

**IMPROVEMENT OF SOLAR WATER PUMPING SYSTEM
PERFORMANCE USING ACTIVELY COOLED PHOTOVOLTAIC MODULES**

CROSS-REFERENCE TO RELATED APPLICATION

[001] This application claims priority to U.S. Provisional Patent Application No. 62/020,835 filed on July 3, 2014, the entire disclosure of which is hereby incorporated by reference in its entirety.

FIELD

[002] This disclosure generally relates to temperature regulation and processing of thermal energy, and more specifically, to methods and systems for actively controlling the temperature of fixed tilt and/or solar tracker mounted photovoltaic modules.

BACKGROUND

[003] Photovoltaic (PV) modules are devices that convert solar energy into electricity. Some known PV modules convert around 85% of incident sunlight into heat. During peak conditions, such modules can generate heat of 850 W/m^2 and module temperatures as high as 70°C . The electrical power produced by PV modules is negatively affected by heat, i.e., the power produced decreases with the increase in module temperature. For example, in bright sunlight, crystalline silicon PV modules may heat up to $20\text{--}30^\circ\text{C}$ above ambient temperature, resulting in a 10-15% reduction in power output relative to the rated power output for the PV module. Moreover, higher PV module temperatures may cause quicker degradation, such as thermal fatigue failure of interconnections between PV cells in the PV module. Accordingly, PV modules may benefit from reduced

temperatures and/or from reducing the rate of increase in temperature.

[004] This Background section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

BRIEF SUMMARY

[005] A first aspect is a solar powered fluid pumping system for supplying a fluid from a fluid source. The system includes a frame assembly, a photovoltaic (PV) module, a pump, and a PV heat exchanger. The PV module is mounted to the frame assembly, and configured to generate an electrical power output from solar energy incident on the PV module. The pump is powered by the PV module to pump the fluid from the fluid source. The PV heat exchanger is in thermal communication with the PV module and fluid communication with the pump. The PV heat exchanger is configured to transfer heat from the PV module to less than all of the fluid.

[006] Another aspect is a solar irrigation system for distributing water from a water source. The system includes a photovoltaic (PV) module, a pump, a PV heat exchanger, and an irrigation apparatus. The photovoltaic (PV) module is configured to generate an

electrical power output from solar energy incident on the PV module. The pump is electrically connected with the PV module to pump the water from the water source. The PV heat exchanger is in thermal communication with the PV module and fluid communication with the pump. The PV heat exchanger is configured to transfer heat from the PV module to less than all of the water. The irrigation apparatus is in fluid communication with the pump to distribute the water.

[007] Various refinements exist of the features noted in relation to the above-mentioned aspects. Further features may also be incorporated in the above-mentioned aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to any of the illustrated embodiments may be incorporated into any of the above-described aspects, alone or in any combination.

BRIEF DESCRIPTION OF THE DRAWINGS

[008] Figure 1 is a perspective view of an example PV module;

[009] Figure 2 is a cross-sectional view of the PV module shown in Figure 1 taken along the line A--A;

[0010] Figure 3 is a cross-sectional view of a heat exchanger;

[0011] Figure 4 is a temperature regulation system including the heat exchanger shown in Figure 3;

[0012] Figure 5 is a cross-sectional illustration of an assembly including a heat exchanger attached to a PV module;

[0013] Figure 6 is a top view of an assembly including a heat exchanger integrated into a PV module;

[0014] Figure 7 is a cross sectional view of the assembly shown in Figure 6 taken along the line A-A in Figure 6;

[0015] Figure 8 is a top view of a stand-alone heat exchanger;

[0016] Figure 9 is a cross sectional view of heat exchanger shown in Figure 8 taken along the line B-B in Figure 8;

[0017] Figure 10 is a top view of a heat exchanger including a plurality of plastic spacers;

[0018] Figure 11 is a cross sectional view of heat exchanger shown in Figure 10 taken along the line C-C in Figure 10;

[0019] Figure 12 is a cross sectional view of a connection assembly for use as an inlet and/or outlet for a heat exchanger;

[0020] Figure 13 is a heat exchanger coupled to a device;

[0021] Figure 14 is a temperature regulation system including an in-ground secondary heat exchanger;

[0022] Figure 15 is another temperature regulation system including an in-ground secondary heat exchanger;

[0023] Figure 16 is a temperature regulation system with a secondary heat exchanger in a body of water;

[0024] Figure 17 is a temperature regulation system with a secondary heat exchanger to provide hot water;

[0025] Figure 18 is a temperature regulation system with a secondary heat exchanger to provide hot air;

[0026] Figure 19 is a temperature regulation system with a PCM based storage and heat exchanger to provide hot water;

[0027] Figure 20 is a temperature regulation system with a secondary heat exchanger to provide hot water to a hot water storage tank;

[0028] Figure 21 is a temperature regulation system configured to provide hot water to coils for underfloor heating;

[0029] Figure 22 is a temperature regulation system with a secondary heat exchanger to provide hot water to a pool;

[0030] Figure 23 is an assembly of PV modules including heat exchangers;

[0031] Figure 24 is another exemplary assembly of PV modules including heat exchangers;

[0032] Figure 25 is an exploded view of the inner and outer layers of an example heat exchanger;

[0033] Figure 26 is a partial view of the assembled heat exchanger shown in Figure 25;

[0034] Figure 27 is a view of the heat exchanger shown in Figure 25 attached to the bottom surface of a laminate;

[0035] Figure 28 is a graph of output power of fixed tilt cooled and uncooled PV modules as a function of the time of day;

[0036] Figure 29 is a side elevation view of an exemplary system including a PV module and heat exchanger mounted on a solar tracker;

[0037] Figure 30A is a graph of output power of cooled and uncooled PV modules as a function of the angle of incidence of light on the PV modules;

[0038] Figure 30B is a graph of short circuit current of cooled and uncooled PV modules as a function of the angle of incidence of light on the PV modules;

[0039] Figure 30C is a graph of open circuit voltage of cooled and uncooled PV modules as a function of the angle of incidence of light on the PV modules;

[0040] Figure 30D is a graph of the temperature of cooled and uncooled PV modules as a function of the angle of incidence of light on the PV modules;

[0041] Figure 31 is a diagram of an example PV module mounted to a roof of a building;

[0042] Figure 32 is a diagram of a PV module flush mounted on the roof of a building;

[0043] Figure 33 is a table of temperature measurements obtained for an uncooled PV module and a cooled PV module installed various distances above a roof;

[0044] Figure 34 is a temperature regulation system including a roof mounted PV module and heat exchanger;

[0045] Figure 35 is a graph of the increase in PV module power output and the increase in water temperature, both as a function of the flow rate of the water through a heat exchanger;

[0046] Figure 36 is a perspective view of a solar powered fluid pumping system for pumping a fluid from a fluid source;

[0047] Figure 37 is a schematic of a portion of the system shown in Figure 36;

[0048] Figure 38 is a top view of an inexpensive heat exchanger including multiple parallel channels;

[0049] Figure 39 is a perspective view of another heat exchanger including multiple parallel channels;

[0050] Figure 40 is an enlarged view of the end sealing of the heat exchanger of Figure 39;

[0051] Figure 41 is an enlarged view of an inlet/outlet portal of the heat exchanger of Figure 39; and

[0052] Figure 42 is an enlarged view of an end of a multi-wall construction of the heat exchanger of Figure 38.

[0053] Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0054] The embodiments described herein generally relate to temperature regulation and control. More specifically, embodiments described herein relate to methods and systems for regulating and controlling temperature using a heat exchanger. Specific embodiments are described herein with reference to photovoltaic (PV) modules. However, the teachings of the present disclosure may be applied to any device that may benefit from enhanced temperature regulation. Moreover, although various embodiments will be discussed with respect to cooling a device, it should be understood that the embodiments described herein may additionally, or alternatively, be used to heat a device with which they are used.

[0055] Referring initially to Figures 1 and 2, a PV module is indicated generally at 100. A perspective view of PV module 100 is shown in Figure 1. Figure 2 is a cross sectional view of PV module 100 taken at line A-A shown in Figure 1. PV module 100 includes a laminate 102 and a frame 104 circumscribing laminate 102.

[0056] Laminate 102 includes a top surface 106 and a bottom surface 108 (shown in Figure 2). Edges 110 extend between top surface 106 and bottom surface 108. In this embodiment, laminate 102 is rectangular shaped. In

other embodiments, laminate 102 may have any suitable shape.

[0057] As shown in Figure 2, this laminate 102 has a laminate structure that includes several layers 118. Layers 118 may include for example glass layers, non-reflective layers, electrical connection layers, n-type silicon layers, p-type silicon layers, and/or backing layers. In other embodiments, laminate 102 may have more or fewer, including one, layer 118, may have different layers 118, and/or may have different types of layers.

[0058] As shown in Figure 1, frame 104 circumscribes laminate 102. Frame 104 is coupled to laminate 102, as best seen in Figure 2. Frame 104 assists in protecting edges 110 of laminate 102. In this embodiment, frame 104 is constructed of four frame members 120. In other embodiments frame 104 may include more or fewer frame members 120.

[0059] Exemplary frame 104 includes an outer surface 130 spaced apart from laminate 102 and an inner surface 132 adjacent laminate 102. Outer surface 130 is spaced apart from and substantially parallel to inner surface 132. In this embodiment, frame 104 is made of aluminum. More particularly, in some embodiments frame 104 is made of 6000 series anodized aluminum. In other embodiments, frame 104 may be made of any other suitable material providing sufficient rigidity including, for example, rolled or stamped stainless steel, plastic, or carbon fiber.

[0060] Figure 3 is a simplified cross-sectional view of a heat exchanger 300 according to one

embodiment of the present disclosure. Heat exchanger 300 includes an inner layer 302, a fluid layer 304, and an outer layer 306. In this embodiment, fluid layer 304 includes a chamber 305 and one or more spacers or spacing material (not shown in Figure 3) to maintain a substantially consistent separation between inner and outer layers 302 and 306. The spacers are connected to inner layer 302 and outer layer 306 to, among other things, prevent bulging of inner or outer layer 302 or 306 when fluid is pumped into chamber 305 of fluid layer 304. Seals 308 connect inner and outer layers 302 and 306 to provide a substantially water tight seal around fluid layer 304, and more specifically around chamber 305. Thus, a heat transfer fluid, such as water, oil, ethylene glycol, etc., may flow through fluid layer 304 to extract heat from a device with which heat exchanger 300 is used, without the fluid contacting the device. In some embodiments, seals 308 may be, additionally or alternatively, spacers or spacing material. Moreover, in some embodiments, seals 308 may be integrally formed with inner layer 302 and/or outer layer 306.

[0061] Inner layer 302 is the portion of heat exchanger 300 that will be in contact with the device to be temperature regulated by heat exchanger 300. Accordingly, inner layer 302 is made from a material having relatively high thermal conductivity, such as aluminum, copper, etc. Moreover, the material for inner layer 302 is selected to conform reasonably well to the surface of the device with which it will be used in order to provide sufficient thermal contact or thermal communication with the surface of the device. In this embodiment, inner layer 302

comprises a sheet that is suitably made of metal. In other embodiments, inner layer 302 may be an aluminum sheet.

[0062] The thickness of inner layer 302 may be varied, e.g., to suit different uses. Thicker sheets may be used to provide increased rigidity, but with a corresponding decrease in flexibility and/or conformability. In some embodiments, inner layer 302 is a thin, metal foil. In one exemplary embodiment, inner layer 302 is a metal foil having a thickness of about 0.1 millimeter. In another embodiment, inner layer 302 is an aluminum foil having a thickness of about 300 micrometers. Other embodiments may use thicker or thinner metal foils. The use of thinner materials for inner layer 302 may increase the flexibility of heat exchanger 300, reduce the weight of heat exchanger 300, and/or permit it to conform to more irregular shaped devices. In general, inner layer 302 may be constructed from any thermally conductive material of sufficient strength and impermeability to retain a heat transfer fluid within heat exchanger 300.

[0063] Outer layer 306 is the portion of heat exchanger 300 opposite the side of heat exchanger 300 that will be in contact with the device to be temperature regulated by heat exchanger 300 (i.e., opposite inner layer 302). In some embodiments, outer layer 306 is made of a material having relatively high thermal conductivity, such as a metal sheet or a metal foil, to permit heat to transfer from fluid layer 304 through outer layer 306 to the air around outer layer 306. In other embodiments, outer layer is fabricated from a material that is not particularly thermally conductive, such as a plastic sheet or film. The thickness of outer layer 306 may be varied to

suit different uses. Thicker sheets may be used to provide increased rigidity, but with a corresponding decrease in flexibility and/or conformability. In some embodiments, outer layer 306 is a thin, metal foil. In other embodiments, outer layer 306 is a thin sheet that is suitably made of plastic. The use of thinner materials for outer layer 306 may increase the flexibility of heat exchanger 300, reduce the weight of heat exchanger 300, and/or permit it to conform to more irregular shaped devices. In general, outer layer 306 may be made of any material of sufficient strength and impermeability to retain a heat transfer fluid within heat exchanger 300. In one example embodiment, outer layer 306 is a transparent acrylic sheet having a thickness of about three millimeters.

[0064] Figure 4 is a simplified diagram of a closed loop temperature control or regulation system 400 including heat exchanger 300 (heat exchanger may alternatively be referred to as a meshplate). Heat exchanger 300 is coupled to a device 402 that may benefit from temperature regulation provided by heat exchanger. In this embodiment, device 402 is a device, such as PV module 100, that generates heat and heat exchanger 300 is used to reduce the temperature and/or slow the rise in temperature of device 402. In other embodiments, heat exchanger 300 may be used to increase the temperature of device 402 and/or slow the decrease in temperature of device.

[0065] In this embodiment, a pump 404 pumps a thermal transfer fluid (e.g., a coolant) to an inlet (not shown in Figure 4) of heat exchanger 300. The transfer fluid passes into chamber 305 of fluid layer 304 through

the inlet. Heat is conducted from device 402 through inner layer 302, where the thermal transfer fluid draws heat off inner layer 302 via convection to actively cool device 402. The thermal transfer fluid exits heat exchanger 300 via an outlet (not shown in Figure 4) and is directed to a fluid heat exchanger 406 (also referred to herein as a secondary heat exchanger). As will be described in more detail below, fluid heat exchanger 406 may be any heat exchange device suitable for extracting the heat carried by the thermal transfer fluid. For example, fluid heat exchanger may be a radiator, an extended length of thermally conductive conduit, a condenser, etc. Moreover, in some embodiments fluid heat exchanger 406 may be part of another system, such that heat extracted from thermal transfer fluid may be used by the other system. In one example embodiment fluid heat exchanger 406 is a radiator used to warm the air inside a structure. In another embodiment fluid heat exchanger 406 is used to heat water.

[0066] As will be readily understood by those of ordinary skill in the art, system 400 may, additionally or alternatively, be used to heat device 402. In such embodiments, thermal transfer fluid having a temperature greater than device 402 is pumped by pump 404 to heat exchanger 300. Within chamber 305, the thermal transfer fluid loses its heat to layer 302 via convection. The heat is conducted through layer 302 to device 402. Fluid heat exchanger 406 then increases the temperature of the heat transfer fluid before pump 404 returns the fluid to heat exchange device 300. A single system 400 may be used to selectively heat or cool device 402 through use of a dual purpose fluid heat exchanger 406 or separate, selectable,

fluid heat exchangers 406: one for heating the thermal fluid and another for cooling the thermal fluid. Thus, device 402 may be cooled by system 400 when its temperatures are relatively high, and warmed by system 400 when its temperatures are relatively cool.

[0067] A controller 408 controls operation of system 400. More specifically, controller 408 controls operation of system 400 to obtain a desired amount of cooling and/or heating of device 402. In some embodiments, controller 408 may monitor a temperature of device 402 with a sensor (not shown). Other embodiments do not include controller 408. In this embodiment, controller 408 is configured to control operation of pump 404. Controller 408 may operate pump 404 continuously, intermittently, and/or may pulse pump 404 to achieve a desired heating/cooling of device 402. In some embodiments, controller 408 may additionally, or alternatively, control operation of fluid heat exchanger 406 and/or heat exchanger 300. In still other embodiments, controller 408 may also control operation of device 402. For example, controller 408 may be a PV system controller that controls operation of a direct current (DC) to alternating current (AC) power converter extracting power from a PV module device 402.

[0068] In this embodiment, controller 408 is configured to operate pump 404 other than continuously. Controller 408 can operate pump 404 at a duty cycle of less than 100% in some embodiments because system 400 cools device 402 faster than the device 402 heats up when pump 404 is turned off (i.e., not pumping). In one example, device 402 is PV module 100 and system 400 is operable to cool down the PV module 100 twice as fast as the PV module

100 heats up due to the high heat capacity and low thermal conductivity of PV module 100. In this example, controller 408 may operate pump 404 with a duty cycle between 30% and 50%. This may provide significant energy gain while reducing pumping costs and coolant usage.

[0069] Controller 408 may be any suitable controller, including any suitable analog controller, digital controller, or combination of analog and digital controllers. In some embodiments, controller 408 includes a processor (not shown) that executes instructions for software that may be loaded into a memory device. The processor may be a set of one or more processors or may include multiple processor cores, depending on the particular implementation. Further, the processor may be implemented using one or more heterogeneous processor systems in which a main processor is present with secondary processors on a single chip. In another embodiment, the processor may be a homogeneous processor system containing multiple processors of the same type. In some embodiments, controller 408 includes a memory device (not shown). As used herein, a memory device is any tangible piece of hardware that is capable of storing information either on a temporary basis and/or a permanent basis. The memory device may be, for example, without limitation, a random access memory and/or any other suitable volatile or non-volatile storage device. The memory device may take various forms depending on the particular implementation, and may contain one or more components or devices. For example, the memory device may be a hard drive, a flash memory, a rewritable optical disk, a rewritable magnetic tape, and/or some combination of the above. The media used by memory device

also may be removable. For example, without limitation, a removable hard drive may be used for the memory device.

[0070] Figure 5 is a cross-sectional illustration of an assembly including heat exchanger 300 attached to PV module 100.

