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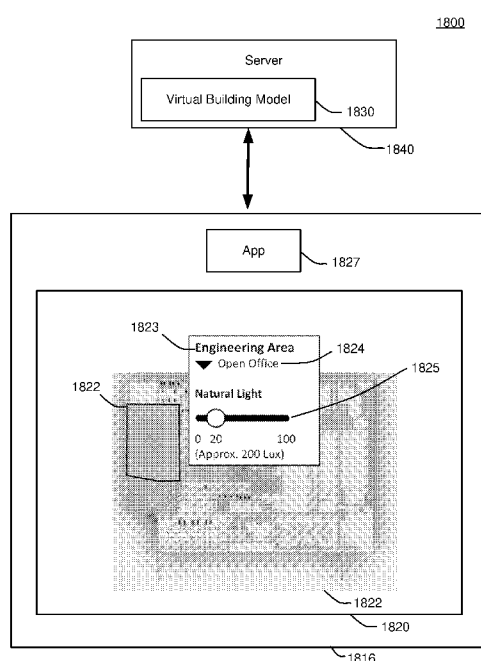


FIG. 18

(57) Abstract: Methods of controlling tintable window(s) comprising determining one or more transmissivities of the one or more tintable windows, wherein the one or more transmissivities are determined to generate a target illuminance level, or approximately the target illuminance level, at one or more grid points in an internal space of a virtual representation of the building, the one or more transmissivities determined based at least in part on attenuated clear sky data that is based at least in part on a predicted clear sky illuminance and readings from a plurality of sensors, and holding, or transitioning, the one or more tintable windows to an end tint state associated with the one or more determined transmissivities.

SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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INTELLIGENCE**CROSS REFERENCES TO RELATED APPLICATIONS**

5 **[0001]** This application claims benefit of and priority to U.S. Provisional Application 63/364,698, titled “INTELLIGENCE,” and filed on May 13, 2022; this application is a continuation-in-part of U.S. Application 18/034,328, filed on April 27, 2023, titled “VIRTUALLY VIEWING DEVICES IN A FACILITY,” which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2021/057678, 10 filed on November 2, 2021, and titled “VIRTUALLY VIEWING DEVICES IN A FACILITY;” PCT/US2021/057678 claims benefit of and priority to U.S. Provisional Application 63/109,306, filed November 3, 2020, titled “ACCOUNTING FOR DEVICES IN A FACILITY” and U.S. Provisional Application 63/214,741, filed June 24, 2021, titled “VIRTUALLY VIEWING DEVICES IN A FACILITY;” PCT/US2021/057678 is a 15 continuation-in-part of International PCT Application PCT/US21/27418, filed April 15, 2021, titled “INTERACTION BETWEEN AN ENCLOSURE AND ONE OR MORE OCCUPANTS;” PCT/US2021/057678 is also a continuation-in-part of International PCT Application PCT/US21/33544, filed May 21, 2021, titled “ENVIRONMENTAL ADJUSTMENT USING ARTIFICIAL INTELLIGENCE;” PCT/US2021/057678 is also 20 a continuation-in-part of International PCT Application PCT/US2021/030798, filed May 5, 2021, titled “DEVICE ENSEMBLES AND COEXISTENCE MANAGEMENT OF DEVICES; PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 16/946,947, filed on July 13, 2020, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” which is a national stage 25 application under 35 U.S.C. §371 to International PCT Application PCT/US2017/062634 (designating the United States), filed November 20, 2017, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK;” International PCT Application PCT/US2017/062634 claims benefit of and priority to U.S. Provisional application 62/426,126, filed on November 23, 2016 and to U.S. Provisional application 30 62/551,649, both titled “titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK;” PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 17/211,697, filed March 24, 2021, titled “COMMISSIONING WINDOW NETWORKS,” which is continuation of U.S. Patent Application Serial No. 15/727,258, filed October 6, 2017, titled

“COMMISSIONING WINDOW NETWORKS;” PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 17/450,091 filed October 06, 2021, titled “MULTI-SENSOR HAVING A LIGHT DIFFUSING ELEMENT AROUND A PERIPHERY OF A RING OF PHOTODETECTORS,” which is a continuation of U.S. Patent Application Serial No. 16/871,976 filed May 11, 2020, titled “ADJUSTING WINDOW TINT BASED AT LEAST IN PART ON SENSED SUN RADIATION,” which is a continuation of U.S. Patent Application Serial No. 14/998,019 filed October 06, 2015 (now U.S. Patent 10,690,540 issued June 23, 2020) and titled “MULTI-SENSOR HAVING A LIGHT DIFFUSING ELEMENT AROUND A PERIPHERY OF A RING OF PHOTODETECTORS;” PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 16/696,887 filed November 26, 2019, titled “SENSING SUN RADIATION,” which is a continuation of U.S. Patent Application Serial No. 15/287,646, filed October 6, 2016 (now U.S. Patent Serial No. 10,533,892) and titled “MULTI-SENSOR,” which is a continuation-in part of U.S. Patent Application 14/998,019, filed October 06, 2015 (now U.S. Patent 10,690,540), titled “MULTI-SENSOR HAVING A LIGHT DIFFUSING ELEMENT AROUND A PERIPHERY OF A RING OF PHOTODETECTORS;” PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 17/380,785 filed July 20, 2021, titled “WINDOW ANTENNAS,” which claims priority to U.S. Patent Application Serial No. 16/099,424, filed November 6, 2018, titled “WINDOW ANTENNAS,” which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US17/31106, filed May 4, 2017, titled, “WINDOW ANTENNAS;” PCT/US2021/057678 is also a continuation-in-part of U.S. Patent Application Serial No. 17/385,810, filed July 26, 2021, titled “WINDOW ANTENNAS,” which claims priority to U.S. Patent Application Serial No. 16/099,424; PCT/US2021/057678 is also a continuation-in-part U.S. Patent Application Serial No. 16/980,305, filed September 11, 2020, titled “WIRELESSLY POWERED AND POWERING ELECTROCHROMIC WINDOWS,” which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US19/22129, filed March 13, 2019, titled “WIRELESSLY POWERED AND POWERING ELECTROCHROMIC WINDOWS;” this application is related to U.S. Patent application 17/250,586, titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS,” and filed on February 5, 2021, which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2019/046524, titled “CONTROL METHODS AND SYSTEMS

USING EXTERNAL 3D MODELING AND NEURAL NETWORKS,” and filed on August 14, 2019; PCT/US2019/046524 claims benefit of and priority to U.S. Provisional Patent Application No. 62/764,821, filed on August 15, 2018 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS,” to U.S. Provisional Patent Application No. 62/745,920, filed on October 15, 2018 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS,” and to U.S. Provisional Patent Application No. 62/805,841 filed on February 14, 2019 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS;”

International PCT application PCT/US2019/046524 is also a continuation-in-part of International PCT application PCT/US2019/023268, filed on March 20, 2019 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED,” which claims benefit of and priority to U.S. Provisional Patent Application No. 62/646,260 filed on March 21, 2018 and titled “METHODS AND SYSTEMS FOR CONTROLLING TINTABLE WINDOWS WITH CLOUD DETECTION” and U.S. Provisional Patent Application No. 62/666,572 filed on May 3, 2018 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED COMPUTING;” International PCT application PCT/US2019/023268 is a continuation-in-part of U.S. Patent Application No. 16/013,770, filed on June 20, 2018 and titled “CONTROL METHOD FOR TINTABLE WINDOWS,” which is a continuation of U.S. Patent Application 15/347,677, titled “CONTROL METHOD FOR TINTABLE WINDOWS” and filed on November 9, 2016; U.S. Patent Application 15/347,677 is a continuation-in-part of International PCT application PCT/US15/29675 filed on May 7, 2015 and titled “CONTROL METHOD FOR TINTABLE WINDOWS,” which claims benefit and priority to 61/991,375 filed on May 9, 2014 and titled “CONTROL METHOD FOR TINTABLE WINDOWS;” U.S. Patent Application 15/347,677 is also a continuation-in-part of U.S. Patent Application 13/772,969, filed on February 21, 2013 and titled “CONTROL METHOD FOR TINTABLE WINDOWS;” International PCT application PCT/US2019/046524 is also a continuation-in-part of U.S. Patent Application No. 16/438,177, titled “APPLICATIONS FOR CONTROLLING OPTICALLY SWITCHABLE DEVICES” and filed on June 11, 2019, which is a continuation of U.S. Patent Application No. 14/391,122, filed on October 7, 2014 and titled “APPLICATIONS FOR CONTROLLING OPTICALLY SWITCHABLE DEVICES;” U.S. Patent Application No. 14/391,122 is a national stage

application under 35 U.S.C. §371 of International PCT Application PCT/US2013/036456, titled “APPLICATIONS FOR CONTROLLING OPTICALLY SWITCHABLE DEVICES” and filed on April 12, 2013, which claims priority to and benefit of U.S. Provisional 61/624,175, titled “APPLICATIONS FOR CONTROLLING OPTICALLY SWITCHABLE DEVICES” and filed on April 13, 2012; this application is related to U.S. Patent Application 16/982,535, titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED COMPUTING,” filed on September 18, 2020, which is a national stage application under 35 U.S.C. §371 of International PCT Application PCT/US2019/023268, titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED COMPUTING,” and filed on March 20, 2019; PCT/US2019/023268 claims benefit of and priority to U.S. Provisional Patent Application No. 62/646,260, filed on March 21, 2018, and titled “METHODS AND SYSTEMS FOR CONTROLLING TINTABLE WINDOWS WITH CLOUD DETECTION,” and to U.S. Provisional Patent Application No. 62/666,572, filed on May 3, 2018 and titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED COMPUTING;” PCT/US2019/023268 is also a continuation-in-part of U.S. Patent Application 16/013,770, titled “CONTROL METHOD FOR TINTABLE WINDOWS,” and filed on June 20, 2018, which is a continuation of U.S. Patent Application 15/347,677, titled “CONTROL METHOD FOR TINTABLE WINDOWS,” and filed on November 9, 2016, which is a continuation-in-part of International Patent Application PCT/US15/29675, titled, “CONTROL METHOD FOR TINTABLE WINDOWS,” filed on May 7, 2015, which claims priority to and benefit of U.S. Provisional Patent Application No. 61/991,375, titled “CONTROL METHOD FOR TINTABLE WINDOWS” and filed on May 9, 2014; U.S. Patent Application 15/347,677 is also a continuation-in-part of U.S. Patent Application No. 13/772,969, titled “CONTROL METHOD FOR TINTABLE WINDOWS” and filed on February 21, 2013; this application is related to U.S. Patent Application Serial No. 17/400,596, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” filed on August 12, 2021, which is a continuation of U.S. Patent Application 16/462,916, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” and filed on May 21, 2019; U.S. Patent Application 16/462,916 is a continuation-in-part of U.S. Patent application 16/082,793, filed September 6, 2018, titled “METHOD OF COMMISSIONING

ELECTROCHROMIC WINDOWS,” which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2017/020805 filed on March 3, 2017, titled METHOD OF COMMISSIONING ELECTROCHROMIC WINDOWS,” which claims benefit of and priority to U.S. Provisional Applications 62,370,174, filed on August 2, 2016 and 62/305,892 filed on March 9, 2016, both titled “METHOD OF COMMISSIONING ELECTROCHROMIC WINDOWS;

U.S. Patent Application 16/462,916 is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2017/062634, which claims benefit and priority to U.S. Provisional Applications 62/551,649, filed on August 29, 2017 and 62/426,126, filed on November 23, 2016; U.S. Patent Application 16/462,916 is a continuation-in-part of U.S. Patent Application 14/951,410, filed on November 24, 2015; U.S. Patent Application 14/951,410 claims benefit of and priority to U.S. Provisional Applications 62/348,181, filed on October 29, 2015 and 62/085,179, filed on November 26, 2014; U.S. Patent Application 14/951,410 is a continuation-in-part of U.S. Patent 14/401,081, filed on November 13, 2014, which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2013/042765, filed on May 24, 2013; PCT/US2013/042765 claims benefit of and priority to U.S. Provisional Application 61/652,021, filed on May 25, 2012; U.S. Patent Application 14/951,410 is also a continuation-in-part of U.S. Patent Application 14/468,778, filed on August 26, 2014, which is a continuation of U.S. Patent Application 13/479,137, filed on May 23, 2012, which is a continuation of U.S. Patent Application 13/049750, filed on March 16, 2011, which is a continuation-in-part of U.S. Patent Application 12/971,576, filed on December 17, 2010, which claims benefit of and priority to U.S. Provisional Application 61/289,319, filed on December 22, 2009; U.S. Patent Application 14/951,410 is also a continuation-in-part of 13/449,248, filed on April 17, 2012; this application is related to U.S. Patent Application 18/100,773, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” and filed on January 24, 2023, which is a continuation of U.S. Patent Application Serial No. 16/946,947, filed on July 13, 2020, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” which is a national stage application under 35 U.S.C. §371 to International PCT Application PCT/US2017/062634 (designating the United States), filed November 20, 2017, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK;” International PCT Application PCT/US2017/062634 claims benefit of and priority to U.S. Provisional application 62/426,126, filed on November 23,

2016 and to U.S. Provisional application 62/551,649, both titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK;” this application is related to U.S. Patent Application 17/931,014, filed on September 9, 2022, titled “METHODS OF CONTROLLING MULTI-ZONE TINTABLE WINDOWS,”

5 which is a continuation of U.S. Patent Application Serial No. 15/762,077, titled “METHODS OF CONTROLLING MULTI-ZONE TINTABLE WINDOWS,” filed on March 21, 2018; U.S. Patent Application Serial No. 15/762,077 is a continuation of U.S. Patent Application 15/762,077, titled “METHODS OF CONTROLLING MULTI-ZONE TINTABLE WINDOWS” and filed on March 21, 2018, which is a national stage

10 application under 35 U.S.C. §371 to International PCT Application PCT/US2016/055005, filed on September 30, 2016, titled “METHODS OF CONTROLLING MULTI-ZONE TINTABLE WINDOWS;” International PCT Application PCT/US2016/055005 is a continuation-in-part of U.S. Patent Application 15/094897, filed on April 18, 2016; International PCT Application PCT/US2016/055005 claims benefit of and priority to U.S.

15 Provisional 62/236,032, filed on October 1, 2015; U.S. Patent Application 14/137,644 is a continuation-in-part of International PCT Application PCT/US2013/069913, filed on November 13, 2013; International PCT Application PCT/US2013/069913 claims benefit of and priority to U.S. Provisional Applications 61/740,651, filed on December 21, 2012 and 61/725,980, filed on November 13, 2012; 14/137,644 is a continuation-in-part of

20 International PCT Application PCT/US2013/031098, filed on March 13, 2013; International PCT Application PCT/US2013/031098 claims benefit of and priority to U.S. Provisional Patent Application 61/610,241, filed on March 13, 2012; each of these applications is hereby incorporated by reference in its entirety and for all purposes.

25 BACKGROUND

[0002] Electrochromism is a phenomenon in which a material exhibits a reversible electrochemically-mediated change in an optical property when placed in a different electronic state, typically by being subjected to a voltage change. The optical property is typically one or more of color, transmittance, absorbance, and reflectance. One well

30 known electrochromic material is tungsten oxide (WO_3). Tungsten oxide is a cathodic electrochromic material in which a coloration transition, transparent to blue, occurs by electrochemical reduction.

[0003] Electrochromic materials may be incorporated into, for example, windows for residential, commercial, and other uses. The color, transmittance, absorbance, and/or

reflectance of such windows may be changed by changing a feature of the electrochromic material, that is, electrochromic windows are windows that can be darkened or lightened electronically. A small voltage applied to an electrochromic device of the window will cause them to darken; reversing the voltage causes them to lighten. This capability allows control of the amount of light that passes through the windows, and presents an opportunity for electrochromic windows to be used as energy-saving devices.

[0004] While electrochromism was discovered in the 1960s, electrochromic devices, and particularly electrochromic windows, still suffer various problems and have not begun to realize their full commercial potential despite many recent advancements in electrochromic technology, apparatus, software, and related methods of making and/or using electrochromic devices.

SUMMARY

[0005] Embodiments pertain to a method controlling one or more tintable windows in a building. The method comprises determining one or more transmissivities of the one or more tintable windows. The one or more transmissivities determined to generate a target illuminance level, or approximately the target illuminance level, at one or more grid points in an internal space of a virtual representation of the building. The one or more transmissivities determined based at least in part on attenuated clear sky data that is based at least in part on a predicted clear sky illuminance and readings from a plurality of sensors. The method further comprising holding, or transitioning, the one or more tintable windows to an end tint state associated with the one or more determined transmissivities.

[0006] Embodiments pertain to a method controlling one or more tintable windows in a building. The method comprises determining one or more transmissivities of one or more tintable windows in the building. The one or more transmissivities are determined based on attenuated clear sky data to generate a target illuminance level, or approximately the target illuminance level, in an internal space of a virtual representation of the building. The method further comprising forecasting an override tint value based on a statistical assessment of past override values. In addition, the method comprise holding, or transitioning, the one or more tintable windows to one or more end tint states associated with the one or more transmissivities determined or to the override tint value if an override is in place.

[0007] Embodiments pertain to a method controlling one or more tintable windows in a building. The method comprises receiving a target level for an internal condition of the building using a virtual representation of the building. The target level comprises one or

more of an illuminance level in an internal space of the building, a heat gain into the internal space of the building, or a color of light in the internal space of the building. The method further comprises determining one or more transmissivities of one or more tintable windows in the building, wherein the one or more transmissivities are determined to generate the target level, or approximately the target level in the building. In addition, the method comprises holding, or transitioning, the one or more tintable windows to an end tint state associated with the one or more transmissivities determined.

[0008] Embodiments pertain to an apparatus for controlling tint of one or more tintable windows in a building, the apparatus comprising at least one controller configured to operatively couple to the one or more tintable windows, the at least one controller further configured to perform, or direct performance of, any one of the methods of controlling one or more tintable windows in a building.

[0009] Embodiments pertain to a non-transitory computer readable medium storing computer executable instructions for controlling tint of one or more zones of tintable windows in a building, when read by one or more processors, cause the one or more processors to execute operations of any one of the methods of controlling one or more tintable windows in a building.

[0010] Embodiments pertain to a system for controlling tint of one or more zones of tintable windows in a building, the system comprises a network configured to operatively couple to the one or more tintable windows and configured to perform any one of the methods of controlling one or more tintable windows in a building.

[0011] These and other features and embodiments will be described in more detail with reference to the drawings.

[0012] Additional aspects and advantages of the present disclosure will become readily apparent to those skilled in this art from the following detailed description, wherein only illustrative embodiments of the present disclosure are shown and described. As will be realized, the present disclosure is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The figures and components therein may not be drawn to scale.

[0014] **FIG. 1A** is a schematic drawing of a cross-section of an electrochromic lite, according to implementations.

[0015] **FIG. 1B** is a schematic drawing of a cross-section of the electrochromic lite in **FIG. 1A**.

[0016] **FIG. 1C** is a schematic drawing of a top down view of the electrochromic lite in **FIG. 1A**.

5 [0017] **FIG. 2A** is a schematic drawing of a cross-section of an IGU with the electrochromic lite described in relation to **FIGS. 1A-1C**, according to implementations.

[0018] **FIG. 2B** is a schematic drawing of a cross-section of an electrochromic device, described in relation to **FIGS. 1A-1C** and a reinforcing pane laminated thereon, according to implementations.

10 [0019] **FIG. 3A** is a schematic drawing of a cross-section of an electrochromic device, according to implementations.

[0020] **FIG. 3B** is a schematic drawing of a cross-section of an electrochromic device in a bleached state, according to implementations.

15 [0021] **FIG. 3C** is a schematic drawing of a cross-section of an electrochromic device in a colored state, according to implementations.

[0022] **FIG. 4** is a simplified block diagram of components of a window controller and components of a window controller system, according to implementations.

[0023] **FIG. 5** is a schematic diagram of a control system for controlling tint of a plurality of tintable windows in a building, according to implementations.

20 [0024] **FIG. 6** is a schematic diagram of a network system with a building management system (BMS), a plurality of distributed local window controllers (WCs), a plurality of network controllers (NCs), and a master controller (MC), according to implementations.

[0025] **FIG. 7** is a schematic diagram of a plurality of tintable windows grouped into zones, according to implementations.

25 [0026] **FIG. 8** is a schematic diagram depicting a virtual building model and associated BIM file(s), according to implementations.

[0027] **FIG. 9** shows an example embodiment of a control system in which a real, physical building includes a controller network for managing and controlling interactive network devices such as one or more tintable windows, according to implementations.

30 [0028] **FIG. 10** is a schematic illustration of a flux-transfer path from the sky to a grid point in an interior space such as a room of a building simulated by a three-phase simulation model, according to an implementation.

[0029] FIG. 11 is a schematic illustration of a sky segment/patch (S_α) providing an illuminance (L_α) through an aperture of a tintable window in a room of a building to provide an illuminance level at a grid point (x) inside the room, according to an aspect.

[0030] FIG. 12A is a three dimensional illustration of a sky dome having a plurality of
5 145 light patches, according to implementations.

[0031] FIG. 12B is a 2D projection of the sky dome shown in FIG. 12A.

[0032] FIG. 13A is an illustration of a 2D projection of the sky dome shown in FIG. 12A depicting illuminance values for light patches based on attenuated clear sky data, in an implementation.

10 [0033] FIG. 13B is an illustration of a 2D top view of a virtual building model used in conjunction with the sky dome to illustrate illuminance levels within the interior of the building, in an implementation.

[0034] FIG. 13C is a bar chart of illuminance levels in various spaces of the virtual building model, in an implementation.

15 [0035] FIG. 14A is a drawing of an isometric view of a portion of a multi-sensor device having a plurality of photosensors equally distributed along the circumference, a photosensor pointed upward vertically, and two infrared sensors pointed upward vertically, according to an implementation.

[0036] FIG. 14B is a schematic drawing of a cross sectional view of a portion of a
20 multi-sensor device having two rings of photosensors and a photosensor pointed upward vertically, according to an implementation.

[0037] FIG. 15 is an isometric view of an example of a multi-sensor device with photosensors directed at various azimuthal and altitudinal angles of the sky, according to an implementation.

25 [0038] FIG. 16A is plot of photosensor readings from thirteen (13) photosensors of multi-sensor device shown in FIG. 14A on a clear sky day on February 16, 2022 in Milpitas California.

[0039] FIG. 16B is plot of photosensor readings from thirteen (13) photosensors of multi-sensor device shown in FIG. 14A on an overcast morning and clear afternoon on
30 April 11, 2022 in Milpitas California.

[0040] FIG. 17 is a diagram depicting operations of a method of generating one or more zones of tintable windows and associated orientations of the tintable windows, according to an implementation.

[0041] FIG. 18 is an illustration of an example of a system in which a virtual building model is used to present a 2D or a 3D model of virtual spaces in a building to a customer based on building information in files (e.g., BIM files) of the virtual building model, according to an implementation.

5 [0042] FIG. 19 is schematic diagram of a system for controlling tint of one or more tintable windows, according to an implementation.

[0043] FIG. 20 is a flowchart depicting operations of a method of controlling one or more tintable windows in a facility such as a building, according to various aspects.

[0044] FIG. 21 is a flowchart depicting operations of an optimization process,
10 according to various aspects.

DETAILED DESCRIPTION

[0045] Different aspects are described below with reference to the accompanying drawings. The features illustrated in the drawings may not be to scale. In the following
5 description, numerous specific details are set forth in order to provide a thorough understanding of the presented implementations. The disclosed implementations may be practiced without one or more of these specific details. In other instances, well-known operations have not been described in detail to avoid unnecessarily obscuring the disclosed implementations. While the disclosed implementations will be described in
10 conjunction with specific examples, it will be understood that it is not intended to limit the disclosed implementations.

[0046] Numeric ranges are inclusive of the numbers defining the range. It is intended that every maximum numerical limitation given throughout this specification includes every lower numerical limitation, as if such lower numerical limitations were expressly
15 written herein. Every minimum numerical limitation given throughout this specification will include every higher numerical limitation, as if such higher numerical limitations were expressly written herein. Every numerical range given throughout this specification will include every narrower numerical range that falls within such broader numerical range, as if such narrower numerical ranges were all expressly written herein.

20 [0047] The term “tintable window” refers to a window (e.g., an architectural window) comprising one or more optically switchable devices (e.g., electrochromic devices). An example of a tintable window is an electrochromic window having one or more tintable devices. In examples involving commissioning of tintable windows, a tintable window is sometimes referred to as an “insulated glass unit” or “IGU.”

25 [0048] The headings provided herein are not intended to limit the disclosure.

[0049] Unless defined otherwise herein, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art. Various scientific dictionaries that include the terms included herein are well known and available to those in the art. Although any methods and materials similar or equivalent to
30 those described herein find use in the practice or testing of the embodiments disclosed herein, some methods and materials are described.

[0050] The terms defined immediately below are more fully described by reference to the Specification as a whole. It is to be understood that this disclosure is not limited to the

particular methodology, protocols, and reagents described, as these may vary, depending upon the context they are used by those of skill in the art.

[0051] As used herein, the singular terms “a,” “an,” and “the” include the plural reference unless the context clearly indicates otherwise.

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I. Introduction and Context of Tintable Windows and Window Controllers

[0052] In order to orient the reader to the embodiments of systems, apparatus, and methods disclosed herein, a brief discussion of electrochromic devices, tintable windows, and window controllers is provided. This initial discussion is provided for context only, and the subsequently described embodiments are not limited to the specific features and fabrication processes of this initial discussion. Moreover, it would be understood that a tintable window may include one or more electrochromic devices in some aspects, and in addition or alternatively, include one or more other optically switchable devices in other aspects.

A. Electrochromic devices

[0053] A particular example of an electrochromic lite is described with reference to **FIGS. 1A-1C**, in order to illustrate embodiments described herein. **FIG. 1A** is a cross-sectional representation (see section cut X'-X' of **FIG. 1C**) of an electrochromic lite **100**, which is fabricated starting with a glass sheet **105**. **FIG. 1B** shows an end view (see viewing perspective Y-Y' of **FIG. 1C**) of electrochromic lite **100**, and **FIG. 1C** shows a top-down view of electrochromic lite **100**. **FIG. 1A** shows the electrochromic lite after fabrication on glass sheet **105**, edge deleted to produce area **140**, around the perimeter of the lite. The electrochromic lite has also been laser scribed and bus bars have been attached. A bus bar (also busbar) is a metallic strip or bar for distributing current. The glass lite **105** has a diffusion barrier **110**, and a first transparent conducting oxide layer (TCO) **115**, on the diffusion barrier. In this example, the edge deletion process removes both TCO **115** and diffusion barrier **110**, but in other embodiments only the TCO is removed, leaving the diffusion barrier intact. The TCO **115** is the first of two conductive layers used to form the electrodes of the electrochromic device fabricated on the glass sheet. In this example, the glass sheet includes underlying glass and the diffusion barrier layer. Thus, in this example, the diffusion barrier is formed, and then the first TCO, an electrochromic stack **125**, (e.g., having electrochromic, ion conductor, and counter electrode layers), and a second TCO **130**, are formed. In one embodiment, the electrochromic device (electrochromic stack and second TCO) is fabricated in an

integrated deposition system where the glass sheet does not leave the integrated deposition system at any time during fabrication of the stack. In one embodiment, the first TCO layer is also formed using the integrated deposition system where the glass sheet does not leave the integrated deposition system during deposition of the electrochromic stack and the (second) TCO layer. In one embodiment, all the layers (diffusion barrier, first TCO, electrochromic stack, and second TCO) are deposited in the integrated deposition system where the glass sheet does not leave the integrated deposition system during deposition. In this example, prior to deposition of electrochromic stack **125**, an isolation trench **120**, is cut through TCO **115** and diffusion barrier **110**. Trench **120** is made in contemplation of electrically isolating an area of TCO **115** that will reside under bus bar 1 after fabrication is complete (see **FIG. 1A**). This is done to avoid charge buildup and coloration of the electrochromic device under the bus bar, which can be undesirable.

[0054] After formation of the electrochromic device, edge deletion processes and additional laser scribing are performed. **FIG. 1A** depicts areas **140** where the device has been removed, in this example, from a perimeter region surrounding laser scribe trenches **150**, **155**, **160**, and **165**. Trenches **150**, **160** and **165** pass through the electrochromic stack and also through the first TCO and diffusion barrier. Trench **155** passes through second TCO **130** and the electrochromic stack, but not the first TCO **115**. Laser scribe trenches **150**, **155**, **160**, and **165** are made to isolate portions of the electrochromic device, **135**, **145**, **170**, and **175**, which were potentially damaged during edge deletion processes from the operable electrochromic device. In this example, laser scribe trenches **150**, **160**, and **165** pass through the first TCO to aid in isolation of the device (laser scribe trench **155** does not pass through the first TCO, otherwise it would cut off bus bar 2's electrical communication with the first TCO and thus the electrochromic stack). The laser or lasers used for the laser scribe processes are typically, but not necessarily, pulse-type lasers, for example, diode-pumped solid-state lasers. For example, the laser scribe processes can be performed using a suitable laser from IPG Photonics (of Oxford, Massachusetts), or from Ekspla (of Vilnius, Lithuania). Scribing can also be performed mechanically, for example, by a diamond tipped scribe. One of ordinary skill in the art would appreciate that the laser scribing processes can be performed at different depths and/or performed in a single process whereby the laser cutting depth is varied, or not, during a continuous path around the perimeter of the electrochromic device. In one embodiment, the edge deletion is performed to the depth of the first TCO.

[0055] After laser scribing is complete, bus bars are attached. Non-penetrating bus bar 1 is applied to the second TCO. Non-penetrating bus bar 2 is applied to an area where the device was not deposited (e.g., from a mask protecting the first TCO from device deposition), in contact with the first TCO or, in this example, where an edge deletion process (e.g., laser ablation using an apparatus having an XY or XYZ galvanometer) was used to remove material down to the first TCO. In this example, both bus bar 1 and bus bar 2 are non-penetrating bus bars. A penetrating bus bar is one that is typically pressed into and through the electrochromic stack to make contact with the TCO at the bottom of the stack. A non-penetrating bus bar is one that does not penetrate into the electrochromic stack layers, but rather makes electrical and physical contact on the surface of a conductive layer, for example, a TCO.

[0056] The TCO layers can be electrically connected using a non-traditional bus bar, for example, a bus bar fabricated with screen and lithography patterning methods. In one embodiment, electrical communication is established with the device's transparent conducting layers via silk screening (or using another patterning method) a conductive ink followed by heat curing or sintering the ink. Advantages to using the above described device configuration include simpler manufacturing, for example, and less laser scribing than conventional techniques which use penetrating bus bars.

[0057] After the bus bars are connected, the device is integrated into an insulated glass unit (IGU), which includes, for example, wiring for the bus bars and the like. In some embodiments, one or both of the bus bars are inside the finished IGU, however in one embodiment one bus bar is outside the seal of the IGU and one bus bar is inside the IGU. In the former embodiment, area 140 is used to make the seal with one face of the spacer used to form the IGU. Thus, the wires or other connection to the bus bars runs between the spacer and the glass. As many spacers are made of metal, e.g., stainless steel, which is conductive, it is desirable to take steps to avoid short circuiting due to electrical communication between the bus bar and connector thereto and the metal spacer. In the embodiments described herein, both of the bus bars are inside the primary seal of the finished IGU.

[0058] FIG. 2A shows a cross-sectional schematic diagram of the electrochromic lite described in relation to FIGS. 1A-1C integrated into an IGU 200. A spacer 205 is used to separate the electrochromic lite from a second lite 210. Second lite 210 in IGU 200 is a non-electrochromic lite, however, the embodiments disclosed herein are not so limited. For example, lite 210 can have an electrochromic device thereon and/or one or more

coatings such as low-E coatings and the like. Lite **201** can be laminated glass, such as depicted in **FIG. 2B** (lite **201** is laminated to reinforcing pane **230**, via resin **235**).

Between spacer **205** and the glass **201** of the electrochromic lite is a primary seal material **215**. This primary seal material is also between spacer **205** and second glass lite **210**.

5 Around the perimeter of spacer **205** is a secondary seal **220**. Bus bar wiring/leads traverse the seals for connection to a controller. Secondary seal **220** may be much thicker than depicted. These seals aid in keeping moisture out of an interior volume **225**, of the IGU. They also serve to prevent argon or other gas in the interior of the IGU from escaping.

[0059] **FIG. 3A** schematically depicts an electrochromic device **300**, in cross-section.

