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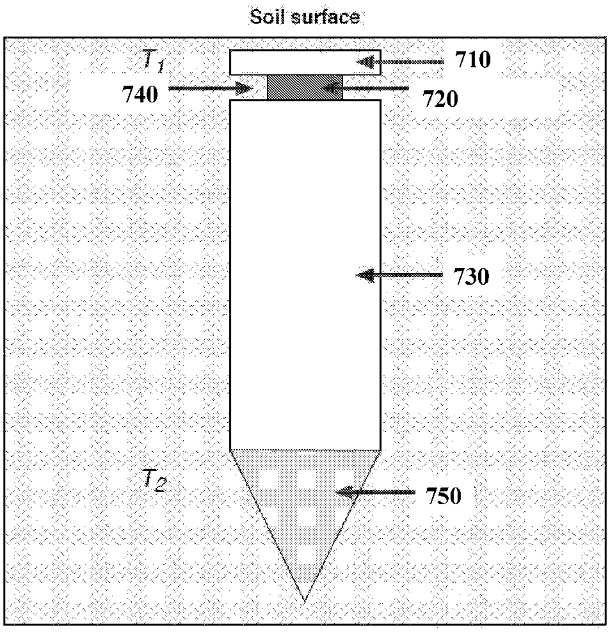

FIG. 7

(57) Abstract: The present disclosure provides a thermoelectric system comprising a first heat exchanger, a heat conducting unit, a thermoelectric generator, and a second heat exchanger. The present disclosure also provides a method for generating power comprising providing a thermoelectric system comprising a first heat exchanger, a heat conducting unit, a thermoelectric generator, and a second heat exchanger; using the thermoelectric generator to generate power; and directing the power to an energy storage system or an electrical load.

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THERMOELECTRIC SYSTEMS, METHODS, AND DEVICES

CROSS-REFERENCE

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/746,175, filed on October 16, 2018, and U.S. Provisional Patent Application No. 62/861,833, filed on June 14, 2019, each of which is entirely incorporated herein by reference.

BACKGROUND

[0002] Over 15 Terawatts of heat is lost to the environment annually around the world by heat engines that require petroleum as their primary fuel source. This is because these engines only convert about 30 to 40% of petroleum's chemical energy into useful work. Waste heat generation is an unavoidable consequence of the second law of thermodynamics.

[0003] The term "thermoelectric effect" encompasses the Seebeck effect, Peltier effect and Thomson effect. Solid-state cooling and power generation based on thermoelectric effects typically employ the Seebeck effect or Peltier effect for power generation and heat pumping. The utility of such conventional thermoelectric devices is, however, typically limited by their low coefficient-of-performance (COP) (for refrigeration applications) or low efficiency (for power generation applications).

[0004] Thermoelectric device performance may be captured by a so-called thermoelectric figure-of-merit, $Z = S^2 \sigma / k$, where 'S' is the Seebeck coefficient, 'σ' is the electrical conductivity, and 'k' is thermal conductivity. Z is typically employed as the indicator of the COP and the efficiency of thermoelectric devices—that is, COP scales with Z. A dimensionless figure-of-merit, ZT, may be employed to quantify thermoelectric device performance, where 'T' can be an average temperature of the hot and the cold sides of the device.

[0005] Applications of conventional semiconductor thermoelectric coolers are rather limited, as a result of a low figure-of-merit, despite many advantages that they provide over other refrigeration technologies. In cooling, low efficiency of thermoelectric devices made from conventional thermoelectric materials with small figure-of-merit limits their applications in providing efficient thermoelectric cooling.

SUMMARY

[0006] Provided herein is a thermoelectric system for generating power through the temperature difference between two environments, such as, for example, a location below a surface (e.g., soil) and a location above a surface (e.g., air).

[0007] In an aspect, a thermoelectric system comprises a first heat exchanger configured for placement below a ground surface, wherein the first heat exchanger is configured to collect or dissipate thermal energy to a location below the ground surface; a heat conducting unit coupled to the first heat exchanger, wherein the heat conducting unit has a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters; a thermoelectric generator comprising a plurality of thermoelectric elements, wherein the thermoelectric generator is coupled to and in thermal communication with the heat conducting unit; a second heat exchanger coupled to and in thermal communication with the thermoelectric generator, wherein the second heat exchanger is configured to collect or dissipate the thermal energy to a location above the ground surface; and a thermally conductive adhesive disposed between the thermoelectric generator and the heat conducting unit, wherein the thermally conductive adhesive has a thermal conductivity of at least 0.5 Watts/meter-Kelvin (W/m-K) at a temperature of 25°C.

[0008] In some embodiments, the heat conducting unit has a length (L) of at least 0.5 meters and a cross-section (C) of at least 0.05 square meters. In some embodiments, the thermoelectric system further comprises an additional thermally conductive adhesive disposed between the thermoelectric generator and the second heat exchanger. In some embodiments, the additional thermally conductive adhesive has a thermal conductivity of at least 0.5 W/m-K at a temperature of 25°C. In some embodiments, the thermoelectric generator has a thermal resistance of at least 1 Kelvins/Watt (K/W). In some embodiments, the thermoelectric generator has a thermal resistance of at least 3 K/W. In some embodiments, the thermoelectric generator has a thermal resistance of at least 5 K/W.

[0009] In some embodiments, the thermoelectric system further comprises one or more sensors powered by the thermoelectric generator. In some embodiments, the one or more sensors measure one or more environment parameters. In some embodiments, the one or more environment parameters comprise temperature, humidity, luminance, wind direction, wind speed, pH level, carbon dioxide concentration, moisture, and chemical composition. In some embodiments, the thermoelectric system comprises a converter. In some embodiments, the converter is a boost converter. In some embodiments, the thermoelectric system further comprises a server, wherein the one or more environment parameters are uploaded to the server. In some embodiments, the thermoelectric system further comprises an energy storage system in electrical communication with the thermoelectric generator, wherein the energy storage system is configured to store electrical energy generated by the thermoelectric generator.

[0010] In an aspect, a method for generating power comprises providing a thermoelectric system comprising (i) a first heat exchanger positioned below a ground surface and configured to collect or dissipate thermal energy to a location below the ground surface; (ii) a heat conducting unit coupled to the first heat exchanger, wherein the heat conducting unit has a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters; (iii) a thermoelectric generator comprising a plurality of thermoelectric elements, wherein the thermoelectric generator is coupled to and in thermal communication with the heat conducting unit; (iv) a second heat exchanger coupled to and in thermal communication with the thermoelectric generator, wherein the second heat exchanger is configured to collect or dissipate the thermal energy to a location above the ground surface; and (v) a thermally conductive adhesive disposed between the thermoelectric generator and the heat conducting unit, wherein the thermally conductive adhesive has a thermal conductivity of at least 0.5 W/m-K at a temperature of 25°C; using the thermoelectric generator to generate power upon flow of the thermal energy (i) from the first heat exchanger to the thermoelectric generator, or (ii) from the second heat exchanger to the thermoelectric generator; and directing the power to an energy storage system or an electrical load.

[0011] In some embodiments, the thermoelectric generator further comprises an additional thermally conductive adhesive disposed between the thermoelectric generator and the second heat exchanger. In some embodiments, the additional thermally conductive adhesive has a thermal conductivity of at least 0.5 W/m-K at a temperature of 25°C. In some embodiments, the thermoelectric generator has a thermal resistance of at least 1 K/W. In some embodiments, the thermoelectric generator has a thermal resistance of at least 3 K/W. In some embodiments, the thermoelectric generator has a thermal resistance of at least 5 K/W.

[0012] In another aspect, a system can comprise a first heat exchanger configured to be disposed below a surface. The first heat exchanger can be configured to collect or dissipate thermal energy. The system can also comprise a second heat exchanger configured to be disposed below the first heat exchanger. The second heat exchanger can be configured to collect or dissipate thermal energy. The system can also comprise a thermoelectric module disposed between and thermally coupled to the first heat exchanger and the second heat exchanger. The thermoelectric module can be configured to generate power upon application of a temperature gradient between the first heat exchanger and the second heat exchanger. The system can also comprise one or more sensors electrically coupled to the thermoelectric module and configured to receive power generated by the thermoelectric module and a transmitter configured to transmit data collected by the one or more sensors.

[0013] In some embodiments, the second heat exchanger comprises a point configured to facilitate insertion of the system into the surface.

[0014] In some embodiments, the system comprises insulation disposed between the first heat exchanger and the second heat exchanger.

[0015] In some embodiments, the one or more sensors are configured to measure one or more environmental parameters. In some embodiments, the one or more environmental parameters comprise temperature, humidity, luminance, wind direction, wind speed, pH level, carbon dioxide concentration, moisture, and chemical composition. In some embodiments, the one or more sensors and/or the transmitter are integrated with a thermoelectric device comprising the first heat exchanger, the second heat exchanger and the thermoelectric module. In some embodiments, the one or more sensors and/or the transmitter are external to a thermoelectric device comprising the first heat exchanger, the second heat exchanger and the thermoelectric module.

[0016] In some embodiments, the second heat exchanger comprises an elongated cylinder that is configured to extend at least 5 centimeters below the surface. In some embodiments, the first heat exchanger and the second heat exchanger comprise plates. In some embodiments, the surface is a surface of a body of water, and the system further comprises a buoyancy element.

[0017] Another aspect of the present disclosure provides a method for transmitting data comprising (a) providing a system below a surface, the system comprising: (i) a first heat exchanger; (ii) a second heat exchanger configured to be disposed below the first heat exchanger; (iii) a thermoelectric module disposed between and thermally coupled to the first heat exchanger and the second heat exchanger; (iv) one or more sensors electrically coupled to the thermoelectric module; and (v) a transmitter electrically coupled to the one or more sensors; (b) using the thermoelectric module to generate power upon flow of thermal energy (i) from the first heat exchanger to the second heat exchanger through the thermoelectric generator, or (ii) from the second heat exchanger to the first heat exchanger through the thermoelectric generator; (c) directing at least a portion of the power to the one or more sensors; and (d) transmitting data collected by the one or more sensors using the transmitter.

[0018] Another aspect of the present disclosure provides a non-transitory computer readable medium comprising machine executable code that, upon execution by one or more computer processors, implements any of the methods above or elsewhere herein.

[0019] Another aspect of the present disclosure provides a system comprising one or more computer processors and computer memory coupled thereto. The computer memory comprises machine executable code that, upon execution by the one or more computer processors, implements any of the methods above or elsewhere herein.

[0020] 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.

INCORPORATION BY REFERENCE

[0021] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference. To the extent publications and patents or patent applications incorporated by reference contradict the disclosure contained in the specification, the specification is intended to supersede and/or take precedence over any such contradictory material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings (also “figure” and “FIG.” herein), of which:

[0023] FIG. 1 shows an example of a first heat exchanger coupled to a heat conducting unit;

[0024] FIG. 2 shows an example of insulating material around the heat conducting unit of FIG. 1;

[0025] FIG. 3 shows an example of a partially assembled thermoelectric system placed in a hole in the ground;

[0026] FIG. 4 shows an example of a fully assembled thermoelectric system with a thermoelectric generator and a second heat exchanger placed above the ground;

[0027] FIG. 5 is an example of a power measurement of the thermoelectric system;

[0028] FIG. 6 shows a computer system that is programmed or otherwise configured to implement methods and systems of the present disclosure;

[0029] FIG. 7 shows an example of a thermoelectric system that is disposed underground;

[0030] FIG. 8 is a chart showing test data generated by testing the thermoelectric system of FIG. 7;

[0031] FIG. 9 shows a second example of a thermoelectric system that can be disposed underground; and

[0032] FIG. 10 is an example of a power measurement of the thermoelectric system of FIG. 9.

DETAILED DESCRIPTION

[0033] While various embodiments of the invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions may occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed.

[0034] The term "nanostructure," as used herein, generally refers to structures having a first dimension (e.g., width) along a first axis that is less than about 1 micrometer ("micron") in size. Along a second axis orthogonal to the first axis, such nanostructures can have a second dimension from nanometers or smaller to microns, millimeters or larger. The dimension (e.g., width) may be less than about 1000 nanometers ("nm"), or 500 nm, or 100 nm, or 50 nm, or smaller. Nanostructures can include holes formed in a substrate material. The holes can form a mesh having an array of holes. In other cases, nanostructure can include rod-like structures, such as wires, cylinders or box-like structure. The rod-like structures can have circular, elliptical, triangular, square, rectangular, pentagonal, hexagonal, heptagonal, octagonal or nonagonal, or other cross-sections.

[0035] The term "nanowire," as used herein, generally refers to a wire or other elongate structure having a width or diameter that is less than or equal to about 1000 nm, or 500 nm, or 100 nm, or 50 nm, or smaller.

[0036] The term "n-type," as used herein, generally refers to a material that is chemically doped ("doped") with an n-type dopant. For instance, silicon can be doped n-type using phosphorous or arsenic.

[0037] The term "p-type," as used herein, generally refers to a material that is doped with a p-type dopant. For instance, silicon can be doped p-type using boron or aluminum.

[0038] The term "metallic," as used herein, generally refers to a substance exhibiting metallic properties. A metallic material can include one or more elemental metals.

[0039] The term "adjacent" or "adjacent to," as used herein, includes 'next to', 'adjoining', 'in contact with', and 'in proximity to'. In an example, a first unit adjacent to a second unit is directly in contact with the second unit. As another example, the first unit is adjacent to the second unit with one or more intervening units between the first unit and the second unit.

[0040] Whenever the term "at least," "greater than," or "greater than or equal to" precedes the first numerical value in a series of two or more numerical values, the term "at least," "greater than" or "greater than or equal to" applies to each of the numerical values in that series of numerical values. For example, greater than or equal to 1, 2, or 3 is equivalent to greater than or equal to 1, greater than or equal to 2, or greater than or equal to 3.