[0071] In this embodiment, laminate 102 includes a front glass 500, solar cells 502 surrounded by an encapsulant 504, and a back sheet 506. In this embodiment, the encapsulant 504 comprises ethylene vinyl acetate (EVA). In other embodiments, any other suitable encapsulant may be used. In this embodiment, back sheet 506 is a polyvinyl fluoride (PVF) material. In other embodiments, back sheet 506 may be any other suitable back sheet material or a laminate of materials, including, for example a laminate of PVF surrounding a polyester material.

[0072] Thermal transfer fluid enters heat exchanger 300 via inlet 508 and passes through chamber 305 to outlet 510. A spacer 512 is contained within chamber 305. Spacer 512 separates inner and outer layers 302 and 306 and slows the flow of the thermal transfer fluid through chamber 305 to permit the thermal transfer fluid to absorb heat from laminate 102. In this embodiment, spacer 512 includes a mesh. More specifically, mesh is a woven-plastic mesh. In other embodiments, spacer 512 may include a non-woven mesh, a metal mesh, a sponge, spacer strips, capillary tubes, or some combination of the above. In this embodiment, mesh 512 is attached to inner and outer layers 302 and 306 and substantially fills chamber 305. In one exemplary embodiment, mesh 512 is approximately 300 micrometers thick.

[0073] Heat exchanger 300 may be permanently or semi-permanently integrated into PV module 100, or may be a standalone component that may be removably attached to a device. A standalone heat exchanger 300 may be coupled to device 402 by any suitable means to provide a thermally connection between inner layer 302 and a surface of device 402. In some embodiments, heat exchanger 300 is connected to device 402 using a thermally conductive adhesive, including for example a double-sided, thermally conductive tape.

[0074] Figure 6 is a top view of an assembly 600 including heat exchanger 300 integrated into PV module 100. Figure 7 is a cross sectional view of assembly 600 taken along the line A-A in Figure 6.

[0075] In assembly 600, heat exchanger 300 is integrally formed with PV module 100 and does not need to be separately adhered to PV module 100. Moreover, heat exchanger 300 uses backsheet 506 of PV module 100 as inner layer 302. Spacer strips 602 extend between inner layer 302 (i.e., backsheet 506) and outer layer 306 to define cavity 305. Although not shown in Figures 6 and 7, cavity 305 also includes spacer 512. In this embodiment, spacer 512 is a metallic mesh 512 capable of withstanding the heat and pressure of lamination with PV module 100. In other embodiments, cavity 305 may include any other suitable filler and/or spacer. Outer layer 306 extends around spacer strips 602 to adhere heat exchanger 300 to PV module 100 and facilitate sealing cavity 305.

[0076] Figure 8 is a top view of a stand-alone heat exchanger 300 of one embodiment. Figure 9 is a cross

sectional view of heat exchanger 300 taken along the line B-B in Figure 8. The embodiment of heat exchanger 300 shown in Figures 8 and 9 is not integrally formed with any device and may be attached to any device, such as PV module 100, by any suitable type of attachment. In this embodiment, two sets of seals 308 are included around spacer 512.

[0077] Figures 10 and 11 show an example heat exchanger 300 in which spacer 512 includes a parallel arrangement of plastic spacers. Figure 10 is a top view, and Figure 11 is a cross sectional view taken along the line C-C in Figure 10. The illustrated heat exchanger 300 provides a serpentine fluid flow through heat exchanger 300. The serpentine fluid flow provides increased heat transfer as compared to non-serpentine fluid flows. Heat exchanger 300 shown in Figures 10 and 11 may be integrated into a device or may be a standalone heat exchanger 300. The gap between adjacent spacers may be any suitable distance that ensures good fluid flow within the system to improve heat transfer and reduce bloating issues.

[0078] Figures 25, 26 and 27 show an example heat exchanger 300 including parallel chambers 305 through which heat transfer fluid passes. Figure 25 is an exploded view of the inner and outer layers 302 and 306. Figure 26 is a partial view of assembled inner and outer layers 302 and 306. Figure 27 is a view of the example heat exchanger 300 attached to the bottom surface 108 of a laminate 102. Although three and four chambers 305 are shown in Figures 25-27, heat exchanger 300 may include any suitable number of chambers 305, whether more or fewer.

[0079] In this embodiment, inner layer 302 is a substantially flat sheet, outer layer 306 is a corrugated sheet, and both inner layer 302 and outer layer 306 are aluminum. Alternatively, inner and outer layers 302, 306 may be any other suitable thermally conductive material. Moreover, inner layer 302 and outer layer 306 may be made of different materials. Inner layer 302 is attached to outer layer 306 by spot welds 2500 between chambers 305. Alternatively or additionally, inner layer 302 may be attached to outer layer 306 by any suitable connector(s), including rivets, nuts and bolts, adhesives, etc. Heat exchanger 300 shown in Figures 25-27 may be integrated into a device or may be a standalone heat exchanger 300.

[0080] In one example, a heat exchanger 300 shown in Figures 25-27 was used to cool PV module 100 positioned in a fixed position (i.e., without solar tracking). A twenty liter per hour (LPH) flow rate of water fluid through heat exchanger 300 produced a 12% power gain and output water that was 2°C hotter than the input water. A 2.5 LPH flow produced a 3% power gain in PV module 100 and output water that was 11°C hotter than the input water. Thus, by varying the rate of flow of water, or other thermal transfer fluid, through heat exchanger 300, the amount of cooling (and accordingly, the power gain) and the temperature gain of the water may be varied. Figure 28 is a graph comparing the maximum power output of PV module 100 with the heat exchanger 300 (the "cooled module") to the maximum power output of an uncooled PV module 100 as a function of the time of day. Figure 35 graphs the increase in power output of the PV module 100 and the increase in temperature of the water used for cooling (i.e., outlet

temperature minus inlet temperature) both as a function of the flow rate of water through the heat exchanger 300.

[0081] Figure 12 is a partial schematic cross section of a suitable connection assembly 1200 for use at inlet 508 and/or outlet 510 of any embodiment of heat exchanger 300. Assembly 1200 includes a male component 1202 positioned inside exchanger 300 and extending through outer layer 306. A female component 1204 is positioned outside of heat exchanger 300 adjacent outer layer 306. Female component 1204 receives and surrounds the portion of male component 1202 that extends outside of heat exchanger 300. A portion of outer layer 306 is trapped between female component 1204 and male component 1202. Tubing 1206, used to transport thermal transfer fluid to and from heat exchanger 300, is inserted into female component 1204 to couple tubing 1206 to male component 1202. Assembly 1200 forms a liquid tight connection to heat exchanger 300. Thermal transfer fluid (e.g., a suitable coolant) may be transferred, via tubing 1206 and assembly 1200, from outside of heat exchanger 300 to the interior of heat exchanger 300, and vice versa.

[0082] Figure 13 is a partially schematic view of heat exchanger 300 coupled to a device 1300. The device may be any suitable device that may benefit from temperature regulation provided by heat exchanger 300.

[0083] Figures 14-22 illustrate various embodiments of closed loop temperature control or regulation system 400 including heat exchanger 300. It should be understood that any of the embodiments of heat exchanger 300 described above may be used in the

temperature regulation systems 400 shown in Figures 14-22. At least some of the temperature regulation systems 400 described herein utilize thermal energy produced by the PV modules 100 for other useful purposes and thus are sometimes referred to herein as solar energy systems.

[0084] Figure 14 is a simplified diagram of a temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and an in-ground secondary heat exchanger 1400. The secondary heat exchanger 1400 is a fluid retaining tank positioned underground. The secondary heat exchanger 1400 may be made of metal, plastic, or any other suitable material or combination of materials. Fluid from the secondary heat exchanger 1400 is pumped through heat exchanger 300 by pump 404. The heated fluid exiting the heat exchanger 300 flows back to the secondary heat exchanger 1400. The heat stored in the fluid in secondary heat exchanger 1400 is dissipated through the secondary heat exchange 1400 into the ground. The dissipation of heat into the ground occurs particularly at times when the fluid is not being used to cool the PV module 100, such as at night. The secondary heat exchanger 1400 is buried a depth "h" below the ground level 1402. In some embodiments, h is a depth below ground level 1402 at which the annual ground temperature is relatively constant. Alternatively, the depth h may be any other suitable depth. In some embodiments, additives (e.g., charcoal, metal dust, etc.) may be added to the soil surrounding the secondary heat exchanger 1400 to enhance the heat transfer between the secondary heat exchanger 1400 and the ground. In still other embodiments secondary heat exchanger 1400 may be positioned on or above ground level.

[0085] Figure 15 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and an in-ground secondary heat exchanger 1500. The secondary heat exchanger 1500 is a serpentine array of tubes positioned underground. The secondary heat exchanger 1500 may be made of metal, plastic, or any other suitable material or combination of materials. The heated fluid exiting the heat exchanger 300 flows through the secondary heat exchanger 1500 before returning to the heat exchanger 300. At least some of the heat stored in the fluid is dissipated through the secondary heat exchange 1500 into the ground. The secondary heat exchanger 1500 is buried a depth "h" below the ground level 1402. In some embodiments, h is a depth below ground level 1402 at which the annual ground temperature is relatively constant. Alternatively, the depth h may be any other suitable depth. In some embodiments, additives may be added to the soil surrounding the secondary heat exchanger 1500 to enhance the heat transfer between the secondary heat exchanger 1500 and the ground. Although shown as a vertical array of tubes, secondary heat exchanger 1500 may be a vertical array of tubes, a horizontal array of tubes, an array of coils, an array of vertical and horizontal tubes, an array of arbitrary angled tubes, and/or any suitable combination of horizontal tubes, vertical tubes, arbitrary angled tubes, and coils.

[0086] Figure 16 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 1600. The secondary heat exchanger 1600 is a serpentine array of tubes disposed in a body of water 1602.

The secondary heat exchanger 1600 may be made of metal, plastic, or any other suitable material or combination of materials. The heated fluid exiting the heat exchanger 300 flows through the secondary heat exchanger 1600 before being returned by pump 404 to the heat exchanger 300. At least some of the heat stored in the fluid is dissipated through the secondary heat exchange 1600 into the body of water 1602. In the illustrated embodiment, Although shown as a horizontal array of tubes, secondary heat exchanger 1600 may be a vertical array of tubes, a horizontal array of tubes, an array of coils, an array of vertical and horizontal tubes, an array of arbitrary angled tubes, and/or any suitable combination of horizontal tubes, vertical tubes, arbitrary angled tubes, and coils.

[0087] Figure 17 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 1700. The cooling fluid flows through heat exchanger 300 in a first fluid loop. The secondary heat exchanger 1700 is configured to transfer at least some of the heat contained in fluid exiting the heat exchanger 300 to a secondary fluid loop. In the illustrated embodiment, the secondary fluid loop provides heated water for residential, commercial, industrial, or any other suitable application. More particularly, the secondary heat exchanger 1700 receives the heated fluid from the heat exchanger 300 and cooler water from a water supply (not shown). A second pump 1702 pumps the water to secondary heat exchanger 1700. The heat contained in the fluid exiting the heat exchanger 300 is transferred to the water pumped into the secondary heat exchanger 1700. The reduced

temperature cooling fluid is returned to the heat exchanger 300 by pump 404. The heated water exits the secondary heat exchanger 1700 and is delivered for use.

[0088] Figure 18 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 1800. The cooling fluid flows through heat exchanger 300 in a first fluid loop. The secondary heat exchanger 1800 is configured to transfer at least some of the heat contained in fluid exiting the heat exchanger 300 to a secondary fluid loop. In the illustrated embodiment, the secondary fluid loop provides heated air for residential, commercial, industrial, or any other suitable application. More particularly, the secondary heat exchanger 1800 receives the heated fluid from the heat exchanger 300 and a cooler air input. A pump, fan, blower, or other suitable motivator (not shown) forces the cooler air into secondary heat exchanger 1800. The heat contained in the fluid exiting the heat exchanger 300 is transferred to the air in secondary heat exchanger 1800. The reduced temperature cooling fluid is returned to the heat exchanger 300 by pump 404. The heated air exits the secondary heat exchanger 1800 and is input to an auxiliary heater 1802 to provide additional heat to the air. Alternatively, the heated air exiting the secondary heat exchanger 1800 is delivered for use without heating by an auxiliary heater 1802.

[0089] Figure 19 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 1900. The cooling fluid flows through heat

exchanger 300 in a first fluid loop. The secondary heat exchanger 1900 is a phase change material (PCM) combined heat storage and heat exchanger configured to transfer at least some of the heat contained in fluid exiting the heat exchanger 300 to a secondary fluid loop. In the illustrated embodiment, the secondary fluid loop provides heated water for residential, commercial, industrial, or any other suitable application. More particularly, the secondary heat exchanger 1900 receives the heated fluid from the heat exchanger 300 and cooler water from a water supply (not shown). A second pump 1902 pumps the water to secondary heat exchanger 1900. The heat contained in the fluid exiting the heat exchanger 300 is transferred, via a phase change material, to the water pumped into the secondary heat exchanger 1900. The reduced temperature cooling fluid is returned to the heat exchanger 300 by pump 404. The heated water exits the secondary heat exchanger 1900 and is delivered for processing and/or use.

[0090] Figure 20 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 2000. The cooling fluid flows through heat exchanger 300 in a first fluid loop. The secondary heat exchanger 2000 is configured to transfer at least some of the heat contained in fluid exiting the heat exchanger 300 to a secondary fluid loop. In the illustrated embodiment, the secondary fluid loop provides heated water for residential, commercial, industrial, or any other suitable application. More particularly, the secondary heat exchanger 2000 receives the heated fluid from the heat exchanger 300 and cooler water from a water supply (not

shown). A second pump 2002 pumps the water to secondary heat exchanger 2000. The heat contained in the fluid exiting the heat exchanger 300 is transferred to the water pumped into the secondary heat exchanger 2000. The reduced temperature cooling fluid is returned to the heat exchanger 300 by pump 404. The heated water exits the secondary heat exchanger 2000 and is delivered to an insulated hot water storage tank 2004. The storage tank 2004 includes an auxiliary heater 2006 to provide additional heat to the water stored in the storage tank 2004. Alternatively, the auxiliary heater 2006 may be omitted. The heated water stored in storage tank 2004 is delivered from the hot water storage tank 2004 for processing and/or use. In the illustrated embodiment, pump 2002 pumps water from storage tank 2004 to secondary heat exchanger 2000, while the water supply provides water into storage tank 2004 as needed. Alternatively, water may be provided to secondary heat exchanger 2000 from the water supply directly.

[0091] Figure 21 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 2100. The secondary heat exchanger 2100 is an array of coils 2102 for underfloor heating or in-wall heating. The coils 2102 are disposed underneath the surface of a floor and/or within the walls (not shown) in a home, office, warehouse, etc. In some embodiments, the coils 2102 are disposed within a floor, such as by being embedded in a concrete foundation. The secondary heat exchanger 2100 may be made of metal, plastic, or any other suitable material or combination of materials. The heated fluid exiting the heat exchanger 300 flows through the secondary heat

exchanger 2100 before being returned by pump 404 to the heat exchanger 300. At least some of the heat stored in the fluid is dissipated through the secondary heat exchange 2100 into the floor and/or through the walls. Secondary heat exchanger 2100 may include a vertical array of tubes, a horizontal array of tubes, an array of coils, an array of vertical and horizontal tubes, an array of arbitrary angled tubes, and/or any suitable combination of horizontal tubes, vertical tubes, arbitrary angled tubes, and coils.

[0092] Figure 22 is a simplified diagram of another temperature regulation system 400 including heat exchanger 300 coupled to PV module 100 and a secondary heat exchanger 2200. The cooling fluid flows through heat exchanger 300 in a first fluid loop. The secondary heat exchanger 2200 is configured to transfer at least some of the heat contained in fluid exiting the heat exchanger 300 to a secondary fluid loop. The secondary fluid loop provides heated water for heating a body of water. In the illustrated embodiment, the body of water is a pool 2202. Alternatively, the body of water may be a pond, a lake, a tub, or any other body of water that may benefit from heating. The secondary heat exchanger 2200 receives the heated fluid from the heat exchanger 300 and cooler water from the pool 2202. A second pump 2204 pumps the water to secondary heat exchanger 2200. The heat contained in the fluid exiting the heat exchanger 300 is transferred to the water pumped into the secondary heat exchanger 2200. The reduced temperature cooling fluid is returned to the heat exchanger 300 by pump 404. The heated water exits the

secondary heat exchanger 2200 and is delivered to the pool 2202.

[0093] PV modules 100 including heat exchangers 300 may be mounted to any suitable support structure. For example, a PV module 100 with heat exchanger 300 may be mounted to a ground based rack, a roof (whether directly or via a rack), a solar tracker, etc.

[0094] Figure 29 is a side elevation view of a system 2900 including PV module 100 and heat exchanger 300 (not visible) mounted to a solar tracker 2902. Tracker 2902 is a horizontal single axis tracker configured to rotate the PV module 100 about an axis of rotation (going into the page) at point 2904. Alternatively, the tracker 2902 may be a multi-axis tracker, a single axis tracker rotating about a different axis of rotation, or any other suitable solar tracker. Moreover, although a single PV module 100 is shown in Figure 29, system 2900 may include more than one PV module 100.

[0095] Solar trackers (sometimes referred to herein as trackers or tracking devices) are used to alter the position of one or more PV modules 100 mounted to the tracker to attempt to control an angle of incidence 2906 of sunlight on the PV modules. Typically, the desired angle of incidence 2906 is normal (i.e. ninety degrees) to the PV module 100. This substantially maximizes the solar energy that is received by the PV modules 100 throughout the day. The increased light intensity on the PV module increases the output current of the PV module 100, thereby leading to increased power output. The introduction of trackers can boost the output power of a solar power plant by, for

example, 10% - 35%. The increased light intensity on the PV module 100 also increases the temperature of the PV module 100. PV modules 100 mounted on solar trackers will often be 10°C - 15°C hotter than a similar module 100 mounted in a fixed position. Heat exchanger 300 reduces the temperature of the PV module 100 and offsets at least a portion of the increased temperature of the PV module 100.