10 Electrochromic device **300** includes a substrate **302**, a first conductive layer (CL) **304**, an electrochromic layer (EC) **306**, an ion conducting layer (IC) **308**, a counter electrode layer (CE) **310**, and a second conductive layer (CL) **314**. Layers **304**, **306**, **308**, **310**, and **314** are collectively referred to as an electrochromic stack **320**. A voltage source **316** operable to apply an electric potential across electrochromic stack **320** effects the
15 transition of the electrochromic device from, for example, a bleached state to a colored state (depicted). The order of layers can be reversed with respect to the substrate.

[0060] Electrochromic devices having distinct layers as described can be fabricated as all solid-state devices and/or all inorganic devices. Such devices and methods of fabricating them are described in more detail in U.S. Patent Application Serial Number
20 12/645,111, entitled "Fabrication of Low-Defectivity Electrochromic Devices," filed on December 22, 2009, and naming Mark Kozlowski et al. as inventors, and in U.S. Patent Application Serial Number 12/645,159, entitled, "Electrochromic Devices," filed on December 22, 2009 and naming Zhongchun Wang et al. as inventors, both of which are hereby incorporated by reference in their entireties. It should be understood, however,
25 that any one or more of the layers in the stack may contain some amount of organic material. The same can be said for liquids that may be present in one or more layers in small amounts. It should also be understood that solid state material may be deposited or otherwise formed by processes employing liquid components such as certain processes employing sol-gels or chemical vapor deposition.

30 [0061] Additionally, it should be understood that the reference to a transition between a bleached state and colored state is non-limiting and suggests only one example, among many, of an electrochromic transition that may be implemented. Unless otherwise specified herein (including the foregoing discussion), whenever reference is made to a bleached-colored transition (or equivalently a clear-tinted transition), the corresponding

device or process encompasses other optical state transitions such as non-reflective-reflective, transparent-opaque, etc. Further, the term “bleached” or “clear” refers to an optically neutral state, for example, uncolored, transparent, or translucent. Still further, unless specified otherwise herein, the “color” or “tint” of an electrochromic transition is not limited to any particular wavelength or range of wavelengths. As understood by those of skill in the art, the choice of appropriate electrochromic and counter electrode materials governs the relevant optical transition.

[0062] In embodiments described herein, the electrochromic device reversibly cycles between a bleached/clear state and a colored/tinted state. In some cases, when the device is in a bleached state, a potential is applied to the electrochromic stack **320** such that available ions in the stack reside primarily in the counter electrode **310**. When the potential on the electrochromic stack is reversed, the ions are transported across the ion conducting layer **308** to the electrochromic material **306** and cause the material to transition to the colored state. In a similar way, the electrochromic device of embodiments described herein can be reversibly cycled between different tint levels (e.g., bleached state, darkest colored state, and intermediate levels between the bleached state and the darkest colored state).

[0063] Referring again to **FIG. 3A**, voltage source **316** may be configured to operate in conjunction with radiant and other environmental sensors. As described herein, voltage source **316** interfaces with a device controller (not shown in this figure). Additionally, voltage source **316** may interface with an energy management system that controls the electrochromic device according to various criteria such as the time of year, time of day, and measured environmental conditions. Such an energy management system, in conjunction with large area electrochromic devices (e.g., an electrochromic window), can dramatically lower the energy consumption of a building.

[0064] Any material having suitable optical, electrical, thermal, and mechanical properties may be used as substrate **302**. Such substrates include, for example, glass, plastic, and mirror materials. Suitable glasses include either clear or tinted soda lime glass, including soda lime float glass. The glass may be tempered or untempered.

[0065] In many cases, the substrate is a glass pane sized for residential window applications. The size of such glass pane can vary widely depending on the specific needs of the residence. In other cases, the substrate is architectural glass. Architectural glass is typically used in commercial buildings, but may also be used in residential buildings, and typically, though not necessarily, separates an indoor environment from an outdoor

environment. In certain embodiments, architectural glass is at least 20 inches by 20 inches, and can be much larger, for example, as large as about 80 inches by 120 inches. Architectural glass is typically at least about 2 mm thick, typically between about 3 mm and about 6 mm thick. Of course, electrochromic devices are scalable to substrates
5 smaller or larger than architectural glass. Further, the electrochromic device may be provided on a mirror of any size and shape.

[0066] On top of substrate **302** is conductive layer **304**. In certain embodiments, one or both of the conductive layers **304** and **314** is inorganic and/or solid. Conductive layers **304** and **314** may be made from a number of different materials, including conductive
10 oxides, thin metallic coatings, conductive metal nitrides, and composite conductors. Typically, conductive layers **304** and **314** are transparent at least in the range of wavelengths where electrochromism is exhibited by the electrochromic layer. Transparent conductive oxides include metal oxides and metal oxides doped with one or more metals. Examples of such metal oxides and doped metal oxides include indium oxide, indium tin
15 oxide, doped indium oxide, tin oxide, doped tin oxide, zinc oxide, aluminum zinc oxide, doped zinc oxide, ruthenium oxide, doped ruthenium oxide and the like. Since oxides are often used for these layers, they are sometimes referred to as “transparent conductive oxide” (TCO) layers. Thin metallic coatings that are substantially transparent may also be used, as well as combinations of TCO’s and metallic coatings.

20 [0067] In some embodiments, commercially available substrates such as glass substrates contain a transparent conductive layer coating. Such products may be used for both substrate and conductive layer. Examples of such glasses include conductive layer coated glasses sold under the trademark TEC Glass™ by Pilkington, of Toledo, Ohio and SUNGATE™ 300 and SUNGATE™ 500 by PPG Industries of Pittsburgh, Pennsylvania.
25 TEC Glass™ is a glass coated with a fluorinated tin oxide conductive layer.

[0068] In some embodiments of the invention, the same conductive layer is used for both conductive layers (i.e., conductive layers). In some embodiments, different conductive materials are used for each conductive layer. For example, in some
embodiments, TEC Glass™ is used for substrate (float glass) and conductive layer
30 (fluorinated tin oxide) and indium tin oxide (ITO) is used for conductive layer. In some embodiments employing TEC Glass™ there is a sodium diffusion barrier between the glass substrate and TEC conductive layer. The function of the conductive layers is to spread an electric potential provided by voltage source **316** over surfaces of the electrochromic stack **320** to interior regions of the stack, with relatively little ohmic

potential drop. The electric potential is transferred to the conductive layers through electrical connections to the conductive layers. In some embodiments, bus bars, one in contact with conductive layer **304** and one in contact with conductive layer **314**, provide the electric connection between the voltage source **316** and the conductive layers **304** and **314**. The conductive layers **304** and **314** may also be connected to the voltage source **316** with other conventional means.

[0069] Overlaying conductive layer **304** is electrochromic layer **306**. In some embodiments, electrochromic layer **306** is inorganic and/or solid. The electrochromic layer may contain any one or more of a number of different electrochromic materials, including metal oxides. Such metal oxides include tungsten oxide (WO_3), molybdenum oxide (MoO_3), niobium oxide (Nb_2O_5), titanium oxide (TiO_2), copper oxide (CuO), iridium oxide (Ir_2O_3), chromium oxide (Cr_2O_3), manganese oxide (Mn_2O_3), vanadium oxide (V_2O_5), nickel oxide (Ni_2O_3), cobalt oxide (Co_2O_3) and the like. During operation, electrochromic layer **306** transfers ions to and receives ions from counter electrode layer **310** to cause optical transitions.

[0070] Generally, the colorization (or change in any optical property – e.g., absorbance, reflectance, and transmittance) of the electrochromic material is caused by reversible ion insertion into the material (e.g., intercalation) and a corresponding injection of a charge balancing electron. Typically some fraction of the ions responsible for the optical transition is irreversibly bound up in the electrochromic material. Some or all of the irreversibly bound ions are used to compensate “blind charge” in the material. In most electrochromic materials, suitable ions include lithium ions (Li^+) and hydrogen ions (H^+) (that is, protons). In some cases, however, other ions will be suitable. In various embodiments, lithium ions are used to produce the electrochromic phenomena.

Intercalation of lithium ions into tungsten oxide (WO_{3-y} ($0 < y \leq \sim 0.3$)) causes the tungsten oxide to change from transparent (bleached state) to blue (colored state).

[0071] Referring again to **FIG. 3A**, in electrochromic stack **320**, ion conducting layer **308** is sandwiched between electrochromic layer **306** and counter electrode layer **310**. In some embodiments, counter electrode layer **310** is inorganic and/or solid. The counter electrode layer may include one or more of a number of different materials that serve as a reservoir of ions when the electrochromic device is in the bleached state. During an electrochromic transition initiated by, for example, application of an appropriate electric potential, the counter electrode layer transfers some or all of the ions it holds to the

electrochromic layer, changing the electrochromic layer to the colored state.

Concurrently, in the case of NiWO, the counter electrode layer colors with the loss of ions.

[0072] In some embodiments, suitable materials for the counter electrode

5 complementary to WO₃ include nickel oxide (NiO), nickel tungsten oxide (NiWO), nickel vanadium oxide, nickel chromium oxide, nickel aluminum oxide, nickel manganese oxide, nickel magnesium oxide, chromium oxide (Cr₂O₃), manganese oxide (MnO₂), and Prussian blue.

[0073] When charge is removed from a counter electrode **310** made of nickel tungsten
10 oxide (that is, ions are transported from counter electrode **310** to electrochromic layer **306**), the counter electrode layer will transition from a transparent state to a colored state.

[0074] In the depicted electrochromic device, between electrochromic layer **306** and counter electrode layer **310**, there is the ion conducting layer **308**. Ion conducting layer **308** serves as a medium through which ions are transported (in the manner of an
15 electrolyte) when the electrochromic device transitions between the bleached state and the colored state. Preferably, ion conducting layer **308** is highly conductive to the relevant ions for the electrochromic and the counter electrode layers, but has sufficiently low electron conductivity that negligible electron transfer takes place during normal operation. A thin ion conducting layer with high ionic conductivity permits fast ion
20 conduction and hence fast switching for high performance electrochromic devices. In certain embodiments, the ion conducting layer **308** is inorganic and/or solid.

[0075] Examples of suitable ion conducting layers (for electrochromic devices having a distinct IC layer) include silicates, silicon oxides, tungsten oxides, tantalum oxides, niobium oxides, and borates. These materials may be doped with different dopants,
25 including lithium. Lithium doped silicon oxides include lithium silicon-aluminum-oxide. In some embodiments, the ion conducting layer includes a silicate-based structure. In some embodiments, a silicon-aluminum-oxide (SiAlO) is used for the ion conducting layer **308**.

[0076] Electrochromic device **300** may include one or more additional layers (not
30 shown), such as one or more passive layers. Passive layers used to improve certain optical properties may be included in electrochromic device **300**. Passive layers for providing moisture or scratch resistance may also be included in electrochromic device **300**. For example, the conductive layers may be treated with anti-reflective or protective oxide or

nitride layers. Other passive layers may serve to hermetically seal electrochromic device **300**.

[0077] **FIG. 3B** is a schematic cross-section of an electrochromic device in a bleached state (or transitioning to a bleached state). In accordance with specific embodiments, an electrochromic device **400** includes a tungsten oxide electrochromic layer (EC) **406** and a nickel-tungsten oxide counter electrode layer (CE) **410**. Electrochromic device **400** also includes a substrate **402**, a conductive layer (CL) **404**, an ion conducting layer (IC) **408**, and conductive layer (CL) **414**.

[0078] A power source **416** is configured to apply a potential and/or current to an electrochromic stack **420** through suitable connections (e.g., bus bars) to the conductive layers **404** and **414**. In some embodiments, the voltage source is configured to apply a potential of a few volts in order to drive a transition of the device from one optical state to another. The polarity of the potential as shown in **FIG. 3B** is such that the ions (lithium ions in this example) primarily reside (as indicated by the dashed arrow) in nickel-tungsten oxide counter electrode layer **410**.

[0079] **FIG. 3C** is a schematic cross-section of electrochromic device **400** shown in **FIG. 3B** but in a colored state (or transitioning to a colored state). In **FIG. 3C**, the polarity of voltage source **416** is reversed, so that the electrochromic layer is made more positive to accept additional lithium ions, and thereby transition to the colored state. As indicated by the dashed arrow, lithium ions are transported across ion conducting layer **408** to tungsten oxide electrochromic layer **406**. Tungsten oxide electrochromic layer **406** is shown in the colored state. Nickel-tungsten oxide counter electrode **410** is also shown in the colored state. As explained, nickel-tungsten oxide becomes progressively more opaque as it gives up (deintercalates) lithium ions. In this example, there is a synergistic effect where the transition to colored states for both layers **406** and **410** are additive toward reducing the amount of light transmitted through the stack and substrate.

[0080] As described above, an electrochromic device may include an electrochromic (EC) layer and a counter electrode (CE) layer separated by an ionically conductive (IC) layer that is highly conductive to ions and highly resistive to electrons. As conventionally understood, the ionically conductive layer therefore prevents shorting between the electrochromic layer and the counter electrode layer. The ionically conductive layer allows the electrochromic and counter electrode layers to hold a charge and thereby maintain their bleached or colored states. In electrochromic devices having distinct layers, the components form a stack which includes the ion conducting layer sandwiched

between the electrochromic electrode layer and the counter electrode layer. The boundaries between these three stack components are defined by abrupt changes in composition and/or microstructure. Thus, the devices have three distinct layers with two abrupt interfaces.

5 [0081] In accordance with certain embodiments, the counter electrode and electrochromic layers are formed immediately adjacent one another, sometimes in direct contact, without separately depositing an ionically conducting layer. In some embodiments, electrochromic devices having an interfacial region rather than a distinct IC layer are employed. Such devices, and methods of fabricating them, are described in U.S.
10 Patent No. 8,300,298 and U.S. Patent Application Serial Number 12/772, 075 filed on April 30, 2010, and U.S. Patent Applications Serial Numbers 12/814,277 and 12/814,279, filed on June 11, 2010 – each of the three patent applications and patent is entitled “Electrochromic Devices,” each names Zhongchun Wang et al. as inventors, and each is incorporated by reference herein in its entirety.

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B. Window Controllers

[0082] A window controller may be used to control tinting of a tintable window. For example, a window controller in communication may be utilized to adjust the tint level, and associated transmissivity, of an electrochromic window. In some embodiments, the
20 window controller is able to transition the electrochromic window between multiple tint states (levels) including a bleached state and a colored state. In one aspect, a window controller is able to transition an electrochromic window to any one of four tint levels (including the bleached state and the colored state). In another aspect, a window controller is able to transition an electrochromic window to any one of four or more tint
25 levels.

[0083] In some embodiments, an electrochromic window can include an electrochromic device (e.g., electrochromic device **400**) on one lite of an IGU (e.g., IGU device **200**) and another electrochromic device (e.g., electrochromic device **400**) on the other lite of the IGU. If the window controller is able to transition each electrochromic device between
30 two states, a bleached state and a colored state, the electrochromic window is able to attain four different states (tint levels), a colored state with both electrochromic devices being colored, a first intermediate state with one electrochromic device being colored, a second intermediate state with the other electrochromic device being colored, and a bleached state with both electrochromic devices being bleached. Embodiments of multi-

pane electrochromic windows are further described in U.S. Patent Number 8,270,059, naming Robin Friedman et al. as inventors, titled “MULTI-PANE ELECTROCHROMIC WINDOWS,” which is hereby incorporated by reference in its entirety.

[0084] In some embodiments, the window controller is able to transition an
5 electrochromic window having an electrochromic device capable of transitioning between two or more tint levels. For example, a window controller may be able to transition the electrochromic window to a bleached state, one or more intermediate levels, and a colored state. In some other embodiments, the window controller is able to transition an electrochromic window incorporating an electrochromic device between any number of
10 tint levels between the bleached state and the colored state. Embodiments of methods and controllers for transitioning an electrochromic window to an intermediate tint level or levels are further described in U.S. Patent Number 8,254,013, naming Disha Mehtani et al. as inventors, titled “CONTROLLING TRANSITIONS IN OPTICALLY SWITCHABLE DEVICES,” which is hereby incorporated by reference in its entirety.

[0085] In some embodiments, a window controller can power one or more
15 electrochromic devices in an electrochromic window. Typically, this function of the window controller is augmented with one or more other functions described in more detail below. Window controllers described herein are not limited to those that have the function of powering an electrochromic device to which it is associated for the purposes
20 of control. That is, the power source for the electrochromic window may be separate from the window controller, where the controller has its own power source and directs application of power from the window power source to the window. However, it is convenient to include a power source with the window controller and to configure the controller to power the window directly, because it obviates the need for separate wiring
25 for powering the electrochromic window.

[0086] Further, the window controllers described in this section are described as standalone controllers which may be configured to control the functions of a single window or a plurality of electrochromic windows, without integration of the window controller into a building control network or a building management system (BMS).
30 Window controllers, however, may be integrated into a building control network or a BMS.

[0087] FIG. 4 depicts a simplified block diagram of some components of a window controller 450 and other components of a window controller system of disclosed embodiments. More detail of components of window controllers can be found in U.S.

Patent Application Serial numbers 13/449,248 and 13/449,251, both naming Stephen Brown as inventor, both titled "CONTROLLER FOR OPTICALLY-SWITCHABLE WINDOWS," and both filed on April 17, 2012, and in U.S. Patent Serial Number 13/449,235, titled "CONTROLLING TRANSITIONS IN OPTICALLY SWITCHABLE DEVICES," naming Stephen Brown et al. as inventors and filed on April 17, 2012, all of which are hereby incorporated by reference in their entireties.

[0088] In FIG. 4, the illustrated components of the window controller 450 include a microprocessor 455 or other processor, a pulse width modulator 460, one or more input 465, and a computer readable medium 470 (e.g., memory) having a configuration file

475. Window controller 450 is in electronic communication with one or more electrochromic devices 400 in an electrochromic window through network 480 (wired or wireless) to send instructions to the one or more electrochromic devices 400. In some embodiments, the window controller 450 may be a local window controller in communication through a network (wired or wireless) to a master window controller.

[0089] In disclosed embodiments, window controller 450 can instruct the PWM 460, to apply a voltage and/or current to electrochromic window 502 to transition it to any one of four or more different tint levels. In disclosed embodiments, electrochromic window 502 can be transitioned to at least eight different tint levels described as: 0 (lightest), 5, 10, 15, 20, 25, 30, and 35 (darkest). The tint levels may linearly correspond to visual transmittance values and solar heat gain coefficient (SHGC) values of light transmitted through the electrochromic window 502. For example, using the above eight tint levels, the lightest tint level of 0 may correspond to an SHGC value of 0.80, the tint level of 5 may correspond to an SHGC value of 0.70, the tint level of 10 may correspond to an SHGC value of 0.60, the tint level of 15 may correspond to an SHGC value of 0.50, the tint level of 20 may correspond to an SHGC value of 0.40, the tint level of 25 may correspond to an SHGC value of 0.30, the tint level of 30 may correspond to an SHGC value of 0.20, and the tint level of 35 (darkest) may correspond to an SHGC value of 0.10.

[0090] Window controller 450 or a master controller in communication with the window controller 450 may employ any one or more control logic components to determine a desired tint level based on signals from the exterior sensor 510 and/or other input. The window controller 450 can instruct the PWM 460 to apply a voltage and/or current to electrochromic window 502 to transition it to the desired tint level.

[0091] It should be understood that control logic and other logic used to implement techniques described above can be implemented in the form of circuits, processors (including general purpose microprocessors, digital signal processors, application specific integrated circuits, programmable logic such as field-programmable gate arrays, etc.), computers, computer software, devices such as sensors, or combinations thereof. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will know and appreciate other ways and/or methods to implement the disclosed techniques using hardware and/or a combination of hardware and software.

[0092] Any of the components or functions of software, firmware, or machine-instructions described in this application, may be implemented as code to be executed by a processor using any suitable computer language such as, for example, Java, C++ or Python using, for example, conventional or object-oriented techniques. The code may be stored as a series of instructions, or commands on a computer or machine readable medium, such as a random-access memory (RAM), a read only memory (ROM), a programmable memory (EEPROM), a magnetic medium such as a hard-drive or a floppy disk, or an optical medium such as a CD-ROM. Any such computer or machine readable medium may reside on or within a single computational apparatus, and may be present on or within different computational apparatuses within a system or network. In some implementations, the computer or machine readable medium is a non-transitory medium.

[0093] In some embodiments disclosed herein, one or more electrochromic devices are operatively coupled to at least one controller and/or processor. A controller may comprise a processing unit (e.g., CPU or GPU). A controller may receive an input (e.g., from at least one device or projected media). The controller may comprise circuitry, electrical wiring, optical wiring, socket, and/or outlet. A controller may receive an input and/or deliver an output. A controller may comprise multiple (e.g., sub-) controllers. An operation (e.g., as disclosed herein) may be performed by a single controller or by a plurality of controllers. At least two operations may be each preconformed by a different controller. At least two operations may be preconformed by the same controller. A device and/or media may be controlled by a single controller or by a plurality of controllers. At least two devices and/or media may be controlled by a different controller. At least two devices and/or media may be controlled by the same controller. The controller may be a part of a control system. The control system may comprise a master controller, floor (e.g., comprising network controller) controller, or a local controller. The local controller may be a target controller. For example, the local controller may be a window controller (e.g.,

controlling a tintable window), enclosure controller, or component controller. The controller may be a part of a hierarchal control system. The hierarchal control system may comprise a main controller that directs one or more controllers, e.g., floor controllers, local controllers (e.g., window controllers), enclosure controllers, and/or component
5 controllers. The target may comprise a device or a media. The device may comprise an electrochromic window, a sensor, an emitter, an antenna, a receiver, a transceiver, or an actuator.

[0094] In some examples, a controlled apparatus is a tintable window (e.g., an electrochromic window). In some embodiments, a dynamic state of an electrochromic
10 window is controlled by altering a voltage signal to an electrochromic device (ECD) used to provide tinting or coloring. An electrochromic window can be manufactured, configured, or otherwise provided as an insulated glass unit (IGU). IGUs may serve as the fundamental constructs for holding electrochromic panes (also referred to as “lites”) when provided for installation in a building. An IGU lite or pane may be a single substrate or a
15 multi-substrate construct, such as a laminate of two substrates.

[0095] The controller may be implemented in an electronic device in various forms of digital computers such as a laptop computer, a desktop computer, a workstation, a personal digital assistant, a server, a blade server, a mainframe computer, and other appropriate computers. The electronic device may also represent various forms of mobile
20 apparatuses such as personal digital assistant, a cellular telephone, a smart phone, a wearable device and other similar computing apparatuses. The parts shown herein, their connections and relationships, and their functions are only as examples, and not intended to limit implementations of the present disclosure as described and/or claimed herein.

[0096] In some implementations, the controller is coupled to memory, such as a non-transitory computer-readable or machine-readable medium. The memory stores
25 instructions for the controller to operate a ECD using methods disclosed herein. In some implementations, the controller comprises a processor. The memory, as a non-transitory computer readable storage medium, may be used to store non-transitory software programs, non-transitory computer executable programs and modules, such as program
30 instructions/modules corresponding to the method for controlling an ECD in the embodiments of the present disclosure. The processor executes the non-transitory software programs, instructions, and modules stored in the memory to execute various functional applications and data processing.

[0097] The memory may include a storage program area and a storage data area, where the storage program area may store an operating system and at least one function required application program; and the storage data area may store data created by the use of the electronic device according to the disclosed methods. In addition, the memory may
5 include a high-speed random access memory, and may also include a non-transitory memory, such as at least one magnetic disk storage device, a flash memory device, or other non-transitory solid-state storage devices. In some embodiments, the memory may optionally include memories remotely provided with respect to the processor, and these remote memories may be connected to the electronic device of the method for controller
10 the ECD. Examples of the above network include but are not limited to the Internet, intranet, local area network, mobile communication network, and combinations thereof.

[0098] Examples of tintable windows, window controllers, their methods of use and their features are presented in U.S. Patent Application Serial No. 15/334,832, filed October 26, 2016, titled "CONTROLLERS FOR OPTICALLY-SWITCHABLE
15 DEVICES," and U.S. Patent Application Serial No. 16/082,793, filed September 6, 2018, titled "METHOD OF COMMISSIONING ELECTROCHROMIC WINDOWS," each of which is herein incorporated by reference in its entirety.

[0099] FIG. 5 is a schematic depiction of a control system 500 for controlling and driving a plurality of tintable windows 502 of a building 504. It may be employed to
20 control the operation of one or more devices associated with a tintable window such as a window antenna. The system 500 can be adapted for use with facility (e.g., a building 504) comprising a commercial office building or a residential building. In this example, the system 500 is designed to function in conjunction with modern heating, ventilation, and air conditioning (HVAC) systems 506, interior lighting systems 507, security systems
25 508, and power systems 509 as a single holistic and efficient energy control system for the entire building 504, or a campus of buildings 504. The system 500 also includes a building management system (BMS) 510. The BMS 510 is a computer-based control system that can be installed in a building to monitor and control the building's mechanical and electrical equipment such as HVAC systems, lighting systems, power systems,
30 elevators, fire systems, and security systems. The BMS 510 can include hardware and associated firmware or software for maintaining conditions in the building 504 according to preferences set by the occupants or by a building manager or other administrator. The software can be based on, for example, internet protocols or open standards.

- [0100] A BMS can be used in large buildings where it functions to control the environment within the building. For example, the BMS **510** may control lighting, temperature, carbon dioxide levels, and/or humidity within the building **504**. There can be several (e.g., numerous) mechanical and/or electrical devices that are controlled by the BMS **510** including, for example, furnaces or other heaters, air conditioners, blowers, and/or vents. To control the building environment, the BMS **510** can turn on and off these various devices, e.g., according to rules and/or in response to conditions. Such rules and/or conditions may be selected and/or specified by a user (e.g., building manager and/or administrator). One function of the BMS **510** may be to maintain a comfortable environment for the occupants of the building **504**, e.g., while minimizing heating and cooling energy losses and costs. In some embodiments, the BMS **510** is configured not (e.g., only) to monitor and control, but also to optimize the synergy between various systems, for example, to conserve energy and lower building operation costs. The illustrated example also depicts clouds **503**.
- [0101] Some embodiments are designed to function responsively or reactively based on feedback. The feedback control scheme may comprise measurements sensed through, for example, thermal, optical, or other sensors. The feedback control scheme may comprise input from an HVAC, interior lighting system, and/or an input from a user control. Examples of control system, methods of its use, and its related software, may be found in US Patent No. 8,705,162, issued April 22, 2014, which is incorporated herein by reference in its entirety. Some embodiments are utilized in existing structures, including commercial and/or residential structures, e.g., having traditional or conventional HVAC and/or interior lighting systems. Some embodiments are retrofitted for use in older facilities (e.g., residential homes).
- [0102] The system **500** includes network controllers (NCs) **512** configured to control a plurality of window controllers **514**. For example, one network controller **512** may control at least tens, hundreds, or thousands of window controllers **514**. Each window controller **514**, in turn, may control and drive one or more electrochromic windows **502**. In some embodiments, the network controller **512** can issue high level instructions such as the final tint state of a tintable window. The window controllers may receive these commands and directly control their associated windows, e.g., by applying electrical stimuli to appropriately drive tint state transitions and/or maintain tint states. The number and size of the tintable (e.g., electrochromic) windows **502** that each window controller **514** can drive, may be generally limited by the voltage and/or current characteristics of

the load on the window controller **514** controlling the respective electrochromic windows **502**. In some embodiments, the maximum window size that the window controller **514** can drive is limited by the voltage, current, and/or power requirements, to cause the requested optical transitions in the electrochromic window **502** within a requested time-
5 frame. Such requirements are, in turn, a function of the surface area of the window. In some embodiments, this relationship is nonlinear. For example, the voltage, current, and/or power requirements can increase nonlinearly with the surface area of the electrochromic window **502**. Without wishing to be bound to theory, in some cases the relationship is nonlinear at least in part because the sheet resistance of the first and second
10 conductive layers increases nonlinearly with distance across the length and width of the first or second conductive layers. In some embodiments, the relationship between the voltage, current, and/or power requirements required to drive multiple electrochromic windows **502** of equal size and shape is directly proportional to the number of the electrochromic windows **502** being driven.

15 **[0103]** FIG. 5 shows an example of a master controller (MC) **511**. The master controller **511** communicates and functions in conjunction with multiple network controllers **512**, each of which network controllers **512** is capable of addressing a plurality of window controllers **514**. In some embodiments, the master controller **511** issues the high level instructions (such as the final tint states of the tintable windows) to the network
20 controllers **512**, and the network controllers **512** then communicate the instructions to the corresponding window controllers **514**. FIG. 5 shows an example of a hierarchical control system comprising the master controller, the network controllers, and the window controllers.

[0104] In some implementations, the various electrochromic windows **502**, antennas, and/or other target devices of the facility (e.g., comprising building or other structure) are
25 (e.g., advantageously) grouped into zones or groups of zones (e.g., wherein each of which includes a subset of the electrochromic windows **502**). For example, each zone may correspond to a set of electrochromic windows **502** in a specific location or area of the facility that should be tinted (or otherwise transitioned) to the same or similar optical
30 states, based at least in part on their location. As another example, consider a building having four faces or sides: A North face, a South face, an East Face, and a West Face. Consider that the building has ten floors. In such an example, each zone can correspond to the set of electrochromic windows **502** on a particular floor and on a particular one of the four faces. In some such embodiments, each network controller **512** can address one

or more zones or groups of zones. For example, the master controller **511** can issue a final tint state command for a particular zone or group of zones to a respective one or more of the network controllers **512**. For example, the final tint state command can include an abstract identification of each of the target zones. The designated network controllers **512** receiving the final tint state command may then map the abstract identification of the zone(s) to the specific network addresses of the respective window controllers **514** that control the voltage or current profiles to be applied to the electrochromic windows **502** in the zone(s).

[0105] In some embodiments, a distributed network of controllers is used to control one or more tintable windows. For example, a network system may be operable to control a plurality of IGUs in accordance with some implementations. One primary function of the network system may be to control the optical states of the electrochromic devices (or other optically-switchable devices) within the IGUs.

[0106] In some embodiments, another function of the network system is to acquire status information (e.g., data) from the IGUs. For example, the status information for a given IGU can include an identification of, or information about, a current tint state of the tintable device(s) within the IGU. The network system may be operable to acquire data from various sensors, such as temperature sensors, photosensors (referred to herein as light sensors), humidity sensors, air flow sensors, or occupancy sensors, antennas, whether integrated on or within the IGUs or located at various other positions in, on or around the building. At least one sensor may be configured (e.g., designed) to measure one or more environmental characteristics, for example, temperature, humidity, ambient noise, carbon dioxide, VOC, particulate matter, oxygen, and/or any other aspects of an environment (e.g., atmosphere thereof). The sensors may comprise electromagnetic sensors.

[0107] The electromagnetic sensor may be configured to sense ultraviolet, visible, infrared, and/or radio wave radiation. The infrared radiation may be passive infrared radiation (e.g., black body radiation). The electromagnetic sensor may sense radio waves. The radio waves may comprise wide band, or ultra-wideband radio signals. The radio waves may comprise pulse radio waves. The radio waves may comprise radio waves utilized in communication. The radio waves may be at a medium frequency of at least about 300 kilohertz (KHz), 500 KHz, 800 KHz, 1000 KHz, 1500 KHz, 2000 KHz, or 2500 KHz. The radio waves may be at a medium frequency of at most about 500 KHz, 800 KHz, 1000 KHz, 1500 KHz, 2000 KHz, 2500 KHz, or 3000 KHz. The radio waves

may be at any frequency between the aforementioned frequency ranges (e.g., from about 300KHz to about 3000 KHz). The radio waves may be at a high frequency of at least about 3 megahertz (MHz), 5 MHz, 8 MHz, 10 MHz, 15 MHz, 20 MHz, or 25 MHz. The radio waves may be at a high frequency of at most about 5 MHz, 8 MHz, 10 MHz, 15

5 MHz, 20 MHz, 25 MHz, or 30 MHz. The radio waves may be at any frequency between the aforementioned frequency ranges (e.g., from about 3MHz to about 30 MHz). The radio waves may be at a very high frequency of at least about 30 Megahertz (MHz), 50 MHz, 80 MHz, 100 MHz, 150 MHz, 200 MHz, or 250 MHz. The radio waves may be at a very high frequency of at most about 50 MHz, 80 MHz, 100 MHz, 150 MHz, 200 MHz,

10 250 MHz, or 300 MHz. The radio waves may be at any frequency between the aforementioned frequency ranges (e.g., from about 30MHz to about 300 MHz). The radio waves may be at an ultra-high frequency of at least about 300 kilohertz (MHz), 500 MHz, 800 MHz, 1000 MHz, 1500 MHz, 2000 MHz, or 2500 MHz. The radio waves may be at an ultra-high frequency of at most about 500 MHz, 800 MHz, 1000 MHz, 1500 MHz,

15 2000 MHz, 2500 MHz, or 3000 MHz. The radio waves may be at any frequency between the aforementioned frequency ranges (e.g., from about 300MHz to about 3000 MHz). The radio waves may be at a super high frequency of at least about 3 gigahertz (GHz), 5 GHz, 8 GHz, 10 GHz, 15 GHz, 20 GHz, or 25 GHz. The radio waves may be at a super high frequency of at most about 5 GHz, 8 GHz, 10 GHz, 15 GHz, 20 GHz, 25 GHz, or 30

20 GHz. The radio waves may be at any frequency between the aforementioned frequency ranges (e.g., from about 3GHz to about 30 GHz).