[0041] Whenever the term “no more than,” “less than,” or “less than or equal to” precedes the first numerical value in a series of two or more numerical values, the term “no more than,” “less than,” or “less than or equal to” applies to each of the numerical values in that series of numerical values. For example, less than or equal to 3, 2, or 1 is equivalent to less than or equal to 3, less than or equal to 2, or less than or equal to 1.

Thermoelectric systems

[0042] In an aspect, a thermoelectric system may comprise a first heat exchanger, a heat conducting unit, and a thermoelectric generator. The system may further include a second heat exchanger. A thermally conductive material may be provided between the thermoelectric generator and the second heat exchanger. The thermally conductive material may be a thermally conductive adhesive.

[0043] The first heat exchanger may be configured for placement below a surface. The surface may be a ground surface or a water surface. In some examples, the first heat exchanger is configured for placement below the ground surface. The distance between the first heat exchanger and the surface may be at least about 1 meter (“m”), 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the first heat exchanger and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m, or less.

[0044] The first heat exchanger may be configured to collect or dissipate thermal energy to a location below the surface. The first heat exchanger may be configured to collect thermal energy from or dissipate thermal energy to a location below the ground surface. For example, depending on the time of day, a location below ground may be cooler than the ground surface, in which case the first heat exchanger may dissipate thermal energy to the location below ground. As another example, the location below ground may be warmer than the ground surface, in which case the first heat exchanger may collect thermal energy from the location below ground.

[0045] The first heat exchanger may collect thermal energy from a location below the surface. The location below the surface may comprise a heat source. The distance between the surface and the heat source may be at least about 1 meter (“m”), 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the heat source and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m, or less.

[0046] The first heat exchanger may dissipate thermal energy to the location below the surface. The distance between the surface and the location below the surface for dissipating thermal energy may be at least about 1 meter ("m"), 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the location below the surface for dissipating thermal energy and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m, or less.

[0047] If the first heat exchanger collects thermal energy, the first heat exchanger may provide the heat to adjacent components (e.g., a heat conducting unit). If the first heat exchanger dissipates thermal energy, the first heat exchanger may expel the thermal energy from adjacent components (e.g., a heat conducting unit). The first heat exchanger can be sufficiently thermally conductive to remove heat from the adjacent components and expel it to the environment.

[0048] The first heat exchanger may comprise one or more heat sinks. The first heat exchanger may be coupled to one or more heat sinks. The heat sink can aid in collecting or dissipating heat. A heat sink can include one or more heat fins which can be sized and arranged to provide increase heat transfer area. A heat sink may be any flexible material, which can be sufficiently thermally conductive to provide low internal thermal resistance and sufficiently thin to bend in a flexible manner. The heat sink may be any design, shape, and/or size. The heat sink can be within or in contact with a matrix. The matrix can be a polymer foil, elastomeric polymer, ceramic foil, semiconductor foil, insulator foil, insulated metal foil or combinations thereof. To increase the surface area presented to the environment for effective thermal transfer, the matrix may be patterned with dimples, corrugations, pins, fins or ribs.

[0049] The heat sink may be formed of electrically insulating material, which can be sufficiently thin (e.g., thickness from about 0.01 millimeter to 1 millimeter) to present a low thermal resistance (e.g., thermal resistance of at most 1 Kelvin/Watt (K/W)). Examples of the insulating material include polymer foil (e.g., polyethylene, polypropylene, polyester, polystyrene, polyimide, etc.); elastomeric polymer foil (e.g., polydimethylsilazane, polyisoprene, natural rubber, etc.); fabric (e.g., conventional cloths, fiberglass mat, etc.); ceramic, semiconductor, or insulator foil (e.g., glass, silicon, silicon carbide, silicon nitride, aluminum oxide, aluminum nitride, boron nitride, etc.); insulated metal foil (e.g., anodized aluminum or titanium, coated copper or steel, etc.); or combinations thereof. The electrically insulating material can be both flexible and stretchable when an elastomeric material is used.

[0050] The first heat exchanger may be of any design, shape, and/or size. The first heat exchanger may comprise one or more heat exchanger components. The heat exchanger components may be any design, shape, and/or size. Examples of possible shapes or designs include but are not limited to: mathematical shapes (e.g., circular, triangular, square, rectangular, pentagonal, or hexagonal), two-dimensional geometric shapes, multi-dimensional geometric shapes, curves, polygons, polyhedral, polytopes, minimal surfaces, ruled surfaces, non-orientable surfaces, quadrics, pseudospherical surfaces, algebraic surfaces, miscellaneous surfaces, riemann surfaces, box-drawing characters, cuisenaire rods, geometric shapes, shapes with metaphorical names, symbols, unicode geometric shapes, other geometric shapes, partial shapes or combination of shapes thereof. The number of heat exchanger components of the first heat exchanger may be at least 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more.

[0051] The heat exchanger components may be plates. The first heat exchanger may comprise at least one metal plate. The first heat exchanger may comprise a plurality of metal plates. The number of metal plates may be 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more. The individual metal plates of the plurality of metal plates may project away from the heat conducting unit along a direction that may be angled with respect to a longitudinal axis of the heat conducting unit. The angle with respect to a longitudinal axis of the heat conducting unit may be at least about 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, or greater. In some cases, the angle with respect to a longitudinal axis of the heat conducting unit may be at most about 90°, 80°, 70°, 60°, 50°, 40°, 30°, 20°, 10°, or less. The individual metal plates of the plurality of metal plates may project away from the heat conducting unit along a direction that may be orthogonal to a longitudinal axis of the heat conducting unit.

[0052] The first heat exchanger may be formed of a metallic (or metal-containing) material. The metallic material may include one or more elemental metals. For example, the metallic material may include one or more of aluminum, titanium, iron, steel, copper, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium and thallium, and their alloys. The first heat exchanger may be formed of a semiconductor-containing material, such as silicon or a silicide. The first heat exchanger may be formed of a polymeric material. The polymeric material may include one or more polymers. For example, the polymeric material may include one or more of polyvinyl chloride, polyvinylidene chloride, polyethylene, polyisobutene, and poly[ethylene-vinylacetate] copolymer. The first heat exchanger may be formed of a composite material. The composite material may include, for example, reinforced plastics, ceramic matrix composites, and metal matrix composites.

[0053] The heat conducting unit may be coupled to the first heat exchanger. The heat conducting unit may be configured for placement adjacent to the first heat exchanger. The heat conducting unit may be formed of a metallic (or metal-containing) material. The metallic material may include one or more elemental metals. For example, the metallic material may include one or more of aluminum, titanium, copper, iron, steel, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium and thallium, and their alloys. The heat conducting unit may be formed of a semiconductor-containing material, such as silicon or a silicide. The heat conducting unit may be formed of a polymeric material. The polymeric material may include one or more polymers. For example, the polymeric material may include one or more of polyvinyl chloride, polyvinylidene chloride, polyethylene, polyisobutene, and poly[ethylene-vinylacetate] copolymer. The heat conducting unit may be formed of a composite material. The composite material may include, for example, reinforced plastics, ceramic matrix composites, and metal matrix composites. The heat conducting unit may comprise a heat pipe, metal or ceramic.

[0054] The heat conducting unit may be any design, shape, and/or size. Examples of possible shapes or designs include but are not limited to: mathematical shapes (e.g., circular, triangular, square, rectangular, pentagonal, or hexagonal), two-dimensional geometric shapes, multi-dimensional geometric shapes, curves, polygons, polyhedral, polytopes, minimal surfaces, ruled surfaces, non-orientable surfaces, quadrics, pseudospherical surfaces, algebraic surfaces, miscellaneous surfaces, riemann surfaces, box-drawing characters, cuisenaire rods, geometric shapes, shapes with metaphorical names, symbols, unicode geometric shapes, other geometric shapes, partial shapes or combination of shapes thereof. The heat conducting unit may be a metal rod. The heat conducting unit may be a heat pipe.

[0055] The heat conducting unit may have a length (L) of at least about 0.1 meters (“m”), 0.2 m, 0.3 m, 0.4 mm, 0.5 m, 0.6 m, 0.7 m, 0.8 m, or greater. In some cases, the heat conducting unit may have a length (L) of at most about 0.8 m, 0.7 m, 0.6 m, 0.5 m, 0.4 m, 0.3 m, 0.2 m, 0.1 m, or less. The heat conducting unit may have a cross-section (C) of at least about 0.01 square meters (“m^2”), 0.02 m^2, 0.03 m^2, 0.04 m^2, 0.05 m^2, 0.06 m^2, 0.07 m^2, 0.08 m^2, 0.09 m^2, 0.1 m^2, 0.2 m^2, 0.3 m^2, 0.4 m^2, 0.5 m^2, 0.6 m^2, 0.7 m^2, 0.8 m^2 or greater. In some cases, the heat conducting unit may have a cross-section (C) of at most about 0.8 m^2, 0.7 m^2, 0.6 m^2, 0.5 m^2, 0.4 m^2, 0.3 m^2, 0.2 m^2, 0.1 m^2, 0.09 m^2, 0.08 m^2, 0.07 m^2, 0.06 m^2, 0.05 m^2, 0.04 m^2, 0.03 m^2, 0.02 m^2, 0.01 m^2, or less. The heat conducting unit may have a length (L) to cross-section (C) ratio of at least about 10, 20, 30, 40, 50, 60, 70, 80, 90, or greater. In some cases, the heat conducting unit may have a length (L) to cross-section (C) ratio of at most about 90, 80, 70, 60, 50, 40, 30, 20, 10, or less. The heat conducting unit may have a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters. The heat conducting unit may have a length (L) of at most 0.1 meters and a cross-section (C) of at least 0.01 square meters. The heat conducting unit may have a length (L) of at least 0.1 meters and a cross-section (C) of at most 0.01 square meters. The heat conducting unit may have a length (L) of at most 0.1 meters and a cross-section (C) of at most 0.01 square meters.

[0056] The heat conducting unit may be insulated with insulating material to minimize heat loss. The insulating material may be in any size, shape and design. The insulating materials may comprise, but not limited to, microporous silica, vacuum insulated panel, silica aerogel, polyurethane rigid panel, foil faced polyurethane rigid panel, polyisocyanurate spray foam, closed-cell polyurethane spray foam, phenolic spray form, thinsulate clothing insulation, urea-formaldehyde panels, urea foam, extruded expanded polystyrene, polystyrene board, phenolic rigid panel, urea-formaldehyde foam, high density fiberglass batts, extruded expended polystyrene, icynene loose-fill, molded expanded polystyrene, home foam, rice hulls, fiberglass batts, cotton batts, icynene spray, cardboard, rock and slag wool batts, cellulose loose-fill, cellulose wet-spray, rock and slag wool loose-fill, fiberglass loose-fill, polyethylene foam, cementitious foam, perlite loose-fill, wood panels, fiberglass rigid panel, vermiculite loose-fill, straw bale, papercrete, softwood, woodchips and other loose-fill wood products, aerated concrete, cellular concrete, snow, hardwood, brick, glass, poured concrete, fiberglass, mineral wool, cellulose, polyurethane foam and polystyreneor, or any other thermally insulating materials. The heat conducting unit may be fully covered by the insulating material. The head conducting unit may be partially covered by the insulating material.

[0057] The thermoelectric system may comprise a thermoelectric generator. The thermoelectric generator may comprise a plurality of thermoelectric elements. The plurality of thermoelectric elements may be in thermal communication with the first heat exchanger. The plurality of thermoelectric elements may be in thermal communication with the heat conducting unit. The plurality of thermoelectric elements may be in thermal communication with the second heat exchanger. The plurality of thermoelectric elements may be used in an industrial setting, such as at a location where there is heat loss. The plurality of thermoelectric elements can be used to generate power upon the application of a temperature gradient across the plurality of thermoelectric elements. Such power can be used to provide electrical energy to various types of devices, such as consumer electronic devices.

[0058] A given thermoelectric element of the plurality of thermoelectric elements can have various non-limiting advantages and benefits. The given thermoelectric element can have substantially high aspect ratios, uniformity of holes or wires, and figure-of-merit, ZT, which can be suitable for optimum thermoelectric performance. With respect to the figure-of-merit, Z can be an indicator of coefficient-of-performance (COP) and the efficiency of the given thermoelectric element, and T can be an average temperature of the hot and the cold sides of the given thermoelectric element. The figure-of-merit (ZT) of the given thermoelectric element may be at least about 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0 or more at 25°C. The figure-of-merit may be from about 0.01 to 3, 0.1 to 2.5, 0.5 to 2.0 or 0.5 to 1.5 at 25°C. The figure of merit (ZT) can be a function of temperature. The ZT may increase with temperature.

[0059] The plurality of thermoelectric elements may be disposed between electrodes. The plurality of thermoelectric elements may comprise an array of nanostructures (e.g., holes or wires). The array of nanostructures can include a plurality of holes or elongate structures, such as wires (e.g., nanowires). The holes or wires can be ordered and have uniform sizes and distributions. As an alternative, the holes or wires may not be ordered and may not have a uniform distribution. There may not be long range order with respect to the holes or wires. The holes or wires may intersect each other in random directions. A given thermoelectric element of the plurality of thermoelectric elements can be either p-type or n-type.

[0060] Alternatively, the thermoelectric elements may not have holes or wires (e.g., the thermoelectric may be non-porous). Such thermoelectric elements can be made of a solid state material, such as, for example, carbon (e.g., graphite or graphene), silicon, germanium, gallium arsenide, aluminum gallium arsenide, silicides, silicon germanium, bismuth telluride, lead telluride, oxides (e.g., SiOx, where ‘x’ is a number greater than zero), gallium nitride and tellurium silver germanium antimony (TAGS) containing alloys. Such thermoelectric elements may be formed by doping a solid-state material, for example. As another example, such thermoelectric elements may be formed according to methods disclosed in U.S. Patent Publication No. 2016/0380175, which is entirely incorporated herein by reference.

[0061] As another alternative, the thermoelectric elements may be formed according to methods disclosed in U.S. Patent Publication No. 2015/0280099, which is entirely incorporated herein by reference.