[0096] Figures 30A-30D compare the characteristics of an uncooled PV module 100 (i.e., without a heat exchanger 300) and a cooled PV module 100 (i.e., with a heat exchanger 300) for various angles of incidence of light on the PV module. In this example, the light was generated using a lamp and the indicated angle of incidence is relative to normal. Thus, at an angle of 0 degrees, the PV module 100 faces the lamp directly and receives the most incident light from the lamp. Figure 30A presents the output power of the modules 100 as a function of the angle of incidence. Figures 30B and 30C show the short circuit current and the open circuit voltage, respectively, of the PV modules 100. The temperature of the PV modules 100 is shown as a function of the angle of incidence in Figure 30D. As can be seen, the cooled module remained significantly cooler than the uncooled module. The cooled module 100 provided higher open circuit voltages at substantially the same short circuit current as the uncooled module 100, thereby generating more output power.

[0097] As mentioned above, PV modules 100 may be mounted to a roof of a building. As is well known, a significant amount of heat enters a building through the roof from sunlight shining on the roof. Placing PV modules on a roof shades the portion of the roof under the PV

module from the sun, thereby reducing the temperature of the roof and potentially reducing the amount of heat entering the building through the roof. Figure 31 is a diagram of a PV module 100 mounted to a roof 3100 of a building 3102. In Figure 31, PV module 100 is mounted such that it is spaced a distance d from the surface of roof 3100. The distance d is often selected to provide clearance to permit air (e.g., wind) to pass between the roof 3100 and the PV module 100 to facilitate cooling the PV module 100. Moreover, some building codes and fire regulations limit the distance d and/or require the space between the PV module 100 and the roof 3100 be closed off to limit the spread of flame in case of fire. Use of heat exchanger 300 with roof mounted PV modules reduces the temperature of the module 100 without reliance on the airflow between the PV module 100 and the roof 3100.

[0098] Figure 33 presents temperature measurements obtained for installation with various distances d (referred to in Figure 33 as "Height") for an uncooled PV module 100 and a cooled PV module 100 (i.e., PV module 100 with heat exchanger 300). As can be seen, the temperature of the PV module 100 (whether cooled or uncooled) increased as the distance d decreased. The cooled module 100, however, was significantly cooler than the uncooled module 100 at all heights and had a smaller temperature change than the uncooled module 100 as the distance d changed. Moreover, when distance d was reduced to zero (i.e., the modules 100 were flush mounted), the temperature of the cooled module 100 was still less than the temperature of the uncooled module at any distance. Similarly, the temperature of the roof under the PV modules

100 increased as the distance d decreased. The roof temperature under the cooled PV module 100 remained cooler than the roof under the uncooled PV module 100 at all distances d . Thus, a cooled PV module 100 (i.e., including heat exchanger 300) may be installed spaced apart from the roof 3100, flush with the roof 3100, or anywhere in between to achieve a desired wind loading on the roof 3100, reduction in roof temperature, and/or aesthetic appearance of the installed system.

[0099] As shown in Figure 34, a roof mounted PV module 100 and heat exchanger 300 may be used as part of any of the example temperature regulation systems 400 described above. The cooling fluid passed through the heat exchanger may be used for additional purposes as described above (for example with respect to Figures 17-22). Thus, a temperature regulation system 400 may include roof mounted PV modules 100 that reduce the temperature of the roof, thereby reducing the temperature in the building and reducing the cost to cool the building. The system 400 also provides hot water (or other thermal transfer fluid) that may be used to heat drinking water, heat non-potable water, heat an environment, etc., thereby further reducing electrical usage (and costs) for the building.

[00100] Additionally, a roof mounted PV module 100, may be recess mounted into the roof. The amount of recess into the roof may be varied to vary the distance between the top surface 106 of the PV module 100 and the surface of the roof. In some embodiments, the PV module may be recessed to position the top surface 106 of the PV module 100 level or below the surface of the roof. Recessing the PV module 100 into the roof reduces the wind

loading on the PV module 100 (and thereby reduces the wind loading on the roof). The reduced wind loading may permit fewer structural components to be used to mount the PV module 100 to the roof, thereby reducing costs.

[00101] It should be recognized that the temperature regulation systems described above may be combined without departing from the scope of this disclosure. For example, a temperature regulation system may include the secondary heat exchanger 1700 and the secondary heat exchanger 1400. Cooling fluid exiting the secondary heat exchanger 1700 may be delivered to secondary heat exchanger 1400 for further heat dissipation. Moreover, the systems described herein are not limited to the uses described above. For example, systems of this disclosure may be used to provide a low grade energy input to vapor absorption systems for cooling applications. Other uses include a wide range of heating applications in the food product industry, dairies, breweries, distilleries, automobile industry, machine industry, chemical industries, paper and pulp industries, timber processing, etc.

[00102] Although the exemplary embodiments were described above with reference to a single device 402 and/or a single PV module 100, the apparatus, methods, and systems described herein are not so limited. A temperature regulation system 400 may include more than one heat exchanger 300 coupled to one or more devices 402. Figures 23 and 24 illustrate two exemplary configurations of such systems. In Figure 23, the system 400 includes four heat exchangers 300. PV modules 100 are coupled to each heat exchanger 300. The fluid flows through the heat exchangers 300 in parallel. Cooling fluid branches off from an input

2300, e.g. the output of pump 404, to provide cooling fluid to each heat exchanger 300. The cooling fluid exiting each heat exchanger 300 is provided to an output 2302 to be delivered to a secondary heat exchanger. In Figure 24, the cooling fluid flows through four heat exchangers 300 in series. The cooling fluid output from one heat exchanger 300 is input to the next heat exchanger 300 in the series. The cooling fluid from the last heat exchanger in the series is delivered to a secondary heat exchanger for extraction of the heat in the cooling fluid. The parallel configuration shown in Figure 23 provides for a greater cooling fluid flow rate than the series configuration shown in Figure 24. The series configuration of Figure 24 provides a higher output temperature for the cooling fluid than the parallel configuration shown in Figure 23. Moreover, the parallel configuration of Figure 23 may provide even more cooling of the PV modules 100 than the series connection of Figure 24.

[00103] Figures 36 and 37 are an embodiment of a solar powered fluid pumping system 4000 for pumping a fluid from a fluid source. The illustrated solar pumping system 4000 is a water pumping system, such as a solar irrigation system, which may be used in remote areas of the world that have inadequate grid-electrification. However, other fluids may be pumped using the solar pumping system 4000.

[00104] The solar pumping system 4000 may include a PV module 100 mounted on a frame assembly 4010 and electrically connected to a pump 4020 for powering the pump. The solar pumping system 4000 described herein may use thermal energy produced by the PV modules 100 for other

purposes and thus is sometimes referred to herein as a solar energy system.

[00105] As discussed above, the PV module 100 includes a laminate configured to generate an electrical power output from solar energy incident on the PV module. The laminate has a structure that includes several layers. These layers may include for example glass layers, non-reflective layers, electrical connection layers, n-type silicon layers, p-type silicon layers, and/or backing layers. In other embodiments, the laminate may have more or fewer, including one layer, may have different layers, and/or may have different types of layers.

[00106] The solar pumping system 4000 of Figure 36 includes multiple PV modules 100 that form a solar array. However, in other embodiments any number of PV modules may be used, including one.

[00107] The PV modules 100 may be mounted to any suitable support structure or frame assembly 4010. For example, a PV module 100 may be mounted to a ground based rack, a roof (whether directly or via a rack) of a structure, a solar tracker, etc. In this embodiment, the frame assembly 4010 is a ground based rack.

[00108] In some embodiments, the PV module 100 is mounted to a solar tracker, as discussed above. The tracker may be a horizontal single axis tracker configured to rotate the PV module 100 about an axis of rotation, a multi-axis tracker, or any other suitable solar tracker. Solar trackers (sometimes referred to herein as trackers or tracking devices) are used to alter the position of one or more PV modules 100 mounted to the tracker to attempt to

control an angle of incidence of sunlight on the PV modules. This substantially maximizes the solar energy that is received by the PV modules 100 throughout the day.

[00109] The PV module 100 converts solar energy into electricity, which is used to power or operate the pump 4020. The pump 4020 converts the electrical energy from the PV module 100 into a mechanical action to move fluid. The fluid is moved from the fluid source through the pump and out through an output line 4024 to another location for use at that location. The pump 4020 may be configured to produce more than 10,000 liters/hour of water exiting at 2 bars pressure.

[00110] In the illustrated embodiment, the fluid source is a body of water. The body of water may be an underground body of water, including a reservoir, an underground lake, an underground river, etc. Alternatively, the body of water may be an open body of water, such as a lake or pond. In other embodiments, the fluid source maybe a storage tank. The storage tank may be fixed at a given location, such as buried underground. In other embodiments, the storage tank is configured to be movable or transportable to different locations, as may be required.

[00111] The PV module 100 may be electrically coupled to the pump 4020 through a controller 4030 and electrical connection 4032. The controller 4030 controls operation of the solar pumping system 4000. In some embodiments, the controller 4030 controls operation of the pump 4020. Controller 4030 may operate pump 4020 continuously, intermittently, and/or may pulse pump 4020 to achieve a desired heating/cooling of PV module 100. In

still other embodiments, controller 4030 may also control operation of PV module 100. For example, controller 4030 may be a PV system controller that controls operation of a direct current (DC) to alternating current (AC) power converter extracting power from a PV module 100.

[00112] In some embodiments, controller 4030 is connected with one or more sensors (not shown) to monitor the solar pumping system 4000 and the conditions in which the system is operating. In this embodiment, the controller 4030 may monitor one or more parameters and/or conditions, such as, the amount of fluid pumped by the pump 4020, runtime of the pump, and the environment in which the pump is operating.

[00113] Controller 4030 may be any suitable controller, including any suitable analog controller, digital controller, or combination of analog and digital controllers. In some embodiments, controller 4030 includes a processor (not shown) that executes instructions for software that may be loaded into a memory device. The processor may be a set of one or more processors or may include multiple processor cores, depending on the particular implementation.

[00114] In some embodiments, the PV module 100 is directly connected to the pump 4020 for powering the pump, such that the solar pumping system 4000 does not include a controller 4030.

[00115] The solar pumping system 4000 may be used to provide the fluid, such as water, for residential, commercial, industrial, or any other suitable application. The solar pumping system 4000 may provide the water (or

other thermal transfer fluid) for purposes, such as, drinking water, providing water to grow crops, non-potable water, for use in manufacturing, cleaning purposes, and conditioning an environment.

[00116] In the illustrated embodiment, the pump 4020 is in fluid communication through output line 4024 with an irrigation apparatus 4040 for distributing the water for growing crops. The irrigation apparatus 4040 may be a hose, sprinkler, mister, sprayer, or include multiple hoses, sprinklers, misters, valves, booster pumps, and/or sprayers.

[00117] In some embodiments, the solar pumping system 4000 includes a heat exchanger 300. In this embodiment, the pump 4020 is in fluid communication with the heat exchanger 300 for supplying the fluid from the fluid source to a heat exchanger 300. The solar pumping system 4000 is an open loop system that regulates the temperature of the PV module. The temperature of the PV module is regulated because the power output of PV modules may fall by as much as 10-15% on hot, sunny days as the modules heat up. Thus, as the PV modules heat up, the efficiency of the PV modules decrease, leading to a decrease in the pumping yield. As a result, heat exchanger 300 is used to reduce the temperature and/or limit the rise in temperature of PV module 100.

[00118] It should be understood that any of the embodiments of heat exchanger 300 described above may be used as heat exchanger 300 in the solar pumping system 4000. Heat exchanger 300 may be permanently or semi-permanently integrated into PV module 100, or may be a

standalone component that may be removably attached to the PV module and/or frame assembly 4010. A semi-permanently integrated heat exchanger 300 is removably attached to the PV module 100 such that one of the sheets of the heat exchanger acts as a layer of the PV module. For example, heat exchanger 300 may be used to replace the PV module glass and/or backsheet.

[00119] A standalone heat exchanger 300 may be coupled to PV module 100 by any suitable means to provide a thermal connection between the heat exchanger and a surface of PV module 100. In some embodiments, heat exchanger 300 is connected to PV module 100 using a thermally conductive adhesive, including for example a double-sided, thermally conductive tape.

[00120] The pump 4020 supplies fluid to the heat exchanger 300 through a by-pass line 4022 connected with the pump's output line 4024. The by-pass line 4022 diverts a portion of the fluid to the heat exchanger 300. The by-pass line 4022 is connected with one or more supply lines 4028, which connect with one or more heat exchangers 300. In some embodiments, the by-pass line 4022 has a by-pass valve 4026 that controls the amount of fluid supplied through the supply line 4028 to the heat exchanger 300. In some embodiments, the by-pass valve 4026 is connected with and controlled by the controller 4030.

[00121] In this embodiment, a small fraction, for example 10-15%, of the water from the output line 4024 is directed into and through the heat exchanger 300 to actively cool the PV module 100 for increasing its efficiency and to provide higher water output from the

solar pumping system 4000 with negligible operating costs. The pump 4020 pumps the fluid or thermal transfer fluid (water) from the body of water to an inlet (not shown in Figures 36 or 37) of heat exchanger 300 for reducing the operating temperature of the PV module 100 by forced convection.

[00122] The fluid passes through the heat exchanger 300, which absorbs heat from PV module 100, via thermal conduction. As such, the heat exchanger 300 is in thermal communication with the PV module 100 and fluid communication with the pump 4020. The fluid or water exits heat exchanger 300 via an outlet (not shown in Figures 36 or 37). The warm water (around 100 lph/module at 40-45C) produced by the heat-exchanger may be used for irrigation or other needs.

[00123] In some embodiments, the controller 4030 controls operation of solar pumping system 4000 to obtain a desired amount of cooling and/or heating of PV module 100. In these embodiments, controller 4030 may monitor a temperature of PV module 100 with a sensor (not shown). In some embodiments, controller 4030 may additionally, or alternatively, control operation of heat exchanger 300.

[00124] The solar pumping system 4000 may provide heated water for residential, commercial, industrial, or any other suitable application. The heated water (or other thermal transfer fluid) may be provide such useful purposes as drinking water, providing water to grow crops, heating non-potable water, and heating an environment (discussed above).

[00125] As shown, the heat exchanger 300 is also in fluid communication with the irrigation apparatus 4040 through irrigation line 4042. In this embodiment, the heated water is directed back into the outgoing water-stream of the irrigation apparatus 4040. The heat exchanger 300 provides the fluid to the irrigation apparatus 4040 after the transfer of heat from the PV module 100 to the fluid. In other embodiments, the heat exchanger may also be in fluid connection with another outlet to supply the heated water for other uses, for example, the heat exchanger 300 may be connected with a storage tank, another outlet for immediate use, or a secondary heat exchanger as discussed above, to provide the heated fluid or water for other uses.

[00126] Figure 38 shows another embodiment of an example heat exchanger 300 similar to Figures 10 and 11. With additional reference to Figure 42, heat exchanger 300 of this embodiment includes multi-wall plastic or polycarbonate sheets, e.g., manufactured using a vacuum thermoforming process. The heat exchanger 300 includes an inner layer or sheet 302, an outer layer or sheet 306, and a parallel arrangement of plastic spacers 308. The gap between adjacent spacers may be any suitable distance that ensures good fluid flow within the system to improve heat transfer and reduce bloating issues. Together, the inner and outer sheets 302 and 306 and the spacers 308 form a chamber 305.

[00127] Vacuum-formed multi-wall (or twin-wall) sheets 302 and 306 provide a low-cost transparent material. The heat exchanger 300 is constructed to prevent bloating when filled with water, and allow attachment of the heat

exchanger to the backside of PV modules 100 with minimal effort. The inner sheet 302 or outer sheet 306 may be designed to absorb UV or IR wavelengths. This multi-wall heat-exchanger 300 is able to cool PV modules 100 by 16°C-17°C, as compared to 20°C for an Aluminum-based heat-exchanger, which may result in a gross energy yield gain of 9-10%.

[00128] In some embodiments, the heat exchanger 300 is approximately 80% of the size of the surface area of the PV module it is in thermal communication with. The heat exchanger 300 may be placed adjacent to the PV module so that the channels run along the entire length of the PV module (portrait mode). After the heat exchanger 300 is formed, fine internal grooves may be cut into the channels, close to the top and bottom of the sheets 302 and 306, to make fluid passages extending between the channels. No grooves are cut in the channels on either the extreme left or right sides of the heat exchanger 300, so the extreme left and right channels act as a side seal. The fluid passages alternate top to bottom to provide a continuous serpentine path through the heat exchanger 300. The top and bottom edges of the heat exchanger 300 are sealed using adhesive tapes, high strength adhesives, epoxy putty material, or any other material/method suitable for making the heat exchanger sides a substantially water-tight or leak proof structure. As such, the heat exchanger 300 has only one inlet and outlet to allow the fluid to flow through the multiple channels. The inlet and outlet portals 508 and 510 have connectors located on the wall opposite the PV module.

[00129] In another embodiment, the heat exchanger 300 has inlet and outlet portals 508 and 510 for each channel except at the extreme ends. In this embodiment, the top and bottom edges are also sealed with a suitable material or method to make the heat exchanger 300 a water-tight or leak proof structure.

[00130] The edges of these embodiments may also be sealed using beading of metal, for example, aluminum, or silicone material. The heat exchanger 300 may be formed with edges that have a small curvature or bend, so that the beading will not touch the PV module when the heat exchanger is placed adjacent to it. Contact between the beading and the PV module prevents thermal contact between the adjacent sheet 306 of the heat exchanger 300 and the PV module, which would result in inefficient cooling of the PV module 100.

[00131] In another embodiment, an external looping between channels may also be used. In this embodiment tubes made of silicone or any other suitable material connect one channel with another. Thus, water is allowed to flow through the external tube to another channel in an alternating manner, providing a serpentine flow through the heat exchanger.

[00132] In yet another embodiment, a common header system externally connects the channels at the top and bottom of the heat exchanger 300. The header system has a tube assembly that seals the top and bottom edges of the heat exchanger. The tube assembly also connects adjacent channels in an alternating manner to provide the serpentine flow through the heat exchanger 300.

[00133] In still other embodiments, the multi-wall heat exchanger 300 is fabricated with closed ends, e.g., by suitably modifying the mold used for fabrication. Fabrication of the heat exchanger 300 with closed ends decreases the cost to manufacture the heat exchanger. In this embodiment, each channel end of the two sheets 302 and 306 are welded together during the thermoforming process. The mold used to fabricate the heat exchanger 300 may be configured to form gaps along alternating channels to provide the serpentine flow. In this embodiment, installation of inlet and outlet portals 508 and 510 are a separate step during the manufacturing process.