[0108] The network system may include any suitable number of distributed controllers having various capabilities or functions. In some embodiments, the functions and arrangements of the various controllers are defined hierarchically.

25 **[0109]** FIG. 6 shows an example of a network system 600 including a plurality of distributed local window controllers (WCs) 604, a plurality of network controllers (NCs) 606, and a master controller (MC) 608. In some embodiments, the MC 608 can communicate with and control at least two, ten, tens, hundred, or hundreds of floors using network controllers 606. The floor controller may be configured to control a floor or a

30 portion of a floor. In various embodiments, the master controller MC 608 issues high level instructions to the NCs 606 over one or more wired and/or wireless communication links. The instructions can include, for example, tint commands for causing transitions in the optical states of the IGUs controlled by the respective NCs 606. Each NC 606 may, in turn, communicate with and control a number of window controllers 604 over one or

more wired and/or wireless links. The communication links may be bidirectional communication links. Master controller **608** is also in communication with a database **620**, and a building management system **624**. The database **620** and BMS **624** are in communication with an external source **610**. In one implementation, external source **610** includes one or more sensors (e.g., a plurality of photosensors) and/or a cloud network.

[0110] The MC **608** may issue communications including tint commands, status request commands, data (for example, sensor data) request commands or other instructions. In some embodiments, the MC **608** issues such communications periodically, at certain predefined times of day (which may change based on the day of week or year), or based at least in part on the detection of particular events, conditions or combinations of events or conditions (for example, as determined by acquired sensor data or based at least in part on the receipt of a request initiated by a user and/or by an application or a combination of such sensor data and such a request). In some embodiments, when the MC **608** determines to cause a tint state change (e.g., alteration) in a set of one or more IGUs, the MC **608** generates or selects a tint value corresponding to the requested tint state. In some implementations, the set of IGUs is associated with a first protocol identifier (ID) (for example, a Building Automation and Control (BAC) network identification (BACnet ID)). The MC **608** may then generate and transmit a communication—referred to herein as a “primary tint command”—including the tint value and the first protocol ID over the link via a first communication protocol (for example, a BACnet compatible protocol). In some embodiments, the MC **608** addresses the primary tint command to the particular NC **606** that controls the particular one or more WCs **604** that, in turn, control the set of IGUs to be transitioned. The NC **606** may receive the primary tint command including the tint value and the first protocol ID and map the first protocol ID to one or more second protocol IDs. In some embodiments, each of the second protocol IDs identifies a corresponding one of the WCs **604**. The NC **606** may subsequently transmit a secondary tint command including the tint value to each of the identified WCs **604** over the link via a second communication protocol. In some embodiments, each of the WCs **604** that receives the secondary tint command then selects a voltage and/or current profile from an internal memory based on the tint value to drive its respectively connected IGUs to a tint state consistent with the tint value. Each of the WCs **304** may then generate and provide voltage and/or current signals over the link to its respectively connected IGUs to apply the voltage or current profile.

[0111] In a similar manner to how the function and/or arrangement of controllers may be arranged hierarchically, tintable windows may be arranged in a hierarchical structure. A hierarchical structure can help facilitate the control of tintable windows at a particular site by allowing rules or user control to be applied to various groupings of tintable windows or IGUs. Further, for aesthetics, multiple contiguous windows in a room and/or other site location may sometimes need to have their optical states correspond and/or tint at the same rate. Treating a group of contiguous windows as a zone can facilitate these goals.

[0112] In some embodiments, IGUs are grouped into zones of tintable windows, each of which zones includes at least one window controller and its respective IGUs. Each zone of IGUs may be controlled by one or more respective NCs and one or more respective WCs controlled by these NCs. For example, each zone can be controlled by a single NC and two or more WCs controlled by the single NC.

[0113] In some embodiments, at least one device is operated in coordination with at least one other device, which devices are coupled to the network. Control of the at least one device may be via Ethernet. For example, A tint level of tintable windows may be adjusted concurrently. When the devices are in use, a zone of devices may have at least one characteristic that is the same. For example, when the tintable windows are in a zone, a zone of tintable windows may have its tint level (automatically) altered (e.g., darkened or lightened) to the same level. For example, when sounds sensors are in a zone, they may sample sound at the same frequency and/or at the same time window. A zone of devices may comprise a plurality of devices (e.g., of the same type). The zone may comprise (i) devices (e.g., tintable windows) facing a particular direction of an enclosure (e.g., facility), (ii) a plurality of devices disposed on a particular face (e.g., façade) of the enclosure, (iii) devices on a particular floor of a facility, (iv) devices in a particular type of room and/or activity (e.g., open space, office, conference room, lecture hall, corridor, reception hall, or cafeteria), (v) devices disposed on the same fixture (e.g., internal or external wall), and/or (vi) devices that are user defined (e.g., a group of tintable windows in a room or on a façade that are a subset of a larger group of tintable windows. The (automatic) adjustment of the devices may done automatically and/or by a user. The automatic changing of device properties and/or status in a zone, may be overridden by a user (e.g., by manually adjusting the tint level). A user may override the automatic adjustment of the devices in a zone using mobile circuitry (e.g., a remote controller, a

virtual reality controller, a cellular phone, an electronic notepad, a laptop computer and/or by a similar mobile device).

[0114] In some embodiments, when instructions relating to the control of a device (e.g., instructions for a window controller or a tintable window) are passed through the network system, they are accompanied with a unique network ID of the device they are sent to. Networks IDs may be helpful to ensure that instructions reach and are carried out on the intended device. For example, a window controller that controls the tint states of more than one IGU, may determine which IGU (tintable window) to control based upon a network ID such as a Controller Area Network (CAN) ID (a form of network ID) that is passed along with the tinting command. In a window network such as those described herein, the term network ID includes but is not limited to CAN IDs, and BACnet IDs. Such network IDs may be applied to window network nodes such as window controllers, network controllers, and master controllers. A network ID for a device may include the network ID of every device that controls it in the hierarchical structure. For example, the network ID of an IGU may include a window controller ID, a network controller ID, and a master controller ID in addition to its own CAN ID.

[0115] FIG. 7 shows various tintable windows (referred to as “IGUs”) 722 grouped into zones 703 of tintable windows. Each zone 703 includes at least one window controller 724 and one or more respective tintable windows 722. In some embodiments, each zone of tintable windows 722 is controlled by one or more respective NCs and one or more respective WCs 724 controlled by these NCs. Each zone 703 may be controlled by a single NC and two or more WCs 724 controlled by the single NC. Thus, a zone 703 can represent a logical grouping of the tintable windows 722. For example, each zone 703 may correspond to a set of one or more tintable windows 722 in a specific location or area of the building that are driven together based on their location or orientation. As a more specific example, consider a site 701 that is a building having ten floors and four faces or sides: A North face, a South face, an East Face, and a West Face. In such an example, each zone 703 may correspond to the set of one or more tintable windows 722 on a particular floor and on a particular one of the four faces. As another example, each zone 703 may correspond to a set of one or more tintable windows 722 that share one or more physical characteristics (for example, device parameters such as size or age). In some embodiments, a zone 703 of tintable windows 722 is grouped based at least in part on one or more non-physical characteristics comprising a security designation or a business hierarchy (for example, tintable windows 722 bounding managers’ offices can be grouped

in one or more zones while tintable windows **722** bounding non-managers' offices can be grouped in one or more different zones).

[0116] In some such implementations, each NC can address all of the tintable windows **722** in each of one or more respective zones **703**. For example, the MC can issue a
5 primary tint command to the NC that controls a target zone **703**. The primary tint command can include an abstract identification of the target zone (hereinafter referred to as a "zone ID"). In some such implementations, the zone ID can be a first protocol ID such as that just described in the example above. The NC may receive the primary tint command including the tint value and the zone ID and may map the zone ID to the d
10 protocol IDs associated with the WCs **724** within the zone. In some embodiments, the zone ID can be a higher level abstraction than the first protocol IDs. In such cases, the NC can first map the zone ID to one or more first protocol IDs, and subsequently map the first protocol IDs to the second protocol IDs.

[0117] In order for tint controls to work (e.g., to allow the window control system to
15 change the tint state of one or more specific tintable windows), a master controller, network controller, and/or other controller responsible for tint decisions, may utilize the network address of the window controller(s) connected to that specific window or set of windows. To this end, a function of commissioning may be used to provide correct assignment of window controller addresses and/or other identifying information to
20 specific windows and window controllers, as well the physical locations of the windows and/or window controllers in buildings. In some embodiments, a goal of commissioning is to correct mistakes and/or other problems made in installing tintable windows in the wrong locations or connecting cables to the wrong window controllers. In some embodiments, a goal of commissioning is to provide semi- or fully automated installation.
25 In other words, allowing installation with little or no location guidance for installers.

[0118] In some embodiments, the commissioning process for a particular tintable window may involve associating an ID for a device (e.g., the tintable window and/or window-related component), with its corresponding local controller. The commissioning process may assign a building location, a relative location, and/or absolute location (e.g.,
30 latitude, longitude, and elevation) to the device (e.g., window or another component). Examples relating to commissioning and/or configuring a network of tintable windows can be found in U.S. Patent Application Serial No. 14/391,122, filed October 7, 2014, titled "APPLICATIONS FOR CONTROLLING OPTICALLY SWITCHABLE DEVICES," U.S. Patent Application Serial No. 14/951,410, filed November 24, 2015,

titled “SELF-CONTAINED EC IGU,” U.S. Provisional Patent Application Serial No. 62/305,892, filed March 9, 2016, titled “METHOD OF COMMISSIONING ELECTROCHROMIC WINDOWS,” and U.S. Provisional Patent Application Serial No. 62/370,174, filed August 2, 2016, titled “METHOD OF COMMISSIONING ELECTROCHROMIC WINDOWS,” each of which is herein incorporated by reference in its entirety.

[0119] After a network of devices (e.g., one or more tintable windows) is physically installed, the network can be commissioned to correct any incorrect assignment of window controllers to the wrong tintable windows (sometimes referred to as “IGUs”) or building locations. In some embodiments, commissioning maps pairs or links individual devices (e.g., tintable windows) and their locations with associated controllers.

II. Additional Introduction

[0120] Some tintable windows can be electronically controlled. Such control may allow control of the amount of light that passes through the tintable windows, and presents an opportunity for tintable windows to control the amount of natural light in spaces of a facility (e.g., a building), the heat load entering the facility, and other internal conditions of the facility by adjusting transmissivity of tintable windows on the skin of the facility and/or controlling settings of other systems (e.g., building systems such as an HVAC system) and their associated controllers.

[0121] As used herein, a “space” refers to a volume within a facility that may serve a specific purpose. A space may be virtual space in a virtual representation of a facility such as a virtual model (e.g., digital twin) or a physical space of the facility. The spaces in a facility may have identifiers associated with the purpose of the space. An example of an identifier of a space is “Conference room A”, “Conference Room B”, or “Marketing Open Office.” A “space type” refers to an attribute of a space that indicates a function of the space. Some examples of space types in an office building include circulation, private office, open office, kitchen, conference room, breakroom, restaurant, fitness center, and lobby. Some examples of space types in an airport building include circulation, gate, restaurant, vendor, office, lounge, and service area. Some examples of space types in a multi-family house building include living room, kitchen, bedroom, bathroom, hallway, lobby, lounge, gym/fitness room, and office.

[0122] Real-time control, or near (approximate) real-time control, of one or more conditions at a facility such as a building may be desired by customers of the facility

(e.g., tenants, other occupants, and/or customer support personnel for the facility). For example, an occupant spending time in a particular three-dimensional space of a building may desire real-time control of the light level (e.g., level of natural light and/or artificial light), color of light, heat load (gain), and/or other condition of their space. In addition, or alternatively, identification of a malfunctioning tintable window, sensor, or other device, a controller, and/or a connection of the controller to a particular device for maintenance, upgrade and/or replacement may be desired.

[0123] Certain embodiments described herein control the amount of natural light in a space of a facility by adjusting transmissivity of the facility's tintable windows based on clear sky illuminance values attenuated based on measured illuminance outside the facility. To create a desired or target natural light level in a facility's space, given the light level outside the facility based on attenuated clear sky illuminance values, the transmissivity of the facility's tintable windows can serve as an independent variable that is adjusted to modulate the amount of light that passes through such windows from outside the facility into the space. By adjusting the transmissivity, the target lux level, or an approximation close to this target, can be achieved. The transmissivity of the facility's tintable windows serves as the adjustable variable (or adjustable "knob") for tuning the amount of natural light passing from outside the facility, through the windows, and into the space.

[0124] Some of these embodiments use illuminance levels outside the facility based at least in part on predicted light conditions (e.g., clear sky values) that are attenuated or adjusted based on sensor data from one or more sensors (e.g., photosensors) positioned outside the facility. The predicated clear sky data are attenuated with a scaling factor based on the measured sensor data; in some instances, this may be considered real-time external light with attenuated clear sky data.

[0125] For example, clear sky data may represent external illuminance under clear sky conditions at a facility's location and this predicted illuminance may be adjusted to account for real-time measured light conditions around the facility provided by sensors at the site of the facility such as on the roof of the facility. The measured illuminance may be used to determine a scaling factor applied to the predicated clear sky data, and by attenuating the by attenuating the predicted, outside light conditions with the measured real-time measurements, accurate light conditions can be used to control and adjust natural light in the space of the facility. In another example, the predicted illuminance may indicate illuminance at the facility emanating or originating from a southern compass

direction at a particular time (e.g., the sun is south of the facility), and none from the northern compass direction. The measured light data, as generated by a plurality of sensors, such as photosensors, may indicate measured illuminance from the northern compass direction; this measured illuminance may be caused by a cloud or building reflecting light at the facility from the northern compass direction. When these predicted light values are attenuated, or scaled, based on the measured light data, the resulting light conditions around the facility may indicate that light is radiating onto the building from both southern and northern directions. These scaled light conditions may then be used to optimize the facility's tintable window transmissivities to cause the space or spaces in the facility to have their desired natural light levels given the outside light conditions. By using the known, measured light conditions outside a facility, the transmissivity of the facility's tintable windows can be optimized to control the resulting natural light in a space of the facility.

[0126] In some implementations, the predicted and measured illuminance outside the facility is simulated by light patches of a virtual sky dome over the facility. The light patches represent a luminance distribution that is based on predicted clear sky data and measured illuminance from the plurality of sensors. The sky above the facility is discretized into a plurality of light patches that make up the sky dome and each light patch has an associated lux level that represents a source or contribution of illuminance. Each light patch may be based on the predicted values which are attenuated by a scaling factor determined from the measured lux data received from the plurality of sensors. As provided herein, to attenuate the clear sky data in the sky dome model, sensor readings of measured light data from the one or more sensors are used to determine a scaling factor applied to the luminance values of the clear sky data for the light patches (luminous patches) of the sky dome; this may create a real-time sky dome with attenuated clear sky data. Some embodiments map the sensor readings and associated attenuated scaling factors to the patches of the sky dome. For example, as discussed in greater detail below, the measured light readings may be from 12 photosensors radially arranged around a central axis and oriented outward perpendicular to the central axis. Some of the embodiments provided herein may map the data generated by these 12 sensors to the patches in the sky dome.

[0127] In alternative or additional embodiments, the transmissivity of a facility's tintable windows may be used to adjust heat gain in a space of facility given the light

conditions outside the facility (e.g., predicted light adjusted by measured light data) to create a target heat gain, or approximation close to the target heat gain, in the space.

III. Virtual Building Model (e.g., Digital Twin)

5 [0128] To address customer satisfaction regarding control of conditions within a building and/or other settings and status of devices at a facility, a digital model and associated file(s) may be associated with the facility and the devices. In certain implementations, the digital model and its associated file(s) are referred to as a “virtual building model” of the facility. An example of virtual building model is a Building
10 Information Model or “BIM”. Some examples of BIM files for a BIM model include a Revit file, a Microdesk file such as a ModelStream file, an IMAGINiT file, an ATG USA file, or similar facility-related digital file. The virtual building model may have associated centralized files integrating all assets at the facility, which can aid occupants and customer support personnel responsible for the facility and/or control of one or more
15 devices within the facility. For example, the virtual building model can be stored in a cloud network accessible and/or updatable by the occupants and customer support personnel.

[0129] In one aspect, a virtual building model may include the location and identifiers of the devices in the building and the current settings and status of the devices in the
20 building. The virtual building model may also include user preferences such as, for example, preferred settings of one or more environmental conditions (e.g., amount of natural light in a space) and preferred settings for one or devices (e.g., transmissivity of a tintable window). In certain implementations, the virtual building model of a facility may be updated to reflect real time, or substantially real time status and settings, of the devices
25 at the facility, which can aid in deployment, maintenance, and control of the devices and environmental conditions at the facility. The virtual building model can also serve as an interactive tool for customers to control in real time, or substantially real time, the environmental conditions (e.g., amount of natural light or heat load) in their space and see visualizations of their changes to environmental conditions on a three-dimensional model
30 of the building and/or see visualizations on the three-dimensional model of the building of how their changes will cause adjustments to settings of devices in the building. For example, a customer can adjust an amount of light for their space and be provided with a visualization on a 3D model of how transmissivity of tintable windows on two adjacent facades to that space would be adjusted to accommodate their adjustment.

[0130] A virtual building model may facilitate management of control of devices at various levels. In certain aspects, a virtual building model may be a BIM that is supplemented with device related information such as through an app (software application). For example, input from customers (e.g., through an app) may be fed into control of the facility using the virtual building mode. The virtual building model may offer a visual proofing tool prior to commissioning or for purposes of maintenance after commissioning. The virtual building model may also offer a virtual reality experience of the facility (including its assets such as devices) to a user of the software application.

[0131] In some cases, a three-dimensional (3D) architectural model may be used to initialize files (e.g., BIM files) of a virtual building model, to incorporate architectural elements of a facility. Ground truth validation (e.g., from a field service engineer) may be used to verify device data in the files of the virtual building model. The virtual building model may be initialized prior to commissioning the devices at the facility. In some cases, the initialized BIM files (such as, e.g., an Autodesk Revit file) incorporate architectural elements of a facility, but not the devices installed in the facility. The BIM files may be updated during commissioning and/or updated by the occupants and or customer support personnel.

[0132] During commissioning of devices at a facility, devices may be installed and differentiated from one another by the installer, e.g., by consulting an external label having an inscribed serial number, bar code, Quick Response (QR) code, radio frequency identification (RF ID), and/or other printed information. In some cases, the process of locating and documenting the devices during and/or after the commissioning process may be entered into the virtual building model by automated and/or manual process. In some cases, commissioning may be performed to provide or correct assignment of window controller addresses and/or other identifying information to specific windows and window controllers, as well the physical locations of the windows and/or window controllers in buildings. For example, commissioning may be used to correct problems made in installing tintable windows in the wrong locations or the connecting of cables to the wrong window controllers. The commissioning process for a particular tintable window involve associating an identification (ID) for the window, or other window-related component, with a network address of its corresponding window controller. The process may (e.g., also) assign a building location and/or absolute location (e.g., latitude, longitude and/or elevation) to the window or other component.

[0133] The tintable windows (e.g., comprising electrochromic devices), electronic ensembles (e.g., containing various sensors, actuators, and/or communication interfaces), and/or associated controllers (e.g., master controllers, network controllers, and/or other controllers, e.g., responsible for tint decisions) may be interconnected in a hierarchical network, e.g., for purposes of coordinated control (e.g., monitoring). For example, one or more controllers may need to utilize the network address of the window controller(s) connected to specific windows or sets of windows. To this end, a function of commissioning may be to provide correct assignment of window controller addresses and/or other identifying information to specific windows and window controllers, as well the physical locations of the windows and/or window controllers in buildings. Another function of commissioning may be to correct the installation of windows at the wrong location or the connecting of cables to the wrong window controllers. The commissioning process for a particular window (e.g., insulated glass unit (IGU)) may involve associating an identification (ID) for the window, or other window-related component, with a network address of its corresponding window controller. The process may (e.g., also) assign a building location and/or absolute location (e.g., latitude, longitude and/or elevation) to the window or other component. Some examples to digital twins are described in PCT Application PCT/US2021/057678, filed on November 2, 2021, and titled “VIRTUALLY VIEWING DEVICES IN A FACILITY,” which is hereby incorporated by reference in its entirety.

[0134] In certain aspects, a control system and/or control interface comprises, or is in communication with, a “virtual building model” of a facility such as a building. For example, the virtual building model may comprise a representative model (e.g., a two-dimensional or three-dimensional virtual depiction) containing structural elements (e.g., walls and doors), building fixtures/furnishings, and one or more interactive target devices (e.g., tintable windows, sensors, emitters, and/or media displays). The virtual building model may reside on a server which is accessible via a graphical user interface, or which can be accessed using a virtual reality (VR) user interface. The VR interface may include an augmented reality (AR) aspect. The virtual building model may be utilized in connection with monitoring and servicing of the building infrastructure and/or in connection with controlling any interactive target devices, and in providing interactive input (e.g., preferences for one or more environmental settings) from, and feedback to, a customer.

[0135] When a new device is installed in the facility (e.g., in a room or space thereof) and is operatively coupled to the network, the new device may be detected (e.g., and included into the virtual building model). The detection of the new device and/or inclusion of the new device into the virtual building model may be done automatically and/or manually. For example, the detection of the new device and/or inclusion of the new device into the virtual building model may be without requiring (e.g., any) manual intervention. Whether present in the original design plans of the enclosure or added at a later time, full details regarding (e.g., each) device (including any unique identification codes) may be stored in the virtual building model, network configuration file, interconnect drawing, and/or architectural drawing (e.g., BIM file such as a Revit file) to facilitate the monitoring, servicing, and/or control functions.

[0136] In some embodiments, a virtual building model comprises a virtual three dimensional (3D) model of the facility. The facility may include static and/or dynamic elements. For example, the static elements may include representations of a structural feature of the facility (e.g., fixtures) and the dynamic elements may include representations of an interactive device with a controllable feature. The 3D model may include visual elements. The visual elements may represent facility fixture(s). The fixture may comprise a wall, a floor, wall, door, shelf, a structural (e.g., walk-in) closet, a fixed lamp, electrical panel, elevator shaft, or a window. The fixtures may be affixed to the structure. The visual elements may represent non-fixture(s). The non-fixtures may comprise a person, a chair, a movable lamp, a table, a sofa, a movable closet, or a media projection. The non-fixtures may comprise mobile elements. The visual elements may represent facility features comprising a floor, wall, door, window, furniture, appliance, people, and/or interactive device(s)). The virtual building model may be similar to virtual worlds used in computer gaming and simulations, representing the environment of the real facility. Creation of a 3D model may include the analysis of a Building Information Modeling (BIM) model (e.g., an Autodesk Revit file), e.g., to derive a representation of (e.g., basic) fixed structures and movable items such as doors, windows, and elevators. In some embodiments, the virtual building model is defined at least in part by using one or more sensors (e.g., optical, acoustic, pressure, gas velocity, and/or distance measuring sensor(s)), to determine the layout of the real facility. Usage of sensor data can be used (e.g., exclusively) to model the environment of the enclosure. Usage of sensor data can be used in conjunction with a 3D model of the facility (e.g., (BIM model) to model and/or control the environment of the enclosure. The BIM model of the facility may be obtained

before, during (e.g., in real time), and/or after the facility has been constructed. The BIM model of the facility can be updated (e.g., manually and/or using the sensor data) during operation and/or commissioning of the facility (e.g., in real time).

[0137] In some embodiments, dynamic elements in a virtual building model include device settings. The device setting may comprise (e.g., existing and/or predetermined): tint values, temperature settings, and/or light switch settings. The device settings may comprise available actions in media displays. The available actions may comprise menu items or hotspots in displayed content. The virtual building model may include virtual representation of the device and/or of movable objects (e.g., chairs or doors), and/or occupants (actual images from a camera or from stored avatars). In some embodiments, the dynamic elements can be devices that are newly plugged into the network, and/or disappear from the network (e.g., due to a malfunction or relocation). The virtual building model can reside in any circuitry (e.g., processor) operatively coupled to the network. The circuitry in which the digital circuitry resides may be in the facility, outside of the facility, and/or in the cloud. In some embodiments, a two-way (e.g., bidirectional) link is maintained between the virtual building model and a real circuitry. The real circuitry may be part of the control system. The real circuitry may be included in the master controller, network controller, floor controller, local controller, or in any other node in a processing system (e.g., in the facility or outside of the facility). For example, the two-way link can be used by the real circuitry to inform the virtual building model of changes in the dynamic and/or static elements so that the 3D representation of the enclosure can be updated, e.g., in real time or at a later (e.g., designated) time. The two-way link may be used by the virtual building model to inform the real circuitry of manipulative (e.g., control) actions entered by a user on a mobile circuitry. The mobile circuitry can be a remote controller (e.g., comprising a handheld pointer, manual input buttons, or touchscreen).

[0138] FIG. 8 depicts a visual representation of a virtual building model **800** which is based, at least in part, on a BIM (e.g., Revit) file **801**. In some embodiments, virtual building model **800** includes a 3D virtual construct which may be virtually navigated to view and interact with target devices using an interface device. The interface may be a mobile device such as a smartphone or a tablet computer. In some embodiments, a virtual representation of the enclosure comprises a virtual augmented reality representation of the virtual building model displayed on the mobile device, wherein the virtual augmented reality representation includes virtual representations of at least some of the real target

devices. The navigation within the virtual building model using a mobile device may be independent of the actual location of the mobile device, or may coincide with the movement of the mobile device within the real enclosure represented by the virtual building model. The mobile device may be operatively (e.g., communicatively) coupled to the network. The mobile device may register its present position in the real facility with a respective position in the virtual building model, e.g., using any geo-location technology. For example, the geo-location anchors coupled to the network.

[0139] In some embodiments, a mobile device (e.g., a smartphone, tablet, or handheld controller) is utilized to detect commissioning data of respective target devices and transmit the commissioning data to the virtual building model and/or BIM system. The mobile device may include geographic tracking capability (e.g., GPS, UWB, Bluetooth, and/or dead-reckoning) so that location coordinates of the mobile device can be transmitted to the virtual building model using any suitable network connection established by the user between the mobile device and the virtual building model. For example, a network connection may at least partly include the transport links used by a hierarchical controller network within a facility. The network connection may be (e.g., entirely) separate from the controller network of the facility (e.g., using a wireless network such as a cellular network). The target device may be outfitted with an optically recognizable ID tag (e.g., sticker with a barcode or a Quick Response (QR) code). Interaction of the mobile device with the target device may be used to populate a virtual representation of the target device in the virtual building model, with a unique identification code and/or other information relating to the target device that is associated with the ID code (e.g., comprised in the ID tag).

[0140] FIG. 9 shows an example embodiment of a control system 900 in which a real, physical building 910 includes a controller network 920 for managing and controlling interactive network devices (e.g., one or more tintable windows). The controller network 920 includes one or more controllers such as, for example, one or more of a master controller comprising a processor, a network controller, and local controller. The structure and contents of building 910 are represented in a 3-D model virtual building model 930 as part of a modeling and/or simulation system executed to manage computing assets at the building 910 and/or control one or more environmental conditions at the building 910. The computing assets may be co-located with or remote from building 910 and/or the controller network 920.

[0141] In the illustrated example, network link **940** is connecting controller network **920** with an interactive target device **912** (e.g., a tintable window such as an electrochromic window). Interactive target device **912** is represented as a virtual object **932** within virtual building model **930**. A network link **940** in building **910** connects the controller network **920** with a plurality of network nodes including one or more network interactive target computing devices. In the illustrated example, network link **940** is connecting controller network **920** with an interactive target device **912**. Interactive target device **912** is represented as a virtual object **932** within virtual building model **930**. A network link **950** connects controller network **920** with virtual building model **930**. In the illustrated example, a customer **914** is shown located in building **900** and in communication with a mobile device (e.g., handheld control unit) **916**. Building **900** includes a physical space **918** associated with customer **914**. Physical space **918** in the building **910** is represented by a virtual space **938** in virtual building model **930**. In certain implementations, physical tintable windows in physical space **918** are represented by virtual tintable windows in virtual building model **930**. Mobile device **916** may include integrated scanning capability (e.g., a camera for capturing an image of a barcode or QR code), and/or may include, or be in communication with, an identification capture device (e.g., a handheld barcode scanner connected with mobile device **916**, e.g., via a Bluetooth link). ID tags may be comprised of, for example, RFID, UWB, radiogenic, reflective, or absorptive materials to enable use of various scanning tools (e.g., identification capture devices). The code(s) or printed matter on an ID tag may comprise device type, electronic and/or material properties of the target device, serial number, types, identifiers of component parts, manufacturer, manufacturing date, and/or any other pertinent information.

[0142] In certain implementations, the virtual building model of a facility stored on a server (e.g., server on a cloud network and/or within the facility) may be updated in real-time, or approximately real-time, to include one or more customer preferences such as a condition of an internal space of the facility. In some cases, the virtual building model is updated to show real-time or approximately real-time, adjustments to one or more devices (e.g., interactive target device **912** in **FIG. 9**) in the facility. For example, the virtual building model may be updated in real-time or approximately real-time, to model future behavior of the facility. For example, a customer may interactively select an internal space in the virtual building model to adjust a preferred amount of light in the space. The customer preference of the preferred amount of light is communicated to the server and

stored in the virtual building model in real-time, or approximately real-time. A visual representation of the future adjusted tint levels of the virtual windows that will meet the preferred condition, and/or the future illuminance levels of the internal spaces in the updated virtual building model may be provided in real time, or approximately real-time, to the customer to show future behavior of the facility. An example of a visual representation of future illuminance levels in virtual spaces of an updated virtual building model is shown in **FIG. 13B**.

[0143] Some examples of digital twins, user interfaces, commissioning, networks, smart objects, 3D representations of buildings and spaces, zones of tintable windows and other groupings of tintable windows, and controlling tintable windows are described in U.S. Patent Application Serial No. 17,400,596, titled “AUTOMATED COMMISSIONING OF CONTROLLERS IN A WINDOW NETWORK,” filed on August 12, 2021, which is hereby incorporated by reference in its entirety.

III. Introduction to Optimization Process

[0144] At a high level, certain tinting methods described herein include an iterative process (sometimes referred to as an “optimization process”) that is designed to create a target illuminance level or lux level of natural light and/or other internal conditions (e.g., color or light, heat gain, etc.) in one or more internal spaces of a building. This optimization process iteratively adjusts (e.g., through one or more iterations), transmissivity level(s) of one or more tintable windows in a virtual building model until the illuminance level of natural light in the internal spaces reaches, or approximately reaches, the targeted level. The transmissivity level or levels of the one or more tintable windows in the virtual building model act as an adjustable knob (independent variable) that are adjusted to create the target level of natural light, or about the target level of light, in the one or more spaces given the external light from the sky on the building. As part of determining the transmissivity required to create the desired target lux in the space, the light from the sky outside the building being transmitted through the tintable windows into the internal space(s) is calculated. This external light transmitted into the building is calculated based on predicted clear sky data attenuated with sensor readings. The illuminance level in the internal spaces is calculated based on the flux transfer of external light from the sky, through the tintable windows, and into the internal spaces within the building according to the three-phase model described below. The external light from the sky is simulated by a virtual sky dome over the building. The sky dome is based on

predicted clear sky data and measured light from one or more sensors such as from a plurality of photosensors in a multi-sensor device on a roof of the building. As described in more detail below, one or more aspects of the predicted clear sky data are adjusted based on the measured light data to provide an accurate, real-world approximation of the external light from the sky. The transmissivity level or levels from the optimization process is then used to determine a final tint state for the one or more tintable windows in the building.