[0062] The plurality of thermoelectric elements may be flexible or substantially flexible. A flexible material can be a material that can be conformed to a shape, twisted, or bent without experiencing plastic deformation. This can enable the thermoelectric elements to be used in various settings, such as settings in which contact area with a heat source or heat sink may be important. The plurality of thermoelectric elements can include at least one semiconductor element which can be flexible. Individual semiconductor elements may be rigid but substantially thin (e.g., 500 nm to 1 mm or 1 micrometer to 0.5 mm) such that they provide a flexible thermoelectric element when disposed adjacent one another.

[0063] The thermoelectric generator may be coupled to the heat conducting unit. The thermoelectric generator may be in thermal communication with the heat conducting unit. The thermoelectric generator may be coupled to the heat conducting unit and in thermal communication with the heat conducting unit.

[0064] The thermoelectric system may comprise a second heat exchanger. The second heat exchanger may be coupled to and in thermal communication with the thermoelectric generator. The second heat exchanger may be configured to collect or dissipate the thermal energy to a location above the ground surface.

[0065] The second heat exchanger may be configured for placement above a surface. The surface may be a ground surface or a water surface. The second heat exchanger may be configured for placement above a ground surface. The distance between the second heat exchanger and the surface may be at least about 1 meter ("m"), 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the second heat exchanger and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m or less.

[0066] The second heat exchanger may be configured to collect or dissipate thermal energy to a location above the surface. The second heat exchanger may be configured to collect thermal energy from or dissipate thermal energy to a location above the ground surface. For example, depending on the time of day, a location above ground may be cooler than the ground surface, in which case the second heat exchanger may dissipate thermal energy to the location above ground. As another example, the location above ground may be warmer than the ground surface, in which case the second heat exchanger may collect thermal energy from the location above ground.

[0067] The second heat exchanger may collect thermal energy from a location above the surface. The location above the surface may be a heat source. The distance between the surface and the heat source may be at least about 1 m, 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the heat source and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m or less. The second heat exchanger may dissipate thermal energy to a location above the surface. The distance between the surface and the location above the surface for dissipating thermal energy may be at least about 1 m, 2 m, 3 m, 4 m, 5 m, 6 m, 7 m, 8 m, 9 m, 10 m, 11 m, 12 m, 13 m, 14 m, 15 m, 16 m, 17 m, 18 m, 19 m, 20 m, or greater. In some cases, the distance between the location above the surface for dissipating thermal energy and the surface may be at most about 20 m, 19 m, 18 m, 17 m, 16 m, 15 m, 14 m, 13 m, 12 m, 11 m, 10 m, 9 m, 8 m, 7 m, 6 m, 5 m, 4 m, 3 m, 2 m, 1 m or less.

[0068] The second heat exchanger may be in thermal communication with the thermoelectric generator. If the second heat exchanger collects thermal energy, the second heat exchanger may provide the heat to adjacent components (e.g., thermoelectric generator). If the second heat exchanger dissipates thermal energy, the second heat exchanger may expel the thermal energy from components (e.g., a thermoelectric generator). The second heat exchanger can be sufficiently thermally conductive to remove heat from the adjacent components and expel it to the environment.

[0069] The second heat exchanger may comprise one or more heat sinks. The second heat exchanger may be coupled to one or more heat sinks. The heat sink can aid in collecting or dissipating heat. A heat sink can include one or more heat fins which can be sized and arranged to provide increase heat transfer area. A heat sink may be any flexible material, which can be sufficiently thermally conductive to provide low internal thermal resistance and sufficiently thin to bend in a flexible manner. The heat sink may be any design, shape, and/or size. The heat sink can be within or in contact with a matrix. The matrix can be a polymer foil, elastomeric polymer, ceramic foil, semiconductor foil, insulator foil, insulated metal foil or combinations thereof. To increase the surface area presented to the environment for effective thermal transfer, the matrix may be patterned with dimples, corrugations, pins, fins or ribs.

[0070] Heat sink may be formed with electrically insulating material, which can be sufficiently thin (e.g., thickness from about 0.01 millimeter to 1 millimeter) to present a low thermal resistance (e.g., thermal resistance of at most 1 K/W). Examples include polymer foil (e.g., polyethylene, polypropylene, polyester, polystyrene, polyimide, etc.); elastomeric polymer foil (e.g., polydimethylsilazane, polyisoprene, natural rubber, etc.); fabric (e.g., conventional cloths, fiberglass mat, etc.); ceramic, semiconductor, or insulator foil (e.g., glass, silicon, silicon carbide, silicon nitride, aluminum oxide, aluminum nitride, boron nitride, etc.); insulated metal foil (e.g., anodized aluminum or titanium, coated copper or steel, etc.); or combinations thereof. The electrically insulating material can be both flexible and stretchable when an elastomeric material is used.

[0071] The second heat exchanger may be in any design, shape, and/or size. The second heat exchanger may comprise one or more heat exchanger components. The heat exchanger components may be any design, shape, and/or size. Examples of possible shapes or designs include but are not limited to: mathematical shapes (e.g., circular, triangular, square, rectangular, pentagonal, or hexagonal), two-dimensional geometric shapes, multi-dimensional geometric shapes, curves, polygons, polyhedral, polytopes, minimal surfaces, ruled surfaces, non-orientable surfaces, quadrics, pseudospherical surfaces, algebraic surfaces, miscellaneous surfaces, riemann surfaces, box-drawing characters, cuisenaire rods, geometric shapes, shapes with metaphorical names, symbols, unicode geometric shapes, other geometric shapes, partial shapes or combination of shapes thereof. The number of heat exchanger components of the second heat exchanger may be at least 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more.

[0072] The heat exchanger components may be plates. The second heat exchanger may comprise a plurality of metal plates. The number of metal plates may be at least 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more. The individual metal plates of the plurality of metal plates may project away from the heat conducting unit along a direction that may be angled with respect to a longitudinal axis of the heat conducting unit. The angle with respect to a longitudinal axis of the heat conducting unit may be at least about 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, or greater. In some cases, the angle with respect to a longitudinal axis of the heat conducting unit may be at most about 90°, 80°, 70°, 60°, 50°, 40°, 30°, 20°, 10° or less. The individual metal plates of the plurality of metal plates may project away from the heat conducting unit along a direction that may be orthogonal to a longitudinal axis of the heat conducting unit.

[0073] The second heat exchanger may be formed of a metallic (or metal-containing) material. The second heat exchanger may include one or more elemental metals. For example, the metallic material may include one or more of aluminum, titanium, copper, iron, steel, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium and thallium, and their alloys. The second heat exchanger may be formed of a semiconductor-containing material, such as silicon or a silicide. The second heat exchanger may be formed of a polymeric material. The polymeric material may include one or more polymers. For example, the polymeric material may include one or more of polyvinyl chloride, polyvinylidene chloride, polyethylene, polyisobutene, and poly[ethylene-vinylacetate] copolymer. The second heat exchanger may be formed of a composite material. The composite material may include, for example, reinforced plastics, ceramic matrix composites, and metal matrix composites.

[0074] The thermoelectric generator may be configured to generate power upon flow of thermal energy from the first heat exchanger to the thermoelectric generator. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the first heat exchanger to the thermoelectric generator during night time. The night time may be the time after sunset and before sunrise. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the second heat exchanger to the thermoelectric generator. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the second heat exchanger to the thermoelectric generator during day time. The day time may be the time after sunrise and before sunset.

[0075] The thermoelectric system may comprise a thermally conductive material, such as a thermally conductive adhesive. The thermally conductive adhesive may be disposed between the thermoelectric generator and the heat conducting unit. The thermally conductive adhesive may have a thermal conductivity of at least about 0.1 Watts/meter-Kelvin (W/m-K), 0.2 W/m-K, 0.3 W/m-K, 0.4 W/m-K, 0.5 W/m-K, 0.6 W/m-K, 0.7 W/m-K, 0.8 W/m-K, 0.9 W/m-K, 1 W/m-K, 1.5 W/m-K, 2.5 W/m-K or greater at a temperature of 25°C. In some cases, the thermally conductive adhesive may have a thermal conductivity of at most about 2.5 W/m-K, 1.5 W/m-K, 1 W/m-K, 0.9 W/m-K, 0.8 W/m-K, 0.7 W/m-K, 0.6 W/m-K, 0.5 W/m-K, 0.3 W/m-K, 0.2 W/m-K, 0.1 W/m-K, or less at a temperature of 25°C. The work-life time of the thermally conductive adhesive may be at least 1 hour, 5 hours, 10 hours, 15 hours, 20 hours, 1 day, 2 days, or longer. In some cases, the work-life time of the thermally conductive adhesive may be at most about 2 days, 1 day, 20 hours, 15 hours, 10 hours, 5 hours, 1 hour, or less.

[0076] The thermoelectric system may further comprise an additional thermally conductive material, such as an additional thermally conductive adhesive. The additional thermally conductive adhesive may be disposed between the thermoelectric generator and the second heat exchanger. The additional thermally conductive adhesive may have a thermal conductivity of at least about 0.1 W/m-K, 0.2 W/m-K, 0.3 W/m-K, 0.4 W/m-K, 0.5 W/m-K, 0.6 W/m-K, 0.7 W/m-K, 0.8 W/m-K, 0.9 W/m-K, 1 W/m-K, 1.5 W/m-K, 2.5 W/m-K or greater at a temperature of 25°C. In some cases, the additional thermally conductive adhesive may have a thermal conductivity of at most about 2.5 W/m-K, 1.5 W/m-K, 1 W/m-K, 0.9 W/m-K, 0.8 W/m-K, 0.7 W/m-K, 0.6 W/m-K, 0.5 W/m-K, 0.3 W/m-K, 0.2 W/m-K, 0.1 W/m-K, or less at a temperature of 25°C. The work-life time of the additional thermally conductive adhesive may be at least about 1 hour, 5 hours, 10 hours, 15 hours, 20 hours, 1 day, 2 days, or longer. In some cases, the work-life time of the additional thermally conductive adhesive may be at most about 2 days, 1 day, 20 hours, 15 hours, 10 hours, 5 hours, 1 hour, or less.

[0077] The additional thermally conductive adhesive may have the same thermal conductivity as the thermally conductive adhesive. The additional thermally conductive adhesive may have a different thermal conductivity as the thermally conductive adhesive. The additional thermally conductive adhesive may have the same work-life time as the thermally conductive adhesive. The additional thermally conductive adhesive may have a different work-life time as the thermally conductive adhesive.

[0078] The thermoelectric generator may have a thermal resistance of at least about 1 Kelvins/Watt (K/W), 2 K/W, 3 K/W, 4 K/W, 5 K/W, 6 K/W, 7 K/W, 8 K/W, 9 K/W, 10 K/W or greater. In some cases, the thermoelectric generator may have a thermal resistance of at most about 10 K/W, 9 K/W, 8 K/W, 7 K/W, 6 K/W, 5 K/W, 4 K/W, 3 K/W, 2 K/W, 1 K/W, or less.

[0079] The thermoelectric system may further comprise one or more sensors powered by the thermoelectric generator. The one or more sensors may comprise, but not limited to, geophone, hydrophone, lace sensor, microphone, seismometer, sound locator, air flow meter, air-fuel ratio (AFR) sensors, blind spot monitor, defect detector, hall effect sensor, wheel speed sensor, airbag sensors, coolant temperature sensor, fuel level sensor, fuel pressure sensor, light sensor, manifold absolute pressure (MAP) sensor, oxygen sensor, oil level sensor, breathalyzer, carbon dioxide sensor, carbon monoxide sensor, electrochemical gas sensor, hydrogen sensor, current sensor, daly detector, electroscope, magnetic anomaly detector, microelectromechanical system (MEMS) magnetic field sensor, metal detector, radio direction finder, voltage detector, actinometer, air pollution sensor, ceilometer, gas detector, humistor, leaf sensor, rain gauge, rain sensor, snow gauge, soil moisture sensor, stream gauge, tide gauge, mass flow sensor, water meter, cloud chamber, neuron detection, air speed indicator, depth gauge, magnetic compass, turn coordinator, flame detector, photodiode, wavefront sensor, barometer, pressure sensor, level sensor, viscometer, bolometer, colorimeter, thermometer, proximity sensor, reed switch, and biosensor.

[0080] The one or more sensors may measure one or more environment parameters. The one or more environment parameters may be related to any characteristics of the environment. The one or more environment parameters may comprise, but not limited to, temperature, humidity, luminance, wind direction, wind speed, pH level, carbon dioxide concentration, moisture, chemical composition, currents and water turbulence, salinity, nutrient element, turbidity, dissolved oxygen, algae and phytoplankton, water level, noise level, atmospheric (barometric) pressure, precipitation, and solar radiation.

[0081] The thermoelectric system may further comprise a converter. The converter may be a boost converter. The boost converter may be a DC-to-DC power converter that may step up voltage from its input to its output. The boost converter may comprise one or more semiconductors. The boost converter may comprise at least one energy storage element. The energy storage element may comprise a capacitor, inductor, or the two in combination. The boost converter may comprise filters to reduce voltage ripple. The filter may be made of one or more capacitors and/or inductors. The converter may be configured to convert a lower voltage to at least about 1 volt (V), 2 V, 2.1 V, 2.2 V, 2.3 V, 2.35 V, 2.4 V, 2.45 V, 2.5 V, 3 V, 3.1 V, 3.2 V, 3.3 V, 3.4 V, 3.5 V, 3.6 V, 3.7 V, 3.8 V, 3.9 V, 4 V, 4.1 V, 4.2 V, 4.3 V, 4.4 V, 4.5 V, 5.0 V or greater. In some cases, the converter may be configured to convert a lower voltage to at most about 5.0 V, 4.5 V, 4.4 V, 4.3 V, 4.2 V, 4.1 V, 4 V, 3.5 V, 3 V, 2.5 V, 2 V, 1.5 V, 1 V or less. The converter may be associated with power management circuitry. The voltage can be used to power circuits directly or to trickle charge a power storage unit such as a battery.