[00134] Figures 39-41 show another embodiment of a heat exchanger 300 with a parallel arrangement of plastic spacers similar to Figures 10 and 11. Figure 39 is a perspective view, and Figures 40 and 41 are enlarged views of an end sealing structure and inlet and outlet portals 508 and 510, respectively. The illustrated heat exchanger 300 provides a serpentine fluid flow through the heat exchanger for increasing heat transfer from the PV module over non-serpentine fluid flows. The gap between adjacent spacers may be any suitable distance that ensures good fluid flow within the heat exchanger 300. The gap should provide efficient heat transfer, while reducing bloating of the heat exchanger 300.

[00135] In this embodiment, the ends of the heat exchanger 300 are sealed with a structural sealant 310 to form a substantially water-tight or leak proof structure. The structural sealant is suitably introduced into each channel and then heat treated with a hot air gun to decrease the time needed to cure. All the channel ends

of the heat exchanger are filled with the sealant 310 to a distance of about 10mm from the free end. A thin layer of very high bonding adhesive tape 312 may be placed along the bonded edges to provide additional protection against leakage and to increase reliability. The grooved region on the heat exchanger 300 is sealed using the adhesive tape 312. A thin section of the multiwall sheet is then added onto the tape for better sealing. All the joints and inlet and outlet portals 508 and 510 are encased in a layer of sealant to increase reliability of the heat exchanger 300 by decreasing risk of leakage.

[00136] The heat exchangers and systems described herein generally provide inexpensive and effective ways to regulate temperature of a device, such as a PV module. Moreover, the temperature regulation provided by the exemplary heat exchangers and systems may permit PV modules to be mounted without the significant gap typically needed between the back of the PV module and an underlying support (such as a roof) to permit natural convective cooling of the PV module. Such flush mounting of PV modules may decrease wind loading on support structures and reduce installation costs. Moreover, experiments have shown that the temperature of the surface beneath PV modules including the exemplary temperature regulation systems may be lower than the surface beneath a PV module without the exemplary temperature regulation systems. This can reduce conductive and/or convective heating of space below the mounting surface. In roof mounted installations, the space beneath the mounting surface may be the interior of a building. Accordingly, the exemplary systems may facilitate reducing

the cooling costs of a building to which PV modules are attached.

[00137] Some embodiments of the heat exchangers disclosed herein can be integrated into the backsheet structure of a PV module using only an encapsulant and can thereby capitalize on existing manufacturing infrastructure and corresponding economy of scale. Some embodiments of the heat exchangers can be used with a simple attachment mechanism to be affixed to nearly any PV modules, thereby making it field-retrofittable and easy to clean and/or replace. These heat exchangers are thus usable to convert a conventional PV system or module into a PV-thermal system.

[00138] Moreover, coolant losses in the exemplary heat exchangers and systems will be negligible in a properly constructed system because coolant is retained within the system, i.e., it is a closed loop system, and there is no provision to allow coolant to intentionally escape. When used to cool PV modules, some heat exchangers of this disclosure have produced a decrease in PV module temperature of 18-20°C, and increased power output of the PV modules by about 10% at peak operating conditions. Other implementations may result in greater or lesser temperature reductions and/or greater or lesser increases in PV module efficiency. Furthermore, some embodiments provide useful dissipation of the heat extracted from a device. For example, the extracted heat may be used to provide heated water, to heat a pool or other body of water or liquid, and/or to heat air.

[00139] When introducing elements of the present invention or the embodiment(s) thereof, the

articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[00140] As various changes could be made in the above without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A solar powered fluid pumping system for supplying a fluid from a fluid source, the system comprising:

a frame assembly;

a photovoltaic (PV) module mounted to the frame assembly, the PV module configured to generate an electrical power output from solar energy incident on the PV modules; and

a pump powered by the PV module to pump the fluid from the fluid source; and

a PV heat exchanger in thermal communication with the PV module and fluid communication with the pump, the PV heat exchanger configured to transfer heat from the PV module to less than all of the fluid.

2. The solar powered fluid pumping system of claim 1, wherein the fluid source is a body of water.

3. The solar powered fluid pumping system of claim 1, wherein the fluid source includes an underground storage tank.

5. The solar powered fluid pumping system of claim 1, wherein the PV heat exchanger comprises an array of tubes or coils.

6. The solar powered fluid pumping system of claim 1, wherein the PV heat exchanger is in fluid communication with the fluid source.

7. The solar powered fluid pumping system of claim 1, wherein the frame assembly is a solar tracker.

8. The solar powered fluid pumping system of claim 1, further comprising an irrigation apparatus in fluid communication with the pump, wherein a majority of the fluid pumped from the fluid source is delivered to the irrigation apparatus.

9. The solar powered fluid pumping system of claim 1, further comprising an output line connected with the pump for providing the fluid to a primary use.

10. The solar powered fluid pumping system of claim 9, wherein the output line is connected with the PV heat exchanger through a by-pass valve to provide a portion of the fluid from the output line to the PV heat exchanger.

11. The solar powered fluid pumping system of claim 9, wherein the primary use is at least one irrigation apparatus.

12. The solar powered fluid pumping system of claim 1, wherein the PV heat exchanger is fluidly coupled to a body of water to provide the water to the body of water after transfer of heat from the PV module to the fluid.

13. The solar powered fluid pumping system of claim 1, further comprising a storage tank, the PV heat exchanger in fluid communication with the storage tank to provide the fluid to the storage tank after transfer of heat from the PV module to the fluid.

14. The solar powered fluid pumping system of claim 1, further comprising an irrigation apparatus, wherein the PV heat exchanger is in fluid communication with the irrigation apparatus to provide the fluid to the irrigation

apparatus after transfer of heat from the PV module to the fluid.

15. A solar irrigation system for distributing water from a water source, the solar irrigation system comprising:

a photovoltaic (PV) module configured to generate an electrical power output from solar energy incident on the PV modules; and

a pump electrically connected with the PV module to pump the water from the water source; and

a PV heat exchanger in thermal communication with the PV module and fluid communication with the pump, the PV heat exchanger configured to transfer heat from the PV module to less than all of the water; and

an irrigation apparatus in fluid communication with the pump to distribute the water.

16. The solar irrigation system of claim 15, further comprising an output line connected with the pump for providing the fluid to the irrigation apparatus.

17. The solar irrigation system of claim 15, wherein the output line is connected with the PV heat exchanger through a by-pass valve to provide a portion of the fluid from the output line to the PV heat exchanger.

18. The solar irrigation system of claim 15, wherein the PV heat exchanger being in fluid communication with the irrigation apparatus to provide the water to the irrigation apparatus after transfer of heat from the PV module to the water.

19. The solar irrigation system of claim 15, wherein the water source is underground.

20. The solar irrigation system of claim 15, further comprising a frame assembly for mounting the PV module.

21. The solar irrigation system of claim 20, wherein the frame assembly is a solar tracker.

22. The solar irrigation system of claim 15, further comprising a storage tank, the PV heat exchanger being in fluid communication with the storage tank to provide the water to the storage tank after transfer of heat from the PV module to the water.

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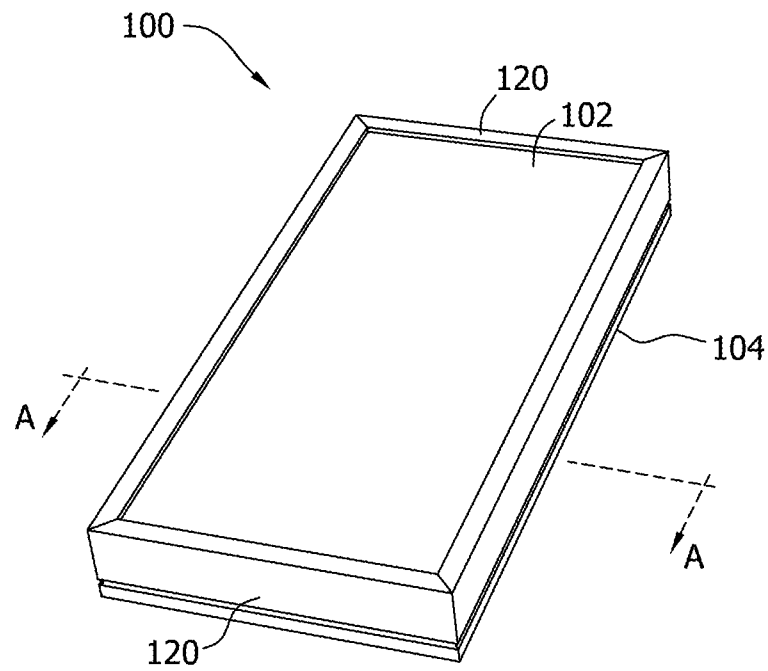


FIG. 1

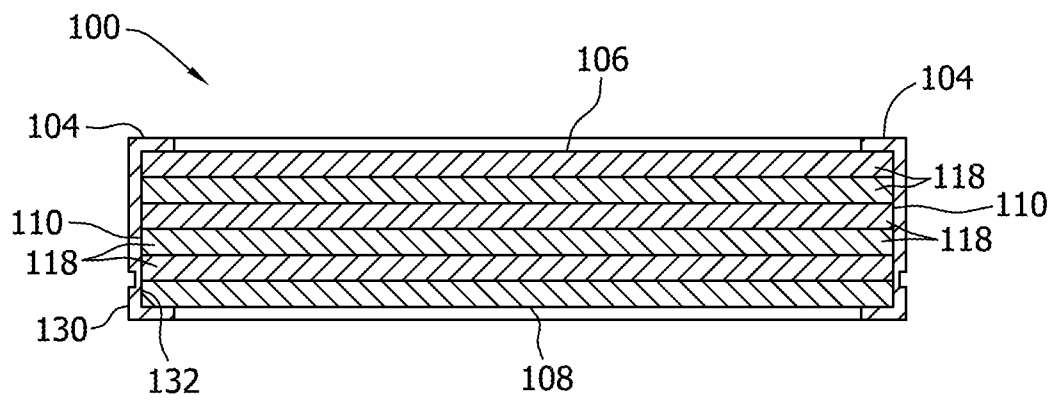


FIG. 2

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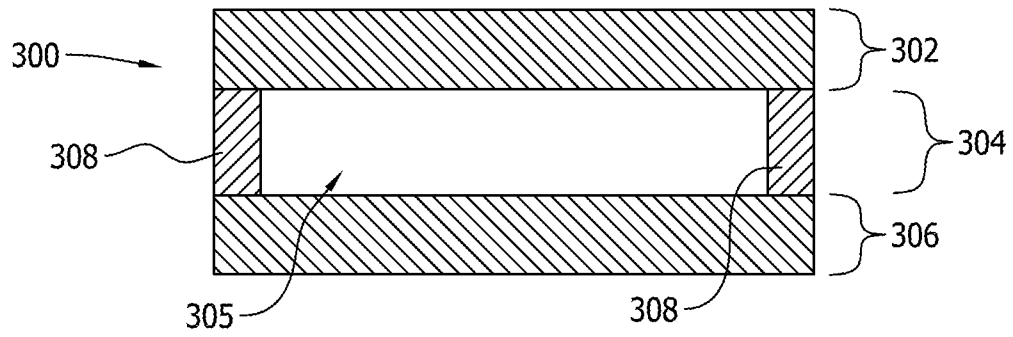


FIG. 3

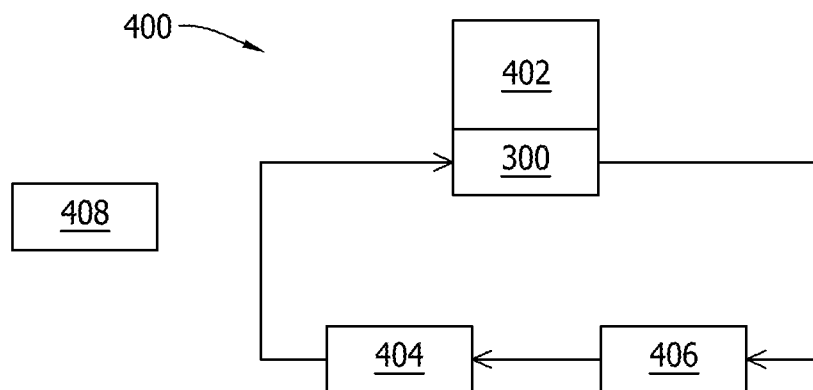


FIG. 4

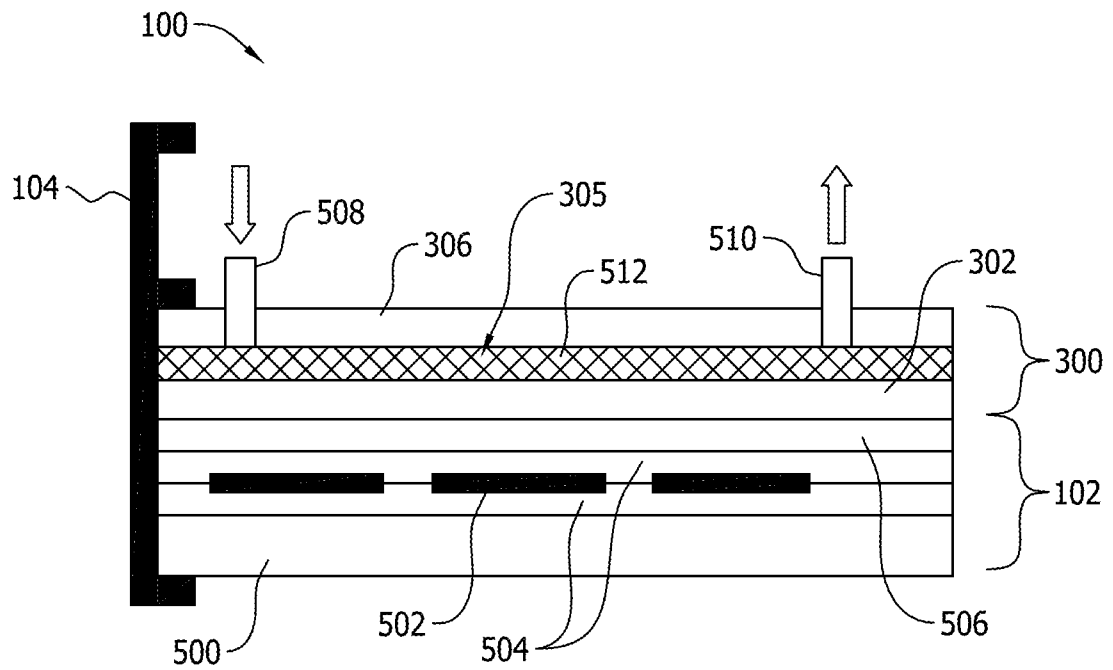


FIG. 5

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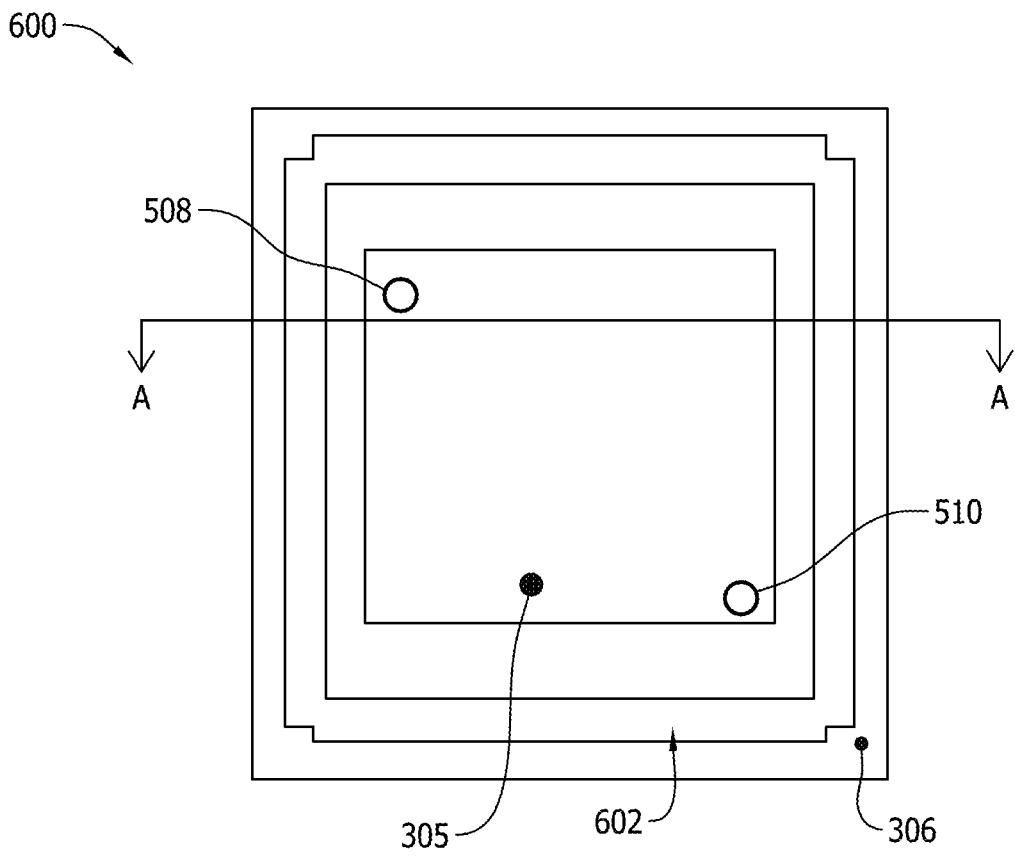