– Three-phase Model

[0145] A three-phase model of the light flux transfer from the sky, through the tintable windows, and into the interior of a building may be utilized to model transmission of light to the internal space of the building. The three-phase model may be included in a 3D model of the building or a virtual building model (e.g., digital twin) of the building. The three-phase model can be used to determine the illuminance or lux level at one or more grid points (with x, y, z coordinates) in the interior of the building. The term “grid point” or “point” generally refers to a virtual location expressed in three-dimensional coordinates (x, y, z) and directional vectors (x-direction, y-direction, z-direction). The three-phase model factors the flux-transfer path from the sky to the grid points into three segments associated with three independent flux transfer matrices: (i) the view “V” matrix – flux transfer between tintable window and grid point in the building, (ii) the transmission “T” matrix - flux transfer through the tintable window, and (iii) the daylight “D” matrix – flux transfer between the sky and the exterior of the tintable window. An example of a three-phase model can be found in Subramaniam, Sarith, “Daylight Simulations with Radiance using Matrix-based Methods,” (October 2017), which is hereby incorporated by reference in its entirety. The total flux transfer between the sky and a vector of grid points within the building is represented by the matrix product $VTDS$. **[0146]** The matrix equation $E = VTDS$ can be utilized to obtain the illuminance matrix “E” representing the illuminance or lux level at each grid point given the “S” matrix of luminance values corresponding to sky conditions at the geographic location of the building. In one aspect, the coefficients of the clear sky “S” matrix may be based on data output from a virtual sky dome model simulation (annual or single point in time) of the light distribution in the sky over the building. In certain aspects, the coefficients of the “S” matrix correspond to luminance levels at clear sky conditions at multiple points in time (e.g., over a year) at a particular geographical location such as the geographical

location of a facility. In certain aspects, an “S” vector represents a vector of luminance levels corresponding to sky conditions at a single point in time at a particular geographical location. The “S” matrix may be calculated by adding multiple “S” vectors at different points in time. The International Commission on Illumination (CIE) and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) provide examples of sky modeling approaches using historical weather data that may be used to determine luminance values under various weather conditions at various points in time for input into an “S” matrix. These models can provide direct and diffuse luminance values parameterized by azimuth and zenith angles. “S” matrix coefficients are obtained by discretization of the underlying sky dome model. Some examples of discretization schemes that can be used include Tregenza and Reinhart schemes. In one aspect, the coefficients of the clear sky “S” matrix may be based on data output from a virtual sky dome model simulation (annual or point in time) of the light distribution in the sky over the building.

[0147] In one aspect, a sky “S” matrix includes coefficients based on predicted values corresponding to clear sky conditions and measured light data based on sensor readings. In one example, the measured light data is used to attenuate or adjust the predicated values. In some cases, scaling factors are applied to the predicated values based on the sensor readings. For example, if an illuminance value corresponding to readings from a sensor are higher than the illuminance values of the light patch to which the sensor is mapped, the illuminance value may be increased by a scaling factor of 0.10.

[0148] FIG. 10 is a schematic illustration of a flux-transfer path from the sky 1001 to a grid point 1005 in an interior space 1020, e.g., a room, of a building simulated by a three-phase simulation model, according to an implementation. As shown, the three-phase model segments a flux-transfer path 1007 from sky “S” 1001 to a grid point 1005 in three phases: (i) a first flux transfer from the sky 1001 to the exterior of tintable window 1012, represented as a “D” daylight phase, (ii) a second flux transfer through tintable window 1012, represented as a “T” transmissivity phase, and (i) a third flux transfer from tintable window 1012 to a grid point 1005 in the interior space 1020, represented as a “V” view phase.

[0149] Various software, such as open-source RADIANCE, can be used to create the coefficients for the V, T, D and S matrices. Employing RADIANCE may require first converting a virtual building model (e.g., BIM file) into the file format expected by RADIANCE. HONEYBEE is an example of open-source software designed to convert

BIM files into the appropriate format for input into RADIANCE. The V, T, and D matrices are developed using site geometry (e.g., location of a building) derived from, for example, the virtual building model (BIM file). In one aspect, a three-phase model may be generated by at least three operations including (1) tracing the path of light from points
5 in an indoor space to the sky by a calculation of the flux-transfer matrices V, T, and D, (2) estimating the brightness of the sky by calculating an “S” sky vector from, e.g. a virtual sky dome simulation, and (3) relating the brightness (illuminance) of the sky to the brightness inside the space. In one aspect, a “S” sky vector can include illuminance levels at different locations of the sky above the building at a point in time simulation of a
10 virtual sky dome. In one example, the illuminance values may include predicted luminance values (corresponding to clear sky conditions) attenuated based on measured luminance levels from a plurality of sensors. In some cases, the attenuation contribution to the predicted luminance values by the readings from each sensor of a plurality of sensors is scaled.

15 **[0150]** In one aspect, a “V” view matrix representing a single tintable window may have dimensions of the number of analysis grid point by the number of incoming incidence-angles (as determined by discretization), a “T” transmissivity matrix representing a single tintable window may have dimensions of the number of outgoing incidence-angles by the number of incoming incidence-angles, and a “D” daylight matrix
20 representing a single tintable window may have dimensions of the number of outgoing incidence-angles by the number of incoming incidence-angles. In various aspects, the “S” sky vector generally has dimensions of the number of discretized sky light patches in the virtual sky dome. Incidence-angle can refer to an angle which light travels “into” or “out of” at a particular flux-transfer plane. Examples of discretization schemes that can be
25 used in three-phase-method illuminance modeling are the Reinhart and Tregenza discretization schemes.

[0151] By multiplying out VTDS, the illuminance (lux) contribution from each tintable window and/or a facade of the building to each grid point can be determined. For a single facade or tintable window, the “V” view matrix specifies (by incidence-angle) the
30 luminous flux transfer between light traveling from the facade or the tintable window to each member of a set of grid points. Also, for a single facade or tintable window, the “D” daylight matrix specifies the flux transfer from discretized patches of sky (e.g., simulated by corresponding patches of a light dome) to a facade or tintable window at different incidence-angles. In addition, for a single point in time, the “S” sky vector specifies the

intensity (luminance) at each light patch of sky in the light dome. In one example, the “D” daylight matrix can be computed based on the apertures (e.g., dimensions and orientation) of the tintable windows in the building and both the interior and exterior geometry as included in the digital twin (BIM file).

5 [0152] FIG. 11 is a schematic illustration of a sky light patch 1102 (ΔS_α) of a virtual sky dome providing illuminance (L_α) through an aperture 1113 of a tintable window into a room 1120 and to a grid point 1105 at x coordinates, according to an aspect. The sky light patch 1102 (S_α) has an angular size, an illuminance (L_α), and a direction. The flux transfer $E(x)_\alpha$ from sky light patch 1102 (S_α) to grid point 1105 (coordinates $X(x,y,z)$) is
 10 determined based on the three phase modeling of the flux transfer. The illuminance level at coordinates X is determined using $E(x)_\alpha = VTDS$ based on illuminance levels from the light patches of the virtual sky dome.

– Sky dome

15 [0153] A “sky dome” refers to a model that represents a luminance distribution from, for example, a celestial hemisphere (alternatively another shape) representing the sky over a facility such as a building. The luminance distribution represents light intensity at different areas or light patches of the sky. The luminance distribution can represent measured luminance values (e.g., from sensor readings) and/or simulated luminance
 20 values. In certain aspects, a sky dome determines the illuminance distribution as a function of the geographical location of the building (e.g., longitude, latitude, meridian), time, and physically measured radiation data from, e.g., one or more sensors at the site of the building. In one aspect, the sky dome simulation also accounts for historic weather data. The simulated data from a sky dome can be utilized to generate annual and/or single
 25 point-in-time illuminance distributions. These illuminance distributions can be used to generate the “S” sky vector and/or “S” matrix for the three-phase model of light flux.

[0154] The sky dome is discretized into a plurality of light patches (e.g., curved three-dimensional segments). Each light patch covers solid angles in azimuthal and altitudinal directions. FIG. 12A is an illustration of a sky dome 1210 having a plurality of 145 light
 30 patches 1120. In this illustration, the sky dome 1210 has the shape of a hemisphere and the light patches are solid angle segments of the hemisphere, each segment covering solid angles in azimuthal and altitudinal directions. In this example, patches 1220 cover azimuthal/altitude solid angles of 0 degrees to 6 degrees, 6 degrees to 18 degrees, 18

degrees to 30 degrees, 30 degrees to 42 degrees, 42 degrees to 54 degrees, 54 degrees to 66 degrees, 66 degrees to 78 degrees, and 78 degrees to 90 degrees. In other examples, other solid angles may be covered by light patches. In addition, or alternatively, other light patch shapes, numbers of light patches, and/or shape of the sky dome may be used.

- 5 For example, solid angle rectangular segments of the hemisphere may be used. **FIG. 12B** is an illustration of a 2D projection of the sky dome **1210** in **FIG. 12A**. The 2D projection includes the light patch id number (1-145) for each light patch along with its azimuthal angle and altitude angle at the center or centroid of each light patch.

- [0155] In certain aspects, a “S” sky vector and/or a “S” sky matrix may include
 10 coefficients based on data provided by the light patches of the sky dome. In some cases, illuminance values are determined at intervals (e.g., a 2 minute time interval, a 3 minute time interval, a five minute time interval, or a ten (10) minute time interval) for each light patch over a year area to determine the coefficients for an “S” sky matrix. In one
 15 example, the illumination values used to determine coefficients are determined based on (1) historical weather condition statistics, including direct and diffuse horizontal illuminance values and dew point, (2) clear sky illumination values, and/or (3) sensor readings. In one example, an illumination value for each light patch is calculated by uniformly sampling illumination values across the light patch.

- [0156] The sky dome generates the illuminance distribution based on clear sky data
 20 attenuated by sensor readings to reflect dynamic changes (obstructions and reflections) in the sky. Various software, such as open source RADIANCE, may be used to generate clear sky data to initialize the illuminance values of the light patches of the sky dome. The clear sky data is calculated based on geographical location of the building (e.g., longitude, latitude, meridian) and time. Sensor data from one or more sensors may then
 25 be used to attenuate the clear sky data in the sky dome model to generate a real time sky dome model with real-time (or approximately real time) values based on attenuated clear sky data.

- [0157] In certain aspects, to attenuate the clear sky data in the sky dome model, sensor readings of measured light data from the one or more sensors are used to determine an
 30 attenuation scaling factor applied to the illuminance values of the clear sky data for the light patches of the sky dome. For instance, at a particular time interval, the clear sky contribution of a light patch may be 500,000 lux. According to one or more photosensors of a multi-sensor device, however, there are rain clouds in the portion of the sky represented by the light patch that causes the illuminance levels to be reduced from the

clear sky value by approximately 70%. Based on these real-time sensor readings, an attenuation scaling factor of 0.70 or higher may be determined and the scaling factor is applied to the illuminance value of the light patch. In some cases, the scaling factors are bound within a range such as, e.g., [0.2, 1], [0.5, 1]. Bounding the attenuation scaling factor to a range applies a conservative attenuation factor. For example, if a sensor is malfunctioning and reading 0 illuminance level, if the attenuation scaling factor is bound between [0.2, 1], an attenuation scaling factor of 0.20 is applied rather than 0.

[0158] In certain implementations, the real-time sky dome with attenuated clear sky data and a three-dimensional model of the building (e.g., a BIM file or a digital twin) with one or more tintable windows are used to predict the amount of light (e.g., natural light) at one or more grid points within the building. The real-time sky dome with attenuated clear sky data is used to determine an illuminance distribution of external light over the building and the individual contributions of its light patches. The three phase model and the three-dimensional virtual model of the building are used to determine the illuminance levels at one or more grid points internal to the building based on the illuminance contributions of the light patches in the real-time sky dome model that simulate external light to the building.

[0159] In one aspect, the real-time sky dome with attenuated clear sky data is based on clear sky data determined for a future time. For example, the clear sky data may be for a future time taking into account the transition time of the tintable window. The clear sky data may be determined for a future time so that a voltage profile can be applied to the tintable window in advance of the future time by at least the transition time to allow the tintable window to transition to the new tint state by the future time.

[0160] **FIG. 13A** is an illustration of a 2D projection of the sky dome **1201** shown in **FIG. 12A** depicting illuminance values for light patches based on attenuated clear sky data. In this illustration, the top is North, bottom South, right East, and left West. The light patch at the center is pointing up vertically. The sky dome includes attenuated clear sky data (e.g., predicted clear sky data attenuated with real-time measured light data by using the measured light data as a scaling factor applied to the predicted clear sky data). The illuminance values for the light patches are illustrated by shading. In this illustration, a set of four light patches **1311** is shown to have positive illuminance values and the other light patches have zero illuminance values.

[0161] **FIG. 13B** is an illustration of a 2D top view of a virtual building model that is used in conjunction with the sky dome **1310** shown in **FIG. 13A**. The illustration shows

illuminance levels in the interior of the building caused by attenuated external light from the sky provided by the positive illuminance levels in the set of four light patches **1311** shown in **FIG. 13A**. For example, the illuminance from outside the building is shown extending into the building in the 2D, or x-y plane. Given that the illuminance is based in the southern part of the hemisphere, the light is seen radiating into the building in a general north-south direction, and with a northern based vector. This **FIG. 13B** also exemplifies how the attenuated clear sky data may be positioned onto a virtual model of a building. Using the building's 3D model and its physical characteristics (e.g., window shapes, sizes, and locations, plus overhangs and external building features), the attenuated clear sky data can be used to project the light into the building internal spaces.

[0162] **FIG. 13C** is a bar chart of transmissivity levels for each of the tintable windows in the virtual building model. This set of transmissivities, in combination with the sky luminance values in **FIG. 13A** produces the horizontal plane illuminances at different points in the space as seen in **FIG. 13B**.

[0163] The real-time sky dome may be used to generate annual and/or point-in-time daylight simulations to determine illuminance values at different locations (e.g., patch locations) of the sky above the building. An annual simulation of the sky dome can be used to populate the sky "S" matrix with illuminance values over a time period of a year. Point in time simulations of the sky dome can be used to populate the sky "S" vector with illuminance values at different locations of the sky above the building at a single time. For example, the illuminance values from the light patches are used to generate the components of the "S" sky vector.

– Sensor data used to attenuate clear sky data

[0164] In certain aspects, clear sky data for a sky dome model is attenuated with sensor data from readings taken by one or more sensors (e.g., one or more photosensors). In one aspect, the sensor data is based on readings from a plurality of photosensors. The sensor data may be based on readings from photosensors of a multi-sensor apparatus such as a multi-sensor apparatus located on a roof of the building (sometimes referred to herein as a "sky sensor"). In one aspect, a multi-sensor apparatus includes a plurality of photosensors (e.g., 8, 10, 12, etc.) horizontally oriented and equally distributed azimuthally along the circumference of a circular housing. In one example, these sensors may be considered radially arranged and equally spaced around a central axis. In one implementation, a multi-sensor apparatus has twelve (12) photosensors pointed toward the horizon and

equally distributed azimuthally along the circumference of a circular housing, one (1) photosensor pointed upward vertically, and two (2) infrared sensors pointed upward vertically. Some examples of multi-sensor apparatus can be found in, e.g., PCT application PCT/US2016/055709, titled “Multi-sensor,” filed on October 6, 2016, which is hereby incorporated by reference in its entirety.

[0165] FIG. 14A is a drawing of an isometric view of a portion of a multi-sensor device having twelve (12) photosensors equally distributed along the circumference, 1 photosensor pointed upward vertically, and two infrared sensors pointed upward vertically, according to an implementation. The multi-sensor device 1400 generally includes a housing 1402, at least one light-diffusing element (or “diffuser”) 1404 and a cover housing (or “cover” or “lid”) 1406. As shown, in some implementations the housing 1402, the diffuser 1404 and the cover 1406 are rotationally symmetric about an imaginary axis 1410 that passes through a center of the multi-sensor device 1400. The multi-sensor device 1400 also includes multiple photosensors 1412. In some specific implementations, the photosensors 1412 are positioned annularly along a ring (for example, the ring can have a center coincident with the axis 1410 and can define a plane orthogonal to the axis 1410). In such implementations, the photosensors 1412 can more specifically be positioned equidistantly along a circumference of the ring. In some implementations, the multi-sensor device 1400 further includes at least one photosensor 1414 having an axis of orientation parallel with and in some instances directed along and concentric with the axis 1410.

[0166] In the illustrated example shown in FIG. 14A, the multi-sensor device 1400 further includes a first infrared sensor 1415A and a second infrared sensor 1415B located on an upper portion of the multi-sensor device 1400 positioned behind a diffuser 1404.

The first infrared sensor 1415A and second infrared sensor 1415B may or may not be visible to the human eye from outside the multi-sensor device 1400. Each of the infrared sensors 1415A, 1415B has an axis of orientation that is parallel with the axis 1410 and faces outward from the top portion of the multi-sensor device 1400 to measure temperature readings based on IR radiation captured from above the multi-sensor device 1400. The first infrared sensor 1415A is separated from the second infrared sensor 1415B by at least about one inch. In certain implementations, the multi-sensor device 1400 is installed on the outside a building or other structure such that both the first infrared sensor 1415A and second infrared sensor 1415B are oriented toward the sky in an approximately vertical direction (e.g., direction of gravity vector). When directed vertically toward the

sky, the first infrared sensor **1415A** and the second infrared sensor **1415B** can output sky temperature readings. In one implementation, the readings taken by the sensors of the multi-sensor device **1400** may be supplied to a building management system and/or to other buildings in the general vicinity. Communication may be established by a cellular communication circuit that also may be included in the multi-sensor **1400** according to a particular implementation.

[0167] In one implementation of the illustrated example shown in **FIG. 14A**, the multi-sensor device **1400** is installed outside a building or other structure with its axis **1410** oriented vertically upward. In this case, each of the first infrared sensor **1415A** and the second infrared sensor **1415B** is oriented vertically upward and the azimuthal orientation of the installed multi-sensor device **1400** is zero and has no impact on the temperature readings from the infrared sensors **1415A**, **1415B** reflecting the sky temperature above the building/structure. The azimuthal orientation of the multi-sensor device **1400** refers to the angle formed between a line directed due North from the installed multi-sensor **1400** and line along the axis **1410**.

[0168] Also shown in **FIG. 14A** is a plurality of radially-extending arrows **1416**. Each of the arrows **1416** represents an axis of orientation of a corresponding one of the photosensors **1412**. Each of the photosensors **1412** is depicted in dotted line indicating that photosensor **1412** itself may or may not be visible to the naked human eye from the exterior of the multi-sensor device **1400** in all implementations (As described in more detail below, the photosensors **1412** are positioned behind a diffuser **1404**). Each of the photosensors **1412** is oriented along a respective axis of orientation extending radially outward from the center of the ring (along the direction of a corresponding one of the arrows **1416**). In some implementations, the angle of detection of each photosensor **1412** is symmetric about the axis of orientation of the light sensor defining a symmetric “viewing cone.” In some implementations, the angle of detection of each photosensor **1412** is approximately 180 degrees (implying an approximately hemispheric angle of detection). In some implementations, each of the photosensors **1412** has an angle of view (distinct from the angle of detection) that overlaps the angle of view of each of the two respective immediately adjacent neighboring photosensors **1412**. The angle of view of the photosensors in multi-sensor device **1400** is the angle defining a viewing cone within which half of the power spectral density in the wavelengths of interest is captured by the light sensor. Generally, the angle of view is twice the angle from the axis of orientation to an outer surface of the viewing cone. In some implementations, each of the photosensors

1412 is the same as the other ones of the photosensors **1412**, and thus, the angles of view of each of the photosensors **1412** are generally the same. In some implementations, the axially-directed photosensor **1414** is of the same type as the photosensors **1412**. In some other implementations, the angle of view of the axially-directed photosensor **1414** can be narrower than, the same as, or wider than the angle of view of each of the photosensors **1412**.

[0169] In certain implementations, a multi-sensor apparatus may have a plurality of photosensors arranged at various azimuthal and altitudinal angles. In one implementation, for example, a multi-sensor apparatus may have a plurality of rings of photosensors, each ring having a plurality of photosensors oriented at a particular altitudinal angle and distributed equally along the circumference at different azimuthal angles. In one instance, for example, a multi-sensor apparatus includes a first ring with a plurality of first photosensors (e.g. 8, 10, 12, etc.) horizontally oriented, a second ring with a plurality of second photosensor at an altitudinal angle in a range of, e.g., 15 to 45 degrees, and a third ring with a plurality of third photosensor at an altitudinal angle in a range of, e.g., 45 to 75 degrees. In this example, the photosensors in each ring are distributed equally along the ring circumference. Some examples of multi-sensor devices having a plurality of photosensors arranged at various azimuthal and altitudinal angles can be found in PCT application PCT/US2015/053041, titled "SUNLIGHT INTENSITY OR CLOUD DETECTION WITH VARIABLE DISTANCE SENSING," filed on September 29, 2015, which is hereby incorporated by reference in its entirety.

[0170] FIG. 14B is a schematic drawing of a cross section of a portion of a multi-sensor device **1450** having a first ring **1460** of photosensors **1462**, a second ring **1470** of photosensors **1472**, and a photosensor **1482** oriented upward vertically along a center axis **1490**, according to an implementation. In one example, the second ring **1470** has a smaller number of photosensors (e.g., 4, 6, 8, etc.) than the first ring **1460** (e.g., 8, 10, 12, etc.). The photosensors **1462**, **1472** are oriented along an altitudinal angle, θ . The photosensors **1472** of the second ring **1470** are oriented along an altitudinal angle, θ , that is between 0 degrees and about 90 degrees. The photosensors **1462** of the first ring **1460** are oriented along an altitudinal angle, θ , that is about 0 degrees. The photosensor **1482** is oriented along an altitudinal angle, θ , that is about 90 degrees. The photosensors **1462**, **1472** in each ring **1460**, **1470** may be distributed equally along the circumference at

different azimuthal angles. In other implementations, additional rings of photosensors may be included.

[0171] **FIG. 15** is an isometric view of an example of a multi-sensor device **1500** with photosensors directed at various azimuthal and altitudinal angles of the sky, according to an implementation. Multi-sensor device **1500** includes a circular honeycomb-configured array **1501** of sensor modules **1520** within a hemispherical enclosure, according to an embodiment. Each sensor module **1520** includes a tube **1522** and one or more sensors (for simplicity, components within each tube are not shown). The circular honeycomb-configured array **1501** is segmented into a circumferential dimension of 24 modules and radial dimension of 4 modules, although other dimensions can be used. In this illustrated example, each of the tubes **1522** in the honeycomb array **1501** is aimed at a different region of the sky. There may be more than one type of sensor in one or more of the tubes **1522**. In one case, the sensors of the multi-sensor device **1500** are photosensors (e.g., CMOS/CCD sensors). Multi-sensor device **1500** includes a shield **1530** (e.g., glass or other transparent material covering) provided over the entire face illustrated as directed upward) of the multi-sensor device **1500**. Shield **1530** may protect the sensors from debris and/or moisture intrusion. The illustrated example shows a cutaway section of the shield **1530** to show inside a sensor module **1520**.

[0172] **FIG. 16A** is plot of photosensor readings from the thirteen (13) photosensors of multi-sensor device **1400** shown in **FIG. 14A** on a clear sky day on February 16, 2022 in Milpitas California. **FIG. 16B** is plot of photosensor readings from thirteen (13) photosensors of multi-sensor device **1400** shown in **FIG. 14A** on an overcast morning and clear afternoon on April 11, 2022 in Milpitas California.

– Mapping sensors to light patches

[0173] In one aspect, a method includes operations for mapping one or more sensors from, e.g., a multi-sensor device, to cardinal (azimuthal) directions. In addition, or alternatively, the method includes mapping one or more sensors to the patches of the virtual sky dome. For example, the position, intrinsic field-of-view (FOV), and azimuthal and altitudinal orientations of each sensor may be used to determine the flux transfer coefficients from each sky dome patch to each sensor. Once directionality of the one or more sensors has been established, the readings from the one or more sensors can be mapped to the light patches of the sky dome using, for example, a discretization scheme (e.g., Tregenza scheme) such as shown in **FIGS. 12A** and **12B**. After this mapping, a

function (e.g., a sigmoid function) is applied on the scaled value (e.g., 0.5 to 1.0) of the sensor readings and clear sky illuminance.

[0174] In one aspect, a method includes operations for mapping a plurality of sensors to cardinal (azimuthal) directions using an $m \times n$ dimensional data frame, where m is the number of daylight minutes, and n is the number of days for which photo sensor inputs, are utilized. As different latitudes correspond to different sun trajectories during different seasons, different sensor(s) (e.g., pointing in different directions) may be important at different times of day and/or season. Incorporating these differences can involve performing a data reduction technique (e.g., Principal Component Analysis) to compress time series information from x number of sensors into a one-dimensional vector capturing the y strongest radiation signals received from each cardinal direction. An example of operations for mapping sensors to cardinal directions can be found in PCT Application PCT/US19/46525, titled "CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS", filed on August 14, 2019, which is hereby incorporated by reference in its entirety.

– Zoning management of tintable windows

[0175] In some cases, a three-dimensional (3D) architectural model may be used to initialize files (e.g., BIM files) of virtual building model such as a digital twin, to incorporate architectural elements of a facility. Ground truth validation (e.g., from a field service engineer) may be used to verify device data in the files of the virtual building model. The virtual building model may be initialized prior to commissioning the devices at the facility. In some cases, the initialized BIM files (such as, e.g., an Autodesk Revit file) incorporate architectural elements of a facility, but not the devices (e.g., electrochromic devices of tintable windows) installed in the facility. The BIM files may be updated during commissioning and/or updated after commissioning by customers such as occupants or customer support personnel. In one example, the BIM files are updated during an optimization process in real-time, or approximately (about) real-time, by a customer.

[0176] In one aspect, one or more virtual spaces of a virtual building model are categorized by space type (e.g., private office, open office, kitchen, conference room, breakroom, and lobby) and/or virtual tintable windows are grouped together in zones, e.g., associated with spaces and/or associated with their orientation. For example, one or more tintable windows that are in locations and orientations that may allow light to be transmitted into a space may be grouped together in a zone. The tinting methods may

adjust one or more zones of tintable windows during the optimization process where each zone includes one or more tintable windows.

[0177] FIG. 17 is a diagram depicting operations of a method of generating one or more zones of tintable windows and associated orientations of the tintable windows. At operation 1, all enclosures (e.g., rooms) with tintable windows in the 3D model of the facility, such as a BIM file or digital twin, are identified. In some implementation, this operation may be completed during a commissioning process, for example; this operation may also be completed independent of a commissioning process. This operation may include accessing information within the 3D model that indicates whether each room is associated with one or more tintable windows. At operation 2, the names of the enclosures are determined or the enclosures are given identifying names. In the illustrated example, the four enclosures are given the names of private office South, Private Office Southwest, Open Office 1, and conference room. At operation 3, the orientations of each of the tintable windows for the spaces are determined from the building information in the files of the digital file.

[0178] At operation 4, the tintable windows associated with an enclosure are grouped into a zone and the zone associated with the space. In the illustrated example, the south-facing tintable windows and the east-facing tintable windows of the space identified as Open Office 1 are grouped together in a zone named "Open Office 1." In some instances, additional or alternative zones or groupings may be made, such as grouping each tintable window with the same orientation. For example, the south facing tintable windows may be grouped together while the east facing tintable windows may be grouped in a separate or different group than the south-facing group. This grouping may enable the control of different zones or areas of tintable windows that bound a single space, for instance. Using the techniques provided herein, each zone of tintable windows bounding at least a part of a space may have the transmissivity of its tintable windows controlled to create the desired natural light level in the space. Such zoning and control could account for different light levels outside of a space that is defined by exterior tintable windows at different compass orientations. For example, for a space having tintable windows defining at least parts of its south and east sides (such as the open office in Figure 17), the techniques may be able to adjust the transmissivity of a zone of south facing tintable windows to account light conditions and light passing through or affecting those tintable windows, while also independently adjusting the transmissivity of a zone of east facing

tintable windows to account light conditions and light passing through or affecting those tintable windows, and together to create the desired natural lux in that space.

[0179] Some examples of zoning management can be found in International PCT Application PCT/US19/46524, titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND NEURAL NETWORKS,” and filed on August 14, 2019 and International PCT Application PCT/US19/23268, titled “CONTROL METHODS AND SYSTEMS USING EXTERNAL 3D MODELING AND SCHEDULE-BASED COMPUTING,” and filed on March 20, 2019, which are hereby incorporated by reference in their entireties.

10 - Optimization operations

[0180] In one aspect, the optimization process includes a sequence of operations that minimize the distance (e.g., squared difference) between a desired illuminance level(s) and the calculated illuminance level(s) in one or more spaces of a virtual building model (e.g., digital twin) by iteratively adjusting the transmissivity level(s) of one or more (virtual) tintable windows in the virtual building model until (A) no further change to the transmissivity level(s) produces negative change in the distance (closer to the desired minima) below a certain value (e.g., -.001) or (B) no further change to the transmissivity level(s) produces a distance that falls below some threshold value.

[0181] In one implementation, the transmissivity level or levels of one or more zones of tintable windows may be adjusted so that the distance between the desired illuminance level(s) and the calculated illuminance level(s) in one or more spaces of a virtual building model is below a certain value. Each zone includes one or more virtual tintable windows.

[0182] Although examples of the optimization process are described with respect to preferred illuminance levels (or lux levels) in the virtual building model, other customer preferences may be included in other implementations. In addition or alternatively, preferences from multiple customers can also be included in the optimization process. In one aspect, one or more weighting factors may be applied to the preferences.

[0183] In one aspect, the tintable windows may be considered to tint instantaneously. In another aspect, the transition time, or tint delay, of the tintable window(s) may be factored into an optimization process.

[0184] In one example of the optimization process where tintable windows are considered to tint instantaneously, an optimization function that minimizes the difference between the i^{th} desired illuminance level, p_i , and the calculated illuminance level, $f_i(T)$, which is a function of transmissivity, T , of the one or more tintable windows, is:

Optimization function: $\operatorname{argmin}_T d(f_i(T), p_i)$ (**Eqn. 1**)

where: i is 1, 2, ..., k where k is the total number of desired light levels

[0185] In one example, the optimization function can be written as

Optimization function: $\operatorname{argmin}_T (f_i(T) - p_i)^2$ (**Eqn. 2**)

5 where: i is 1, 2, ..., k where k is the total number of desired light levels

[0186] In another example, the tintable windows are considered to tint over a period of time based on their tint transition rates and associated voltage ramps. In this example, the optimization process may consider illuminance levels of all zones of a building constrained by tint transition rate and associated voltage ramp and the current transmissivity of the one or more tintable windows, and the time until the next tinting opportunity (e.g., next time interval of an optimization process).

IV. Tinting methods with optimization process

[0187] In certain aspects, control logic for implementing tinting methods includes a process, such as an iterative process (e.g., an optimization process), designed to create a target or desired illuminance level in one or more spaces of a virtual representation of a building based on external light from the sky simulated by a virtual sky dome and based on light flux from the sky to the one or more spaces according to a three phase model. The external light simulated by the virtual sky dome is based on predicted illuminance that is attenuated or scaled based on measured readings generated by sensors at the building.

[0188] During the iterative process, the transmissivity (optimized variable) of the one or more tintable windows (e.g., vector with values between 0 and 1 that is used to multiple the “T” matrix) is iteratively adjusted while holding other parameters constant (e.g. the daylight “D” matrix and/or view “V” matrix) until so that the illuminance level in the one or more internal virtual spaces in the building reach, or approximately reach, the target illuminance level(s). At each iteration, the illuminance level at grid points in the one or more internal virtual spaces is determined using the “V” “T” “D” and “S” matrices of the three phase model of light flux. The three phase model of light flux represents external light from attenuated clear sky data passing through the one or more tintable windows in their current tint state, and into the internal space(s) in the building. The virtual sky dome determines an illuminance distribution of light patches from the sky above the building as a function of geographical location of the building (e.g., longitude, latitude, meridian), time, and physically measured radiation data from, e.g., one or more sensors at the site of the building. The simulated data from the sky dome can be utilized to generate annual

and/or single point-in-time illuminance distributions. The illuminance values from light patches of the sky dome can be used to determine the coefficients for the “S” matrix or “S” vector. The attenuated clear sky data of the sky dome is calculated from predicted clear sky data attenuated by readings of measured data from one or more sensors (e.g.,
5 photosensors from a multi-sensor device on a roof of the building). Each sensor is mapped to one or more light patches of the sky dome to determine the contribution of measured external light from each sensor to the light patches.

[0189] During the optimization process, the “T” matrix may be multiplied by a vector with values between 0 and 1 representing the adjustments to transmissivities of one or
10 more tintable windows in the building. During the optimization process, the vector can be used as an independent variable that is iteratively adjusted until the illuminance level at the grid point is at, or approximately at, the target illuminance level. For example, the “T” matrix may be multiplied by a vector representing adjustments to transmissivities of tintable windows on sides or facades of the building.