[0082] The thermoelectric system may further comprise a server. The thermoelectric system may further comprise a plurality of servers. The number of servers may be 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, or more. The one or more environment parameters may be uploaded to the server. The one or more environment parameters may be uploaded to the plurality of servers. The server may be a central server for an entire system, or it may be specific to a particular network. The server may be used for multiple purposes, for example, but not limited to, retaining environment parameters generated by one or more sensors, storing environment parameters, and analyzing environment parameters. The server may support communications between different users of the thermoelectric system. The server may support communications between the users of the thermoelectric system and the thermoelectric system.

[0083] The server may provide controlling signals to one or more devices according to the communications. The one or more devices may comprise any devices, for example, but not limited to, consumer electronics, telecommunication devices, office devices, agricultural devices, lights, household equipment, safety equipment, or medical equipment. The consumer electronics may comprise TVs, photo equipment and accessories, cameras (video, film), speaker, radio / hi-fi systems, or video projectors. The telecommunication devices may comprise mobile phones, modems, router, phone cards, or telephones. The office devices may comprise shredders, faxes, copiers, projectors, cutting machine, and typewriters. The agricultural devices may comprise, but not limited to, tractor, cultivator, chisel plow, harrow, subsoiler, rotator, roller, trowel, seed drill, liquid manure spreader, sprayer, sprinkler system, produce sorter, farm truck, grain dryer, conveyor belt, mower, hay rake, bulk tank, milking machine, grinder-mixture, or livestock trailer. The household devices may comprise cooler, blender, fan, refrigerator, heater, oven, air-conditioner, dishwasher, washer and dryer, vacuum cleaner, and microwave. The safety equipment may comprise rescue equipment, carbon monoxide detector, surveillance cameras, and surveillance monitors. The medical equipment may comprise stethoscope, suction device, thermometer, tongue depressor, transfusion kit, tuning fork, ventilator, watch, stopwatch, weighing scale, crocodile forceps, bedpan, cannula, cardioverter, defibrillator, catheter, dialyzer, electrocardiograph machine, enema equipment, endoscope, gas cylinder, gauze sponge, hypodermic needle, syringe, infection control equipment, an oximeter or oximeters that monitors oxygen levels of the user, instrument sterilizer, kidney dish, measuring tape, medical halogen penlight, nasogastric tube, nebulizer, ophthalmoscope, otoscope, oxygen mask and tubes, pipette, dropper, proctoscope, reflex hammer, and sphygmomanometer. The controlling signals may comprise, but not limited to, a signal to turn on a given device, a signal to turn off a given device, a signal to switch working modes of a given device, and a signal to lower or increase the power of a given device.

[0084] A database may be connected with one or more servers. The database may be connected with the one or more devices through the one or more servers. The one or more servers and/or the one or more devices may be powered by the thermoelectric system. The connection may be a wired connection or wireless connection. The wireless connection may include a Wi-Fi receiver, a component for accessing a mobile data standard such as a 3G or 4G LTE data signal, or a Bluetooth receiver.

[0085] The one or more environment parameters may be uploaded to a database. The database may be connected to centralized data processing. The centralized data processing may be cloud-based, internet-based, locally accessible network (LAN)-based, or a dedicated reading center using pre-existent or new platforms. The thermoelectric system may comprise one or more software. The software can rely on structured computation, for example providing registration, segmentation and other functions, with the centrally-processed output made ready for downstream analysis. The software may rely on unstructured computation, artificial intelligence or deep learning.

[0086] The thermoelectric system may further comprise an energy storage system in electrical communication with the thermoelectric generator. The energy storage system may be configured to store electrical energy generated by the thermoelectric generator. The energy stored in the energy storage system may be at least about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or greater of the energy generated by the thermoelectric generator. In some cases, the energy stored in the energy storage system may be at most about 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, or less of the energy generated by the thermoelectric generator. The energy storage system may comprise a battery. The battery may be a solid-state battery (e.g., lithium ion battery).

Method for generating power

[0087] In another aspect, a method for generating power may comprise providing a thermoelectric system comprising a first heat exchanger, a heat conducting unit, a thermoelectric generator, a second heat exchanger, and a thermally conductive adhesive; using the thermoelectric generator to generate power; and directing the power to an energy storage system or an electrical load.

[0088] The first heat exchanger may be positioned below a ground surface and configured to collect or dissipate thermal energy to a location below the ground surface, as described elsewhere herein. The first heat exchanger may comprise at least one heat exchanger component, as described elsewhere herein. The heat conducting unit may be coupled to the first heat exchanger, as described elsewhere herein. The heat conducting unit may have a length (L) of at least about 0.1 meters (“m”), 0.2 m, 0.3 m, 0.4 mm, 0.5 m, 0.6 m, 0.7 m, 0.8 m, or greater. In some cases, the heat conducting unit may have a length (L) of at most about 0.8 m, 0.7 m, 0.6 m, 0.5 m, 0.4 m, 0.3 m, 0.2 m, 0.1 m, or less. The heat conducting unit may have a cross-section (C) of at least about 0.01 square meters ("m^2"), 0.02 m^2, 0.03 m^2, 0.04 m^2, 0.05 m^2, 0.06 m^2, 0.07 m^2, 0.08 m^2, 0.09 m^2, 0.1 m^2, 0.2 m^2, 0.3 m^2, 0.4 m^2, 0.5 m^2, 0.6 m^2, 0.7 m^2, 0.8 m^2 or greater. In some cases, the heat conducting unit may have a cross-section (C) of at most about 0.8 m^2, 0.7 m^2, 0.6 m^2, 0.5 m^2, 0.4 m^2, 0.3 m^2, 0.2 m^2, 0.1 m^2, 0.09 m^2, 0.08 m^2, 0.07 m^2, 0.06 m^2, 0.05 m^2, 0.04 m^2, 0.03 m^2, 0.02 m^2, 0.01 m^2, or less. The heat conducting unit may have a length (L) to cross-section (C) ratio of at least about 10, 20, 30, 40, 50, 60, 70, 80, 90, or greater. In some cases, the heat conducting unit may have a length (L) to cross-section (C) ratio of at most about 90, 80, 70, 60, 50, 40, 30, 20, 10 or less. The heat conducting unit may have a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters. The heat conducting unit may have a length (L) of at most 0.1 meters and a cross-section (C) of at least 0.01 square meters. The heat conducting unit may have a length (L) of at least 0.1 meters and a cross-section (C) of at most 0.01 square meters. The heat conducting unit may have a length (L) of at most 0.1 meters and a cross-section (C) of at most 0.01 square meters.

[0089] The thermoelectric generator may comprise a plurality of thermoelectric elements, as described elsewhere herein. The thermoelectric generator may be coupled to and in thermal communication with the heat conducting unit, as described elsewhere herein. The second heat exchanger may be coupled to and in thermal communication with the thermoelectric generator, as described elsewhere herein. The second heat exchanger may be configured to collect or dissipate the thermal energy to a location above the ground surface, as described elsewhere herein. The thermally conductive adhesive may be disposed between the thermoelectric generator and the heat conducting unit, as described elsewhere herein. The thermally conductive adhesive may have a thermal conductivity of at least about 0.1 W/m-K, 0.2 W/m-K, 0.3 W/m-K, 0.4 W/m-K, 0.5 W/m-K, 0.6 W/m-K, 0.7 W/m-K, 0.8 W/m-K, 0.9 W/m-K, 1 W/m-K, 1.5 W/m-K, 2.5 W/m-K or greater at a temperature of 25°C. In some cases, the thermally conductive adhesive may have a thermal conductivity of at most about 2.5 W/m-K, 1.5 W/m-K, 1 W/m-K, 0.9 W/m-K, 0.8 W/m-K, 0.7 W/m-K, 0.6 W/m-K, 0.5 W/m-K, 0.3 W/m-K, 0.2 W/m-K, 0.1 W/m-K, or less at a temperature of 25°C.

[0090] The thermoelectric generator may generate power upon flow of the thermal energy from the first heat exchanger to the thermoelectric generator. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the first heat exchanger to the thermoelectric generator during night time. The night time may be the time after sunset and before sunrise. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the second heat exchanger to the thermoelectric generator. The thermoelectric generator may be configured to generate power upon flow of thermal energy from the second heat exchanger to the thermoelectric generator during day time. The day time may be the time after sunrise and before sunset.

[0091] The energy storage system or the electrical load may be in electrical communication with the thermoelectric generator. The energy storage system may be configured to store electrical energy generated by the thermoelectric generator. The energy stored in the energy storage system may be at least about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or greater of the energy generated by the thermoelectric generator. In some cases, the energy stored in the energy storage system may be at most about 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, or less of the energy generated by the thermoelectric generator. The energy storage system may comprise a battery. The electrical load may be configured to consume electrical energy generated by the thermoelectric generator. The energy consumed by the electrical load may be at least about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% or greater of the energy generated by the thermoelectric generator. In some cases, the energy consumed by the electrical load may be at most about 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, or less of the energy generated by the thermoelectric generator.

[0092] The thermoelectric system may further comprise an additional thermally conductive material, such as an additional thermally conductive adhesive. The additional thermally conductive adhesive may be disposed between the thermoelectric generator and the second heat exchanger. The additional thermally conductive adhesive may have a thermal conductivity of at least about 0.1 W/m-K, 0.2 W/m-K, 0.3 W/m-K, 0.4 W/m-K, 0.5 W/m-K, 0.6 W/m-K, 0.7 W/m-K, 0.8 W/m-K, 0.9 W/m-K, 1 W/m-K, 1.5 W/m-K, 2.5 W/m-K or greater at a temperature of 25°C. In some cases, the additional thermally conductive adhesive may have a thermal conductivity of at most about 2.5 W/m-K, 1.5 W/m-K, 1 W/m-K, 0.9 W/m-K, 0.8 W/m-K, 0.7 W/m-K, 0.6 W/m-K, 0.5 W/m-K, 0.3 W/m-K, 0.2 W/m-K, 0.1 W/m-K, or less at a temperature of 25°C. The work-life time of the additional thermally conductive adhesive may be at least about 1 hour, 5 hours, 10 hours, 15 hours, 20 hours, 1 day, 2 days, or greater. In some cases, the work-life time of the additional thermally conductive adhesive may be at most about 2 days, 1 day, 20 hours, 15 hours, 10 hours, 5 hours, 1 hour, or less.

[0093] FIG. 1 shows an example of a first heat exchanger coupled to a heat conducting unit. The first heat exchanger 101 may comprise a plurality of metal plates 103. In the illustrated example, the first heat exchanger comprises 6 metal plates. The individual metal plates of the plurality of metal plates 103 may project away from the heat conducting unit along a direction that may be angled with respect to a longitudinal axis of the heat conducting unit 102. In the illustrated example, the individual metal plates of the plurality of metal plates 103 project away from the heat conducting unit along a direction that is orthogonal to a longitudinal axis of the heat conducting unit 102. The heat conducting unit 102 may be configured for placement adjacent to the first heat exchanger 101. The heat conducting unit 102 may be formed of a heat pipe or metallic (or metal-containing) material. In the illustrated example, the heat conducting unit 102 is formed of copper.

[0094] FIG. 2 shows an example of insulating material around the heat conducting unit of FIG. 1. The heat conducting unit 102 may be insulated with insulating material 201 to minimize heat loss. The insulating material 201 may be in any size, shape and design. In the illustrated example, the insulating material 201 is in a sheet form so the heat conducting unit 102 is wrapped by the insulting material 201. The insulating materials may comprise, but not limited to, microporous silica, vacuum insulated panel, silica aerogel, polyurethane rigid panel, foil faced polyurethane rigid panel, polyisocyanurate spray foam, closed-cell polyurethane spray foam, phenolic spray form, thinsulate clothing insulation, urea-formaldehyde panels, urea foam, extruded expanded polystyrene, polystyrene board, phenolic rigid panel, urea-formaldehyde foam, high density fiberglass batts, extruded expended polystyrene, icynene loose-fill, molded expanded polystyrene, home foam, rice hulls, fiberglass batts, cotton batts, icynene spray, cardboard, rock and slag wool batts, cellulose loose-fill, cellulose wet-spray, rock and slag wool loose-fill, fiberglass loose-fill, polyethylene foam, cementitious foam, perlite loose-fill, wood panels, fiberglass rigid panel, vermiculite loose-fill, straw bale, papercrete, softwood, woodchips and other loose-fill wood products, aerated concrete, cellular concrete, snow, hardwood, brick, glass, poured concrete, fiberglass, mineral wool, cellulose, polyurethane foam and polystyreneor, or any other thermally insulating materials. In the illustrated example, the heat conducting unit 102 is fully covered by the insulating material 201.

[0095] FIG. 3 shows an example of a partially assembled thermoelectric system placed in a hole in the ground. The partially assembled thermoelectric system may comprise a first heat exchanger 301, a heat conducing unit (cannot be seen), insulating material 302, and a thermoelectric generator 303. The heat conducting unit may be configured for placement adjacent to the first heat exchanger 301. In the illustrated example, the heat conducting unit is fully covered by the insulating material 302. The thermoelectric generator 303 may be coupled to the heat conducting unit. In the illustrated example, the thermoelectric generator 303 is placed on the top of the heat conducting unit. The thermoelectric generator 303 may be in thermal communication with the heat conducting unit. The thermoelectric generator 303 may comprise a plurality of thermoelectric elements. The plurality of thermoelectric elements may be in thermal communication with the first heat exchanger 301 and the heat conducting unit.

[0096] FIG. 4 shows an example of a fully assembled thermoelectric system with a thermoelectric generator and a second heat exchanger placed above the ground. The fully assembled thermoelectric system may comprise a first heat exchanger (cannot be seen), a heat conducing unit (cannot be seen), insulating material (cannot be seen), a thermoelectric generator 401, a thermally conductive adhesive (cannot be seen), and a second heat exchanger 402. The second heat exchanger 402 may be coupled to and in thermal communication with the thermoelectric generator 401. The second heat exchanger 402 may be configured to collect thermal energy from or dissipate the thermal energy to a location above the ground surface. In the illustrated example, the second heat exchanger 402 is configured for placement above a ground surface. The second heat exchanger 402 may comprise one or more heat sinks 403. The heat sink 403 can aid in collecting or dissipating thermal energy.

