurality of luminaires (104) within an environment (100), wherein one or more of the luminaires (104) are operable to transmit information via visible light communication,

wherein the controller (304) is configured to determine a first set (202a) of at least one of said one or more luminaires (104) that are to be used to transmit information to a user device (106) in the environment (100) via visible light communication and that are transmitting the same information to the user device (106) via visible light communication;

wherein the controller (304) comprises an interface configured to receive an input signal to reduce the energy consumption of the plurality of luminaires (104); and

wherein the controller (304) is configured to:

determine, for the first set of luminaires (202a), a minimum lighting intensity required to transmit information to the user device (106) via visible light communication; and

in response to receiving the input signal, control the first set of luminaires (202a) to reduce the lighting intensity of the first set of luminaires (202a) from a current

5 intensity to an intensity equal to or greater than the minimum lighting intensity required to transmit information to the user device (106) via visible light communication.

14. A computer program comprising instructions embodied on computer-readable storage and configured so as when the computer program is executed on a computing device,
10 the computing device is arranged to carry out a method according to any of claims 1 to 12.

15. A system comprising:

a plurality of luminaires (104), wherein one or more of the luminaires (104) comprise a lighting driver (314) configured to cause the one or more luminaires (104) to
15 transmit information via visible light communication; and

the controller (304) according to claim 13, wherein the controller is implemented in hardware or software, a central device or across one or more of the plurality of luminaires (104).

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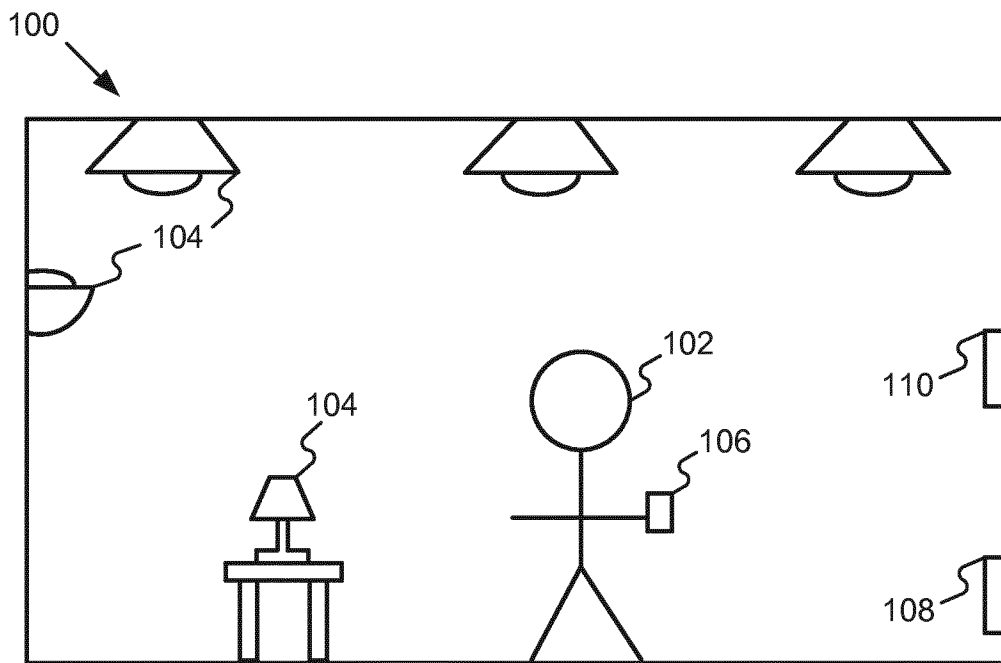