15 [0190] In one implementation, a virtual building model may be used to facilitate receiving information associated with preferences for a space or building, such as desired amount of light in a space from a customer (e.g., an occupant such as a tenant of the building or a customer service manager (CSM)). The amount of light corresponds to an illuminance or lux level. For example, the customer or customers may adjust the desired
20 amount of light in the space based on a scale from, e.g., 0 to 100 1 to 100, or other similar range. The low end of the scale may correspond to a level of light in the space that results from one or more tintable windows associated with the space being at their lowest level of transmissivity (e.g., about 0.5%, about 1%, or about 2%) and the high end of the scale may correspond to the level of light in the space that results from the one or more tintable
25 windows being at their highest level of transmissivity (e.g., about 52% or about 75%). In one example, the low end of the scale corresponds to approximately 200 lux and the high end of the scale corresponds to 1400 lux. In one instance, a scale of 1 to 100 refers to 0.5% to 52% transmissivity. Once the customer enters their preferred amount of light for a space, the files (e.g., BIM file) of the virtual building model may be updated in real
30 time, or approximately real-time, with the corresponding illuminance level through, for example, an app (software application). The virtual building model stored on a server on, e.g., a cloud network, and/or within the building, may be updated in real-time, or approximately real-time, to include the customer preference for the amount of light and the tint state or tint states of one or more tintable windows may be adjusted to meet the

desired amount of natural light using the optimization process. A virtual representation of the building and/or space, such as the virtual building model displayed in an app or on an electronic device, such as a tablet or computer, may offer visual simulation and proofing of customer preferences and adjustments to the tint state(s) of the tintable windows that result. For example, the virtual representation of the building and/or space display on an electronic device such as a computer may show the resulting illuminance level (associated with the customer preference of the amount of light) in the internal space or spaces of the building (e.g., as shown in **FIG. 13B**) from the optimization process based on the simulated external light currently on the building from the virtual sky dome (e.g., as shown in **FIG. 13A**).

[0191] **FIG. 18** is an illustration of an example of a system **1800** in which a virtual building model **1830** may be used to present a 2D or a 3D virtual model of spaces in a building to a customer based on building information in files (e.g., BIM file) of the virtual building model **1830**. System **1800** can be used to receive information associated with a target amount of light for a space in the building and update preferences in files of virtual building model **1830** stored on a server **1840** (e.g., a server on a cloud network) with a corresponding desired illuminance level for the space. The system **1800** includes a mobile device **1816** with a display **1820** and at least one application **1827**. The 2D or 3D virtual model may be interactively navigated in conjunction with display **1820** of mobile device **1816**. The at least one application **1827** is configured to perform rendering, navigation, updating, and identification functions in concert with the virtual building model **1830**. Updating the files of the virtual building model may be done using at least one database in which the virtual building model may reside (e.g., in a memory). The database may be at the building, at another facility, or in the cloud. In the illustrated example, display **1820** includes a 2D virtual model **1822** of spaces in a building. In this example, a customer has selected a virtual space **1822** that is identified as an “Engineering Area” **1823** with a space type of “Open Office” **1824**. The customer can then adjust the amount of light in the space **1822** using a slider bar **1825**. The slider bar **1825** allows the customer to adjust the amount of light in the space **1822** on a scale of 1 to 100. In this example, the amount of light is set to 20, which corresponds to approximately 200 lux. The amount of light corresponds to an illuminance or lux level. The files of the virtual building model may be updated, e.g., in real time, with the preferred illuminance level corresponding to the amount of light selected by the customer.

[0192] The techniques described herein, such as the optimization process, may then determine a transmissivity or transmissivities of one or more tintable windows in the building that provide the illuminance level, or approximately the illuminance level, associated with the customer's preferred amount of light in the space. In some cases, the optimization process takes less than 1 minute, less than 2 minutes, less than 3 minutes, etc. The display 1820 may then be updated to display the desired illuminance level of the space and/or tinted version of the one or more tintable windows. Instructions may then be sent to one or more window controllers to apply the voltage profiles that tint the one or more tintable windows according to the determined transmissivity or transmissivities.

[0193] FIG. 19 is schematic diagram of a system 1900 for controlling tint of one or more tintable windows, according to an implementation. The system 1900 includes a cloud network 1910 and a user interface 1920 configured to receive input from one or more customers. Cloud network 1910 is in electronic communication with the user interface 1920 to receive data input from the one or more customers, update the data, and provide updated data to the user interface. For example, input from the one or more customers may be stored in real-time or approximately real-time, in the cloud network 1910, the files of the virtual building model updated, and visualizations of future behavior at the facility may provided on a 3D model on the user interface 1920 in real-time, or approximately real time. An example of input includes information regarding groupings of tintable windows into one or more zones. Another example of input includes customer preferences such as target values (e.g., target lux values for one or more internal spaces) for a condition of one or more internal spaces in the facility. The cloud network 1920 may have a server configured to store information for each facility such as a virtual building model. System 1900 also includes a service 1930 including an intelligence service 1932 configured to perform one or more operations and a tint state manager 1934 configured to manage the tint state instructions received from intelligence service 1932 and forward final tint instructions to one or more window controllers. For example, tint state manager 1934 may determine whether an override is in place and apply an override tint state if the override is in place. Intelligence service 1932 is in electronic communication with the cloud network 1910 to communication data, e.g., information in the files of the virtual building model and/or the sky matrix or sky vector coefficients. Intelligence service 1932 is configured to determine sensor readings, e.g., by receiving sensor readings stored on cloud network 1910. Alternatively, intelligence service 1932 may be in communication with one or more sensors via cloud network 1910 or via a communication network to

receive sensor readings from one or more sensors. System **1900** also includes a site design system **1940** and a commissioning service **1950** in communication with the site design system **1940**. Site design system **1940** may communicate information about the facility such as the latitude and longitude of the facility. As at least part of a

5 commissioning process, commissioning service **1950** is configured to determine and output a clear sky matrix, and V, T, D, S matrix coefficients for each tintable window at the facility to the cloud network **1910**.

[0194] In one embodiment, techniques described herein, such as the iterative process may incorporate preferred values of metrics in addition to illuminance may be used to
10 determine the transmissivity of tintable windows. For example, preferences for amount of heat radiated into the space may be incorporated into the optimization process. In another example, preference for reduced energy consumption may factor into the optimization process.

[0195] In some embodiments, a tintable window may have discrete end tint states, such
15 as 2, 4, 6, 8, 10, 12, or more tint states. In some such implementations, control logic of a tinting method determines an end tint state for each tintable window that is associated with the transmissivity determined by the optimization process and a window controller can transition the tintable window to the end tint state associated with the transmissivity determined by the optimization process. For example, the control logic may determine the
20 end tint state associated with one of the tint states of the tintable window by first rounding up (or rounding down) the transmissivity determined by the optimization process to the closest transmissivity corresponding to a tint state of the tintable window. For example, in on aspect tintable windows are configured to transition to a plurality of 4 tint states (T1-T4) with tint 1 (T1) being a clear state and tint 4 (T4) being the darkest state. In one
25 aspect, T1 corresponds to a transmissivity through a tintable window of about 50% (+/- 10%), T2 corresponds to a transmissivity through a tintable window in a range of about 25% to about 30% (+/- 10%), T3 corresponds to a transmissivity through a tintable window of about 7% (+/- 10%), and T4 (darkest tint state) corresponds to a transmissivity through a tintable window of about 1% (+/- 10%).

30 [0196] In this example, the control logic may round up (alternatively round down) the transmissivity determined by the optimization process to the closest transmissivity associated with one of the 4 tint states. In one instance, for example, if the transmissivity for a first tintable window is determined to be 22% by the optimization process, the control logic may round up to 25% transmissivity, which is associated with tint state T2.

The window controller may then send tint instructions and/or apply voltage profile to transition the tintable window to T2.

[0197] While some of the examples presented herein describe tintable windows as configured with four discrete tint states, this disclosure is not limited. For example, the disclosed examples also apply to tintable windows having 2, 3, 4, 5, 6, 7, 8, 9, 10, or even more tint levels. As another example, one or more tintable windows may be configured to hold any transmissivity with a range of transmissivity levels, and is considered to have an “infinite” number of tint states. In this example, the control logic may apply a voltage profile to each tintable window that is associated with the transmissivity level determined to cause the target illuminance level in the internal space rather than rounding the transmissivity to a level corresponding with a discrete tint state.

[0198] FIG. 20 is a flowchart 2000 depicting operations of a method of controlling one or more tintable windows in a facility such as a building, according to various implementations. In some cases, one or more of the operations may be implemented by at least one window controller (e.g., master window controller, network window controller, or local window controller) operatively coupled to the one or more tintable windows. The at least one window controller is also in electronic communication with a server (e.g., a server in the cloud) on which a virtual representation (e.g., digital twin) of the building resides. The server and/or the at least one window controller may be in communication with one or more sensors, e.g., via a building management system. In other cases, one or more of the operations may be implemented by a BMS in operative communication with one or more window controllers operatively coupled to the one or more tintable windows and in electronic communication with a server on which a virtual representation of the building resides. In yet other cases, one or more of the operations may be implemented by a server in the cloud on which the virtual representation of the building resides.

[0199] At operation 2020, a virtual building model such as a 3D model e.g., a digital twin of the building is updated based on one or more preferences or inputs provided which may be provided by one or more customers of the building such as, e.g., an occupant of the building, a building manager, or a customer service personnel, or that may be provided as a default or initial input. This input may be received as described herein, such as stored on a memory or input through an app or other program. The preferences include a target amount of light, such as the amount of natural light, for one or more internal spaces in the building. A target illuminance level is determined from the

desired amount of light and the target illuminance level is updated in the files of the virtual representation stored on a server (e.g., a server in the cloud or in the building).

[0200] For example, a system (e.g., system **1800** shown in **FIG. 18**) may use files (e.g., BIM file) from the virtual representation to illustrate 2D or 3D virtual spaces in a building to the customer. The customer may then interactively navigate through 2D or 3D virtual spaces of the virtual building to select a space to input a preference such as the amount of light in the space. For example, the customer may adjust the amount of light on a scale of 1 to 100 as described with respect to **FIG. 18**. The low end of the scale may correspond to the highest transmissivity level of the tintable windows associated with the one or more internal spaces and the high end of the scale may correspond to the lowest transmissivity of the one or more tintable windows. The control logic may determine an illuminance level corresponding to the desired amount of light. In certain aspects, the customer may input their preference on a mobile device with an application that is configured to perform rendering, navigation, updating, and/or identification functions in concert with the virtual representation. The preferences including the corresponding illuminance level are transmitted to the server on which the files of the virtual model of the building resides. Updating the files of the virtual representation may be done using at least one database in which the virtual building model may reside (e.g., in a memory). The database may be at the building, at another facility, or in the cloud. In one aspect, based on input by the customer, the files of the virtual building model may be updated in real-time, or approximately real-time, with the preferred illuminance level corresponding to the amount of light selected by the customer and/or one or more other preferences.

[0201] In one aspect, multiple customers provide input of desired amounts of light for one or more spaces in the building. If the desired amounts of light are for the same space, an average, weighted average, or mean of the amounts of light may be calculated and the corresponding illuminance level for the space updated in the files of the virtual representation. In one aspect, the customers may be prioritized and weighting factors applied to their input based on the prioritization.

[0202] At operation **2030**, the control logic determines a luminance distribution from light patches of a virtual sky dome. **FIG. 12A** illustrates an example of a hemispheric sky dome **1201** with one hundred forty five (145) light patches **1210**. Each light patch covers a first solid angle in the azimuthal direction and a second solid angle in the altitude direction. The luminance distribution represents light intensity at the light patches of the sky above the building. The sky dome determines the illuminance distribution as a

function of the geographical location of the building (e.g., longitude, latitude, meridian), time, and physically measured radiation data from, e.g., one or more sensors at the site of the building. The simulated data from a sky dome can be utilized to generate annual and/or single point-in-time illuminance distributions. These illuminance distributions can be used to generate the “S” sky vector and/or “S” matrix for the three-phase model of light flux.

[0203] The control logic uses the sky dome model to simulate an illuminance distribution based on clear sky data attenuated by sensor readings to reflect dynamic changes in the sky. Various software, such as open source RADIANCE, may be used to generate clear sky data to initialize the illuminance values of the light patches of the sky dome. The clear sky data is calculated based on geographical location of the building (e.g., longitude, latitude, meridian) and time.

[0204] Sensor data from one or more sensors may then be used to attenuate the initialized clear sky data in the sky dome model to generate a real time sky dome model with real-time, or approximately real time, values that reflect dynamic changes based on attenuated clear sky data. The readings used to attenuate the clear sky data may be from one or more sensors at the site of the building. For example, the readings may be received from one or more photosensors in a multi-sensor device 1400 in FIG. 14A or multi-sensor device 1500 shown in FIG. 15. In one aspect, the multi-sensor device is located on a roof of the building.

[0205] In certain aspects, to attenuate the clear sky data in the sky dome model, sensor readings of measured light data from the one or more sensors are used to determine an attenuation scaling factor applied to the illuminance values of the clear sky data for the light patches of the sky dome. For instance, at a particular time interval, the clear sky contribution of a light patch may be 500,000 lux. According to one or more photosensors of a multi-sensor device, however, there are rain clouds in the portion of the sky represented by the light patch that causes the illuminance levels to be reduced from the clear sky value by approximately 70%. Based on these real-time sensor readings, an attenuation scaling factor of 0.70 or higher may be determined and the scaling factor is applied to the illuminance value of the light patch. In some cases, the scaling factors are bound within a range such as, e.g., [0.2, 1], [0.5, 1]. Bounding the attenuation scaling factor to a range applies a conservative attenuation factor. For example, if a sensor is malfunctioning and reading 0 illuminance level, if the attenuation scaling factor is bound between [0.2, 1], an attenuation scaling factor of 0.20 is applied rather than 0.

[0206] In one aspect, a method includes operations for mapping one or more sensors from, e.g., a multi-sensor device, to cardinal (azimuthal) directions. In addition or alternatively, the method includes mapping one or more sensors to the patches of the virtual sky dome. For example, the position, intrinsic field-of-view (FOV), and azimuthal and altitudinal orientations of each sensor may be used to determine the flux transfer coefficients from each sky dome patch to each sensor. Once directionality of the one or more sensors has been established, the readings from the one or more sensors can be mapped to the light patches of the sky dome using, for example, a discretization scheme (e.g., Tregenza scheme) such as shown in **FIGS. 12A** and **12B**. After this mapping, a function (e.g., a sigmoid function) is applied on the scaled value (e.g., 0.5 to 1.0) of the sensor readings and clear sky illuminance.

[0207] In some cases, the illuminance distribution from the sky dome may also account for historic weather data. For example, the clear sky data (e.g., illuminance) used to initialize the virtual sky dome may account for trends in historic weather data at the site of the building.

[0208] In one aspect, the files of the virtual sky dome may be stored on a server (e.g., a server on a cloud network). The sensor readings are communicated to the server and the files of the virtual sky dome model are updated, e.g., at intervals and/or at the initiation of the optimization process.

[0209] The control logic uses the illuminance distribution from the sky dome to generate coefficients for the “S” sky matrix or “S” sky vector used in a three-phase model of light flux. The “S” sky vector and/or a “S” sky matrix may include coefficients based on data provided by the light patches of the sky dome. In some cases, illuminance values are determined at intervals (e.g., a 2 minute time interval, a 3 minute time interval, a five minute time interval, or a ten (10) minute time interval) for each light patch over a year area to determine the coefficients for an “S” sky matrix. In one example, the illumination values used to determine coefficients are determined based on (1) historical weather condition statistics, including direct and diffuse horizontal illuminance values and dew point, (2) clear sky illumination values, and/or (3) sensor readings. In one example, an illumination value for each light patch is calculated by uniformly sampling illumination values across the light patch.

[0210] At operation **2040**, the control logic uses processes described herein to determine a level or levels of transmissivity of the one or more tintable windows of the building that provide the target illuminance level, or approximately the target illuminance

level, at one or more spaces (or grid points in the spaces) of the virtual representation based on the simulated distribution of external light from the virtual sky dome and the three-phase model of light flux transfer. In some instances, these grid points in the spaces may include a point on the floor of the space.

5 [0211] In one aspect, the “T” matrix may be multiplied by a vector with values between 0 and 1 representing the adjustments to transmissivities of one or more tintable windows in the building. During the process at operation 2040, the vector can be used as an independent variable that is iteratively adjusted until the illuminance level at the grid point is at, or approximately at, the target illuminance level. For example, the “T” matrix
10 may be multiplied by a vector representing adjustments to transmissivities of tintable windows on sides or facades of the building. During the process, the transmissivity (optimized variable) of the one or more tintable windows is iteratively adjusted using the vector with values between 0 and 1 while the parameters of the other matrices (e.g., daylight “D” matrix, view “V” matrix, and/or “S” matrix) are held constant until the
15 illuminance level at the one or more internal virtual spaces (grid points) in the building reach, or approximately reach, the target illuminance level(s). As used herein, approximately reaching the illuminance level can refer to reaching an illuminance level of one of within about 1%, within about 2%, within about 3%, within about 4%, and within about 5%. At each iteration, the illuminance level at the one or more internal virtual
20 spaces is determined using the “V” “T” “D” and “S” matrices of the three phase model of light flux.

[0212] In one implementation, the optimization process includes a set of multi-objective optimization operations applied to the matrix equation $E = VTDS$. The multi-objective optimization operations minimize the distance function (squared difference) between the
25 desired illuminance level(s) and the calculated illuminance levels at the grid points at the one or more spaces of the virtual building model. In one aspect, the control logic may determine the optimization function is at a minimum if the calculated distance function falls below some threshold. In addition or alternatively, the control logic may determine the optimization function is at a minimum if the gradient of the distance function (with
30 respect to window transmissivity) falling below some threshold.

[0213] In one aspect, the optimization process may use an optimization function to minimize the difference such as one of the optimization functions in **Eqn. 1** and **Eqn. 2** above. In an example where the one or more tintable windows are considered to tint instantaneously, the optimization function that minimizes the difference between the i^{th}

desired illuminance level, p_i , and the calculated illuminance level, $f_i(T)$, which is a function of transmissivity, T , of the one or more tintable windows, is either **Eqn. 1** or the simplified version provided by **Eqn. 2**. As an example where the one or more tintable windows are considered to tint over a period of time based on their tint transition rates and associated voltage ramps, the optimization process may consider illuminance levels of all zones of a building constrained by tint transition rate and associated voltage ramp and the current transmissivity of the one or more tintable windows, and the time until the next tinting opportunity (e.g., next time interval of an optimization process). In some cases, the optimization process takes less than 1 minute, less than 2 minutes, less than 3 minutes, etc. In one aspect, once the optimization process is complete, the interactive display of the virtual building model is updated to display the desired illuminance level of the space and/or the tinted version of the one or more tintable windows associated with the transmissivity determined by the optimization process.

[0214] **FIG. 21** includes a flowchart depicting an example of operations of an optimization process, according to implementations. The operations illustrated in **FIG. 21** may be, e.g., sub-operations of operation **2040** of the method depicted in flowchart **2000** shown in **FIG. 20**, according to an implementation.

[0215] At operation **2042**, the control logic calculates an illuminance level (e.g., $f_i(T)$) at a grid point (or grid points) in each three dimensional space of the one or more internal spaces of the virtual representation of the building. The matrix equation $E = VTDS$ can be utilized to obtain the illuminance matrix “E” representing the illuminance or lux level at each grid point given the “S” matrix of luminance values corresponding to sky conditions at the geographic location of the building. In one aspect, the coefficients of the clear sky “S” matrix may be based on data output from a virtual sky dome model simulation (annual or single point in time) of the light distribution in the sky over the building. In certain aspects, the coefficients of the “S” matrix correspond to luminance levels at clear sky conditions at multiple points in time (e.g., over a year) at a particular geographical location such as the geographical location of a facility. In certain aspects, an “S” vector represents a vector of luminance levels corresponding to sky conditions at a single point in time at a particular geographical location. The “S” matrix may be calculated by adding multiple “S” vectors at different points in time. The “V” view matrix specifies (by angle) the light flux transfer between light traveling from the one or more tintable windows to the grid point in the space. The “D” daylight matrix specifies the flux transfer from the sky to the aperture(s) of the one or more tintable windows and can be calculated based on

the dimensions and orientations of the tintable windows. The “T” matrix specifies the current transmissivities of the one or more tintable windows. During the optimization process, the illuminance level at the grid point of each of the one or more virtual spaces is determined based on the current levels of transmissivity of the tintable windows.

5 [0216] In one implementation, the sub-operations may include a set of multi-objective optimization operations applied to the matrix equation $E = VTDS$. The multi-objective optimization operations minimize the distance function (squared difference) between the desired illuminance level(s) and the calculated illuminance levels at the grid points at the one or more spaces of the virtual building model. The optimization process may use an
10 optimization function to minimize the difference such as one of optimization functions in Eqn. 1 and Eqn. 2.

[0217] At operation **2043**, the control logic calculates the distance function (squared difference) between the desired illuminance level(s) and the calculated illuminance levels at the grid points at the one or more spaces of the virtual building model.

15 [0218] At operation **2044**, the control logic determines if the optimization function is at a minimum. In one aspect, the control logic may determine the optimization function is at a minimum if the calculated distance function falls below some threshold. In addition or alternatively, the control logic may determine the optimization function is at a minimum if the gradient of the distance function (with respect to window transmissivity) falling
20 below some threshold. For example, the control logic may iteratively adjust the transmissivity level(s) of one or more (virtual) tintable windows in the virtual building model until no further change to the transmissivity level(s) produces negative change in the distance function (closer to the desired minima) below a certain value (e.g., -.001).

[0219] If the optimization is determined to not be at a minimum at operation **2044**, the
25 control logic adjusts the current transmissivity level or levels of the one or more virtual tintable windows (operation **2046**). In one case, if the difference is negative, the transmissivity is increased and if the difference is positive the transmissivity is decreased. In one aspect, the transmissivity level or levels may be adjusted by one of approximately 1%, approximately 2%, approximately 3%, approximately 4%, and approximately 5%.

30 [0220] In one implementation, the control logic adjusts the current transmissivity level or levels of one or more zones of virtual tintable windows at operation **2046**. For example, the transmissivity of the one or more zones tintable windows associated with the one or more spaces may be adjusted. For example, the transmissivity of the south-facing tintable windows and the east-facing tintable windows grouped together in the zone

named “Open Office 1” in **FIG. 17** may be adjusted to meet a desired illuminance level in the Open Office 1 space.

[0221] If the optimization is determined to be at a minimum at operation **2044**, the control logic proceeds to operation **2050**. At operation **2050**, the control logic determines a tint state for each tintable window of the one or more tintable windows that is associated with the transmissivity determined by the optimization process. For example, a tintable window may be configured to tint to a plurality of tint states, each tint state associated with a level of transmissivity. The control logic may determine which of the plurality of tint states is associated with a transmissivity determined by the optimization process by rounding up (alternatively rounding down) the transmissivity determined by the optimization process to the closest level transmissivity corresponding to a tint state of the plurality of tint states. For instance, in one aspect the one or more tintable windows may be configured to transition to 4 tint states (T1-T4) with tint 1 (T1) being a clear state and tint 4 (T4) being the darkest state. T1 corresponds to a transmissivity through a tintable window of about 50% (+/- 10%), T2 corresponds to a transmissivity through a tintable window in a range of about 25% to about 30% (+/- 10%), T3 corresponds to a transmissivity through a tintable window of about 7% (+/- 10%), and T4 (darkest tint state) corresponds to a transmissivity through a tintable window of about 1% (+/- 10%). In this example, the control logic may round up (alternatively round down) the transmissivity determined by the optimization process to the next transmissivity level associated with one of the 4 tint states. For example, if the transmissivity for a first tintable window is determined to be 22% by the optimization process, the control logic may round up to 25% transmissivity, which is associated with tint state T2, and determine that the 22% transmissivity determined by the optimization process is associated with the tint state of T2. While some of the examples presented herein describe tintable windows as having four tint states, this disclosure is not limited to such windows. For example, the disclosed examples also apply to tintable windows having 2, 3, 4, 5, 6, 7, 8, 9, 10, or even more tint levels.

[0222] In one aspect, the one or more tintable windows may be configured to hold any transmissivity with a range of transmissivity levels and is considered to have an “infinite” number of tint states. In this example, the control logic does not perform operation **2050**. At operation **2070**, the control logic may apply a voltage profile to hold each of the one or more tintable windows at the transmissivity level determined at operation **2040**.

[0223] Optionally, (denoted by dashed line) the control logic includes operation **2060**.

At operation **2060**, the control logic applies one or more overrides if an override is in place. In some cases, the control logic may determine whether one or more overrides are in place. If there is an override in place, the control logic sets the final tint state to the
5 override value at operation **2070**. In implementations that do not include optional operation **2060**, the control logic sets the final tint state to the tint level determined at operation **2050**.

[0224] In some cases, the override(s) may be from one or more occupants. For example, the override may be input by a current occupant (e.g., a tenant) of the space that would
10 like to override the control system and set the tint level. In other cases, the override(s) may be from a utility company, customer support personnel, building management personnel, etc. For example, an override may be a high demand (or peak load) override, which is associated with a requirement of a utility that energy consumption in the building be reduced. For example, on particularly hot days in large metropolitan areas, it
15 may be necessary to reduce energy consumption throughout the municipality in order to not overly tax the municipality's energy generation and delivery systems. In such cases, the building management may override the tint level from the control logic to ensure that all tintable windows have a high tint level. In this example, this override may override a user's manual override. There may be levels of priority in the override values. The
20 override may be input from, e.g., a remote controller, a virtual reality controller, a cellular phone, an electronic notepad, a laptop computer, or and/or by a similar mobile device).

[0225] In one aspect, the control logic may be configured to provide statistically-informed foreknowledge of site-specific override values based on past data (also referred to herein as "historical data"). For example, past override values used at a building may
25 be utilized. The site specific values may be stored in memory as time series data. The ability to use past data obtained at a specific location for which a forecast is desired to be made enables the forecast to potentially be more accurate. In one example, determining a forecasted override involves a statistical assessment of the past data such as by taking a mean, an average, or a weighted average of one or more past override values. In another
30 example, determining a forecasted override involves the use of machine learning classification algorithms suitable for clustering time series information into groups whose longitudinal sensor values exhibit similar shapes and patterns. According to the desired level of granularity (for a given hour of day, time of day, week, month, or season of the year), identified cluster centroids will show the trajectory of the mean values of all

records in that time frame whose similarity amongst themselves can be quantitatively distinguished from other groups of similar records. Such distinctions between groups allows for statistically founded inference with respect to “typical” condition desired to be monitored at a given location during a current timeframe.

- 5 **[0226]** At operation **2080**, the control logic transitions (or sends instructions to one or more controllers to transition) the one or more tintable windows to a final tint state if the tintable window(s) are currently at a different tint state. Alternatively, if the tintable windows are currently in the final tint state, the control logic holds (or sends instructions to one or more controllers to hold) the one or more tintable windows in the final tint state.
- 10 **[0227]** In certain implementations, the control logic transitions, or holds, tintable windows based on the zoning of the tintable windows. For example, a transmissivity and final tint state may be determined for a zone of tintable windows, and the control logic may transition or hold the zone of tintable windows according to that transmissivity determined for the zone.
- 15 **[0228]** In some cases, a customer spending time in a space of a building may desire real-time control of the level of natural light and/or level of artificial light in the space. This may be the case where a customer prefers sunlight over artificial lighting from, for example, incandescent, light-emitting diode (LED), or fluorescent lighting. Also, it has been found that certain tintable windows may impart too much of a blue color to the room
- 20 in their darker tint states. This blue color is offset by allowing a portion of unfiltered daylight to enter the room. customer motivations related to the building include lowering energy use through reduction of heating, air-conditioning, and lighting. For example, a customer might want to tint the windows to transmit a certain amount of sunlight through the window so that less energy is needed for artificial lighting and/or heating. A customer
- 25 may also want to harvest the sunlight to collect the solar energy and offset heating demand. In these cases, the control logic may adjust one or more levels of artificial lighting as well as the transmissivities of one or more tintable windows in the virtual building model that cause a desired level of natural light and/or level of artificial light in the space. Alternatively, the control logic may adjust one or more levels of artificial
- 30 lighting as well as the transmissivities of one or more tintable windows in the virtual building model that cause a desired level of color and/or intensity of light in the space. Some examples of control logic that adjust artificial lighting to augment color can be found in U.S. Patent Application 15/762,077, titled “METHODS OF CONTROLLING

MULTI-ZONE TINTABLE WINDOWS,” and filed on March 21, 2018, which is hereby incorporated by reference in its entirety.

[0229] Terms such as “a”, “an” and “the” are not intended to refer to only a singular entity but include the general class of which a specific example may be used for

5 illustration. The terminology herein is used to describe specific embodiments of the invention(s), but their usage does not delimit the invention(s).

[0230] When ranges are mentioned, the ranges are meant to be inclusive, unless otherwise specified. For example, a range between value 1 and value 2 is meant to be inclusive and include value 1 and value 2. The inclusive range will span any value from
10 about value 1 to about value 2. The term “adjacent” or “adjacent to,” as used herein, includes next to,” “adjoining,” “in contact with,” and “in proximity to.”

[0231] As used herein, including in the claims, the conjunction “and/or” in a phrase such as “including X, Y, and/or Z”, refers to inclusion of any combination or plurality of X, Y, and Z. For example, such phrase is meant to include X. For example, such phrase
15 is meant to include Y. For example, such phrase is meant to include Z. For example, such phrase is meant to include X and Y. For example, such phrase is meant to include X and Z. For example, such phrase is meant to include Y and Z. For example, such phrase is meant to include a plurality of Xs. For example, such phrase is meant to include a plurality of Ys. For example, such phrase is meant to include a plurality of Zs. For
20 example, such phrase is meant to include a plurality of Xs and a plurality of Ys. For example, such phrase is meant to include a plurality of Xs and a plurality of Zs. For example, such phrase is meant to include a plurality of Ys and a plurality of Zs. For example, such phrase is meant to include a plurality of Xs and Y. For example, such phrase is meant to include a plurality of Xs and Z. For example, such phrase is meant to
25 include a plurality of Ys and Z. For example, such phrase is meant to include X and a plurality of Ys. For example, such phrase is meant to include X and a plurality of Zs. For example, such phrase is meant to include Y and a plurality of Zs. The conjunction “and/or” is meant to have the same effect as the phrase “X, Y, Z, or any combination or plurality thereof.” The conjunction “and/or” is meant to have the same effect as the
30 phrase “one or more X, Y, Z, or any combination thereof.”

[0232] The term “operatively coupled” or “operatively connected” refers to a first element (e.g., mechanism) that is coupled (e.g., connected) to a second element, to allow the intended operation of the second and/or first element. The coupling may comprise physical or non-physical coupling (e.g., communicative coupling). The non-physical

coupling may comprise signal-induced coupling (e.g., wireless coupling). Coupled can include physical coupling (e.g., physically connected), or non-physical coupling (e.g., via wireless communication). Operatively coupled may comprise communicatively coupled.

[0233] An element (e.g., mechanism) that is “configured to” perform a function includes a structural feature that causes the element to perform this function. A structural feature may include an electrical feature, such as a circuitry or a circuit element. A structural feature may include an actuator. A structural feature may include a circuitry (e.g., comprising electrical or optical circuitry). Electrical circuitry may comprise one or more wires. The electrical circuitry may be configured to couple to an electrical power source (e.g., to the electrical grid). For example, the electrical circuitry may comprise a socket. Optical circuitry may comprise at least one optical element (e.g., beam splitter, mirror, lens and/or optical fiber). A structural feature may include a mechanical feature. A mechanical feature may comprise a latch, a spring, a closure, a hinge, a chassis, a support, a fastener, or a cantilever, and so forth. Performing the function may comprise utilizing a logical feature. A logical feature may include programming instructions. Programming instructions may be executable by at least one processor. Programming instructions may be stored or encoded on a medium accessible by one or more processors. Additionally, in the following description, the phrases “operable to,” “adapted to,” “configured to,” “designed to,” “programmed to,” or “capable of” may be used interchangeably where appropriate.

[0234] Modifications, additions, or omissions may be made to any of the above-described implementations without departing from the scope of the disclosure. Any of the implementations described above may include more, fewer, or other features without departing from the scope of the disclosure. Additionally, the steps of described features may be performed in any suitable order without departing from the scope of the disclosure. Also, one or more features from any implementation may be combined with one or more features of any other implementation without departing from the scope of the disclosure. The components of any implementation may be integrated or separated according to particular needs without departing from the scope of the disclosure.

[0235] It should be understood that certain aspects described above can be implemented in the form of logic using computer software in a modular or integrated manner. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will know and appreciate other ways and/or methods to implement the present invention using hardware and a combination of hardware and software.