[0097] FIG. 5 is an example of a power measurement of the thermoelectric system. In the illustrated example, the horizontal axis represents the date and the perpendicular axis represents the power generated. This figure shows that power can be generated every day during six days of power measurement. This figure also shows that, for each day of the six days, the maximum power is generated in the middle of the day, with a secondary peak in the middle of the night.

[0098] FIG. 7 shows an example of a thermoelectric system that can be positioned entirely below a surface, e.g., below a ground surface or below the surface of a body of water. The thermoelectric system can utilize naturally occurring temperature gradients in the top 5 centimeters (cm), 10 cm, 15 cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, 80 cm, 90 cm, or 100 cm of soil to generate power. During the day, soil near the surface may be warmer than soil far from the surface due to the effects of solar radiation, which may be more pronounced near the surface. At night, soil near the surface may be cooler than soil far from the surface due to the effects of radiative cooling, which may also be more pronounced near the surface.

[0099] The thermoelectric system can include a cap 710. The cap 710 can be made of a thermally conductive material and be configured to collect or dissipate thermal energy. Thermally conductive materials for thermoelectric systems are described in detail in a previous portion of this disclosure. The cap 710 can have a cross-section that is circular, semi-circular, elliptical, triangular, rectangular, pentagonal, hexagonal, a partial-shape, or any combination thereof. The cap 710 can have a diameter of at least about 10 cm, 20 cm, 30 cm, 40 cm, or more. The cap 710 can have a height of at least about 2 cm, 3 cm, 4 cm, 5 cm, 10 cm, 15 cm, or more.

[00100] The thermoelectric system can include a thermoelectric module 720. The thermoelectric module 720 can be made of a plurality of thermoelectric elements that are in thermal communication with the cap 710 and a shaft 730. The plurality of thermoelectric elements can be used to generate power upon the application of a temperature gradient across the plurality of thermoelectric elements (e.g., between the cap 710 and the shaft 730). Thermoelectric elements for thermoelectric systems are described in detail in a previous portion of this disclosure.

[00101] The shaft 730 can be in thermal communication with the thermoelectric module 720 and can be made of a thermally conductive material. The shaft 730 can be made of the same thermally conductive material as the cap 710, or it can be made of a different thermally conductive material. In some cases, the shaft 730 may be formed or coated with a corrosion-resistant material, such as, for example, stainless steel or aluminum. Like the cap 710, the shaft 730 can be configured to collect or dissipate thermal energy.

[00102] The shaft 730 can have a cross-section that is circular, semi-circular, elliptical, triangular, rectangular, pentagonal, hexagon, a partial-shape, or any combination thereof. The shaft 730 may have the same cross-section as the cap 710. The shaft 730 can have a length of at least about 1 cm, 2 cm, 3 cm, 4 cm, 5 cm, 10 cm, 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, 80 cm, 90 cm, 100 cm, 110 cm, or more. In some cases, the shaft 730 can be an elongated cylinder.

[00103] The thermoelectric system can also include thermal insulation 740 disposed in the area between the cap 710 and the shaft 730 that is not occupied by the thermoelectric module 720. The thermal insulation 740 can ensure that heat is directed through the thermoelectric module 720, which can maximize its power output.

[00104] The thermoelectric system can also include a point 750 disposed at the end of the shaft 730. The point 750 can facilitate insertion of the thermoelectric system into the ground. The point 750 may be thermally conductive or non-conductive.

[00105] The cap 710, the thermoelectric module 720, the shaft 730, and the point 750 can be joined together with mechanical fasteners (e.g., rivets, bolts, or screws); welded, soldered, or brazed together; or held together with an adhesive.

[00106] The thermoelectric system of FIG. 7 can include a boost converter. The boost converter can be a DC-to-DC power converter configured to step up a voltage generated by the thermoelectric module. Boost converters are described in greater detail in a previous portion of this disclosure.

[00107] The thermoelectric system of FIG. 7 can be electrically coupled to one or more sensors (e.g., environmental sensors). The one or more sensors can operate using power generated by the thermoelectric system and stepped up by the boost converter. Examples of sensors that may obtain power from the thermoelectric system are described in detail in a previous section of this disclosure. The sensors may be integrated with the thermoelectric system of FIG. 7, or they may be external to the thermoelectric system of FIG. 7. External sensors may be connected to the thermoelectric system by wires.

[00108] The thermoelectric system of FIG. 7 can also be electrically coupled to a radio or transmitter. The radio or transmitter can transmit data generated by the sensors to an Internet-connected server. Together, the thermoelectric system, the one or more sensors, and the radio or transmitter can form a self-powered remote-sensing network.

[00109] In some cases, the thermoelectric system of FIG. 7 may be disposed underwater rather than underground. In such cases, the thermoelectric system can also have a buoyant element connected to the cap 710. The buoyant element can allow the thermoelectric system to float.

[00110] FIG. 8 is a chart showing test data generated by testing the thermoelectric system of FIG. 7 on several different days. The chart shows the amount of power generated by the thermoelectric system on each day and the weather conditions on that day.

[00111] FIG. 9 shows a second example of a thermoelectric system that can be disposed underground. The thermoelectric system of FIG. 9, like the thermoelectric system of FIG, 7, can utilize the naturally occurring temperature gradients in the top 100 cm of soil to generate power.

[00112] The thermoelectric system can include a top plate 910 and a bottom plate 920. The top plate 910 and the bottom plate 920 can be made of a thermally conductive material and be configured to collect or dissipate thermal energy. The top plate 910 and the bottom plate 920 can have a large surface area to facilitate heat absorption and/or dissipation. The top plate 910 and the bottom plate 920 can be separated by a gap. The gap can impede direct heat transfer between the top 910 and the bottom plate 920, or vice versa, instead directing the heat through a thermoelectric module 930. The gap can be filled with insulation to further reduce direct heat transfer between the top plate 910 and the bottom plate 920.

[00113] The thermoelectric module 930 can be disposed between the top plate 910 and the bottom plate 920. The thermoelectric module 930 can be made of thermoelectric elements. The thermoelectric elements can be used to generate power upon the application of a temperature gradient across the plurality of thermoelectric elements (e.g., between the top plate 710 and the bottom plate 730). The thermoelectric module 930 may have a smaller surface area than the top and bottom plates.

[00114] The thermoelectric system can be held together by screws 940. Like the thermoelectric system of FIG. 7, the thermoelectric system of FIG. 9 can be electrically coupled to a boost converter, sensors, and a transmitter or radio.

[00115] FIG. 10 is an example of a power measurement of the thermoelectric system of FIG. 9. In the illustrated example, the horizontal axis represents the time and the vertical axis represents the power generated by the thermoelectric system.

Methods for forming thermoelectric devices

[00116] A thermoelectric element as described herein can be formed using electrochemical etching. The thermoelectric element may be formed by cathodic or anodic etching, in some cases without the use of a catalyst. The thermoelectric element can be formed without use of a metallic catalysis. The thermoelectric element can be formed without providing a metallic coating on a surface of a substrate to be etched. This can also be performed using purely electrochemical anodic etching and suitable etch solutions and electrolytes. As an alternative, a thermoelectric can be formed using metal catalyzed electrochemical etching in suitable etch solutions and electrolytes, as described in, for example, PCT/US2012/047021, filed July 17, 2012, PCT/US2013/021900, filed January 17, 2013, PCT/US2013/055462, filed August 16, 2013, PCT/US2013/067346, filed October 29, 2013, each of which is entirely incorporated herein by reference.

[00117] A thermoelectric element can be formed using one or more sintering processes. The one or more sintering processes comprise spark plasma sintering, electro sinter forging, pressureless sintering, microwave sintering, and liquid phase sintering. For example, the thermoelectric element can be formed using one of the techniques described in PCT/US2015/022312, filed March 24, 2014, which is entirely incorporated herein by reference. The spark plasma sintering may be conducted by using a spark plasma sintering instrument. The spark plasma sintering instrument may apply external pressure and an electric field simultaneously to enhance the densification of a precursor of the thermoelectric element. The spark plasma sintering instrument may use a direct current (DC) pulse as the electric current to create spark plasma and spark impact pressure.

[00118] A thermoelectric can alternatively be formed by heating an uncompacted powder in a mold as described in U.S. Patent Publication 2016/0380175, filed on December 29, 2016, which is entirely incorporated herein by reference.

Computer control systems

[00119] The present disclosure provides computer control systems that are programmed to implement methods of the disclosure. FIG. 6 shows a computer system 601 that is programmed or otherwise configured to control the thermoelectric system disclosed herein. The computer system 601 can regulate various aspects of the present disclosure, such as, for example, collecting one or more environment parameters, analyzing one or more environment parameters, and controlling the percentage of power stored in the energy storage system. The computer system 601 can be an electronic device of a user or a computer system that is remotely located with respect to the electronic device. The electronic device can be a mobile electronic device.

[00120] The computer system 601 includes a central processing unit (CPU, also “processor” and “computer processor” herein) 605, which can be a single core or multi core processor, or a plurality of processors for parallel processing. The computer system 601 also includes memory or memory location 610 (e.g., random-access memory, read-only memory, flash memory), electronic storage unit 615 (e.g., hard disk), communication interface 620 (e.g., network adapter) for communicating with one or more other systems, and peripheral devices 625, such as cache, other memory, data storage and/or electronic display adapters. The memory 610, storage unit 615, interface 620 and peripheral devices 625 are in communication with the CPU 605 through a communication bus (solid lines), such as a motherboard. The storage unit 615 can be a data storage unit (or data repository) for storing data. The computer system 601 can be operatively coupled to a computer network (“network”) 630 with the aid of the communication interface 620. The network 630 can be the Internet, an internet and/or extranet, or an intranet and/or extranet that is in communication with the Internet. The network 630 in some cases is a telecommunication and/or data network. The network 630 can include one or more computer servers, which can enable distributed computing, such as cloud computing. The network 630, in some cases with the aid of the computer system 601, can implement a peer-to-peer network, which may enable devices coupled to the computer system 601 to behave as a client or a server.

[00121] The CPU 605 can execute a sequence of machine-readable instructions, which can be embodied in a program or software. The instructions may be stored in a memory location, such as the memory 610. The instructions can be directed to the CPU 605, which can subsequently program or otherwise configure the CPU 605 to implement methods of the present disclosure. Examples of operations performed by the CPU 605 can include fetch, decode, execute, and writeback.

[00122] The CPU 605 can be part of a circuit, such as an integrated circuit. One or more other components of the system 601 can be included in the circuit. In some cases, the circuit is an application specific integrated circuit (ASIC).

[00123] The storage unit 615 can store files, such as drivers, libraries and saved programs. The storage unit 615 can store user data, e.g., user preferences and user programs. The computer system 601 in some cases can include one or more additional data storage units that are external to the computer system 601, such as located on a remote server that is in communication with the computer system 601 through an intranet or the Internet.

[00124] The computer system 601 can communicate with one or more remote computer systems through the network 630. For instance, the computer system 601 can communicate with a remote computer system of a user. Examples of remote computer systems include personal computers (e.g., portable PC), slate or tablet PC’s (e.g., Apple® iPad, Samsung® Galaxy Tab), telephones, Smart phones (e.g., Apple® iPhone, Android-enabled device, Blackberry®), or personal digital assistants. The user can access the computer system 601 via the network 630.

[00125] Methods as described herein can be implemented by way of machine (e.g., computer processor) executable code stored on an electronic storage location of the computer system 601, such as, for example, on the memory 610 or electronic storage unit 615. The machine executable or machine-readable code can be provided in the form of software. During use, the code can be executed by the processor 605. In some cases, the code can be retrieved from the storage unit 615 and stored on the memory 610 for ready access by the processor 605. In some situations, the electronic storage unit 615 can be precluded, and machine-executable instructions are stored on memory 610.

[00126] The code can be pre-compiled and configured for use with a machine having a processer adapted to execute the code, or it can be compiled during runtime. The code can be supplied in a programming language that can be selected to enable the code to execute in a pre-compiled or as-compiled fashion.

[00127] Aspects of the systems and methods provided herein, such as the computer system 601, can be embodied in programming. Various aspects of the technology may be thought of as "products" or "articles of manufacture" typically in the form of machine (or processor) executable code and/or associated data that is carried on or embodied in a type of machine readable medium. Machine-executable code can be stored on an electronic storage unit, such as memory (e.g., read-only memory, random-access memory, flash memory) or a hard disk. "Storage" type media can include any or all of the tangible memory of the computers, processors or the like, or associated modules thereof, such as various semiconductor memories, tape drives, disk drives and the like, which may provide non-transitory storage at any time for the software programming. All or portions of the software may at times be communicated through the Internet or various other telecommunication networks. Such communications, for example, may enable loading of the software from one computer or processor into another, for example, from a management server or host computer into the computer platform of an application server. Thus, another type of media that may bear the software elements includes optical, electrical and electromagnetic waves, such as used across physical interfaces between local devices, through wired and optical landline networks and over various air-links. The physical elements that carry such waves, such as wired or wireless links, optical links or the like, also may be considered as media bearing the software. As used herein, unless restricted to non-transitory, tangible "storage" media, terms such as computer or machine "readable medium" refer to any medium that participates in providing instructions to a processor for execution.