FIG. 6

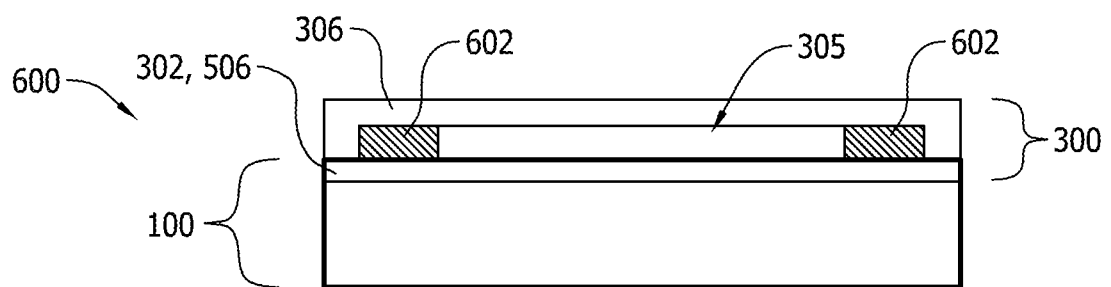


FIG. 7

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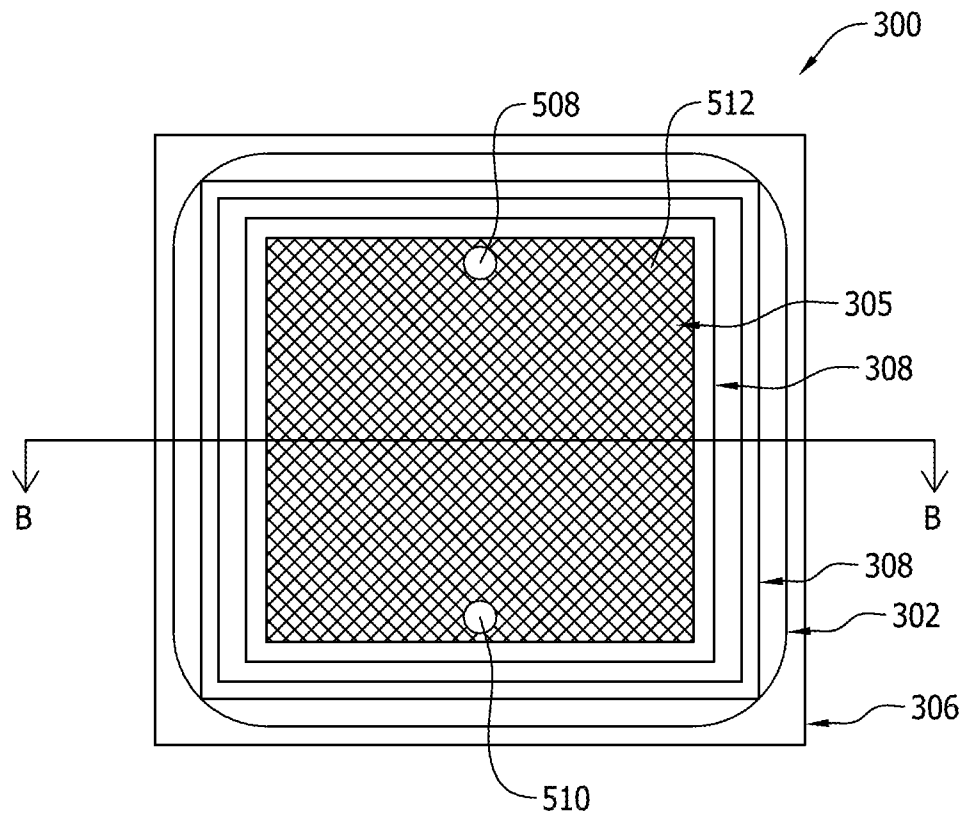


FIG. 8

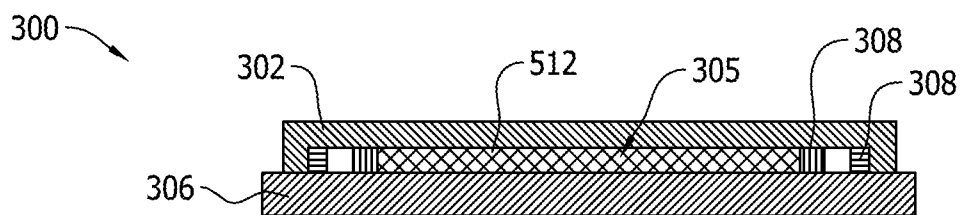


FIG. 9

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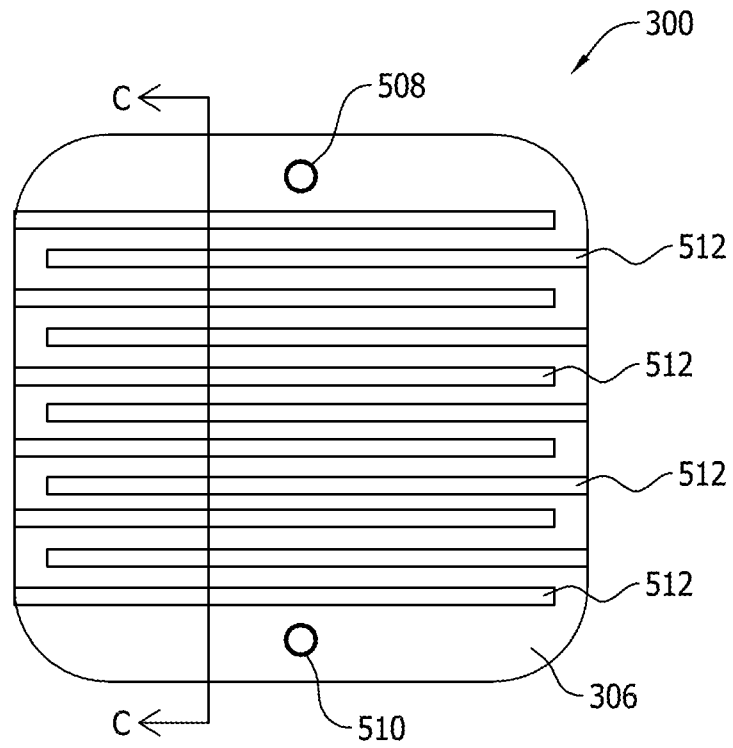


FIG. 10

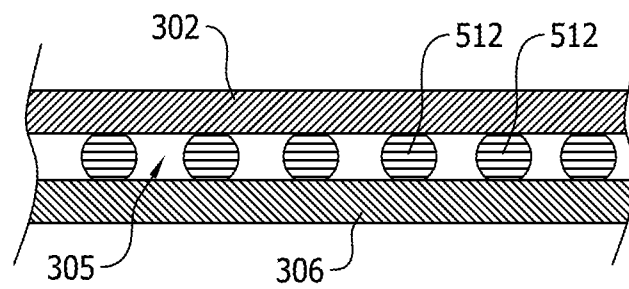


FIG. 11

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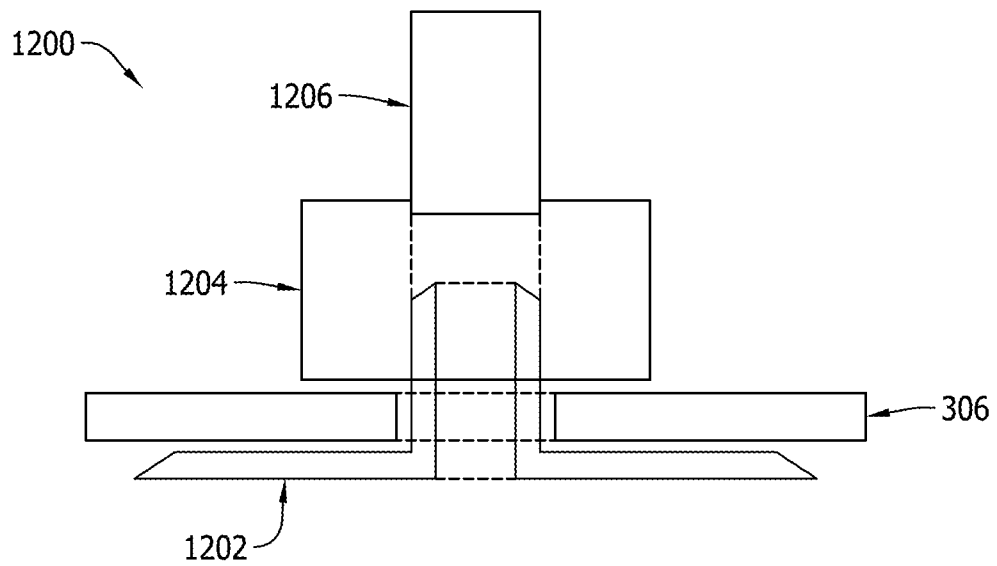


FIG. 12

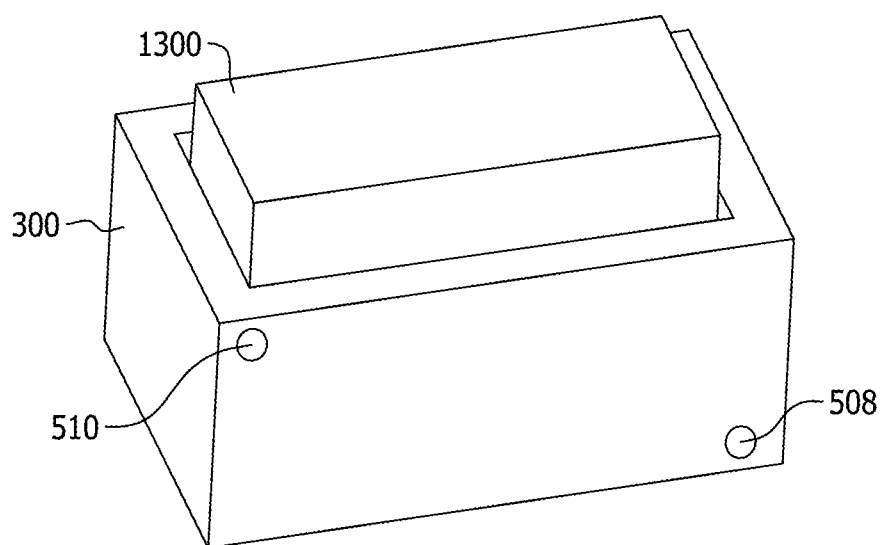


FIG. 13

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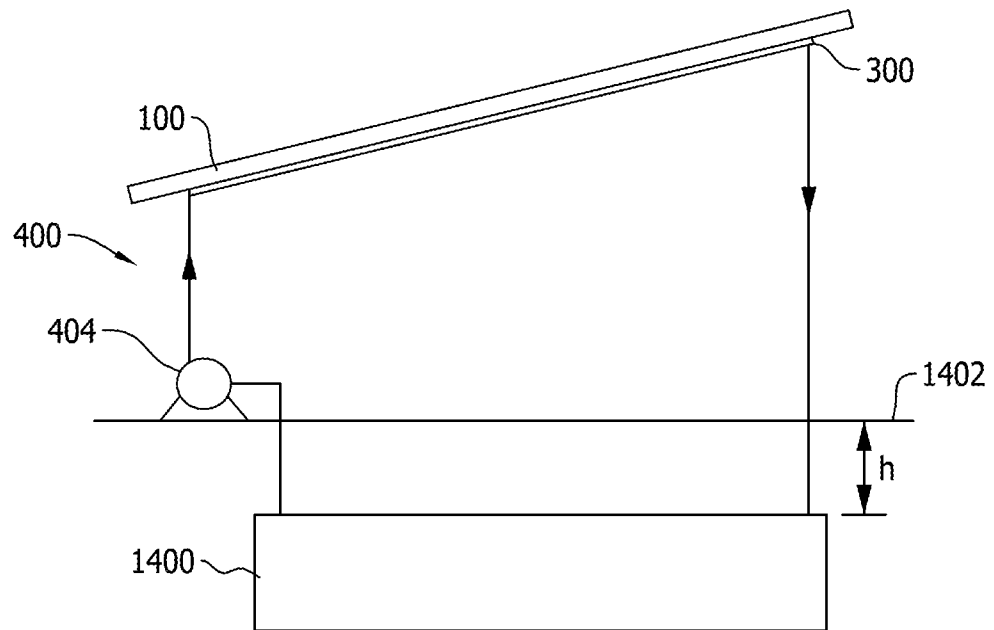


FIG. 14

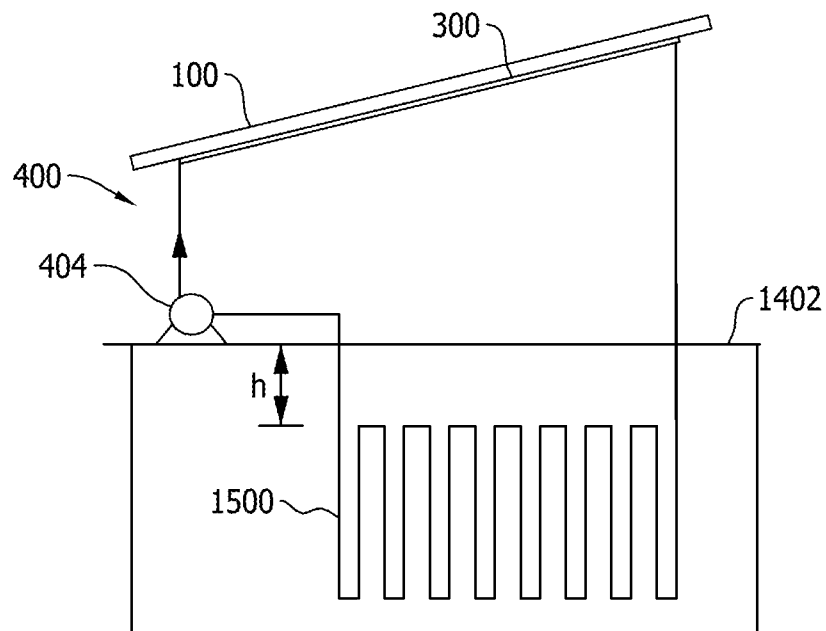


FIG. 15

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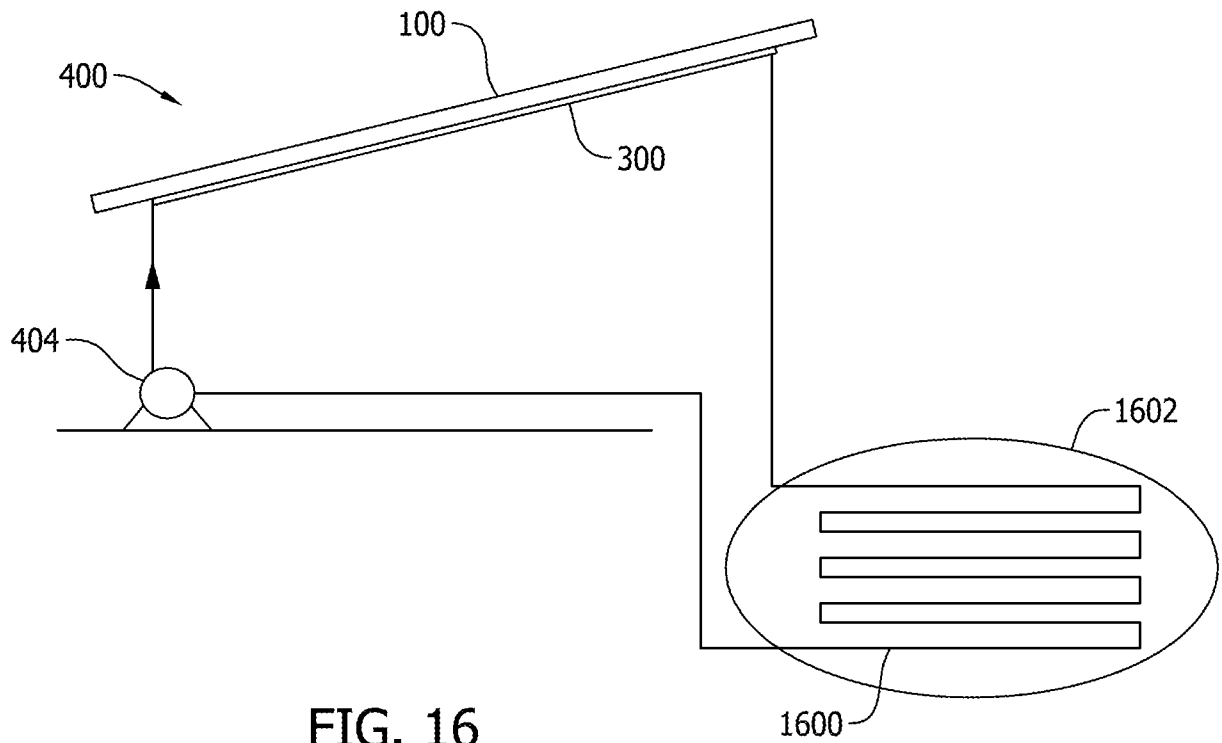


FIG. 16

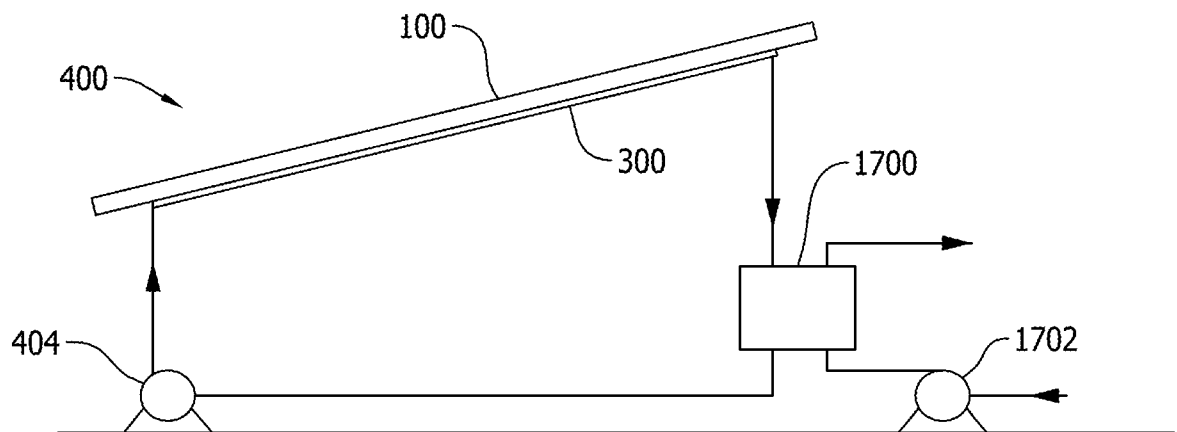


FIG. 17

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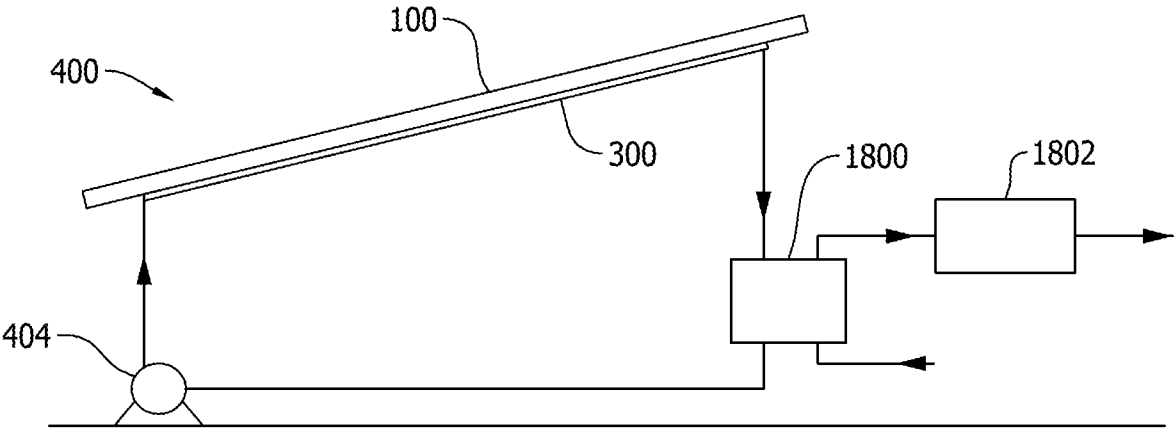