[0236] Any of the software components or functions described in this application, may be implemented as software code using any suitable computer language and/or computational software such as, for example, Java, C, C#, C++ or Python, LabVIEW, Mathematica, or other suitable language/computational software, including low level code, including code written for field programmable gate arrays, for example in VHDL. The code may include software libraries for functions like data acquisition and control, motion control, image acquisition and display, etc. Some or all of the code may also run on a personal computer, single board computer, embedded controller, microcontroller, digital signal processor, field programmable gate array and/or any combination thereof or any similar computation device and/or logic device(s). The software code may be stored as a series of instructions, or commands on a CRM such as a random access memory (RAM), a read only memory (ROM), a magnetic medium such as a hard-drive or a floppy disk, or an optical medium such as a CD-ROM, or solid state storage such as a solid state hard drive or removable flash memory device or any suitable storage device. Any such CRM may reside on or within a single computational apparatus, and may be present on or within different computational apparatuses within a system or network. Although the foregoing disclosed implementations have been described in some detail to facilitate understanding, the described implementations are to be considered illustrative and not limiting. It will be apparent to one of ordinary skill in the art that certain changes and modifications can be practiced within the scope of the appended claims.

[0237] The terms “comprise,” “have” and “include” are open-ended linking verbs. Any forms or tenses of one or more of these verbs, such as “comprises,” “comprising,” “has,” “having,” “includes” and “including,” are also open-ended. For example, any method that “comprises,” “has” or “includes” one or more steps is not limited to possessing only those one or more steps and can also cover other unlisted steps. Similarly, any composition or device that “comprises,” “has” or “includes” one or more features is not limited to possessing only those one or more features and can cover other unlisted features.

[0238] All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (*e.g.*, “such as”) provided with respect to certain implementations herein is intended merely to better illuminate the present disclosure and does not pose a limitation on the scope of the present disclosure otherwise claimed. No language in the specification should be construed as indicating any non-claimed element essential to the practice of the present disclosure.

[0239] Groupings of alternative elements or implementations of the present disclosure disclosed herein are not to be construed as limitations. Each group member can be referred to and claimed individually or in any combination with other members of the group or other elements found herein. One or more members of a group can be included
5 in, or deleted from, a group for reasons of convenience or patentability. When any such inclusion or deletion occurs, the specification is herein deemed to contain the group as modified thus fulfilling the written description of all Markush groups used in the appended claims.

CLAIMS

WHAT IS CLAIMED IS:

- 5 1. A method of controlling one or more tintable windows in a building, the method comprising:
- determining one or more transmissivities of the one or more tintable windows, wherein the one or more transmissivities are determined to generate a target illuminance level, or approximately the target illuminance level, at one or more grid points in an
- 10 internal space of a virtual representation of the building, the one or more transmissivities determined based at least in part on attenuated clear sky data that is based at least in part on a predicted clear sky illuminance and readings from a plurality of sensors; and
- holding, or transitioning, the one or more tintable windows to an end tint state associated with the one or more determined transmissivities.
- 15 2. The method of claim 1, wherein if an override is in place, overriding the end tint state with an override tint value.
3. The method of claim 2, further comprising forecasting the override tint value based on a statistical assessment of past tint overrides.
4. The method of claim 1, wherein the plurality of sensors comprises a plurality
- 20 of photosensors.
5. The method of claim 1, wherein the plurality of sensors is in a multi-sensor device on a roof of the building.
6. The method of claim 1, wherein the plurality of sensors is in a multi-sensor device on a roof of the building.
- 25 7. The method of claim 1, wherein:
- the plurality of sensors includes a first set of sensors and a second set of sensors;
- the first set of sensors and the second set of sensors are centered about a central axis; and
- each sensor of the second set of sensors is oriented at an acute angle with respect
- 30 to the central axis.

8. The method of claim 1, wherein the attenuated clear sky data includes predicted clear sky illuminance attenuated by applying an attenuating scaling factor based on the readings from the plurality of sensors.

5 9. The method of claim 1, further comprising receiving readings from the plurality of sensors.

10. The method of claims 1 or 9, further comprising attenuating clear sky data based at least in part on a predicted clear sky illuminance and readings from the plurality of sensors.

10 11. The method of claim 1, wherein the predicted clear sky illuminance is predicted to occur at a future time.

12. The method of claim 1, wherein the predicted clear sky illuminance is based at least in part on historic weather data.

13. The method of claim 1, further comprising:
using a virtual sky dome based at least in part on the attenuated clear sky data to
15 simulate external sky radiation impinging the virtual representation of the building; and
using the external sky radiation to determine whether the one or more transmissivities generate the target illuminance level, or approximately the target illuminance level, at the one or more grid points in the internal space of the virtual representation of the building.

20 14. The method of claim 13, wherein:
the virtual sky dome includes a plurality of light patches; and
the attenuated clear sky data is based on a predicted clear sky illuminance attenuated based on readings from one or more sensors mapped to the plurality of light patches.

25 15. The method of claim 1, further comprising iteratively adjusting transmissivities of virtual tintable windows in the virtual representation of the building until a current illuminance level in the internal space is at, or approximately at, the target illuminance level.

16. The method of claim 15, further comprising at each iteration, determining the current illuminance level in the internal space based on the attenuated clear sky data and a current transmissivity or transmissivities of the virtual tintable windows.

17. The method of claim 16, further comprising determining the current
5 illuminance level in the internal space (i) using the attenuated clear sky data to determine external light impinging the virtual tintable windows and (ii) calculating light passing through the virtual tintable windows at the current transmissivity or transmissivities into the internal space.

18. The method of claim 1, further comprising adjusting transmissivities of
10 virtual tintable windows in the virtual representation of the building until a current illuminance level in the internal space is at, or approximately at, the target illuminance level.

19. The method of claim 18, further comprising determining, at a plurality of
15 times, the current illuminance level in the internal space based on the attenuated clear sky data and a current transmissivity or transmissivities of the virtual tintable windows.

20. The method of claim 19, further comprising determining the current
illuminance level in the internal space (i) using the attenuated clear sky data to determine external light impinging the virtual tintable windows and (ii) calculating light passing through the virtual tintable windows at the current transmissivity or transmissivities into
20 the internal space.

21. The method of claim 1, further comprising rounding up or rounding down the one or more transmissivities to levels associated with a tint state of a plurality of tint states of the one or more tintable windows.

22. The method of claim 1, wherein the one or more tintable windows are
25 grouped into one or more zones of tintable windows.

23. The method of claim 22, wherein:

the one or more tintable windows are grouped into two or more zones of tintable windows,

a first zone of tintable windows is associated with a first section of a space,

a second zone of tintable windows is associated with a second section of the space, and the first zone of tintable windows faces a compass direction different than the second zone of tintable windows.

24. The method of claim 1, wherein the virtual representation of the building is a digital twin of the building.

25. The method of claim 1, further comprising receiving information associated with the target illuminance level for the internal space.

26. The method of claim 25, wherein the information is received using a digital representation of the building and/or an application on a mobile device.

27. A method of controlling one or more tintable windows in a building, the method comprising:

determining one or more transmissivities of one or more tintable windows in the building, wherein the one or more transmissivities are determined based on attenuated clear sky data to generate a target illuminance level, or approximately the target illuminance level, in an internal space of a virtual representation of the building; and

forecasting an override tint value based on a statistical assessment of past override values; and

holding, or transitioning, the one or more tintable windows to one or more end tint states associated with the one or more transmissivities determined or to the override tint value if an override is in place.

28. A method of controlling one or more internal conditions in a building, the method comprising:

receiving a target level for an internal condition of the building using a virtual representation of the building, wherein the target level comprises one or more of an illuminance level in an internal space of the building, a heat gain into the internal space of the building, or a color of light in the internal space of the building;

determining one or more transmissivities of one or more tintable windows in the building, wherein the one or more transmissivities are determined to generate the target level, or approximately the target level in the building; and

holding, or transitioning, the one or more tintable windows to an end tint state associated with the one or more transmissivities determined.

29. The method of claim 28, wherein the one or more transmissivities are determined based at least in part on attenuated clear sky data.

5 30. The method of claim 29, further comprising:

using a virtual sky dome based at least in part on the attenuated clear sky data to simulate external sky radiation impinging the virtual representation of the building; and

using the external sky radiation to determine whether the one or more transmissivities cause the target level, or approximately the target level, at the internal
10 space of the virtual representation of the building.

31. The method of claim 30, wherein:

the virtual sky dome includes a plurality of light patches; and

the attenuated clear sky data is based on a predicted clear sky illuminance attenuated based on readings from one or more sensors mapped to the plurality of light
15 patches.

32. An apparatus for controlling tint of one or more tintable windows in a building, the apparatus comprising at least one controller configured to operatively couple to the one or more tintable windows, the at least one controller further configured to perform, or direct performance of, any one of the methods of claims 1 to 31.

20 33. A non-transitory computer readable medium storing computer executable instructions for controlling tint of one or more zones of tintable windows in a building, when read by one or more processors, cause the one or more processors to execute operations of any one of the methods of claims 1 to 31

25 34. A system for controlling tint of one or more zones of tintable windows in a building, the system comprises a network configured to operatively couple to the one or more tintable windows and configured to perform any one of the methods of claims 1 to 31.

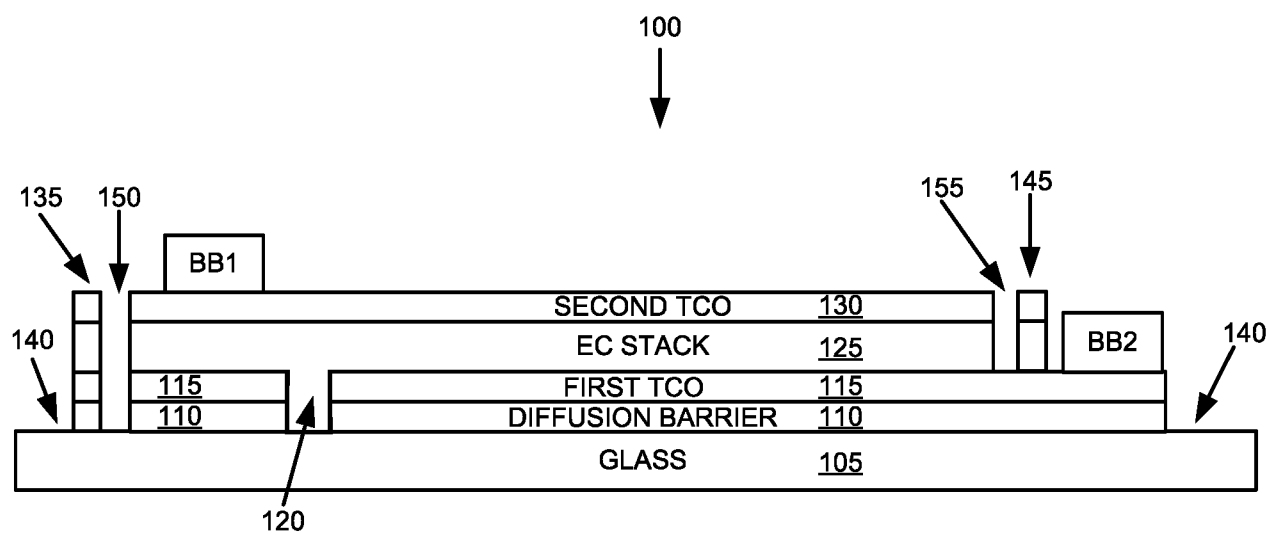


FIG. 1A

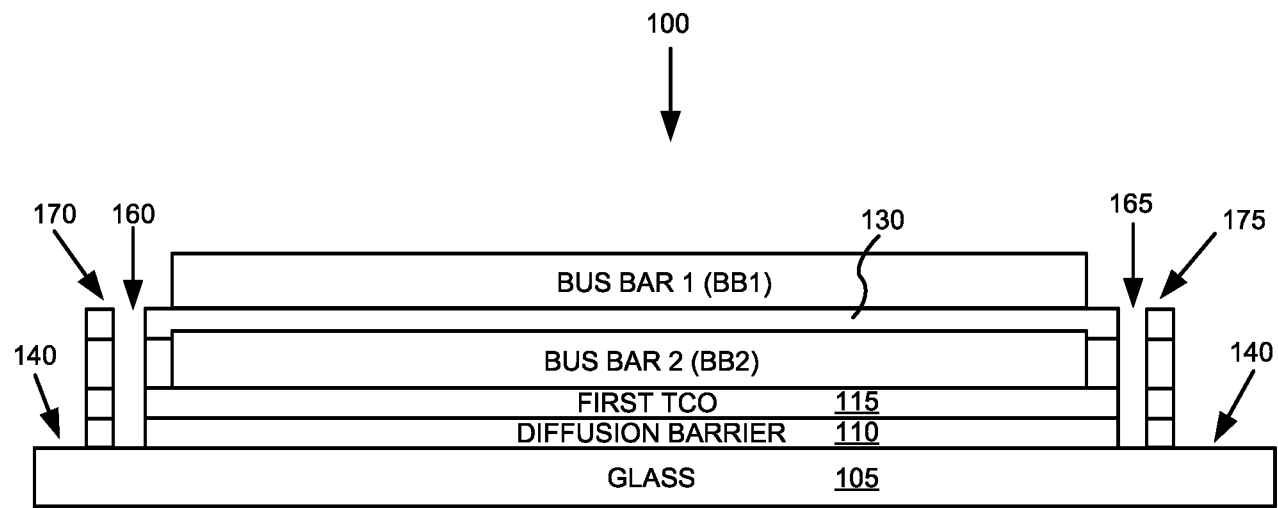
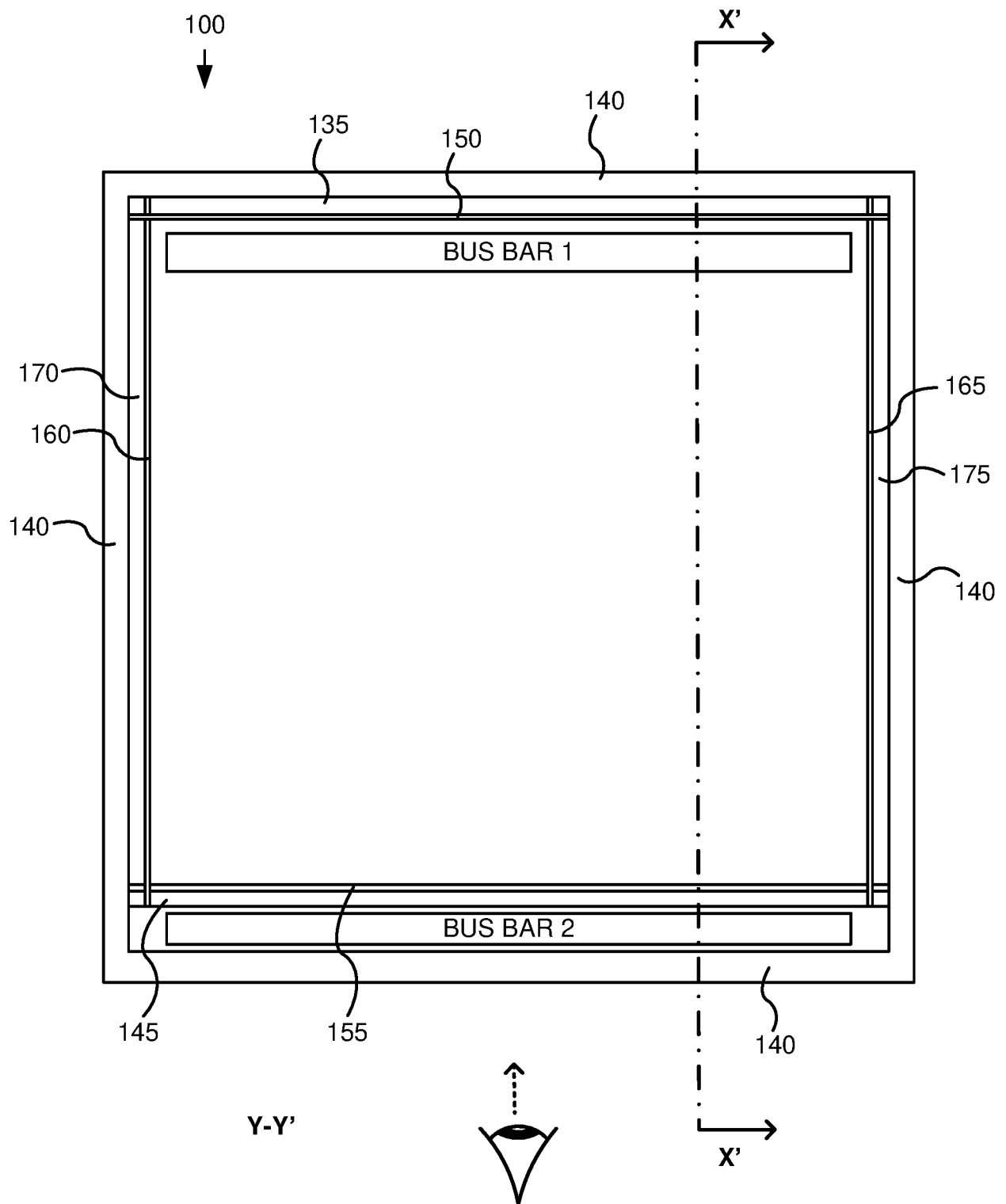


FIG. 1B

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**FIG. 1C**

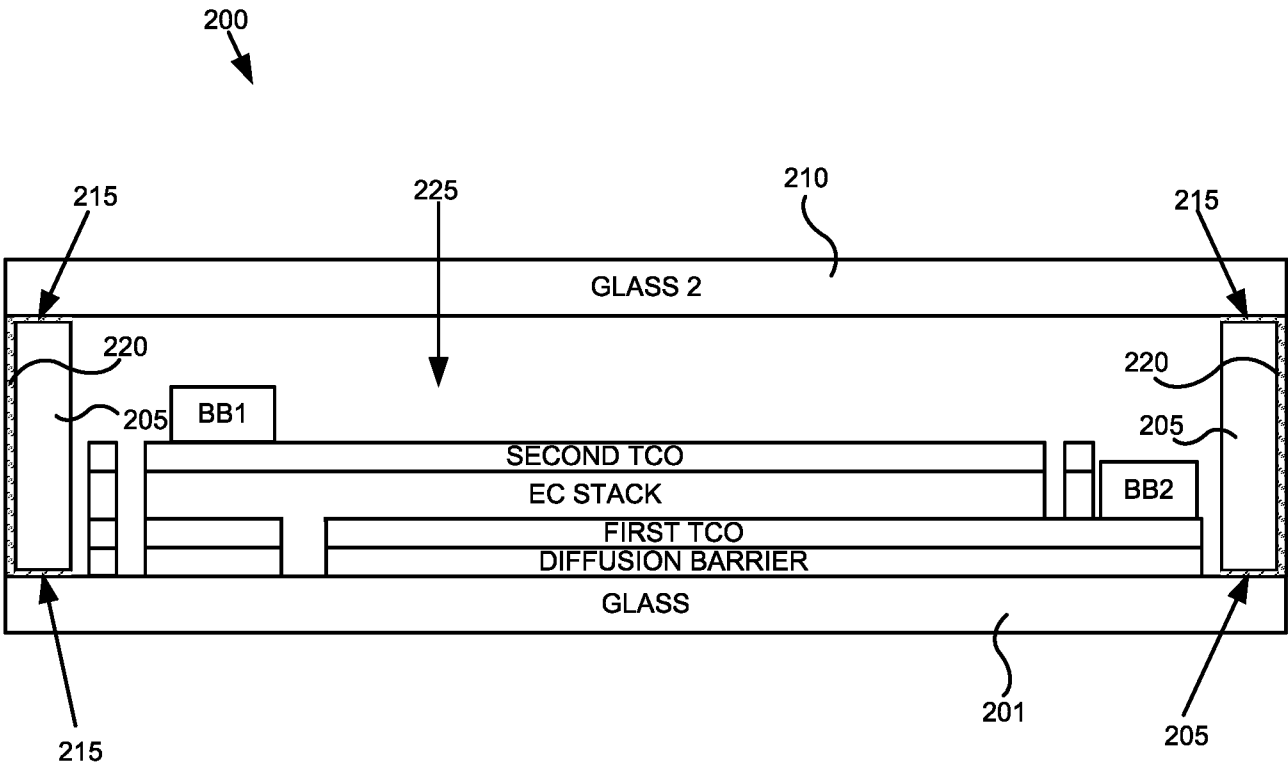


FIG. 2A

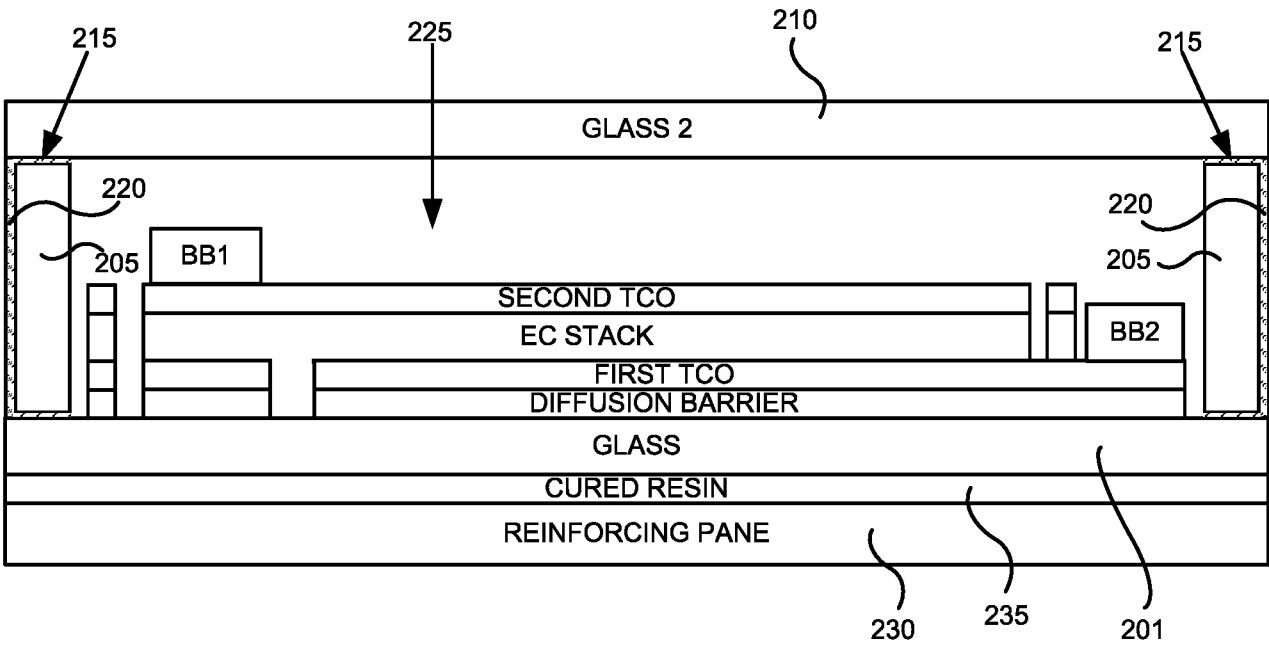


FIG. 2B

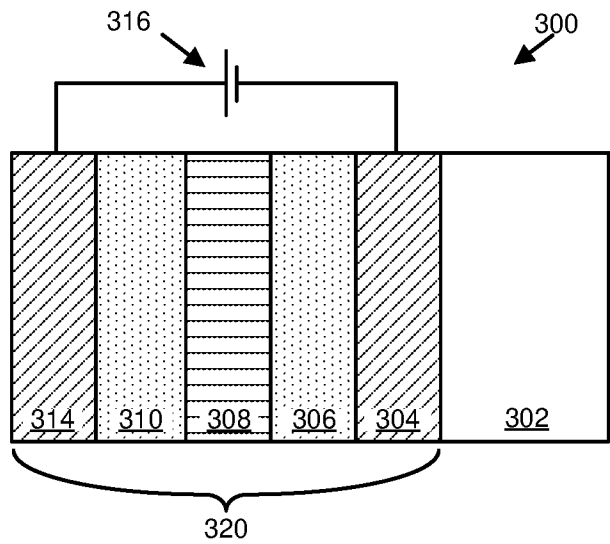


FIG. 3A

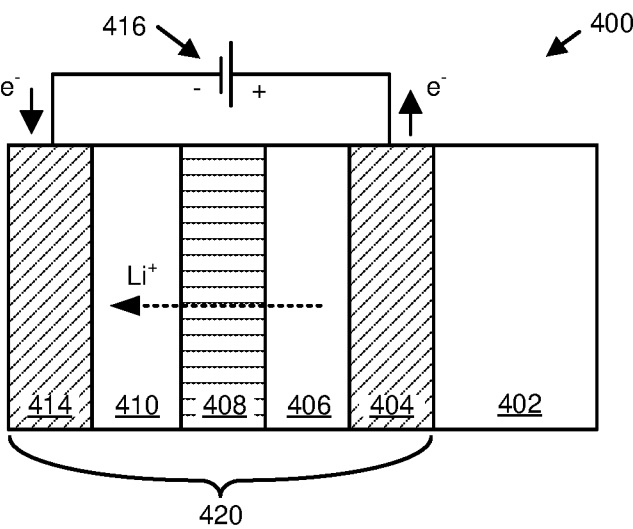


FIG. 3B

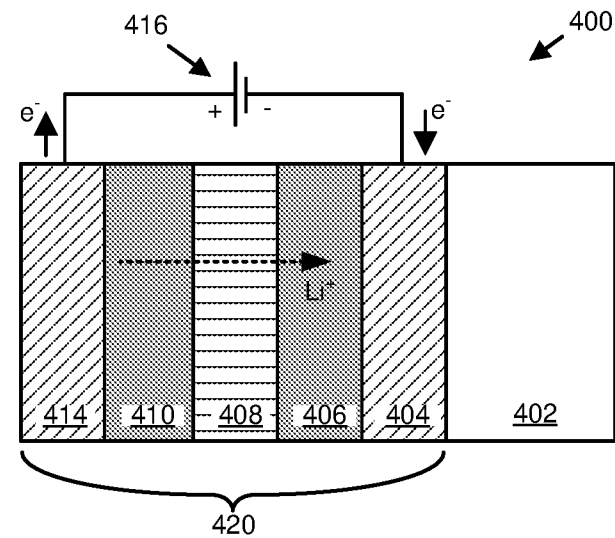
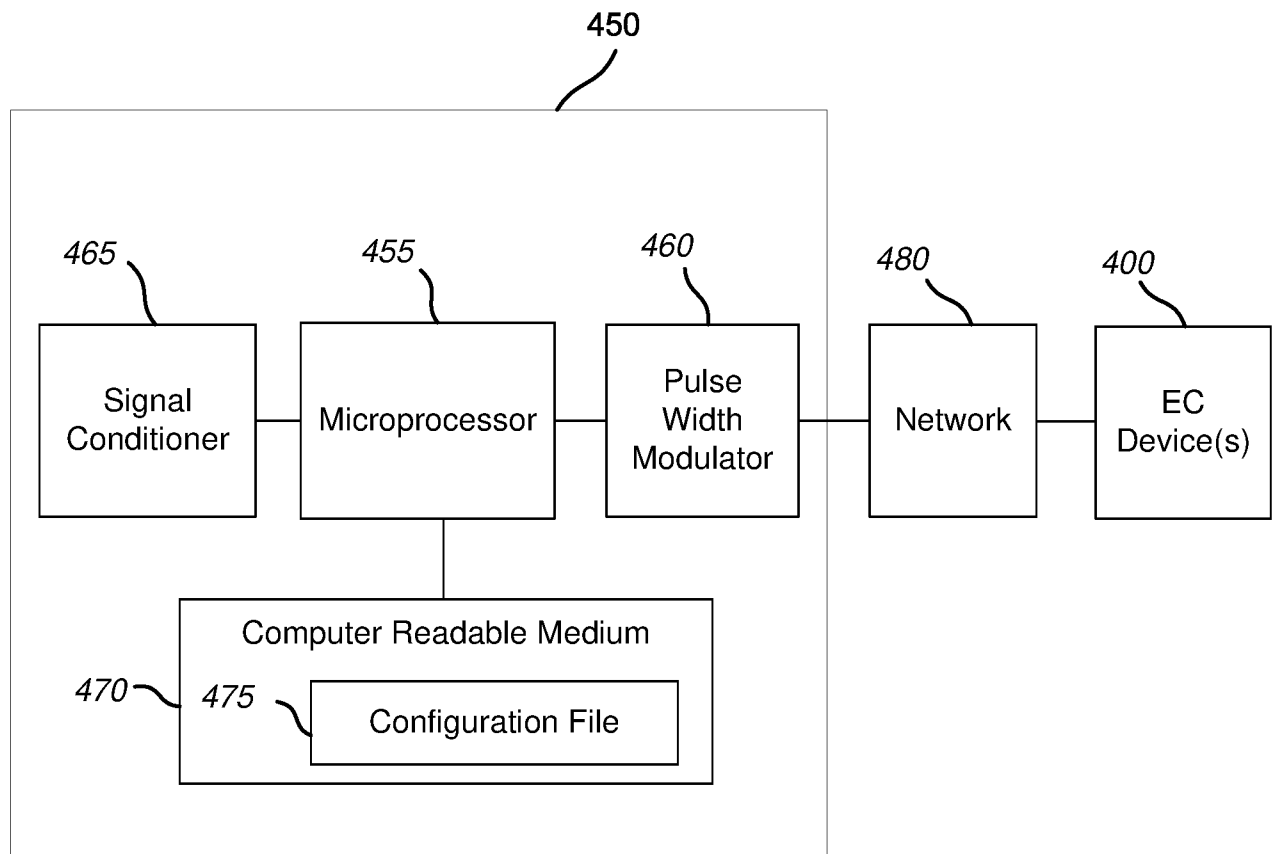