[00128] Hence, a machine readable medium, such as computer-executable code, may take many forms, including but not limited to, a tangible storage medium, a carrier wave medium or physical transmission medium. Non-volatile storage media include, for example, optical or magnetic disks, such as any of the storage devices in any computer(s) or the like, such as may be used to implement the databases, etc. shown in the drawings. Volatile storage media include dynamic memory, such as main memory of such a computer platform. Tangible transmission media include coaxial cables; copper wire and fiber optics, including the wires that comprise a bus within a computer system. Carrier-wave transmission media may take the form of electric or electromagnetic signals, or acoustic or light waves such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media therefore include for example: a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, DVD or DVD-ROM, any other optical medium, punch cards paper tape, any other physical storage medium with patterns of holes, a RAM, a ROM, a PROM and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave transporting data or instructions, cables or links transporting such a carrier wave, or any other medium from which a computer may read programming code and/or data. Many of these forms of computer readable media may be involved in carrying one or more sequences of one or more instructions to a processor for execution.

[00129] The computer system 601 can include or be in communication with an electronic display 635 that comprises a user interface (UI) 640 for providing, for example, the power measurement and the environment parameters. Examples of UI's include, without limitation, a graphical user interface (GUI) and web-based user interface.

[00130] Methods and systems of the present disclosure can be implemented by way of one or more algorithms. An algorithm can be implemented by way of software upon execution by the central processing unit 605. The algorithm can, for example, be configured to analyze the one or more environment parameters.

[00131] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. It is not intended that the invention be limited by the specific examples provided within the specification. While the invention has been described with reference to the aforementioned specification, the descriptions and illustrations of the embodiments herein are not meant to be construed in a limiting sense. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. Furthermore, it shall be understood that all aspects of the invention are not limited to the specific depictions, configurations or relative proportions set forth herein which depend upon a variety of conditions and variables. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is therefore contemplated that the invention shall also cover any such alternatives, modifications, variations or equivalents. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A thermoelectric system, comprising:

a first heat exchanger configured for placement below a ground surface, wherein said first heat exchanger is configured to collect thermal energy from or dissipate said thermal energy to a location below said ground surface;

a heat conducting unit coupled to said first heat exchanger, wherein said heat conducting unit has a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters;

a thermoelectric generator comprising a plurality of thermoelectric elements, wherein said thermoelectric generator is coupled to and in thermal communication with said heat conducting unit; and

a second heat exchanger coupled to and in thermal communication with said thermoelectric generator, wherein said second heat exchanger is configured to collect said thermal energy from or dissipate said thermal energy to a location above said ground surface.

2. The thermoelectric system of claim 1, further comprising a thermally conductive material disposed between said thermoelectric generator and said heat conducting unit, wherein said thermally conductive material has a thermal conductivity of at least 0.5 Watts/meter-Kelvin (W/m-K) at a temperature of 25°C.

3. The thermoelectric system of claim 1, wherein said heat conducting unit has a length (L) of at least 0.5 meters and a cross-section (C) of at least 0.05 square meters.

4. The thermoelectric system of claim 2, further comprising an additional thermally conductive material disposed between said thermoelectric generator and said second heat exchanger.

5. The thermoelectric system of claim 4, wherein said additional thermally conductive material has a thermal conductivity of at least 0.5 W/m-K at a temperature of 25°C.

6. The thermoelectric system of claim 1, wherein said thermoelectric generator has a thermal resistance of at least 1 Kelvins/Watt (K/W).

7. The thermoelectric system of claim 6, wherein said thermoelectric generator has a thermal resistance of at least 3 K/W.

8. The thermoelectric system of claim 7, wherein said thermoelectric generator has a thermal resistance of at least 5 K/W.

9. The thermoelectric system of claim 1, further comprising one or more sensors powered by said thermoelectric generator.

10. The thermoelectric system of claim 9, wherein said one or more sensors measure one or more environment parameters.

11. The thermoelectric system of claim 10, wherein said one or more environment parameters comprise temperature, humidity, luminance, wind direction, wind speed, pH level, carbon dioxide concentration, moisture, and chemical composition.

12. The thermoelectric system of claim 1, further comprising a converter.

13. The thermoelectric system of claim 12, wherein said converter is a boost converter.

14. The thermoelectric system of claim 10, further comprising a server, wherein said one or more environment parameters are uploaded to said server.

15. The thermoelectric system of claim 1, further comprising an energy storage system in electrical communication with said thermoelectric generator, wherein said energy storage system is configured to store electrical energy generated by said thermoelectric generator.

16. The thermoelectric system of claim 1, wherein said thermally conductive material is a thermally conductive adhesive.

17. A method for generating power, comprising:

providing a thermoelectric system comprising (i) a first heat exchanger positioned below a ground surface and configured to collect thermal energy from or dissipate said thermal energy to a location below said ground surface; (ii) a heat conducting unit coupled to said first heat exchanger, wherein said heat conducting unit has a length (L) of at least 0.1 meters and a cross-section (C) of at least 0.01 square meters; (iii) a thermoelectric generator comprising a plurality of thermoelectric elements, wherein said thermoelectric generator is coupled to and in thermal communication with said heat conducting unit; and (iv) a second heat exchanger coupled to and in thermal communication with said thermoelectric generator, wherein said second heat exchanger is configured to collect said thermal energy from or dissipate said thermal energy to a location above said ground surface;

using said thermoelectric generator to generate power upon flow of said thermal energy (i) from said first heat exchanger to said thermoelectric generator, or (ii) from said second heat exchanger to said thermoelectric generator; and

directing said power to an energy storage system or an electrical load.

18. The method for generating power of claim 17, wherein said thermoelectric generator further comprises a thermally conductive material disposed between said thermoelectric generator and said second heat conducting unit.

19. The method for generating power of claim 18, wherein said thermally conductive material has a thermal conductivity of at least 0.5 W/m-K at a temperature of 25°C.

20. The method for generating power of claim 17, wherein said thermoelectric generator has a thermal resistance of at least 1 K/W.

21. The method for generating power of claim 20, wherein said thermoelectric generator has a thermal resistance of at least 3 K/W.

22. The method for generating power of claim 21, wherein said thermoelectric generator has a thermal resistance of at least 5 K/W.

23. A system, comprising:

a first heat exchanger configured to be disposed below a surface, wherein said first heat exchanger is configured to collect thermal energy from or dissipate said thermal energy to a location below said surface;

a second heat exchanger configured to be disposed below said first heat exchanger, wherein said second heat exchanger is configured to collect said thermal energy from or dissipate said thermal energy to a location below said first heat exchanger;

a thermoelectric module disposed between and thermally coupled to said first heat exchanger and said second heat exchanger, wherein said thermoelectric module is configured to generate power upon application of a temperature gradient between said first heat exchanger and said second heat exchanger;

one or more sensors electrically coupled to said thermoelectric module and configured to receive power generated by said thermoelectric module; and

a transmitter electrically coupled to said one or more sensors and configured to transmit data collected by said one or more sensors.

24. The system of claim 23, wherein said second heat exchanger comprises a point configured to facilitate insertion of said system into said surface.

25. The system of claim 23, further comprising insulation disposed between said first heat exchanger and said second heat exchanger.

26. The system of claim 23, wherein said one or more sensors are configured to measure one or more environmental parameters.

27. The system of claim 26, wherein said one or more environmental parameters comprise temperature, humidity, luminance, wind direction, wind speed, pH level, carbon dioxide concentration, moisture, and chemical composition.

28. The system of claim 23, wherein said one or more sensors and/or said transmitter are integrated with a thermoelectric device comprising said first heat exchanger, said second heat exchanger and said thermoelectric module.

29. The system of claim 23, wherein said one or more sensors and/or said transmitter are external to a thermoelectric device comprising said first heat exchanger, said second heat exchanger and said thermoelectric module.

30. The system of claim 23, wherein said second heat exchanger comprises an elongated cylinder that is configured to extend at least 5 centimeters below said surface.

31. The system of claim 23, wherein said first heat exchanger and said second heat exchanger comprise plates.

32. The system of claim 23, wherein said surface is a surface of a body of water, and wherein said system further comprises a buoyancy element.

33. A method for transmitting data, comprising:

(a) providing a system below a surface, said system comprising: (i) a first heat exchanger; (ii) a second heat exchanger configured to be disposed below said first heat exchanger; (iii) a thermoelectric module disposed between and thermally coupled to said first heat exchanger and said second heat exchanger; (iv) one or more sensors electrically coupled to said thermoelectric module; and (v) a transmitter electrically coupled to said one or more sensors;

(b) using said thermoelectric module to generate power upon flow of thermal energy (i) from said first heat exchanger to said second heat exchanger through said thermoelectric generator, or (ii) from said second heat exchanger to said first heat exchanger through said thermoelectric generator;

(c) directing at least a portion of said power to said one or more sensors; and

(d) transmitting data collected by said one or more sensors using said transmitter.

.