FIG. 18

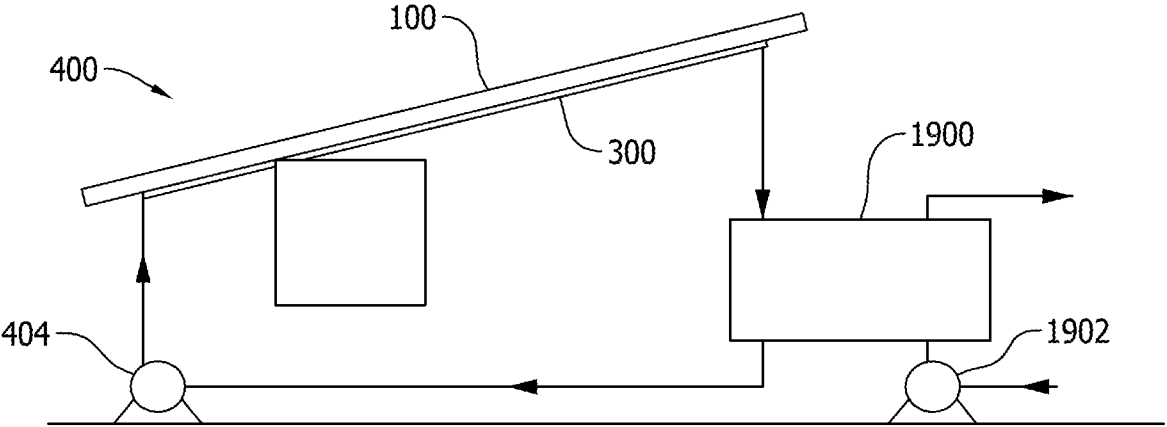


FIG. 19

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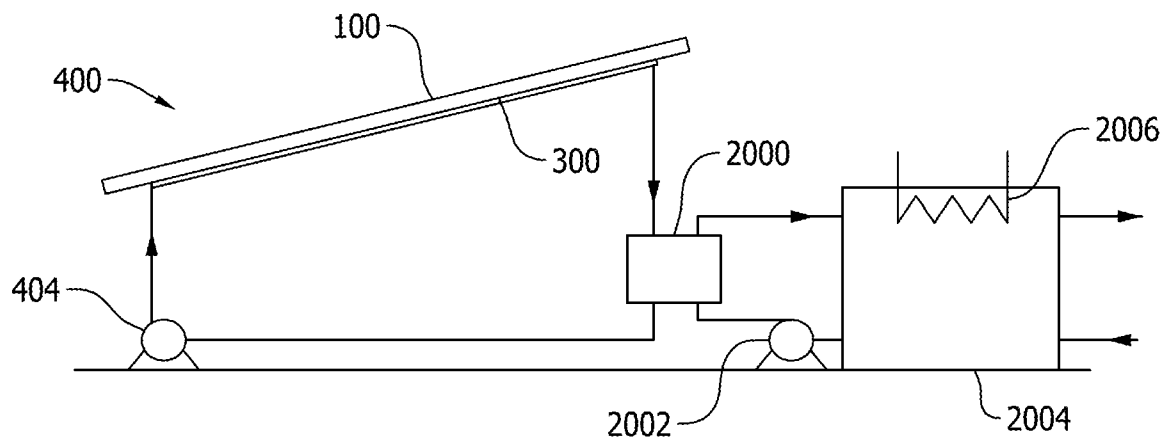


FIG. 20

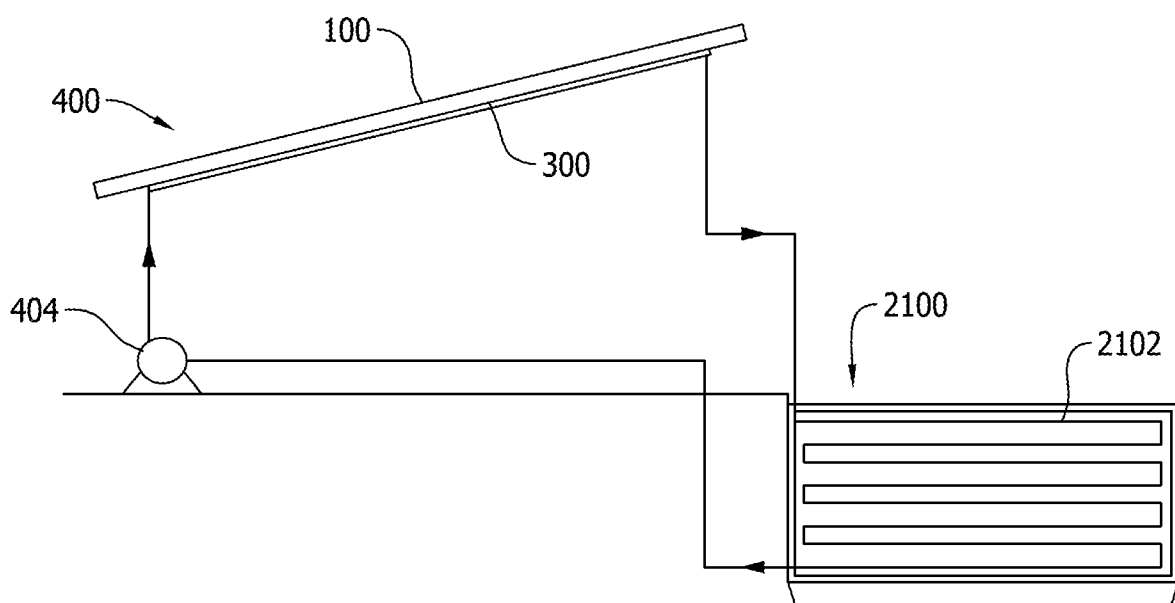


FIG. 21

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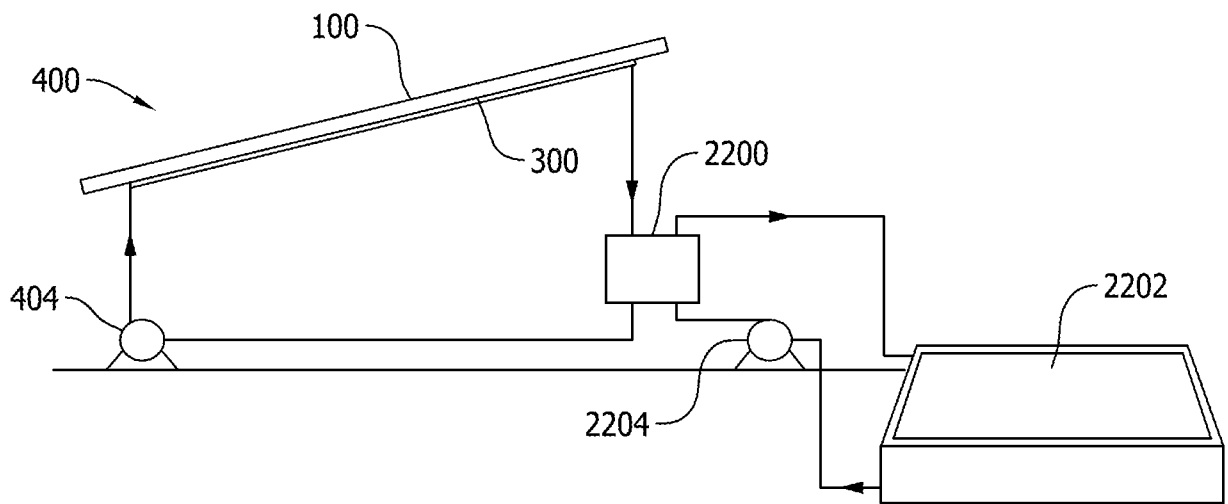


FIG. 22

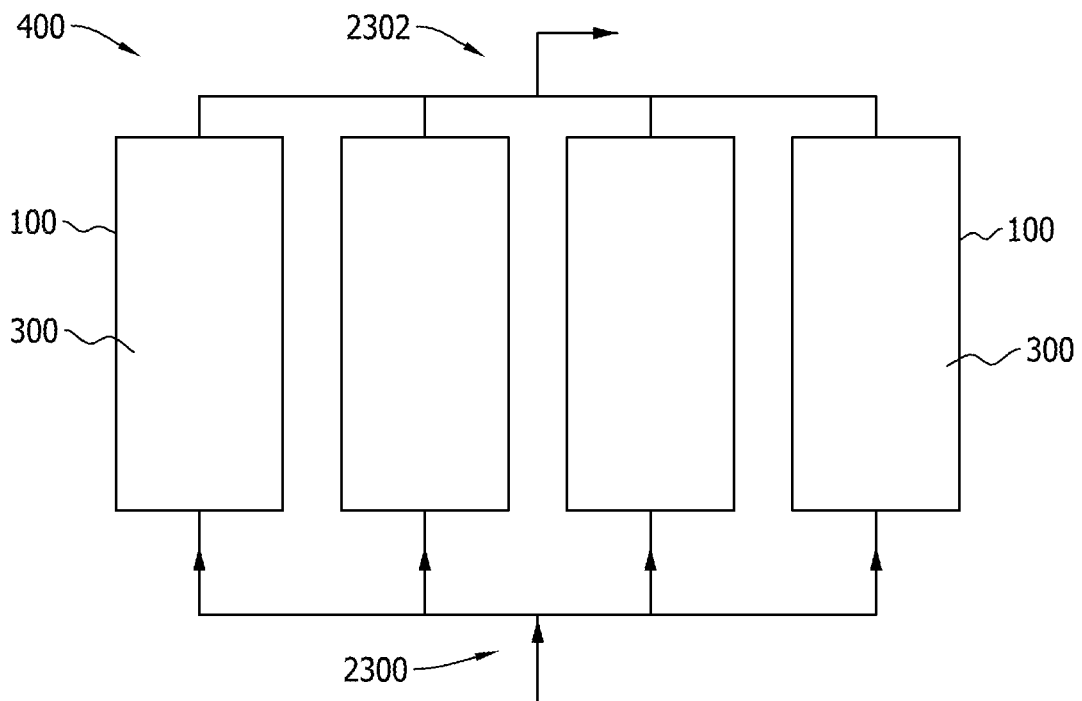


FIG. 23

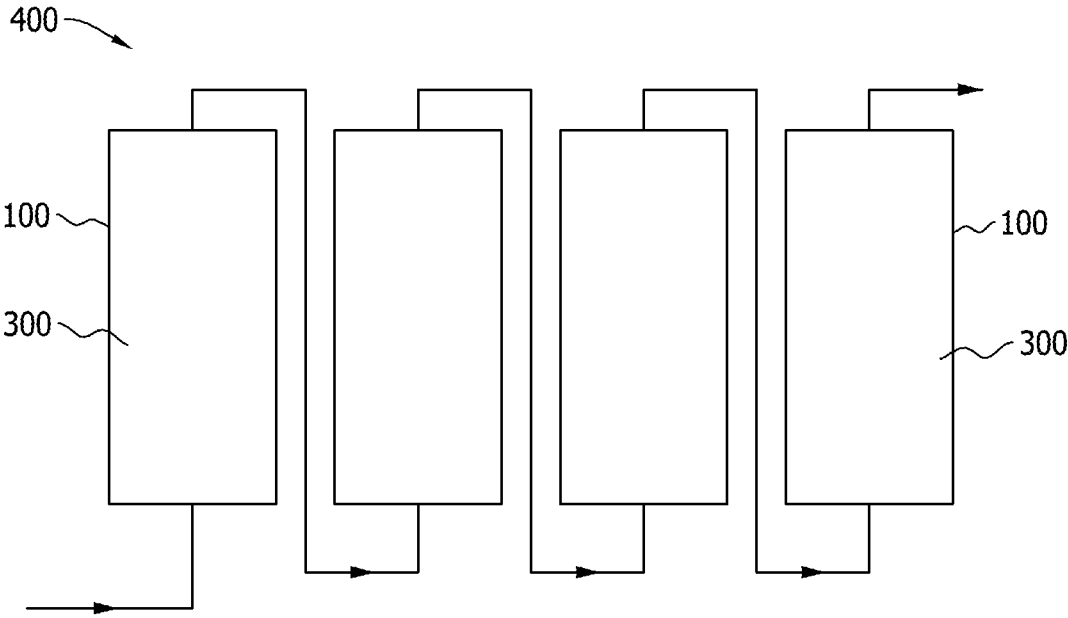


FIG. 24

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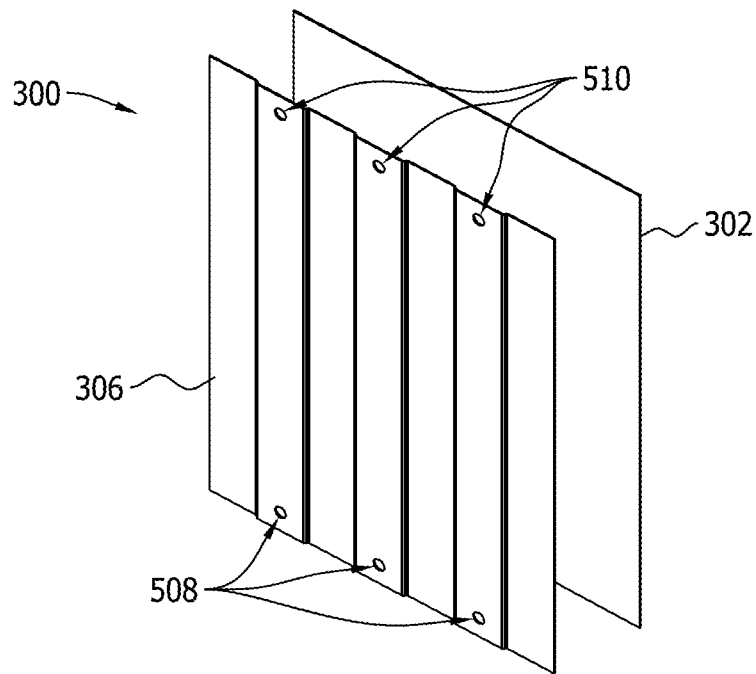


FIG. 25

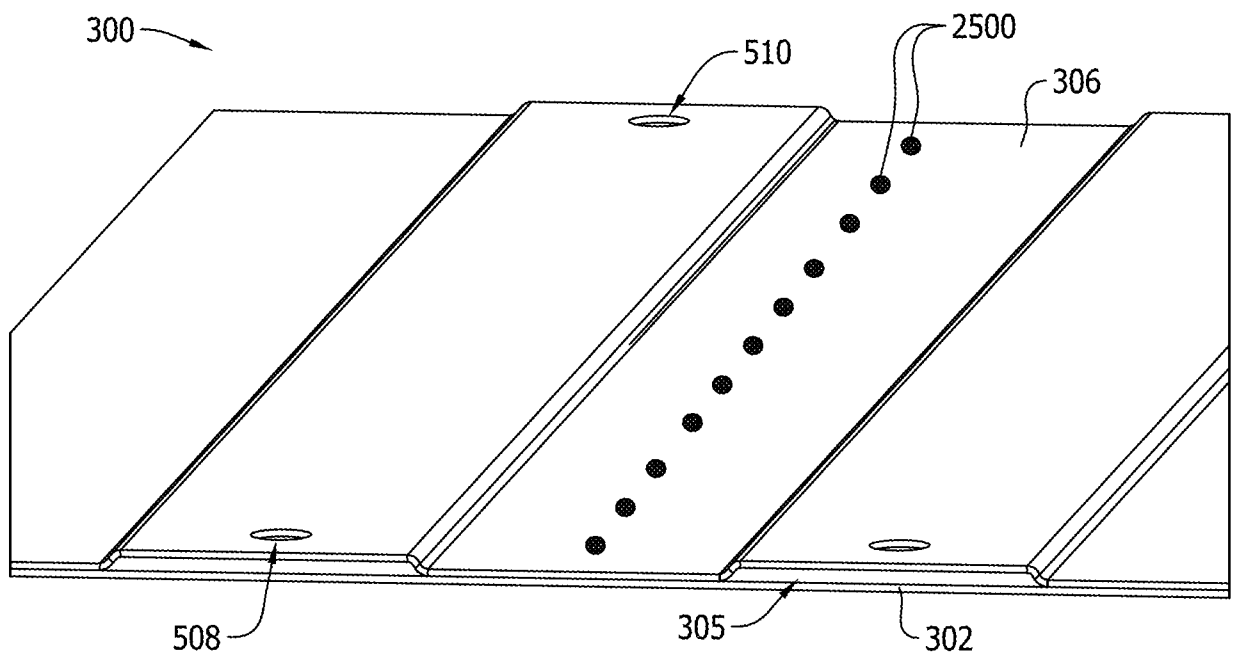


FIG. 26

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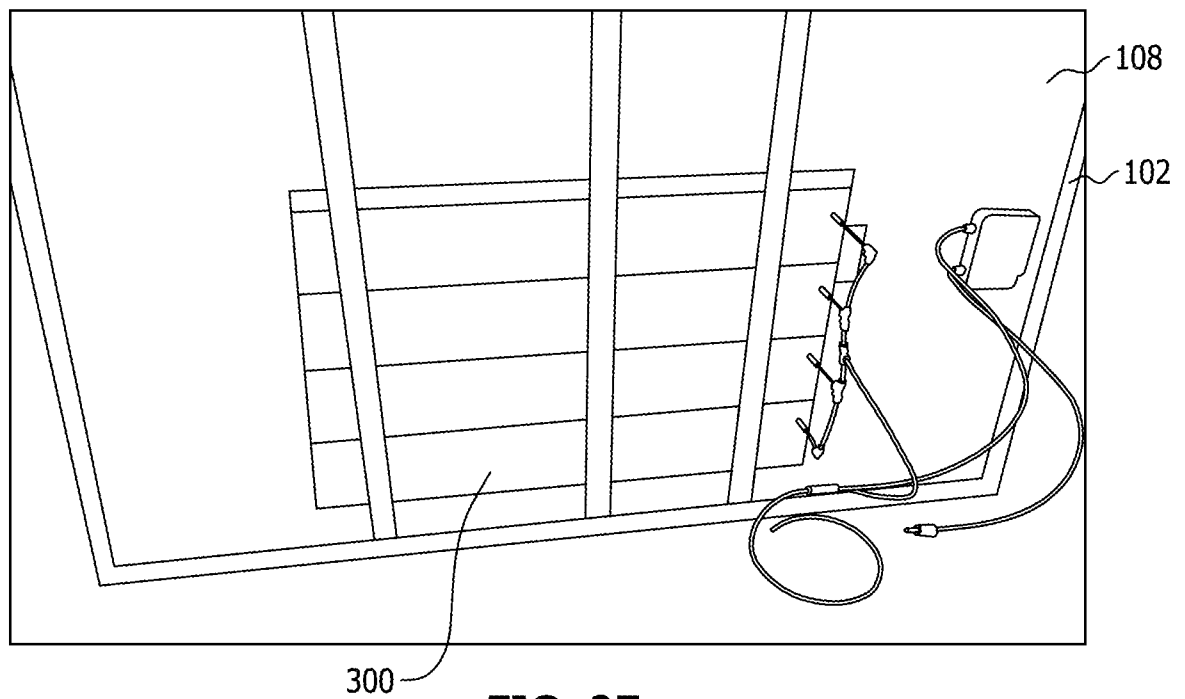