Figure 1

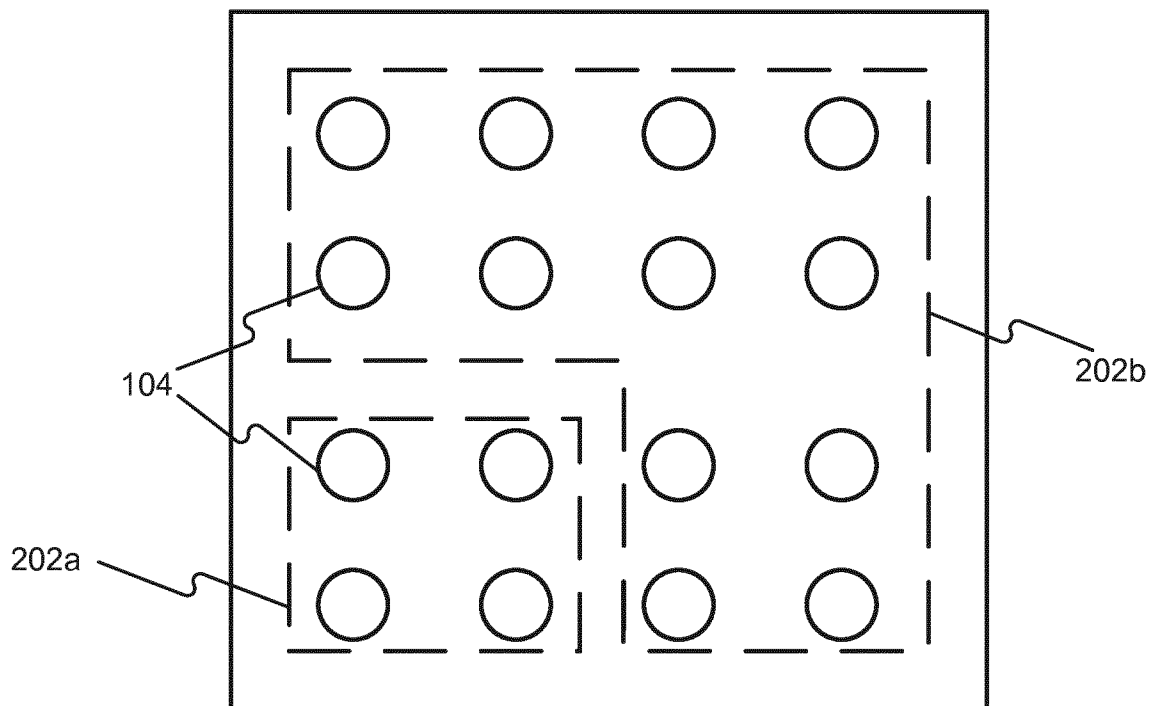


Figure 2

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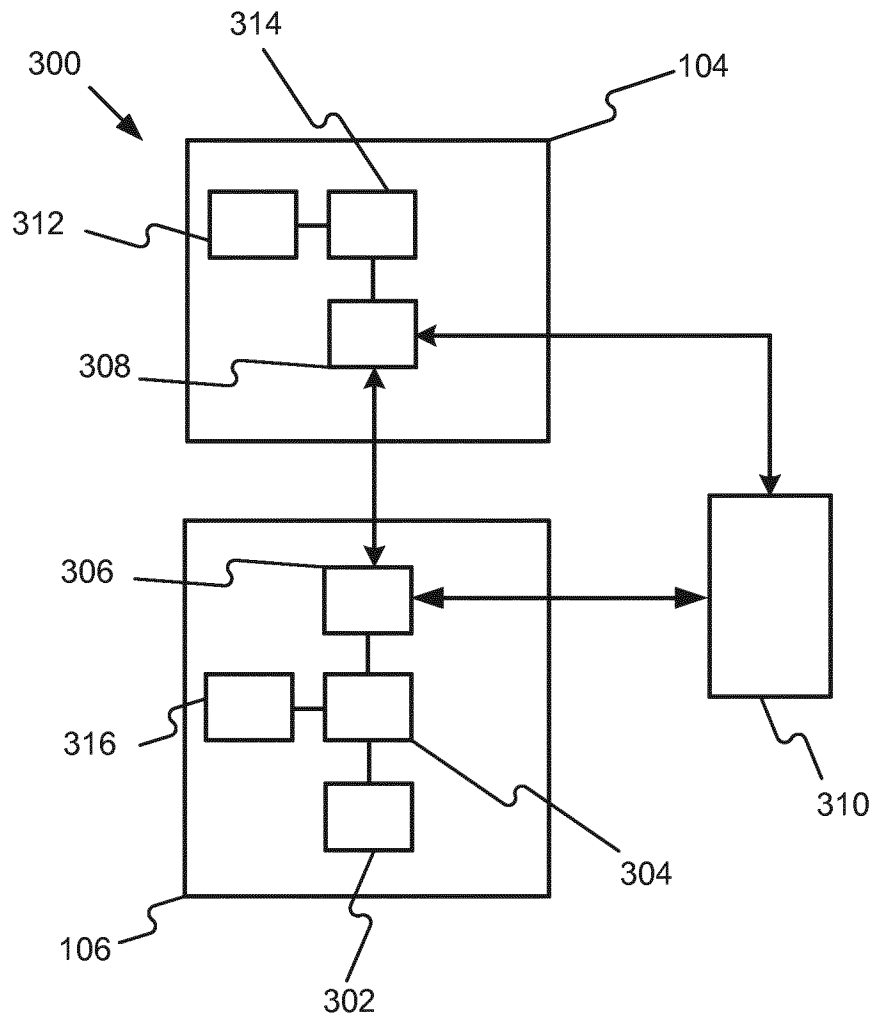