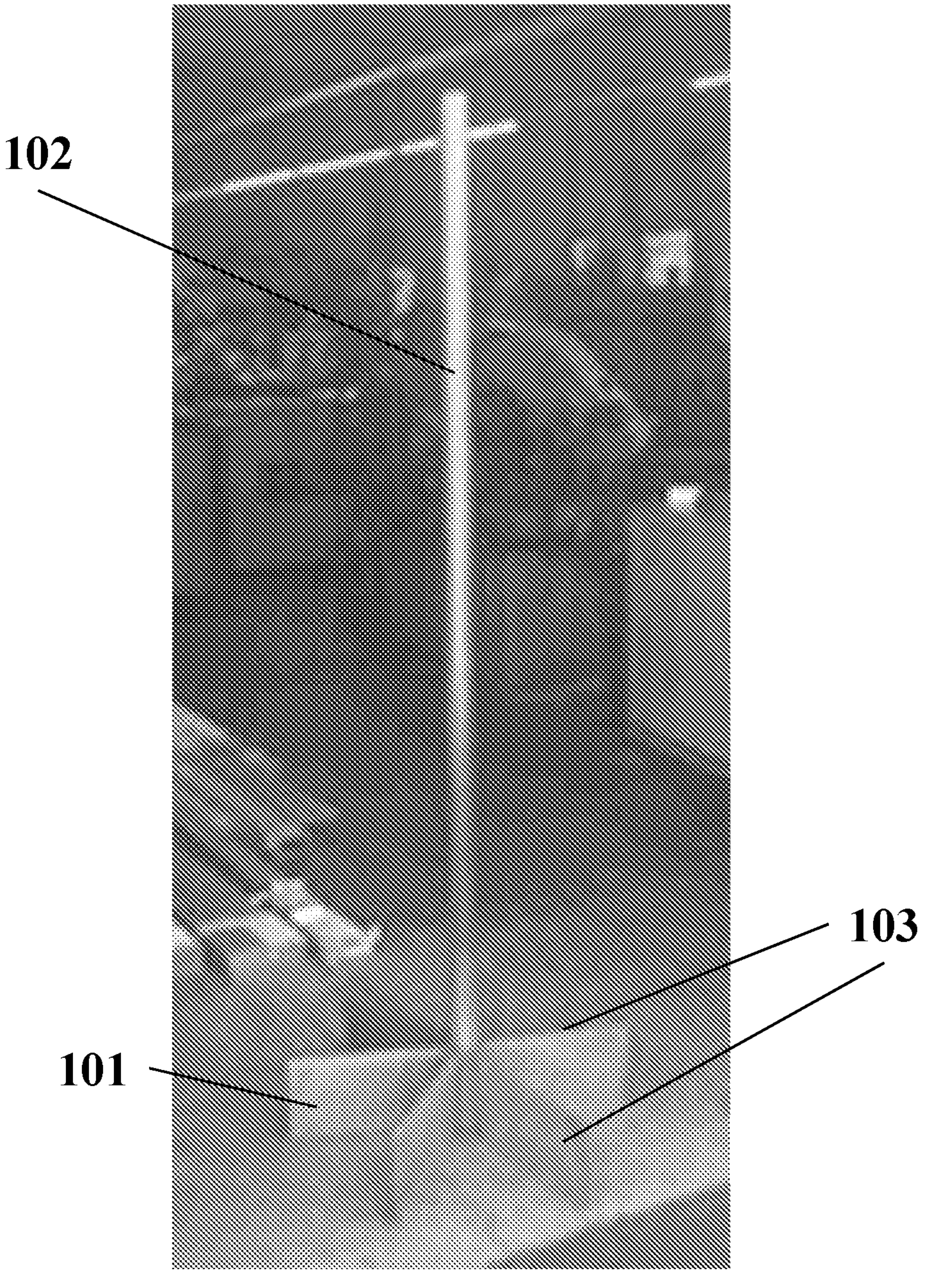

FIG. 1

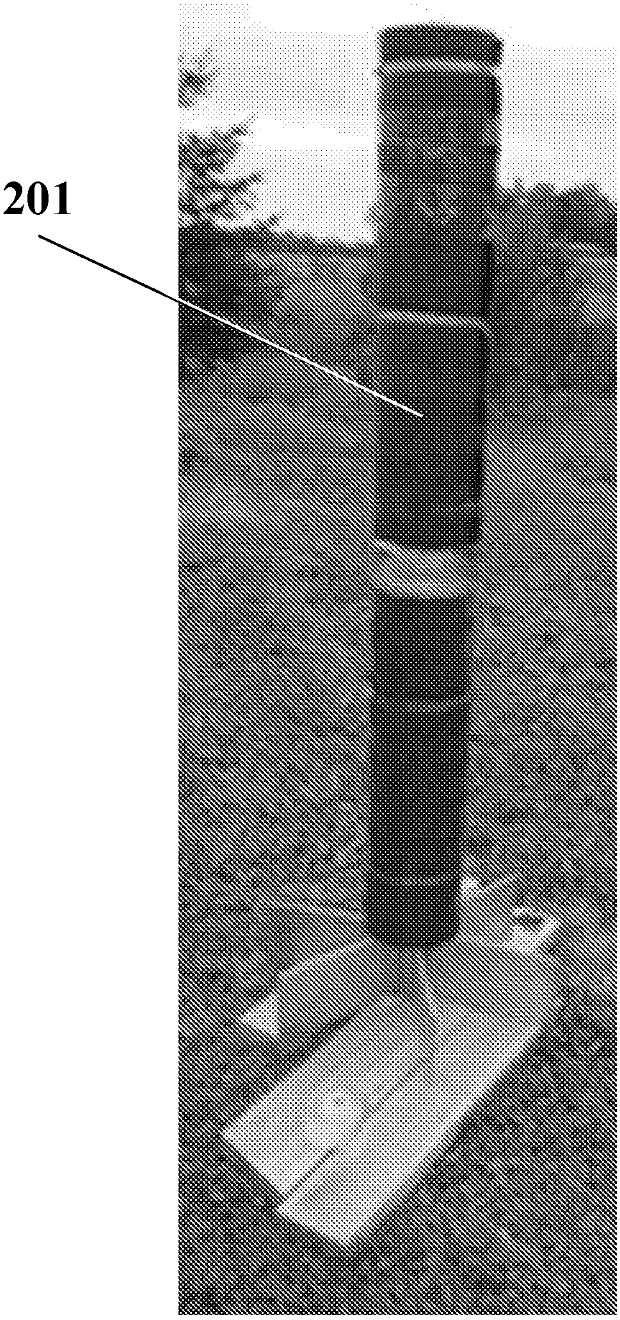

FIG. 2

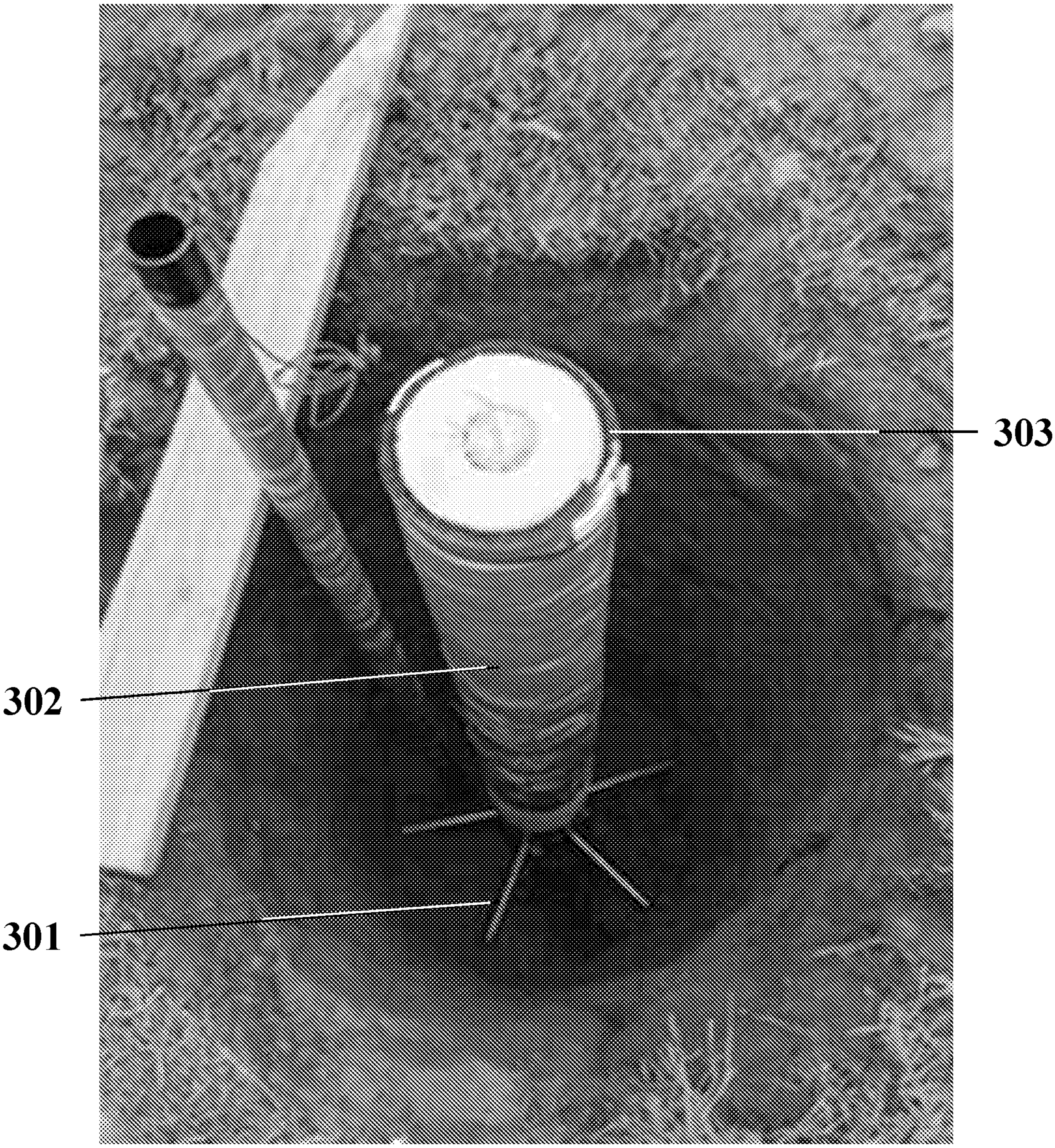

FIG. 3

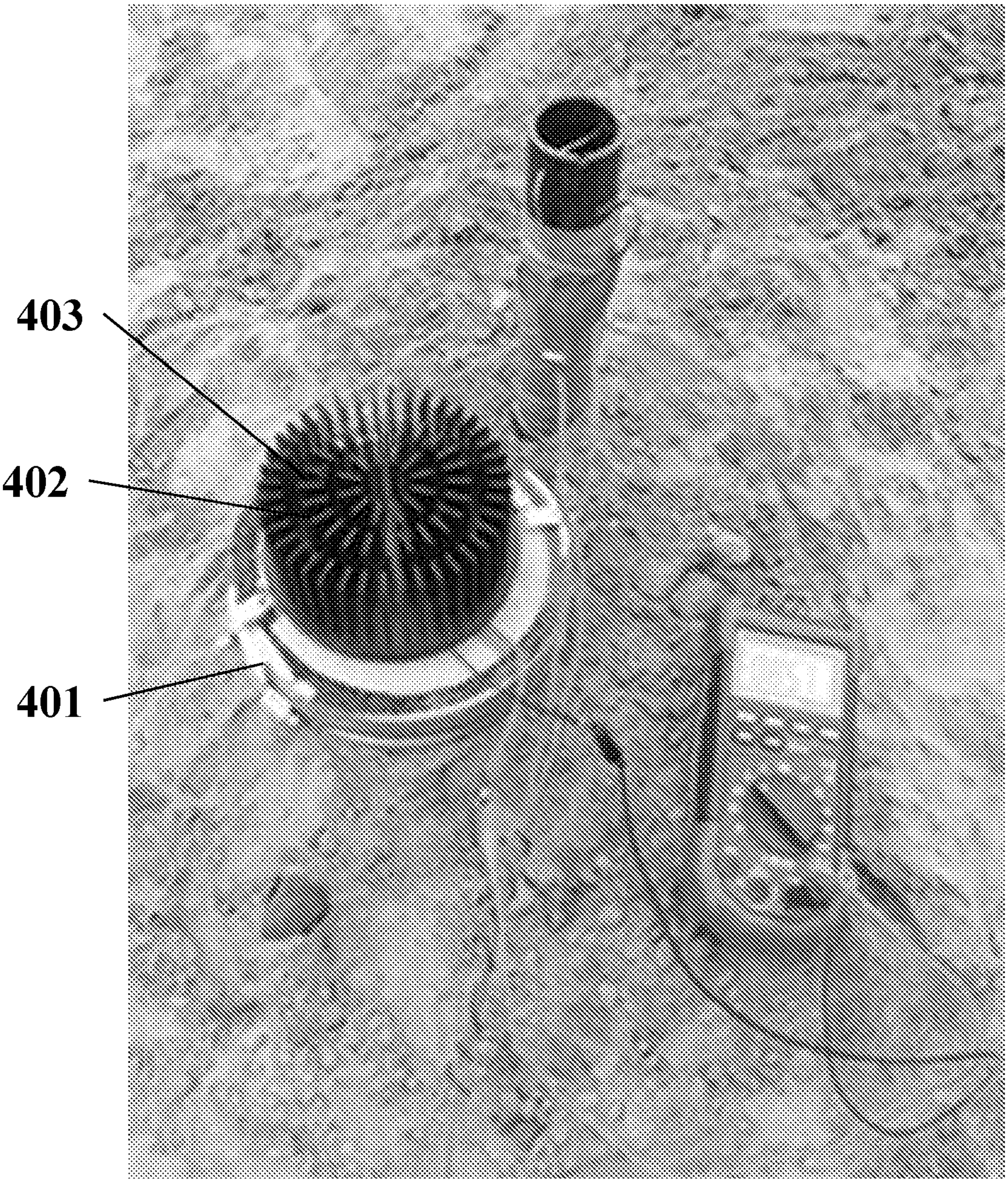

FIG. 4

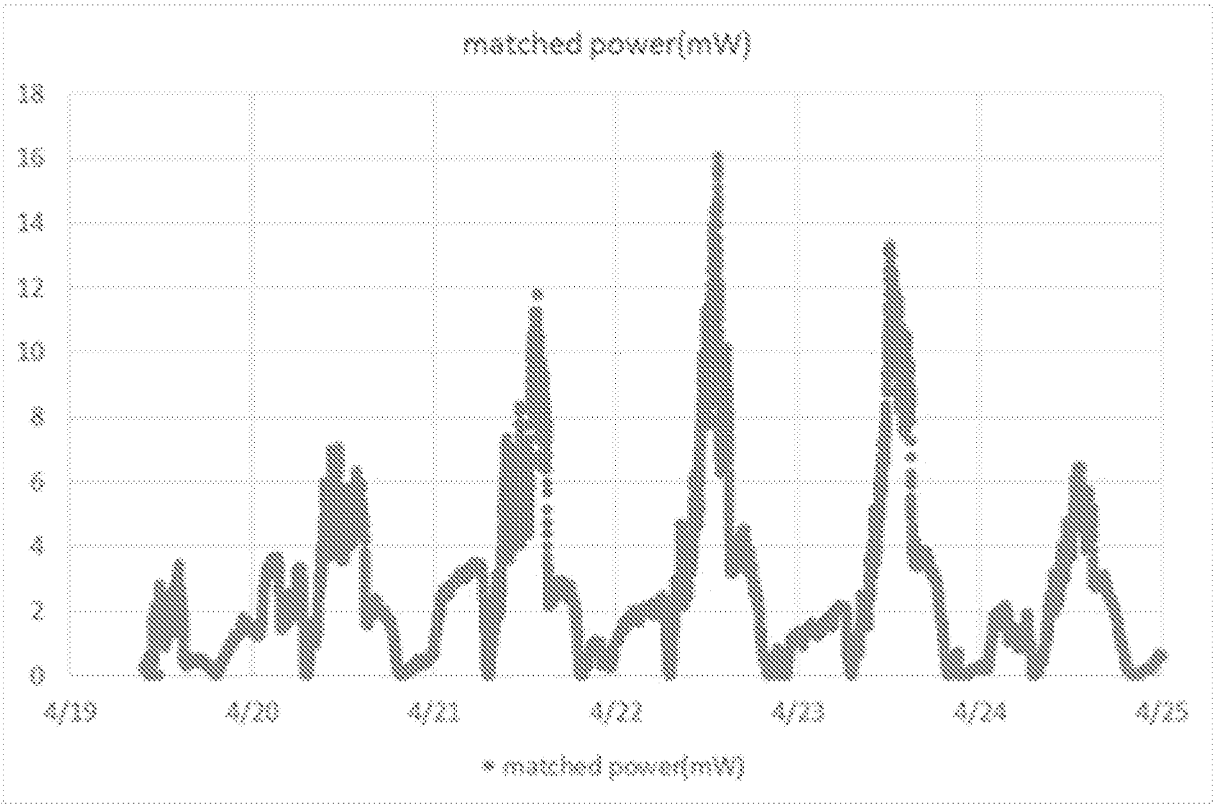
matched power(mW)
18
16
14
12
10
8
6
4
2
0
4/19
4/20
4/21
4/22
4/23
4/24
4/25
• matched power(mW)