FIG. 27

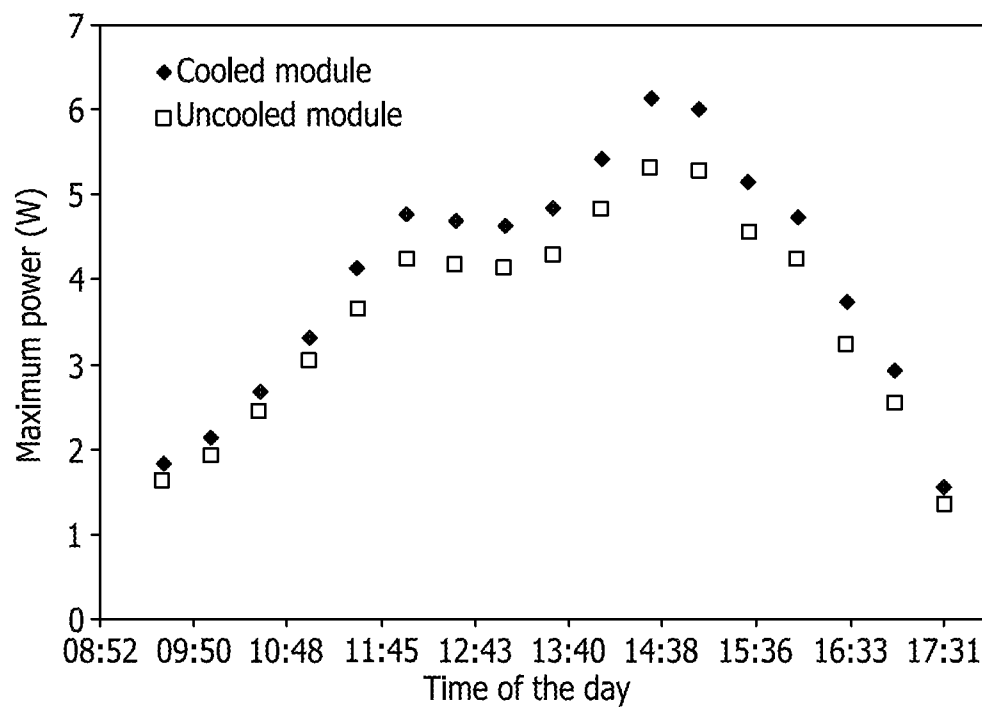


FIG. 28

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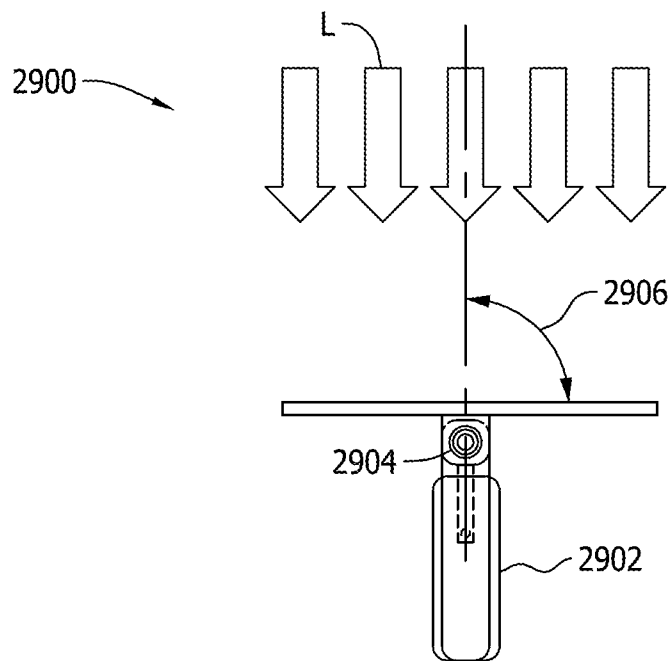


FIG. 29

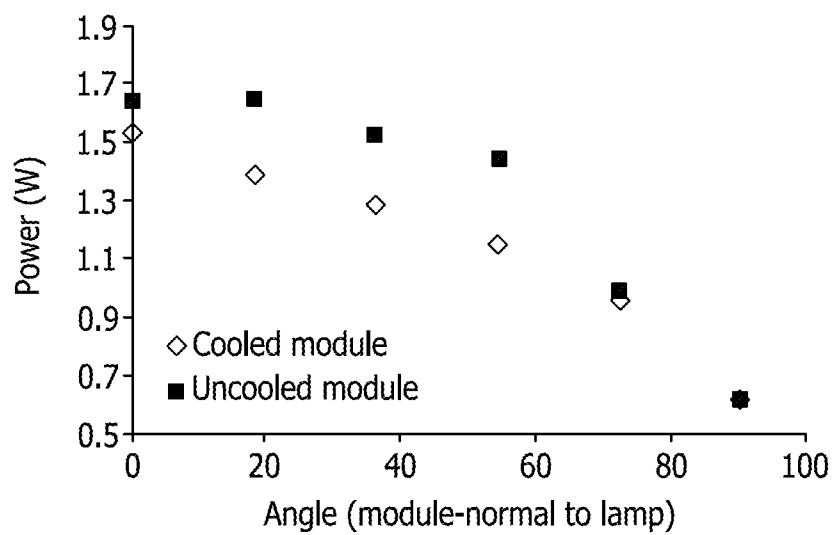


FIG. 30A

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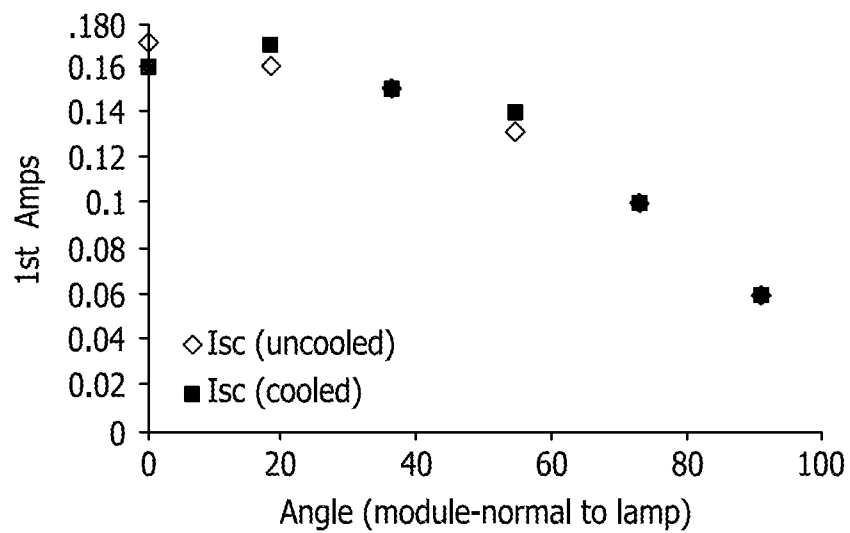


FIG. 30B

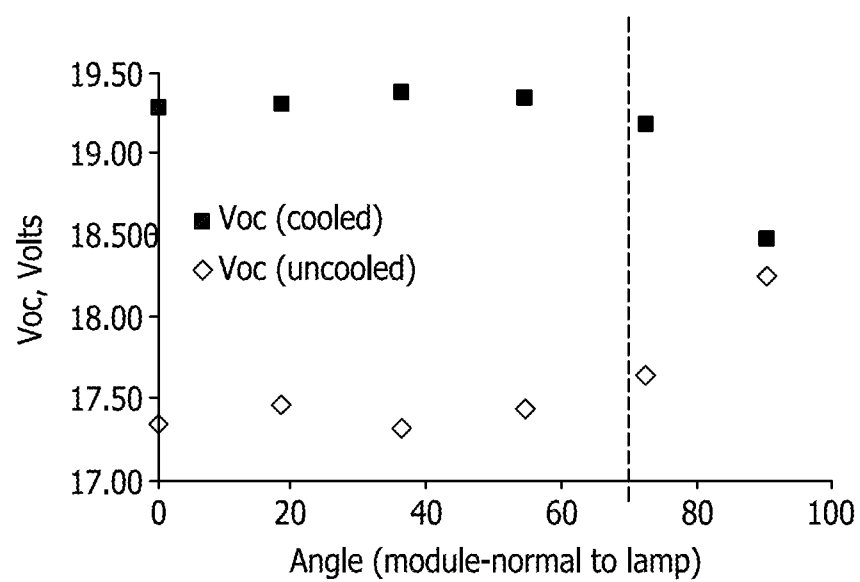


FIG. 30C

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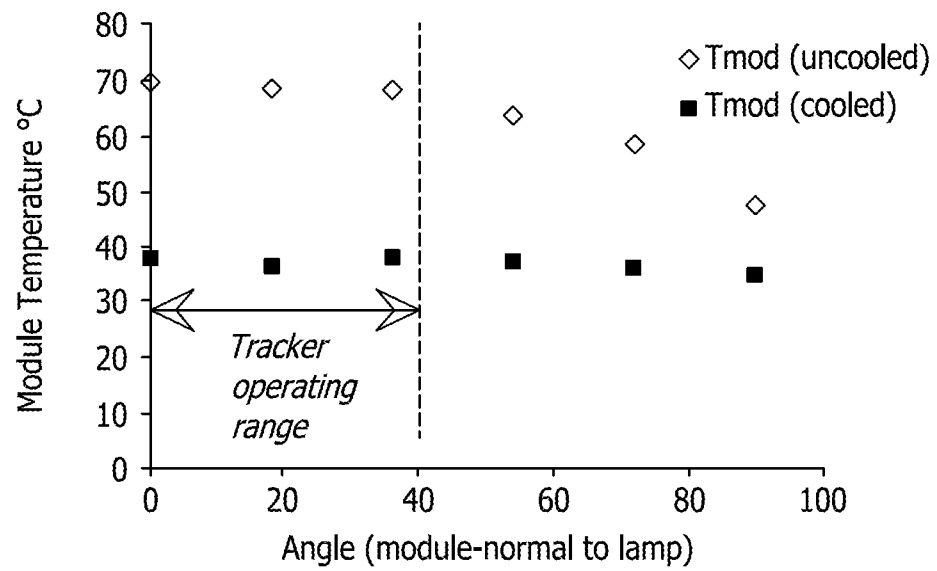


FIG. 30D

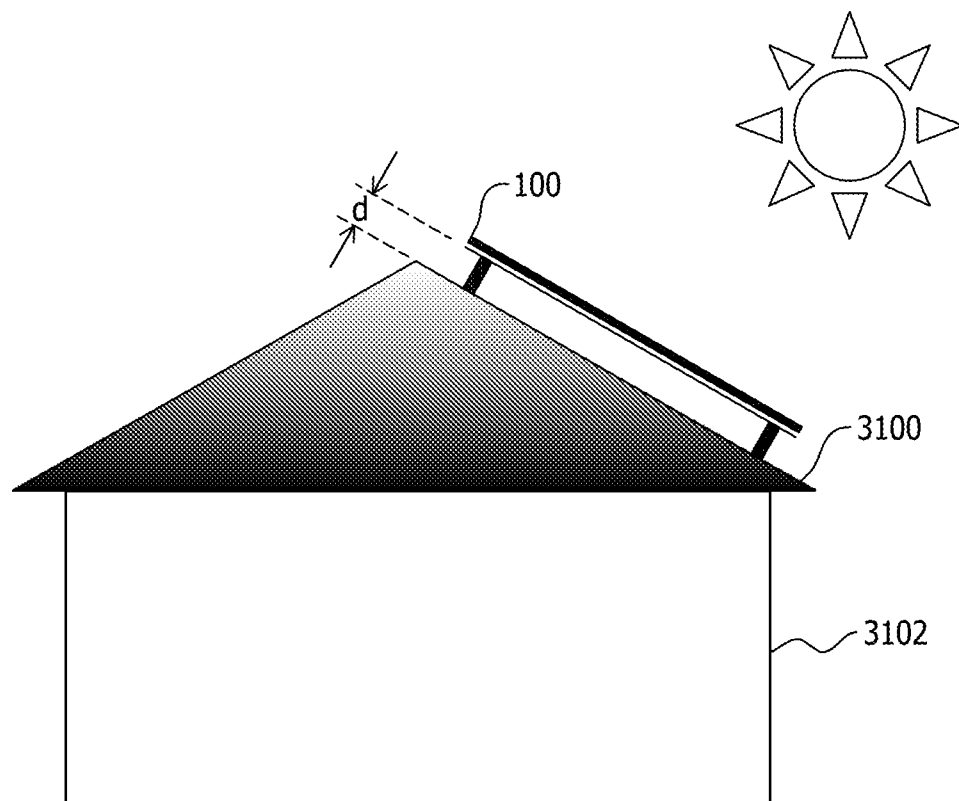


FIG. 31

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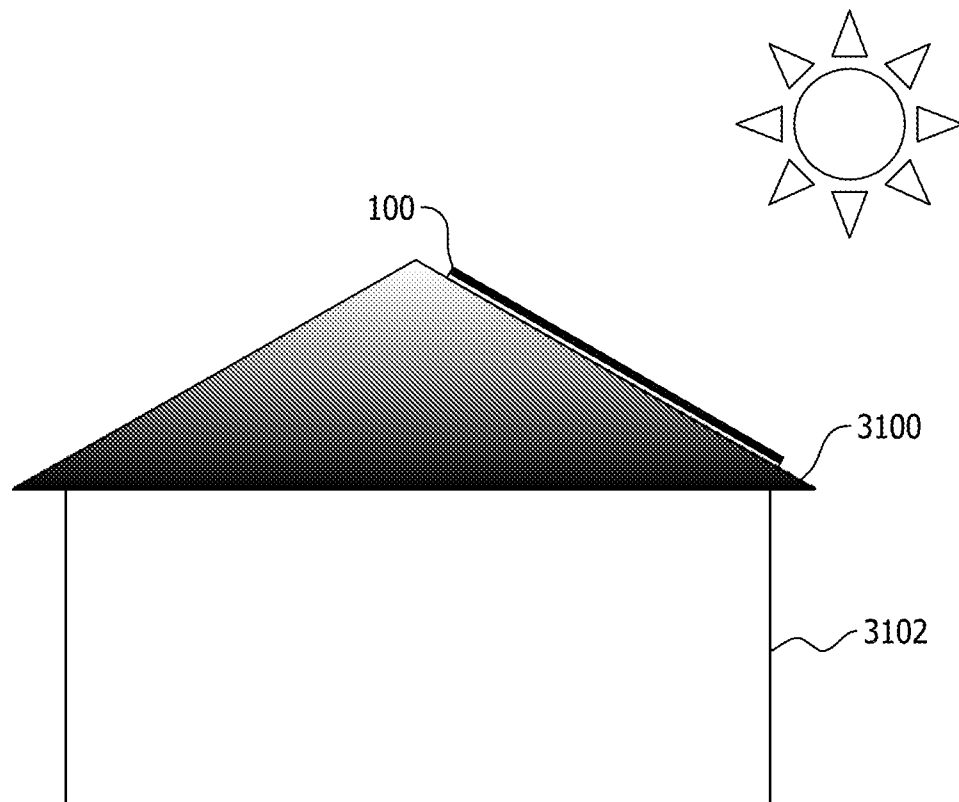


FIG. 32

Height [mm]	Module cooling	Measured temperature [°C]		
		Roof under module	Module	Open roof
0	No	45.9	62	58
0	Yes	41.8	40	59
10	No	41.5	58	58
10	Yes	40.1	38	57
20	No	39.8	52.3	58
20	Yes	37.2	35.4	57