FIG. 3C

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**FIG. 4**

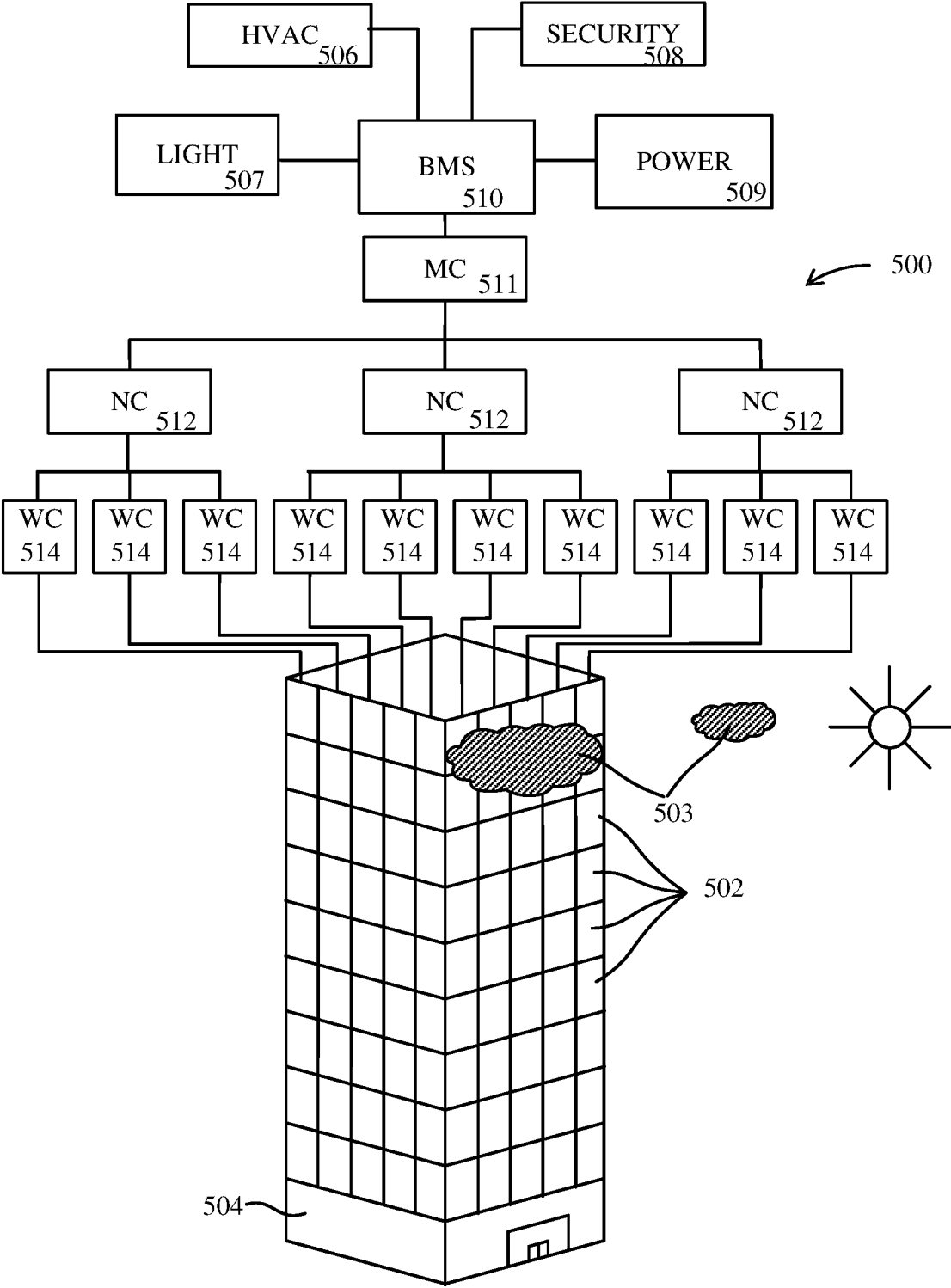
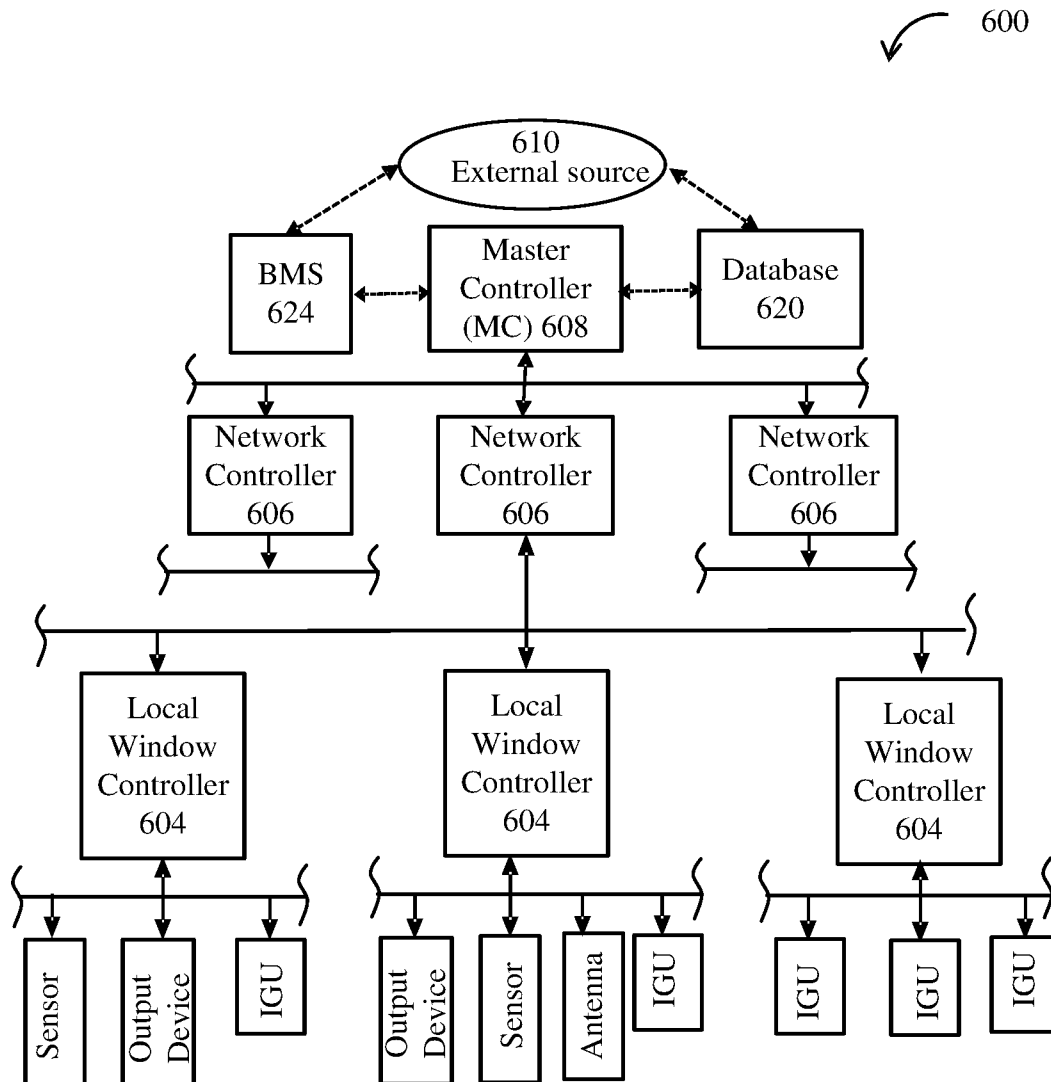
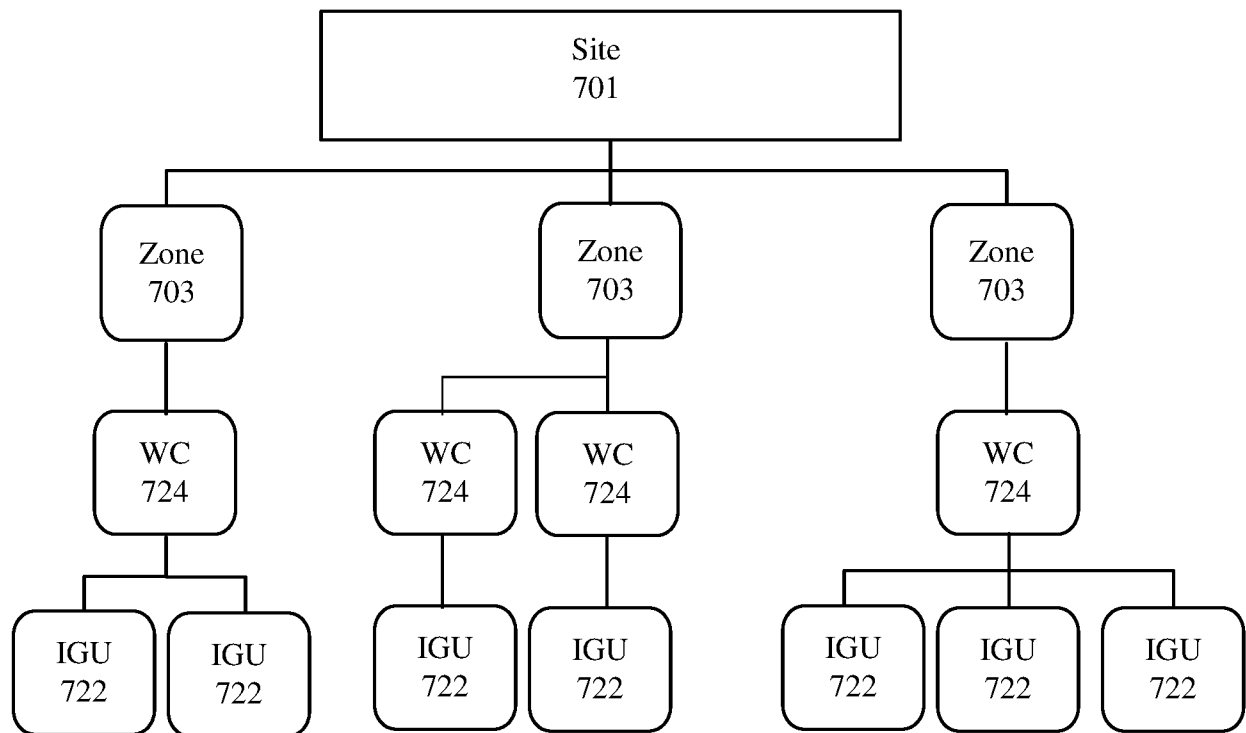


FIG. 5

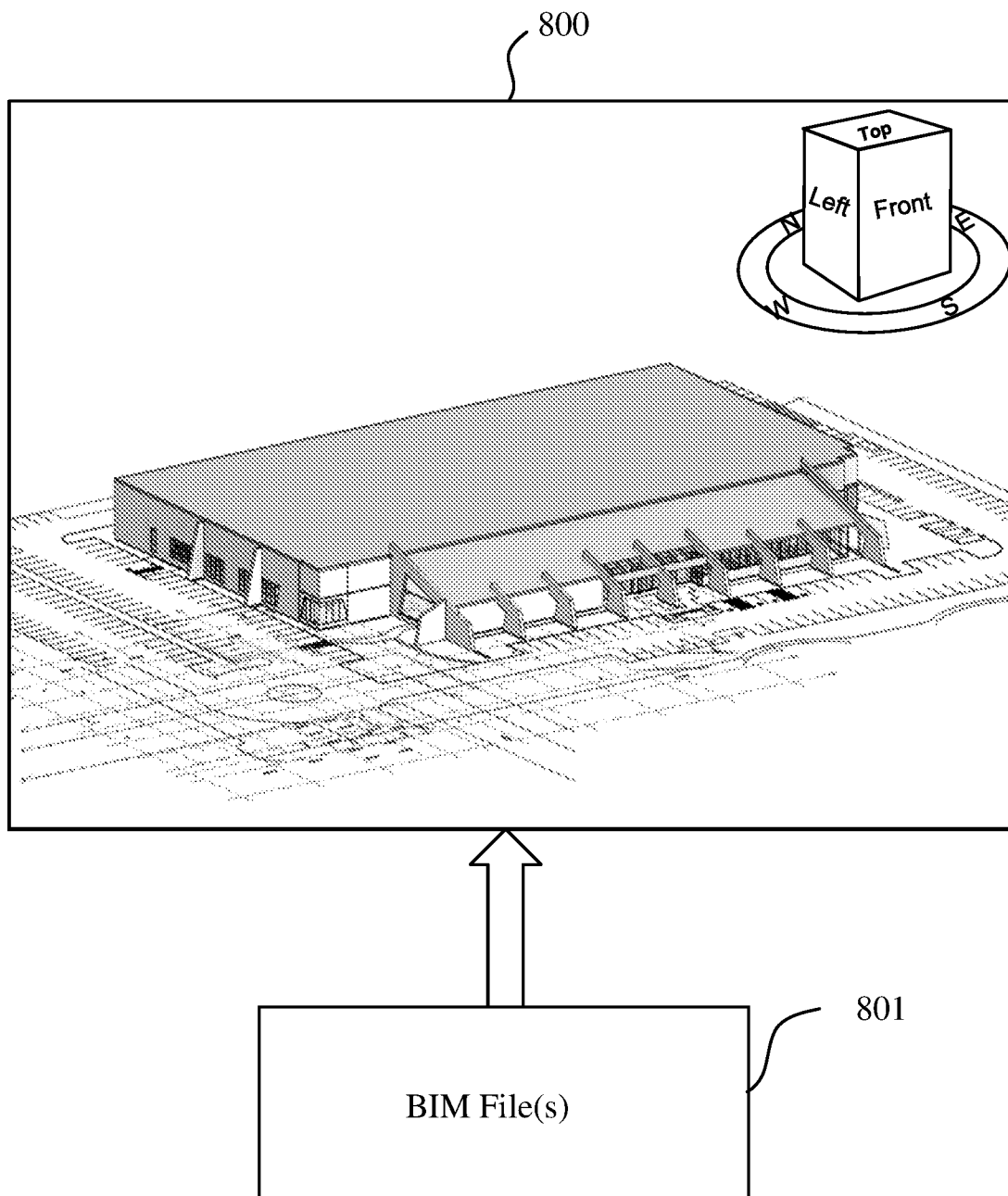
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**FIG. 6**

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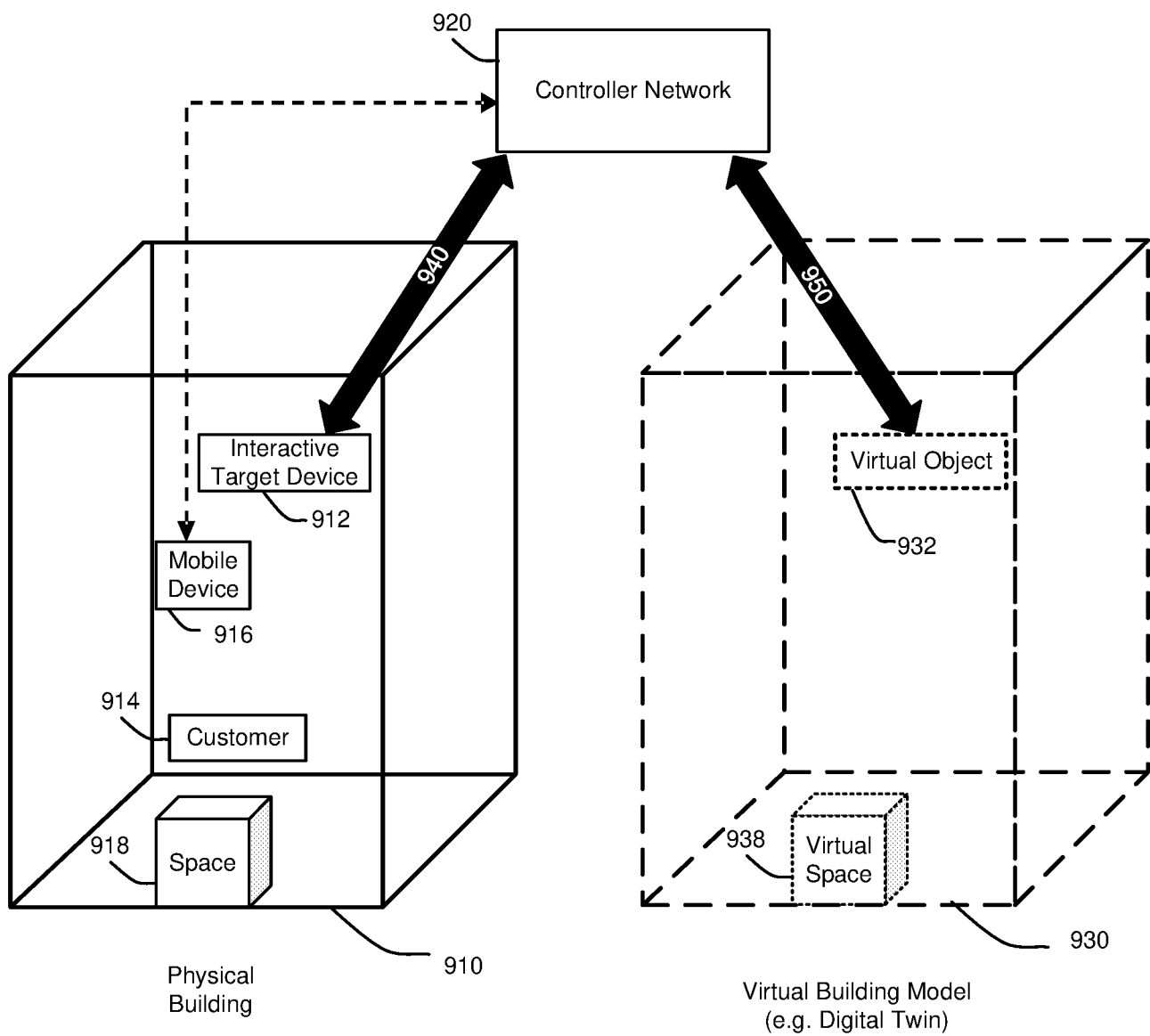
**FIG. 7**

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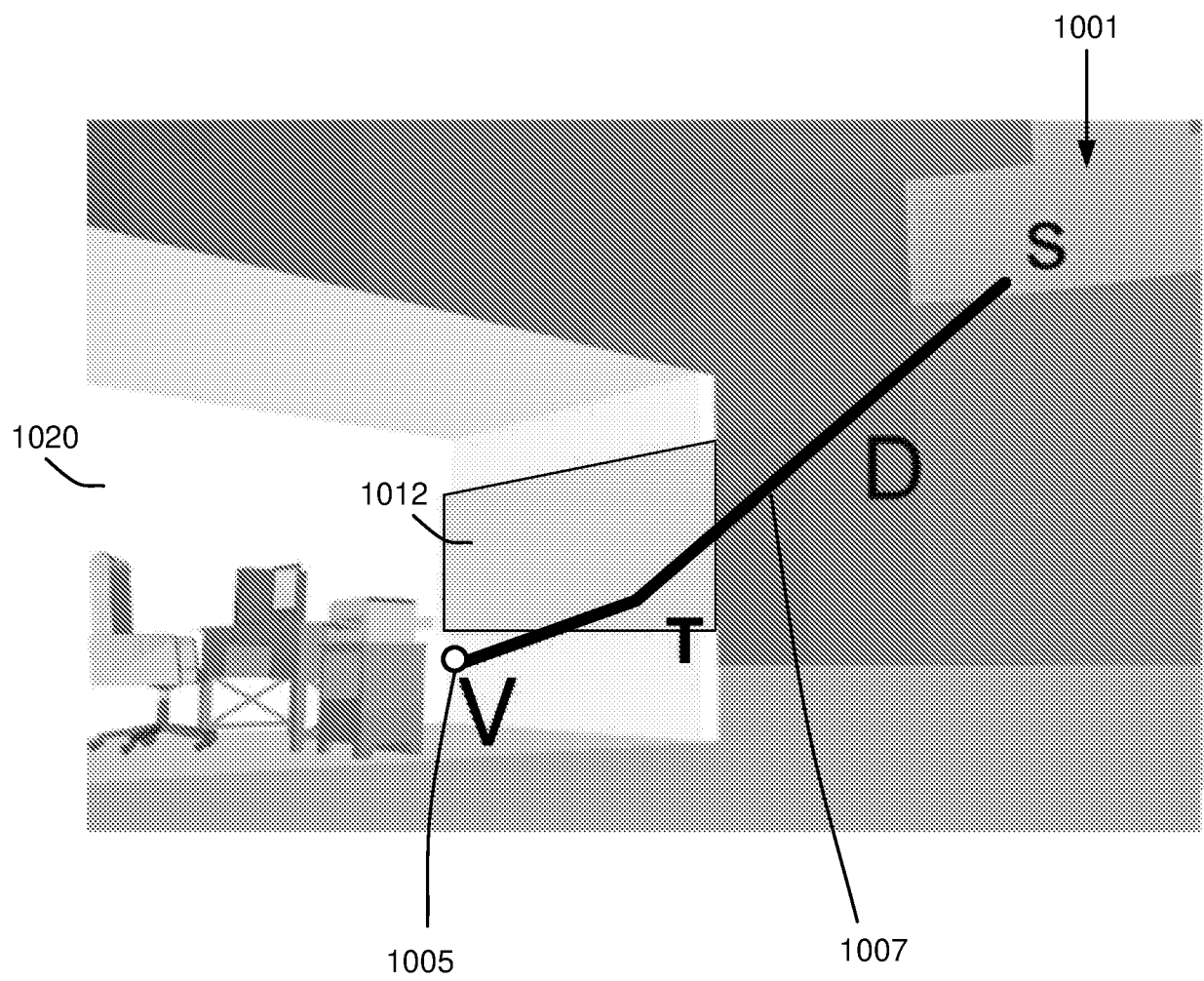
**FIG. 8**

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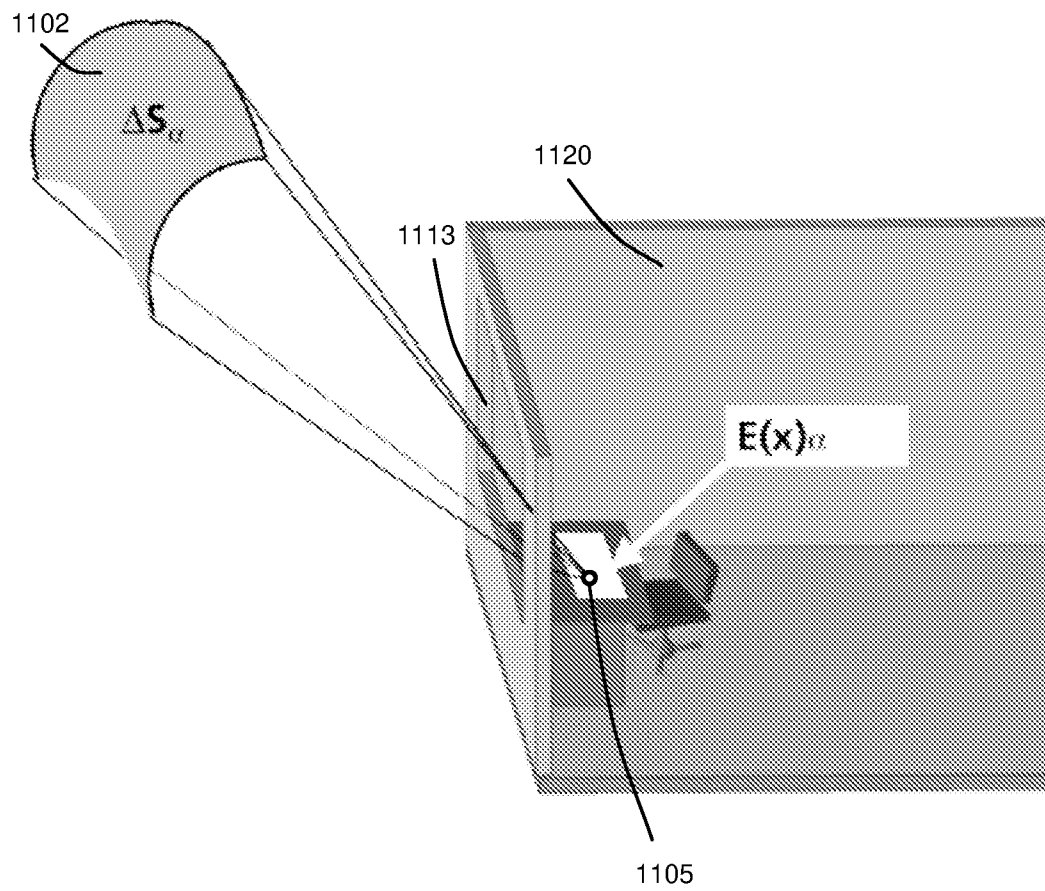
900

**FIG. 9**

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**FIG. 10**

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**FIG. 11**

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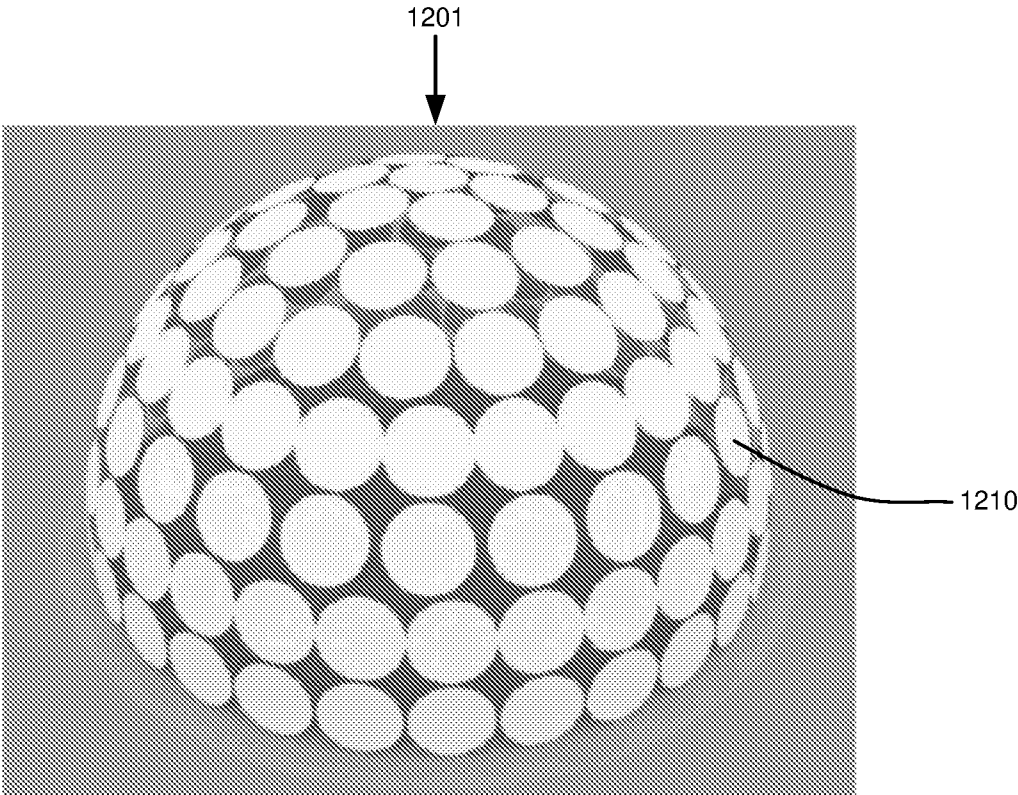


FIG. 12A

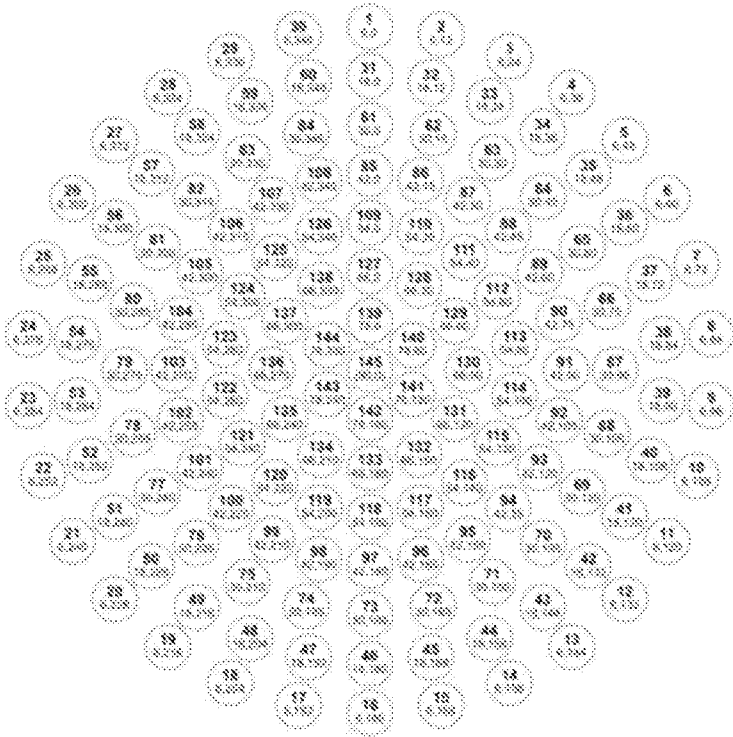


FIG. 12B

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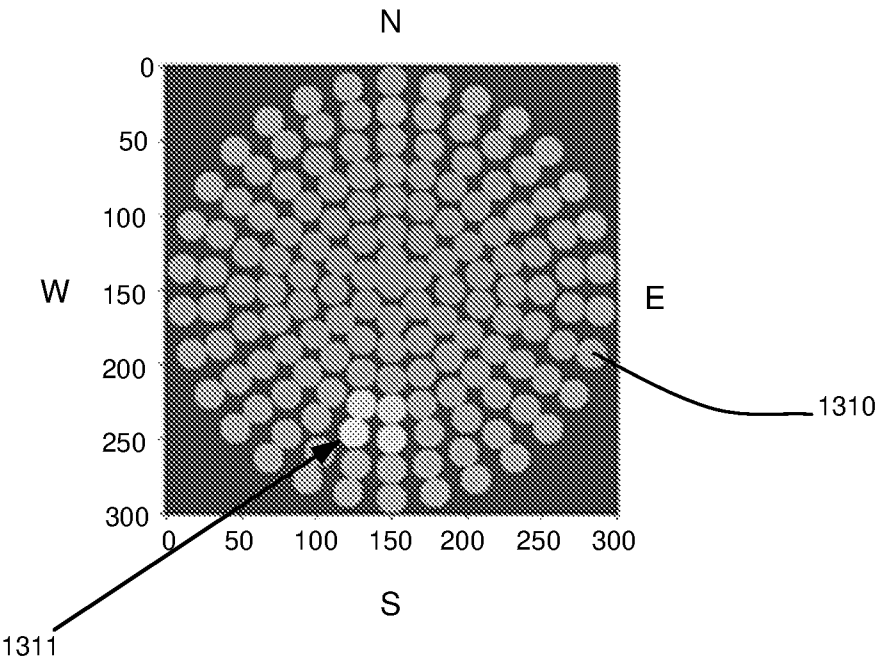


FIG. 13A

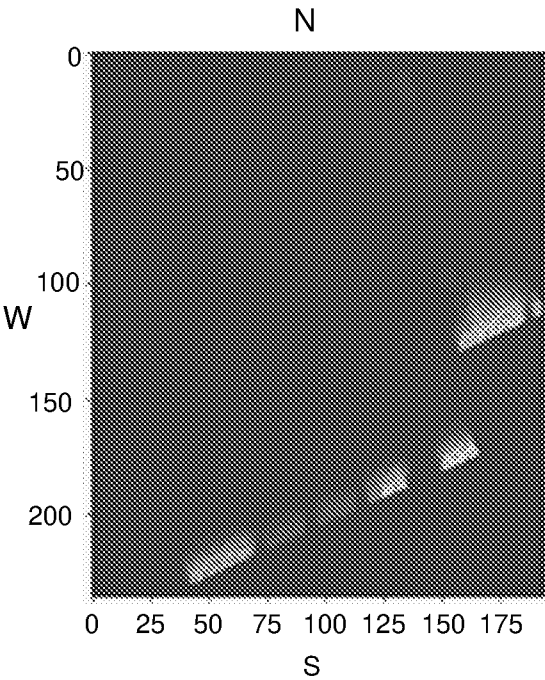


FIG. 13B

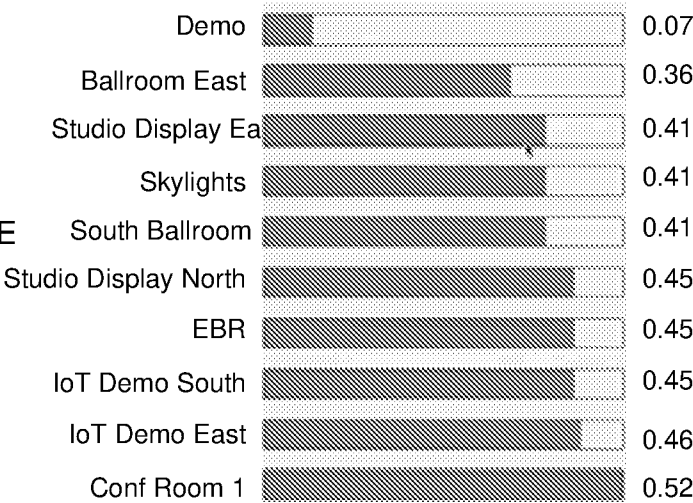


FIG. 13C

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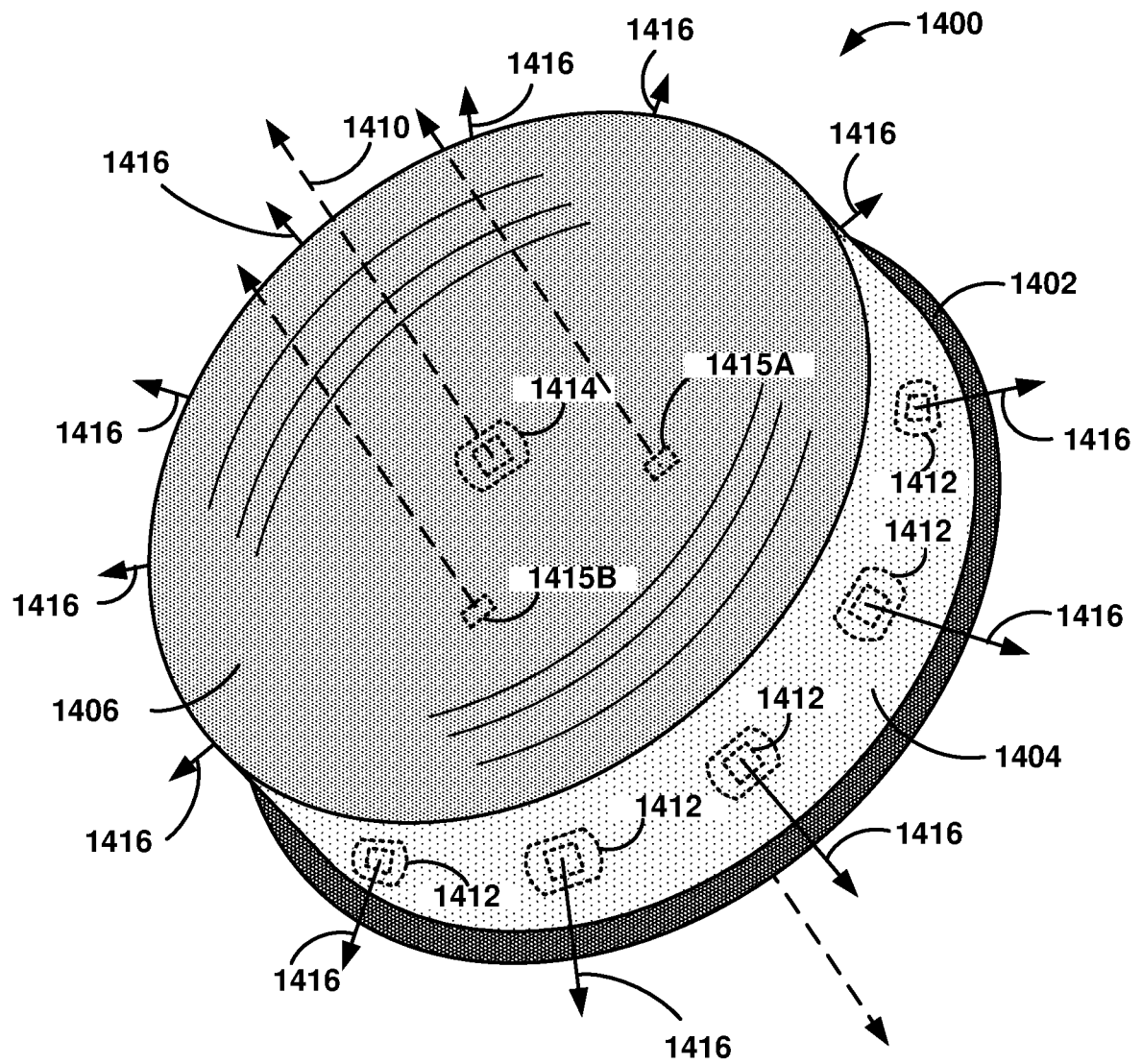