FIG. 5

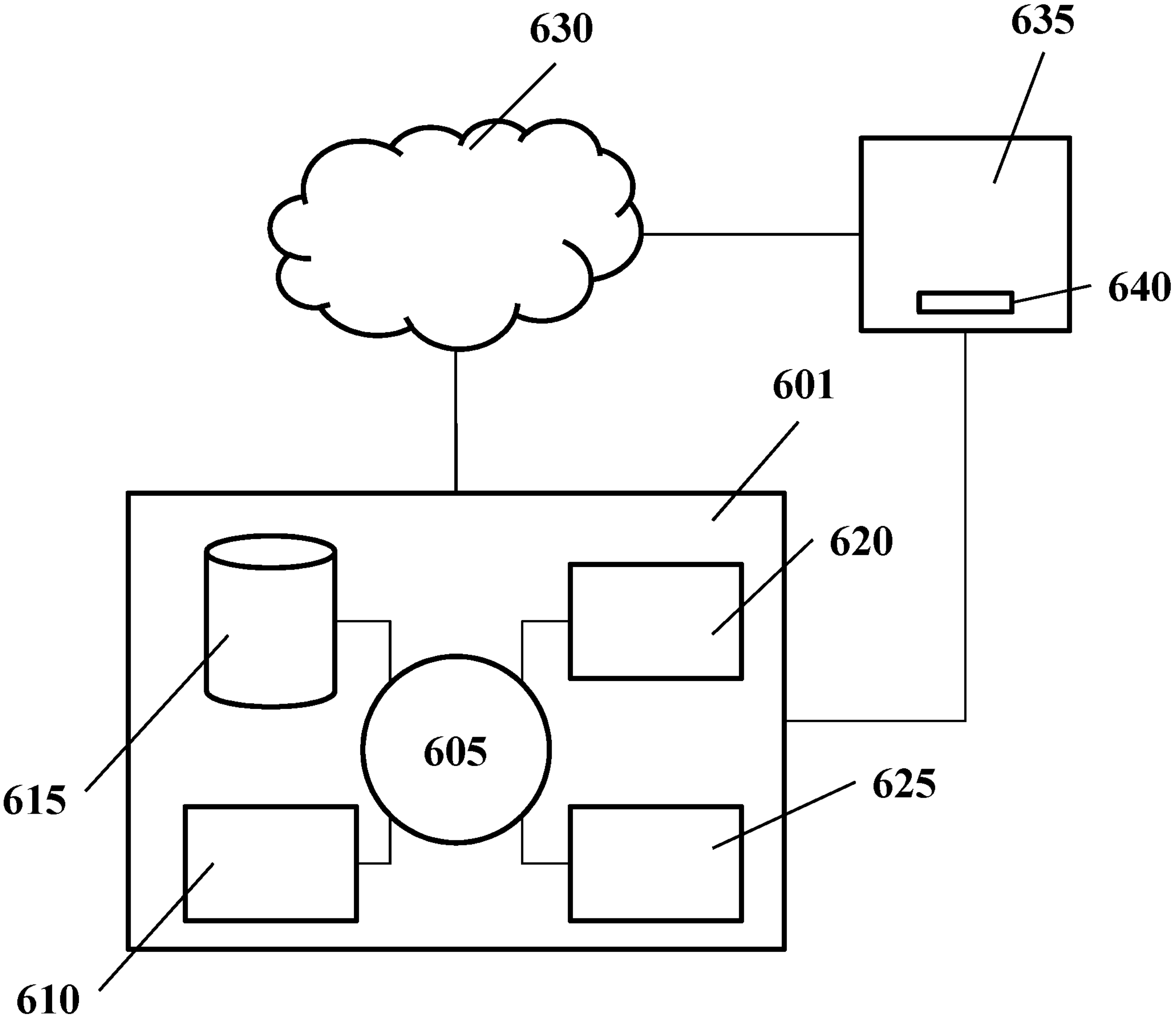

FIG. 6

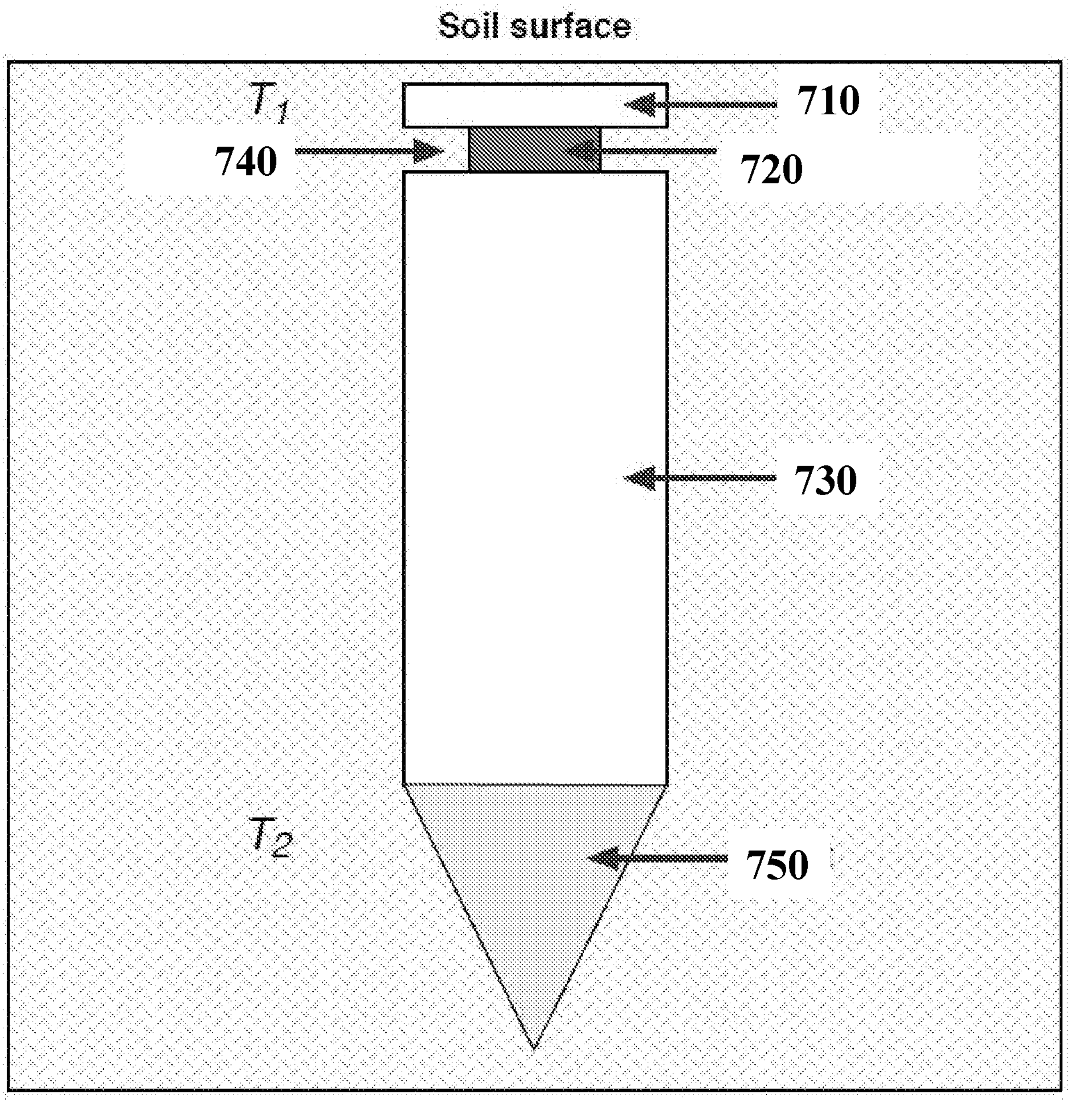

FIG. 7

Location	**Date**	**Temperature (°F)**		**Conditions**	**Power (µW)**
		Low	**High**		
San Mateo County, California	04/06/2019	49	62	light rain	117
	04/07/2019	47	67	overcast	128
	04/13/2019	41	71	sunny	277
	04/14/2019	42	62	sunny	348

FIG. 8

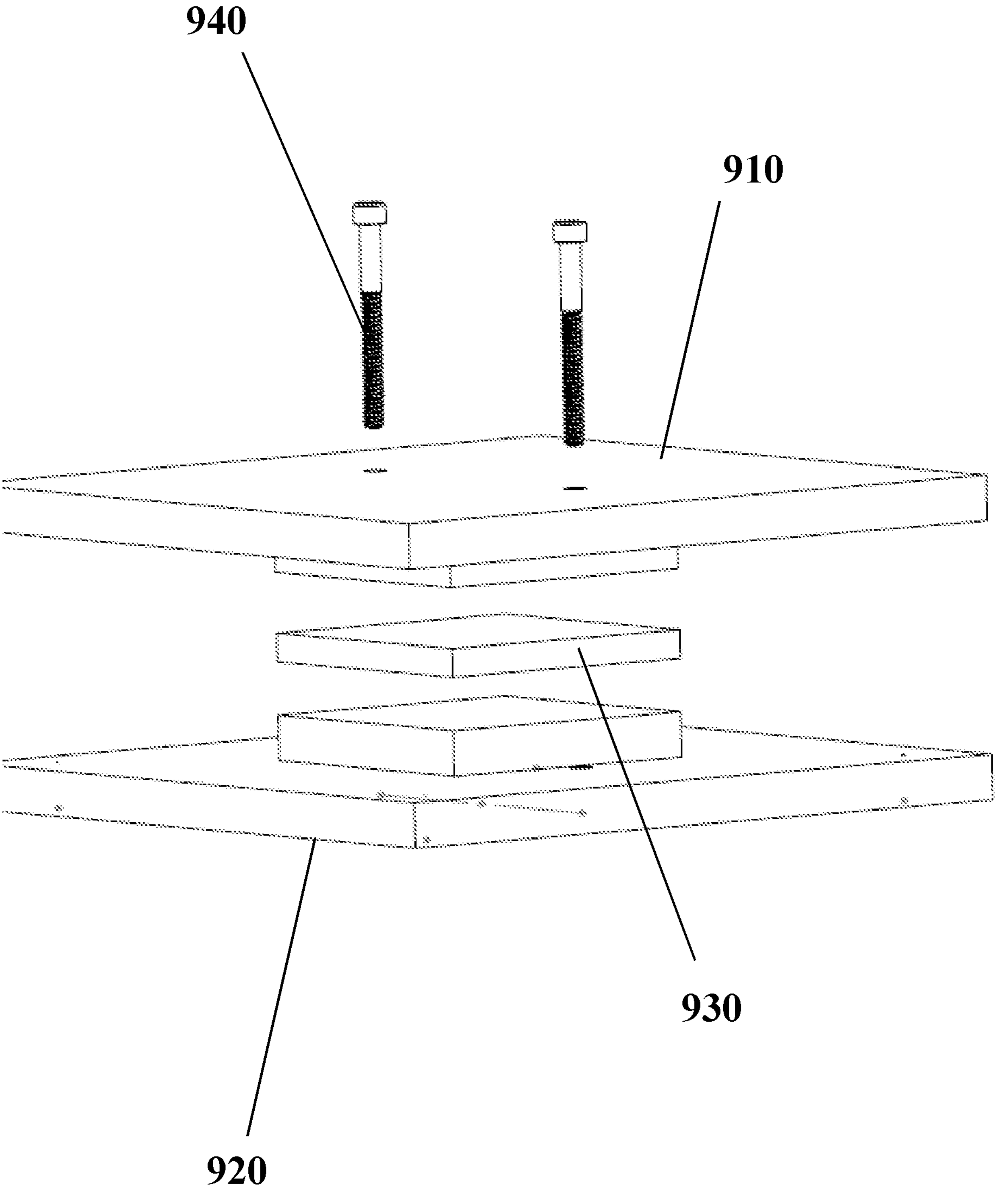

FIG. 9

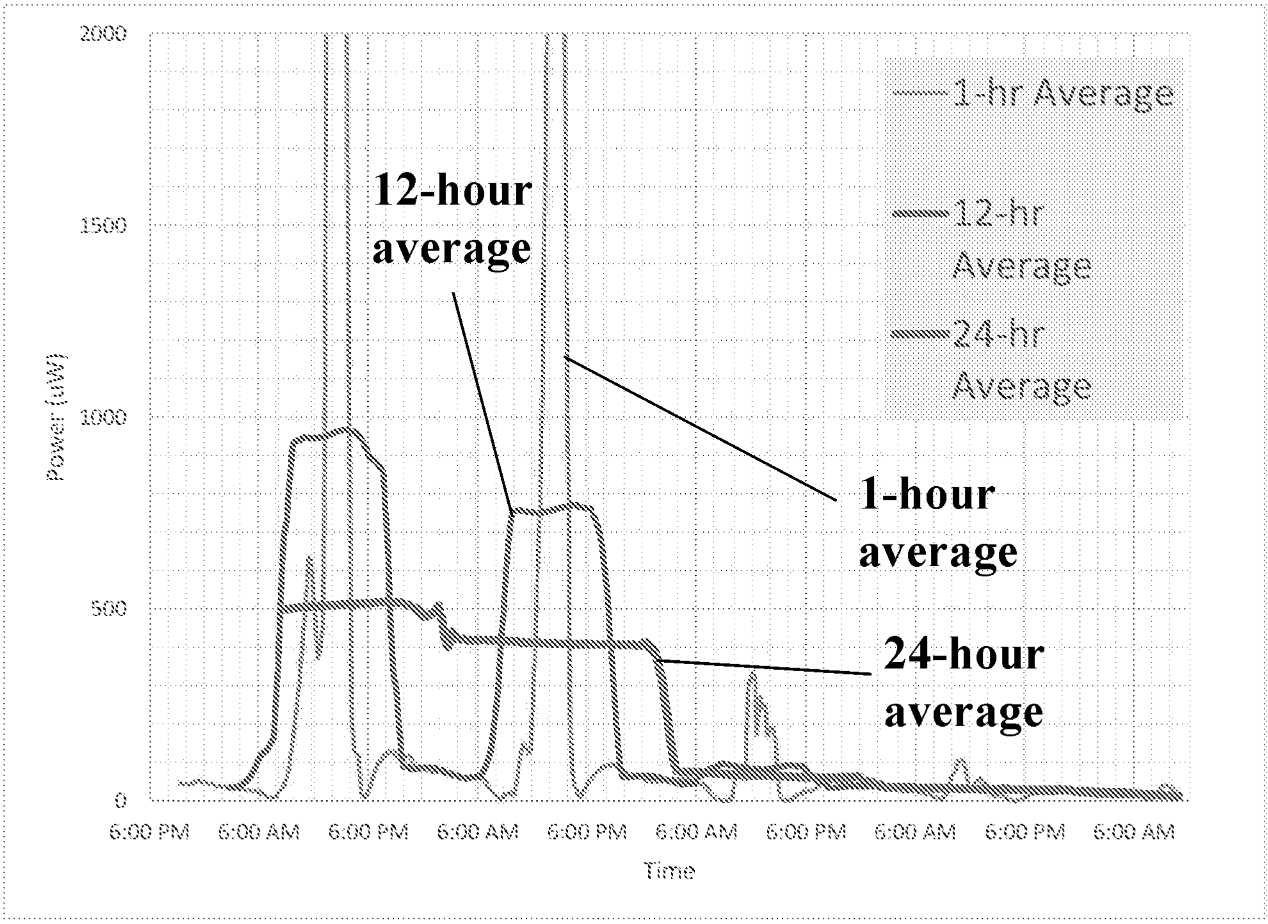
2000
1500
1000
500
0
Power (uW)
6:00 PM
6:00 AM
6:00 PM
6:00 AM
6:00 PM
6:00 AM
6:00 PM
6:00 AM
6:00 PM
6:00 AM
Time
1-hr Average
12-hr Average
24-hr Average
12-hour average
1-hour average
24-hour average

FIG. 10