FIG. 33

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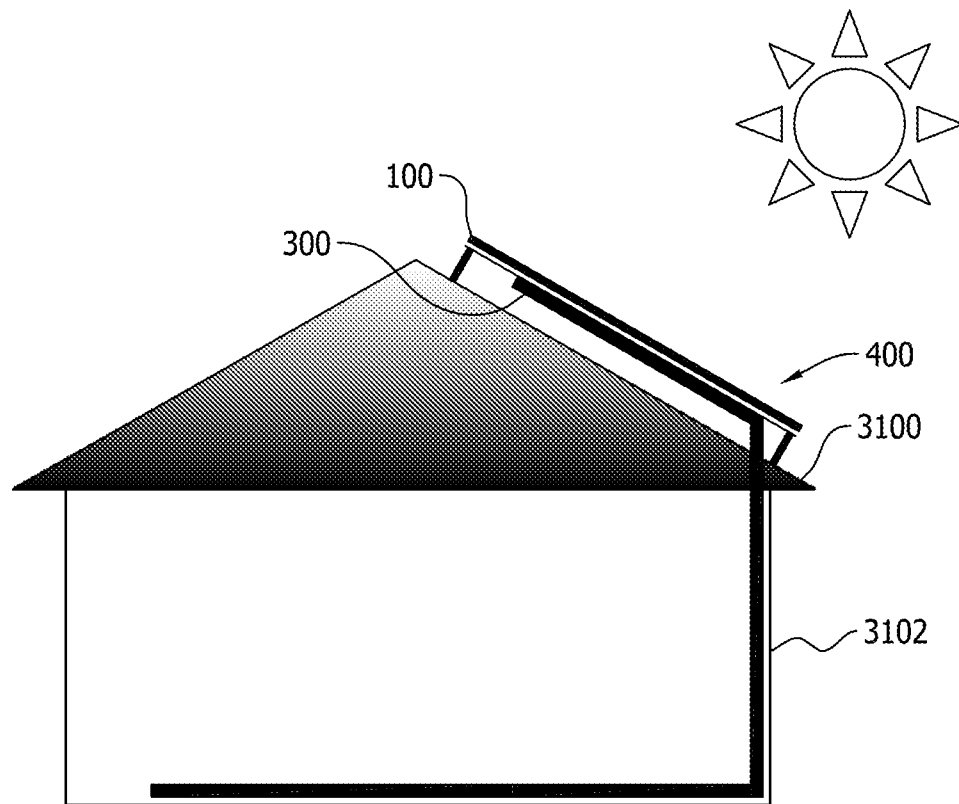


FIG. 34

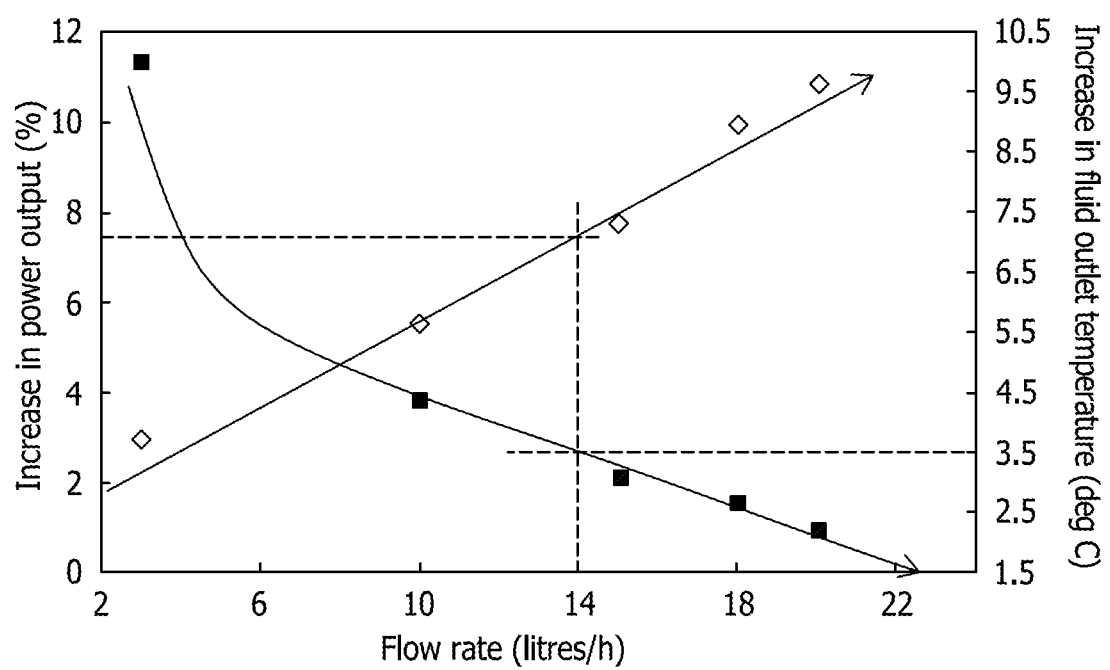


FIG. 35

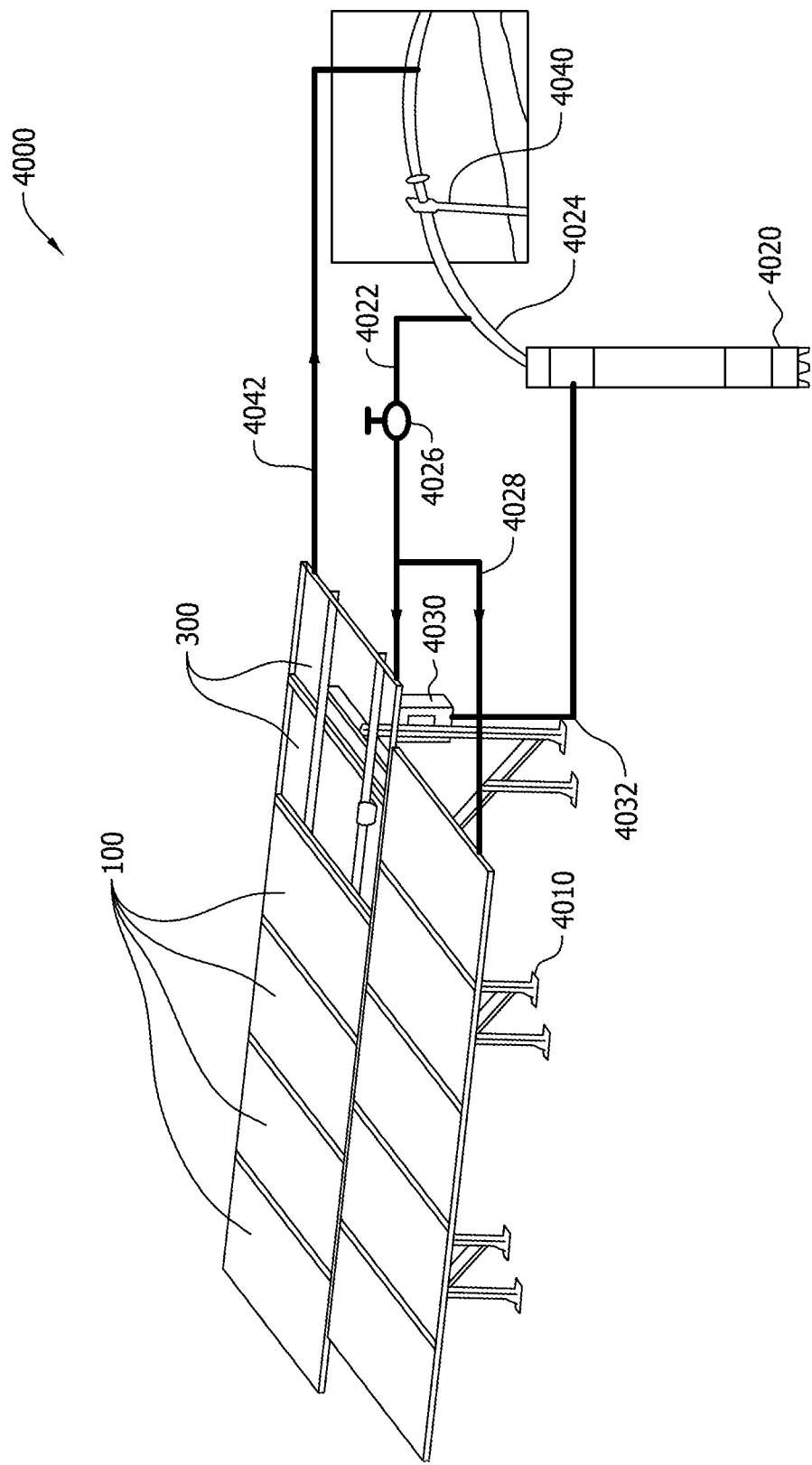


FIG. 36

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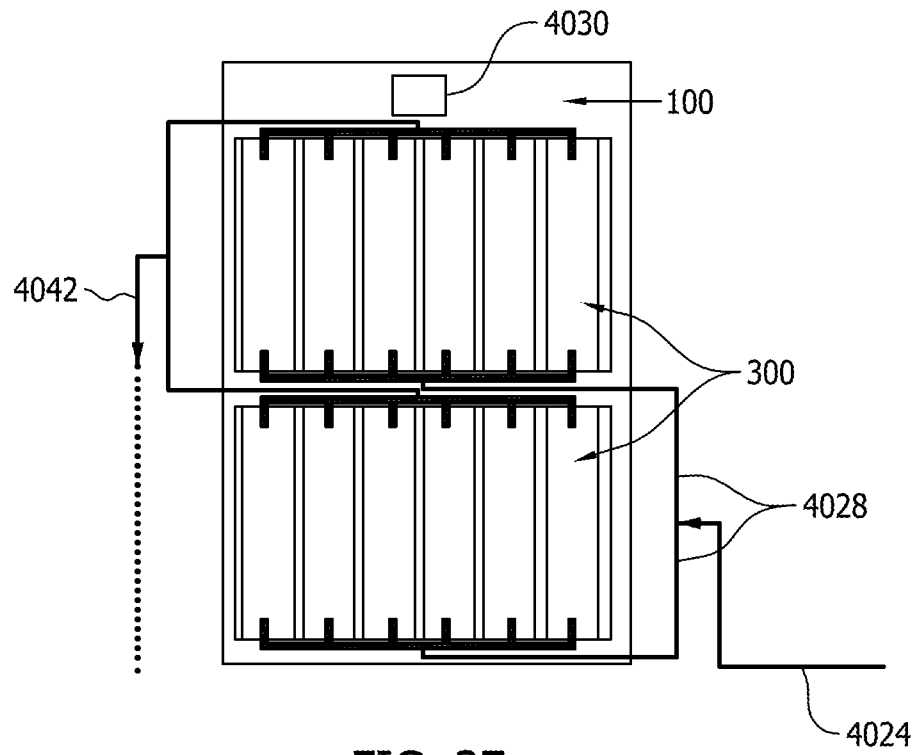


FIG. 37

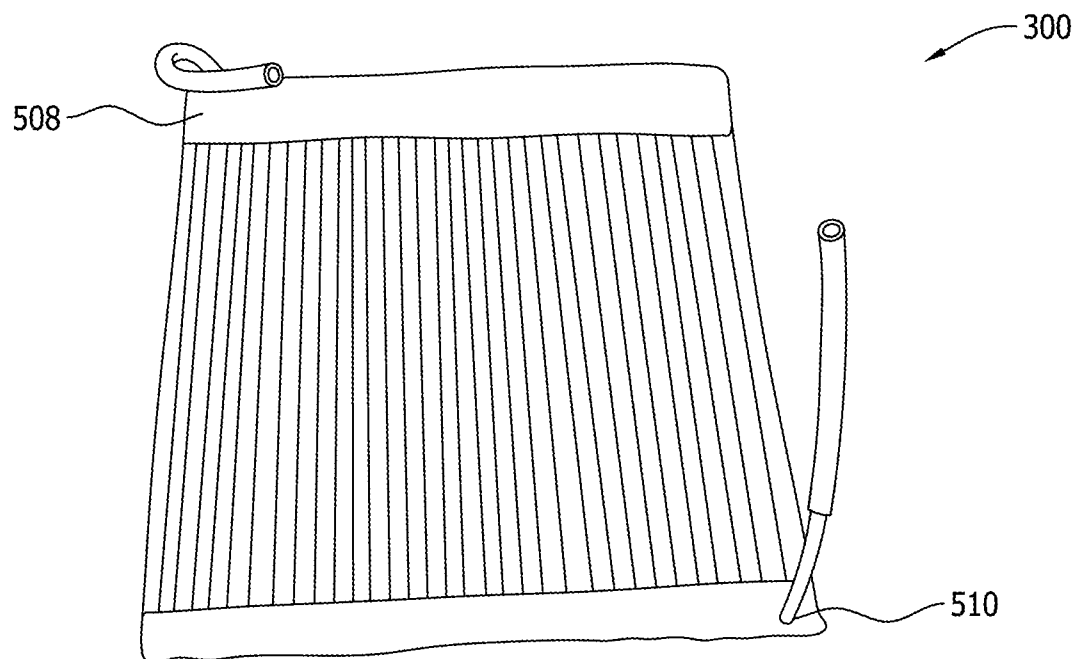


FIG. 38

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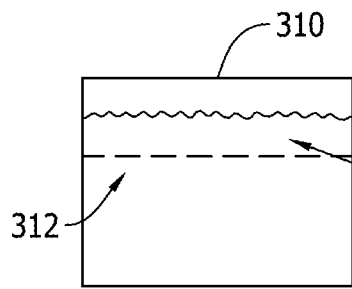


FIG. 40

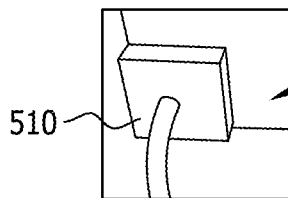


FIG. 41

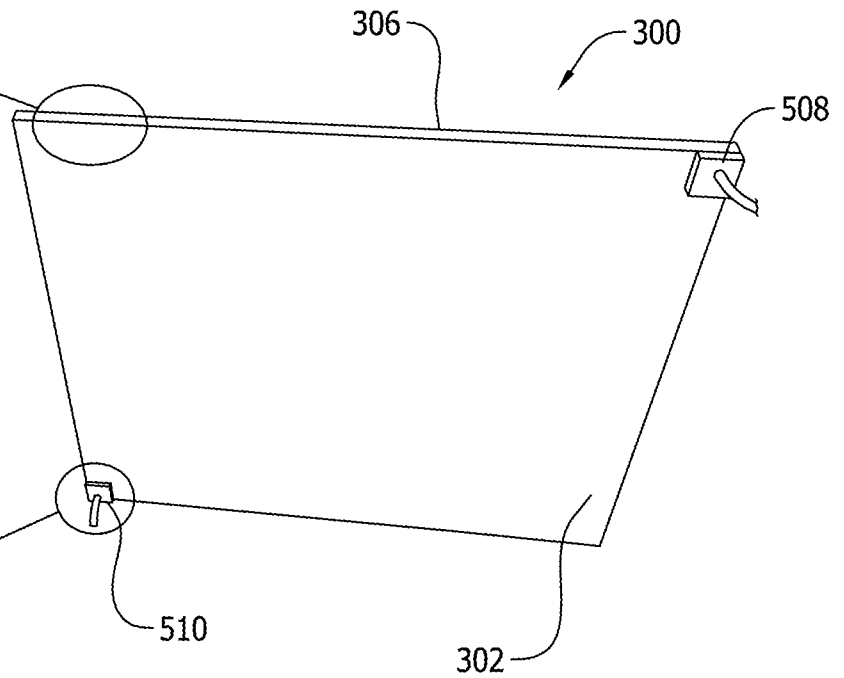


FIG. 39

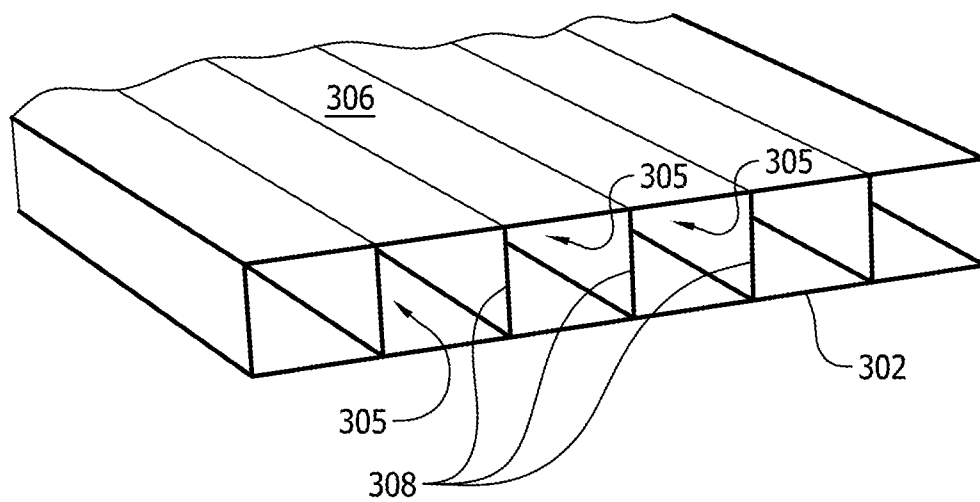


FIG. 42

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/038585

A. CLASSIFICATION OF SUBJECT MATTER
INV. A01G9/24 F04B17/00 H02S40/42
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A01G F04B H02S

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

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

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/011802 A1 (MAYDAN DAN [US]) 20 January 2011 (2011-01-20) paragraphs [0005], [0018], [0026] - [0027], [0035]; claims; figures -----	1-3,5-22
X	US 2012/211409 A1 (DUBOWSKY STEVEN [US] ET AL) 23 August 2012 (2012-08-23) paragraphs [0024], [0027] - [0028], [0040]; claims; figures -----	1-3,5,7, 9,10,13
X	WO 96/08683 A1 (JOHNSON COLIN FRANCIS [NZ]) 21 March 1996 (1996-03-21) page 10, line 32 - page 11, line 18; figures page 21, line 7 - line 14; claims ----- -/--	1,2,6,7, 9



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

25 August 2015

Date of mailing of the international search report

03/09/2015

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Fax: (+31-70) 340-3016

Authorized officer

Oliveira, Casimiro

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/038585

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FR 2 973 985 A1 (NERGY B [FR]) 19 October 2012 (2012-10-19) page 10, line 25 - page 13, line 14 page 14, line 1 - page 15, line 4; figures -----	1-3,6-8, 14,15, 18-22
Y	JP S57 186074 A (MATSUSHITA ELECTRIC IND CO LTD) 16 November 1982 (1982-11-16) abstract; figures -----	1-3,6-8, 14,15, 18-22

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2015/038585

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