FIG. 14A

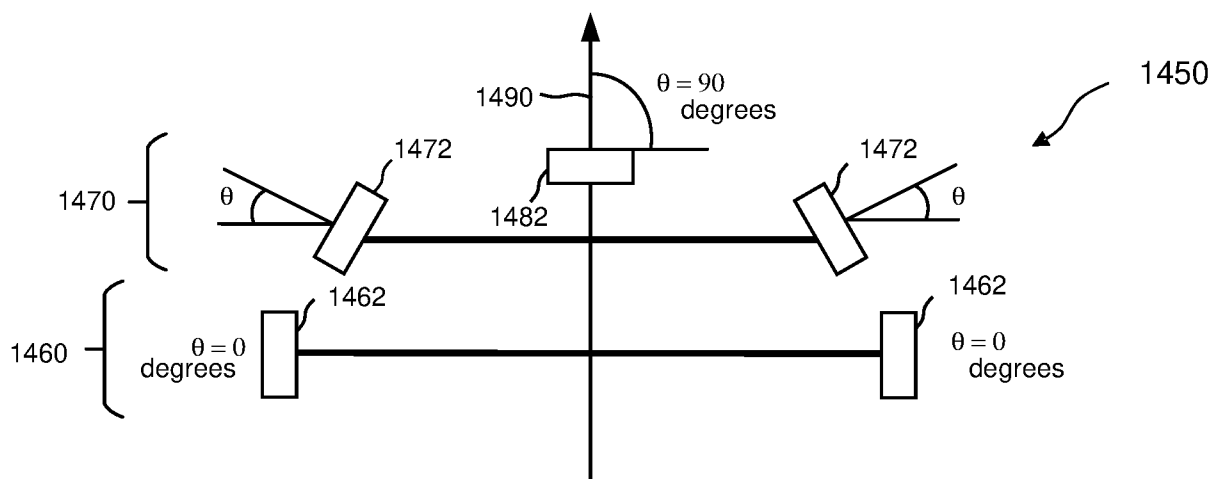


FIG. 14B

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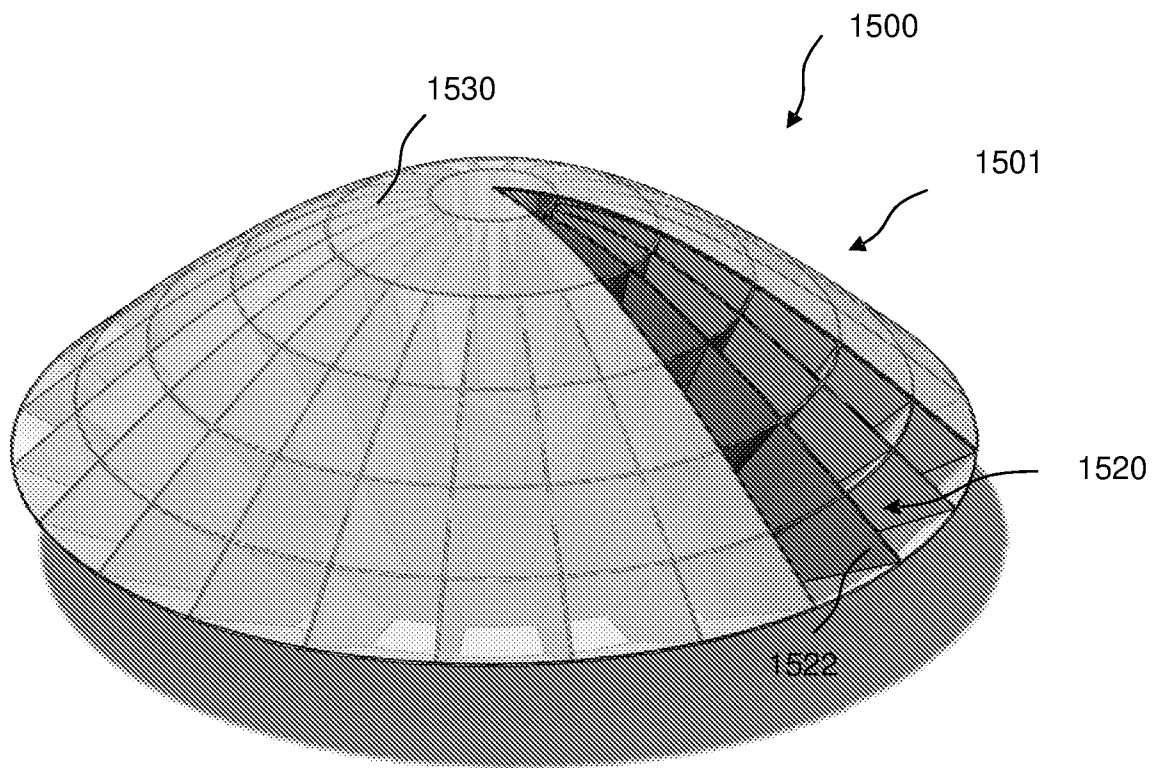
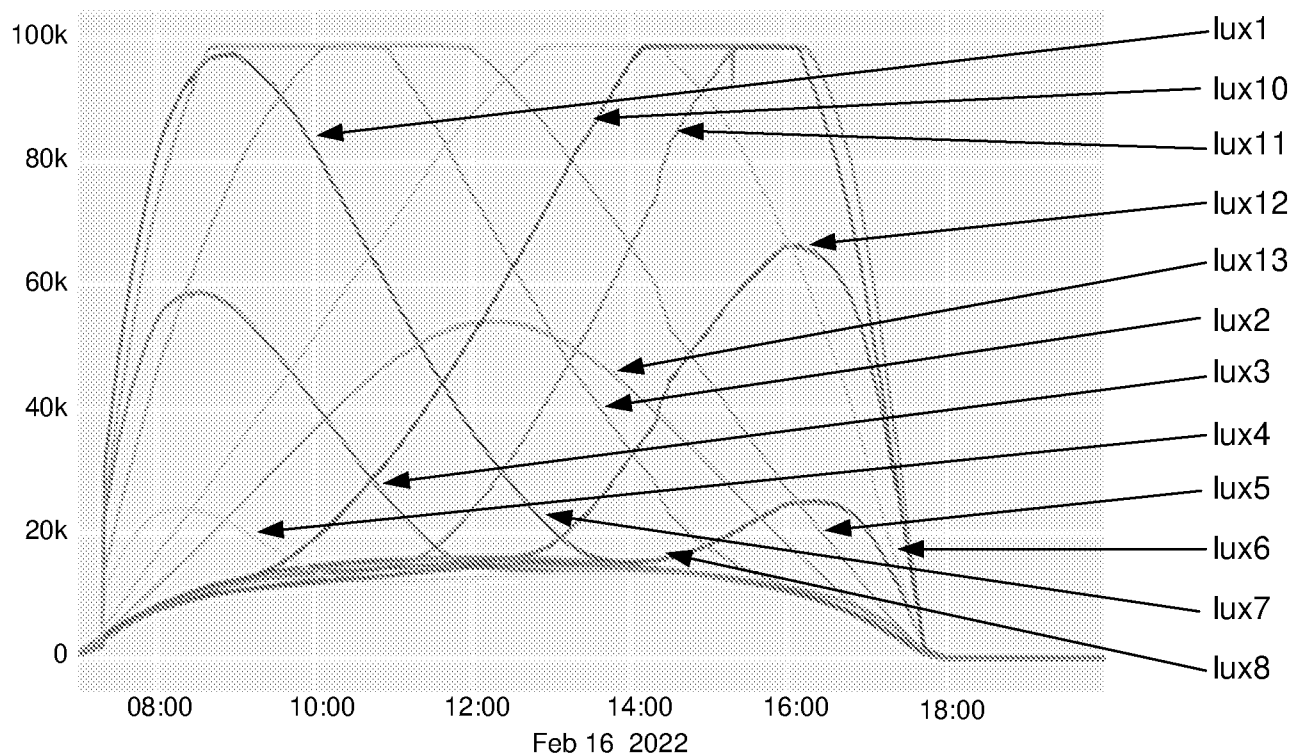
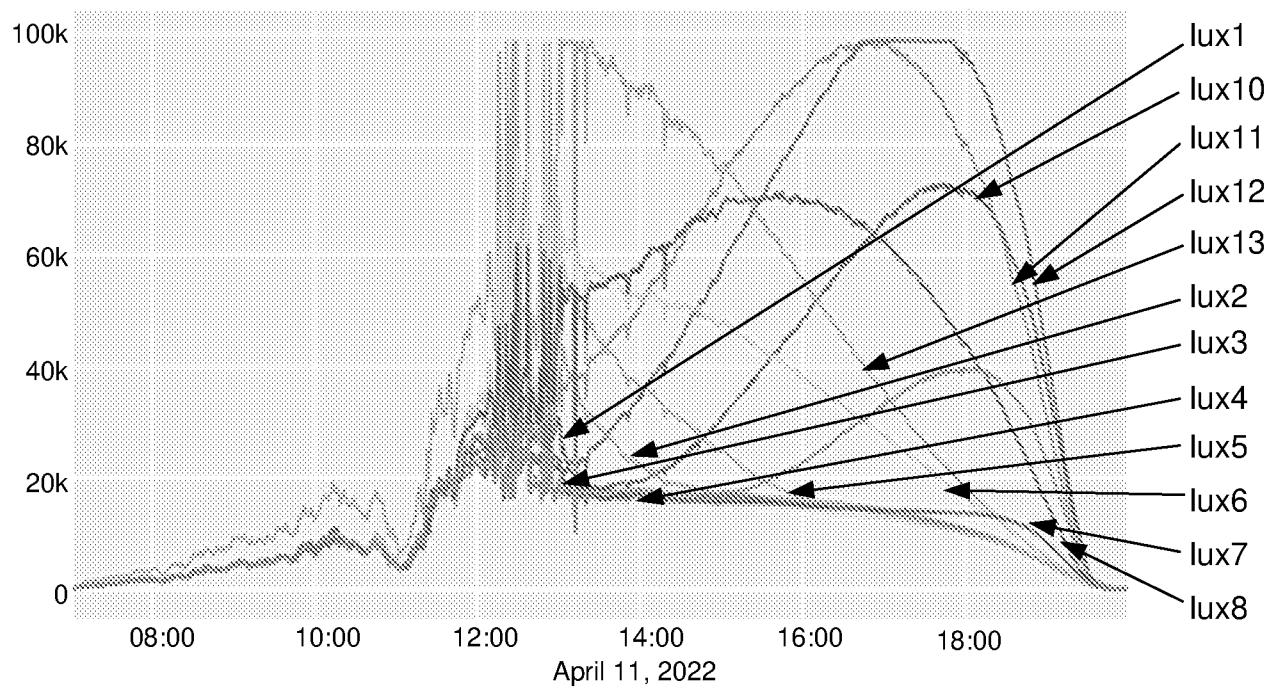
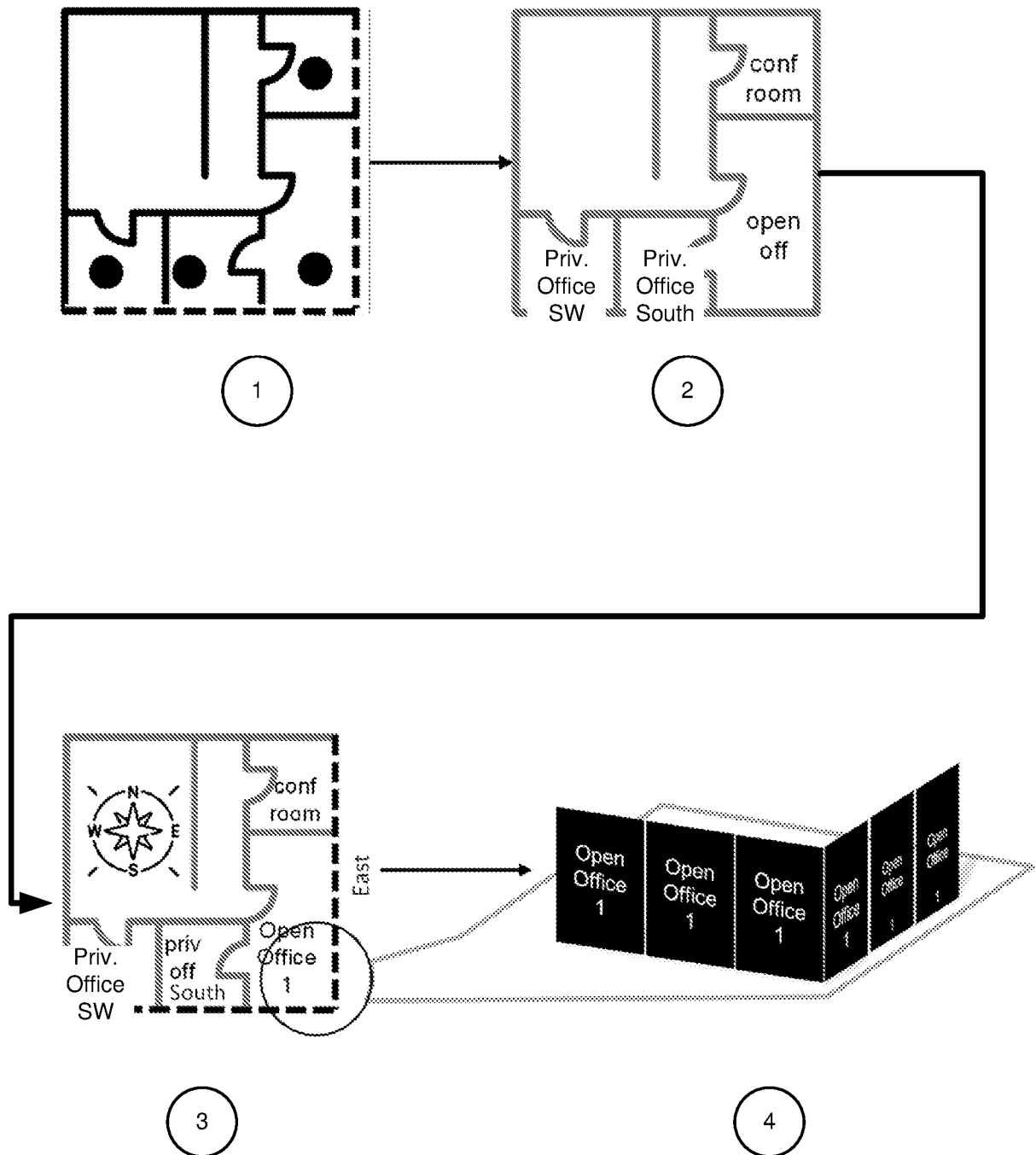


FIG. 15

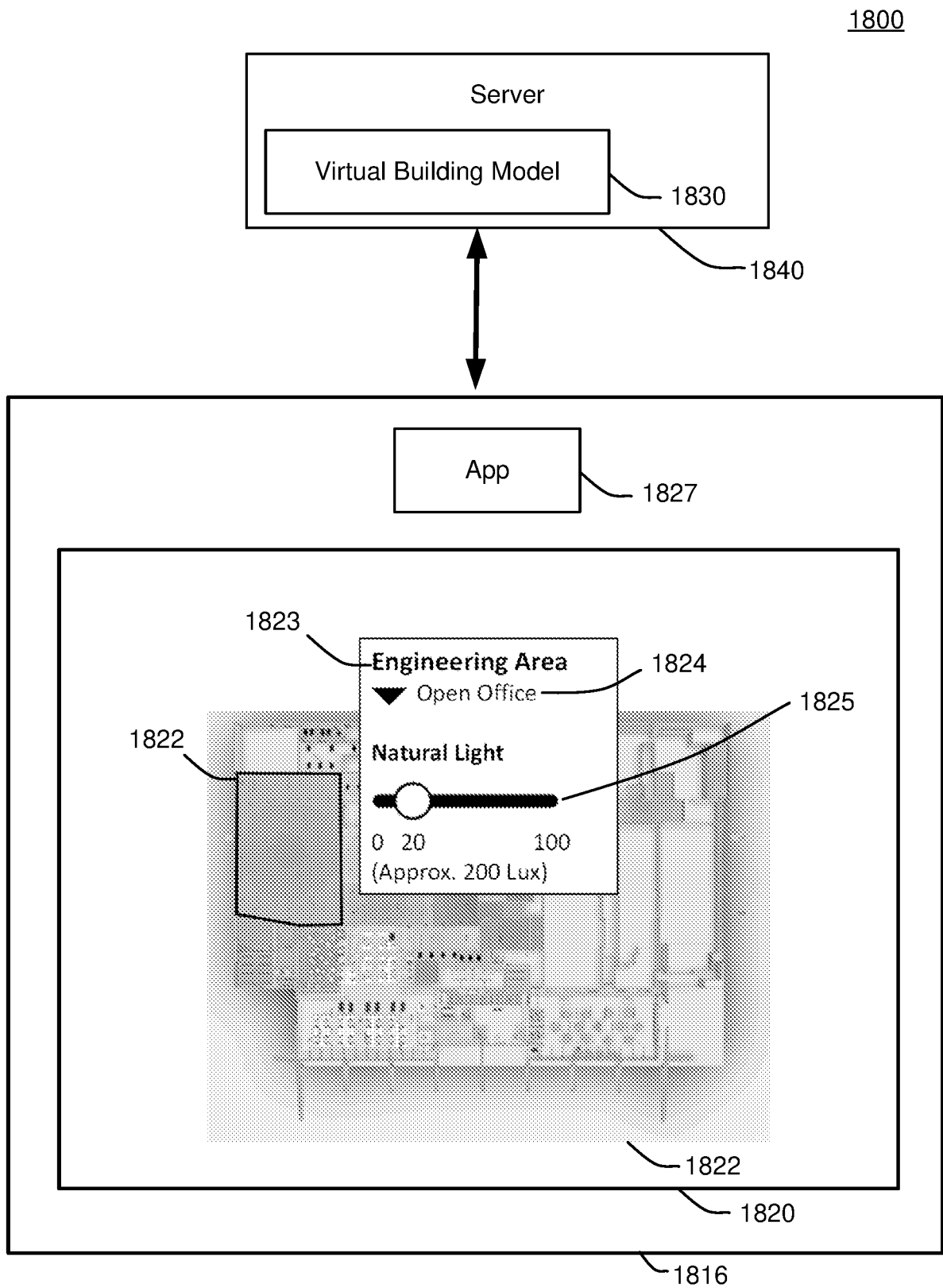
17/22

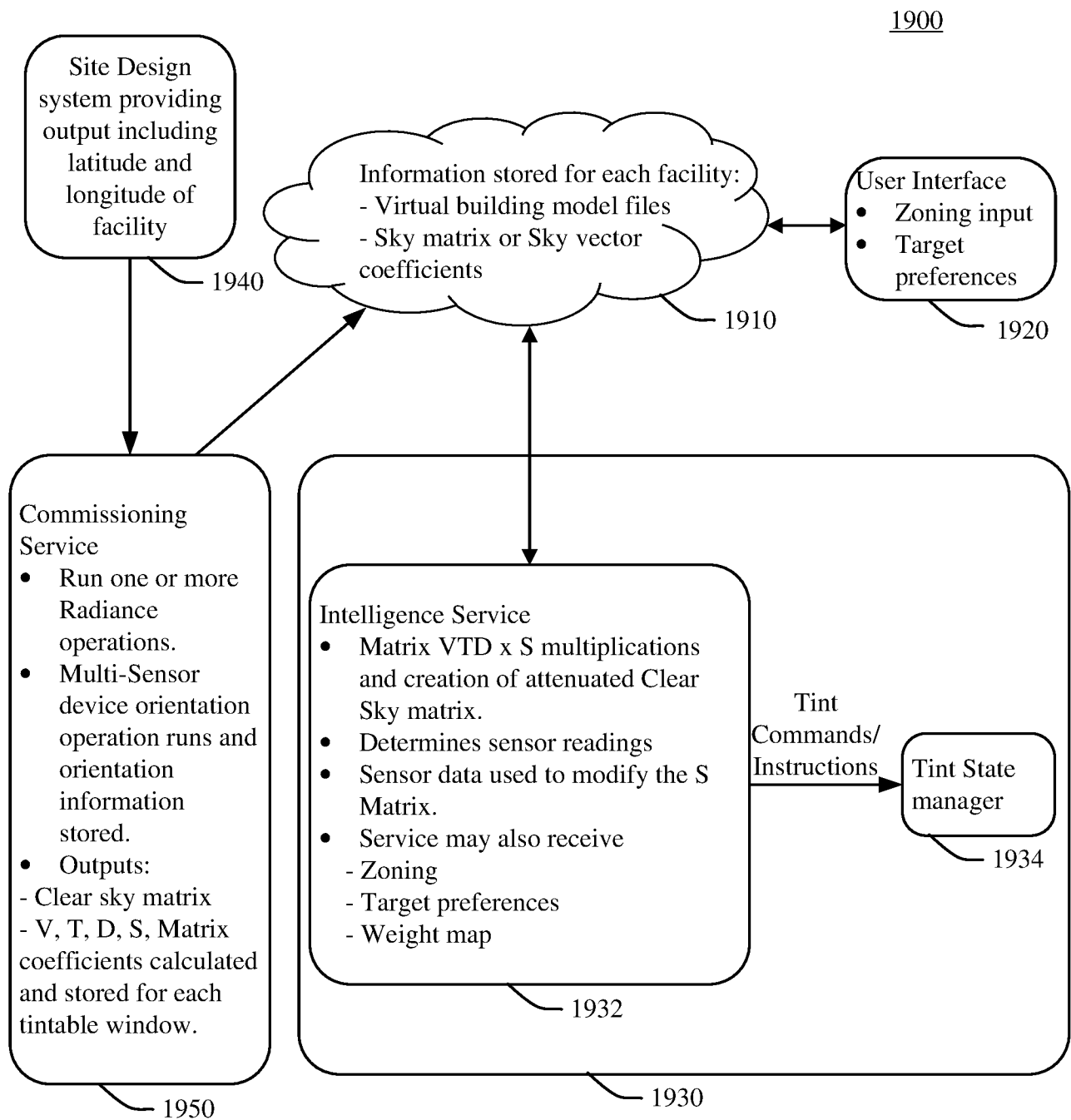
**FIG. 16A****FIG. 16B**

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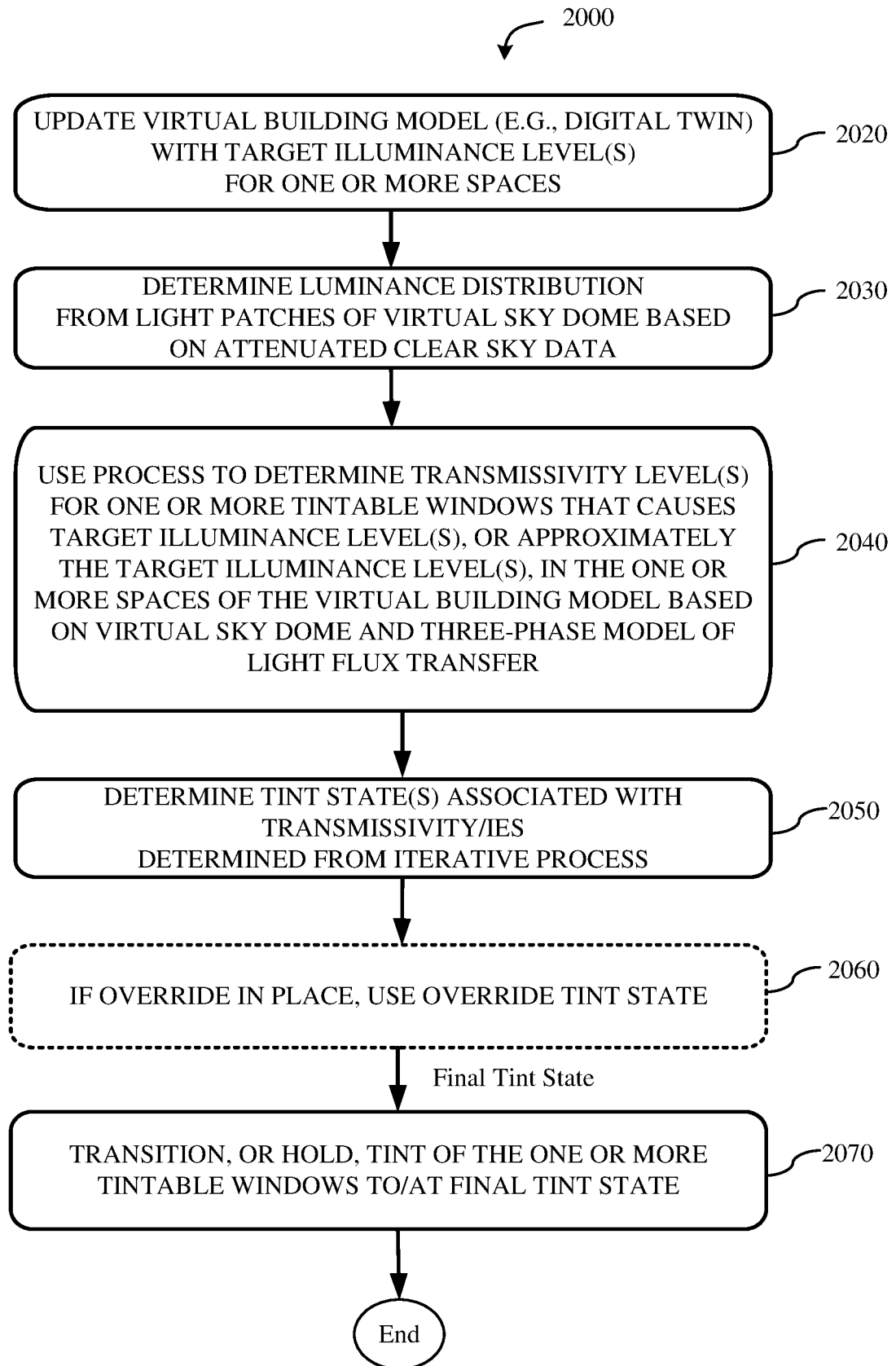
**FIG. 17**

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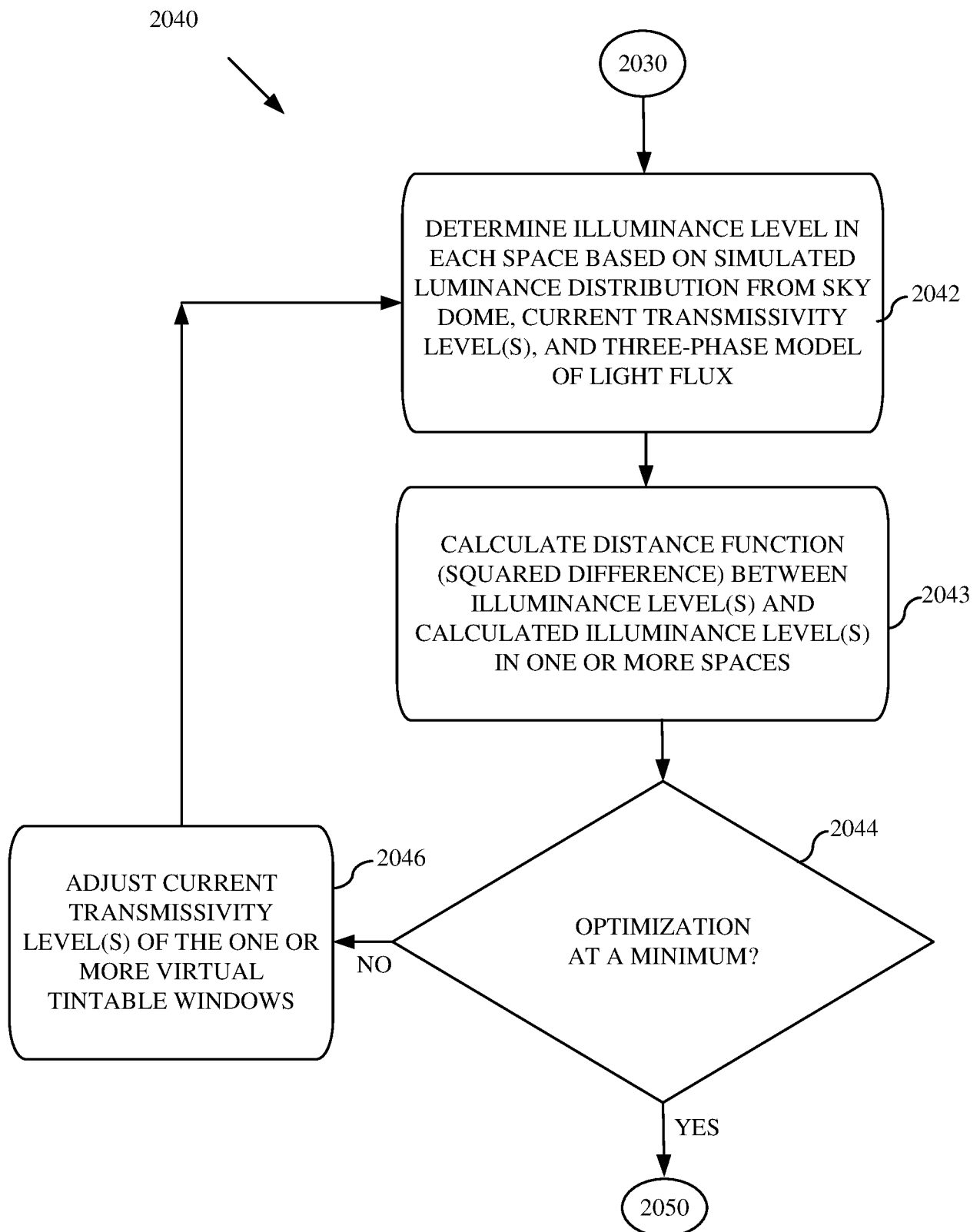
**FIG. 18**

**FIG. 19**

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**FIG. 20**

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**FIG. 21**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2023/022140

A. CLASSIFICATION OF SUBJECT MATTER**G02F 1/163**(2006.01)i; **E06B 9/24**(2006.01)i; **E06B 3/67**(2006.01)i

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)

G02F 1/163(2006.01); E06B 9/24(2006.01); G02B 26/00(2006.01); G05B 15/02(2006.01); H04N 5/232(2006.01);
H04N 5/247(2006.01); H05B 45/22(2020.01); H05B 47/11(2020.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: tintable window, illuminance, clear sky, virtual, simulation, override, heat gain,
predict, sensor**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2018-0307114 A1 (VIEW, INC.) 25 October 2018 (2018-10-25) paragraphs [0010], [0016], [0081], [0084]-[0087], [0096]-[0100], [0105], [0135], [0140], [0174]-[0175], [0181], [0245]; claim 1; and figures 3, 5, 8, 21	1-12,15-20,22-29,32-34 13-14,21,30-31
Y	US 2019-0294018 A1 (VIEW, INC.) 26 September 2019 (2019-09-26) paragraphs [0195], [0197], [0229], [0232]; and figures 14-15	1-12,15-20,22-29,32-34
Y	US 2020-0007762 A1 (DALLMEIER ELECTRONIC GMBH & CO. KG) 02 January 2020 (2020-01-02) paragraphs [0015], [0048]; and figure 3	7
Y	US 2020-0260556 A1 (VIEW, INC.) 13 August 2020 (2020-08-13) paragraph [0228]; and claim 1	16-17,20
A	US 2007-0053053 A1 (JAY MOSKOWITZ) 08 March 2007 (2007-03-08) paragraphs [0057]-[0061]; and figures 1-5	1-34



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

“D” document cited by the applicant in the international application

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“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

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“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

“&” document member of the same patent family

Date of the actual completion of the international search

08 September 2023

Date of mailing of the international search report

08 September 2023

Name and mailing address of the ISA/KR

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189 Cheongsa-ro, Seo-gu, Daejeon
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