Figure 3

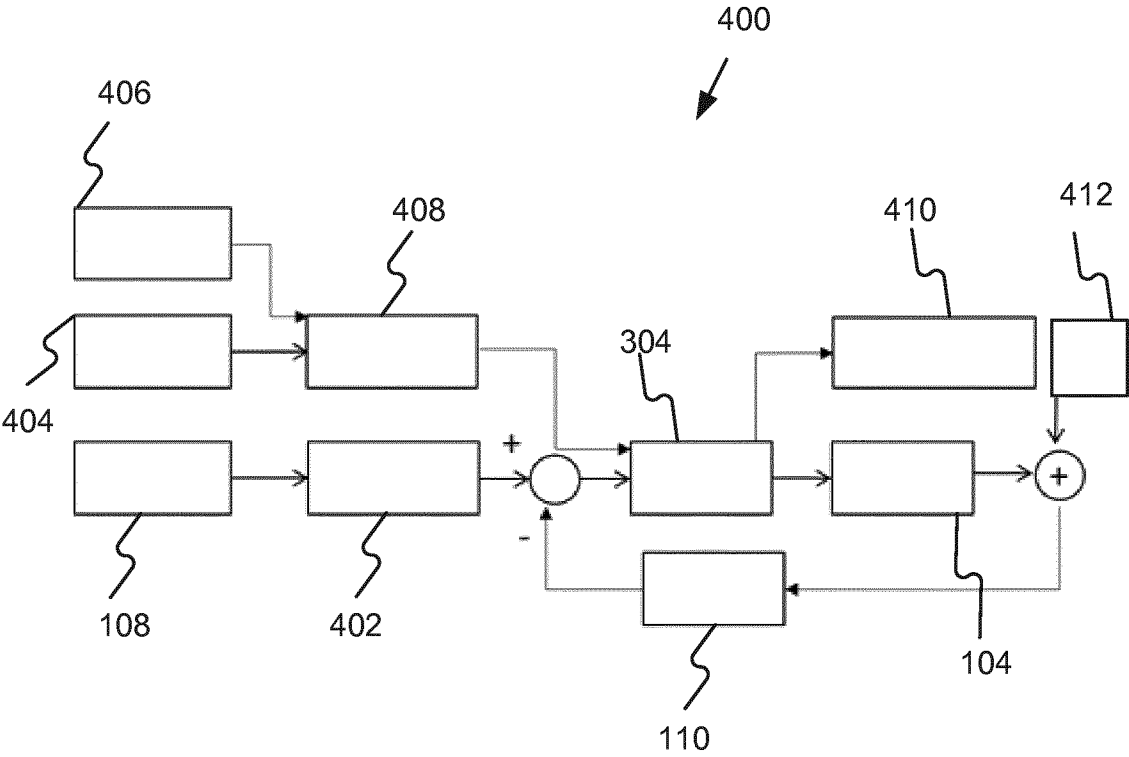


Figure 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/070348

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B37/02 H04B10/116
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H05B H04B G06Q H04W A61L F21S F21V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2014/086590 A1 (GANICK AARON [US] ET AL) 27 March 2014 (2014-03-27) page 2, paragraphs 14, 19; figures 1-69 page 4, paragraph 81 - page 30, paragraph 330 in particular, from page 4, par. [0081] to page 9, par. [0127]; from page 11, par. [0162] to page 15, par. [0191]; from page 25 to page 26, par. [0300]; page 27, par. [0308]; pages 27-28, par. [0314]; Figs. 1-7, 17-23, 58 ----- -/--	1,4-6, 12,13,15 2,3,7-11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

5 September 2019

Date of mailing of the international search report

13/09/2019

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/070348

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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A	page 1, lines 2-6; figures 1-3 page 2, line 3 - page 5, line 3 page 5, line 29 - page 11, line 10 in particular, from page 5, line 30 to page 8, line 24; Figs. 1, 2 -----	2-11
Y	US 9 700 641 B2 (KENALL MFG CO [US]) 11 July 2017 (2017-07-11) column 1, lines 9-12; figures 1, 2, 9A-9G, 12, 13 column 1, line 52 - column 2, line 24 column 4, line 7 - column 8, line 67 column 14, line 36 - column 18, line 60 column 22, line 12 - column 25, line 29 -----	2,3,7,8
Y	ZAFAR FAHAD ET AL: "Dimming schemes for visible light communication: the state of research", TECHNICAL REPORT OF WIRELESS NETWORKING GROUP, COORDINATED SCIENCE LABORATORY; DEPT. ELECTRICAL AND COMPUTER ENGINEERING; UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, US, vol. 22, no. 2, 1 April 2015 (2015-04-01), pages 29-35, XP011579863, ISSN: 1536-1284, DOI: 10.1109/MWC.2015.7096282 [retrieved on 2015-04-27] the whole document -----	9-11
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International application No

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