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(54) Title: INTEGRATED HEAT SINK AND SYSTEM FOR ENHANCED THERMAL POWER GENERATION

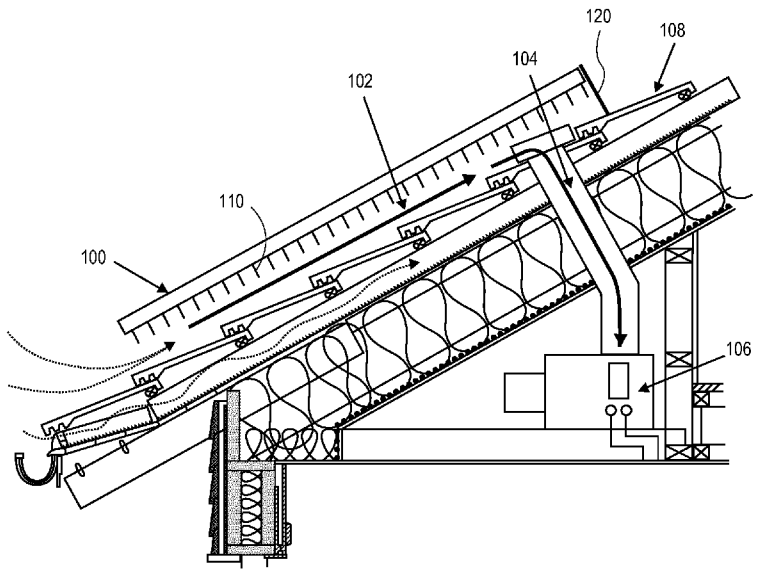


FIG. 9

(57) Abstract: The present invention is a method of providing a system having at least one photovoltaic module and defining a heat recapture gap below the photovoltaic module. The heat recapture gap is sized to allow for fluid flow between a first heat emissive surface and a second heat emissive surface. Resistance to convective heat transfer out of the first heat emissive surface relative to the resistance of convective heat transfer out of a light exposed surface of the photovoltaic module is reduced. Finally, heat is captured by flowing fluid through the heat recapture gap from the photovoltaic module.

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INTEGRATED HEAT SINK AND SYSTEM FOR ENHANCED THERMAL POWER GENERATION

Description

Cross-Reference to Related Applications

[01] This application claims the benefit of priority to U.S. Provisional Application No. 61/314,514 filed March 16, 2010, fully incorporated herein by reference for all purposes.

Field of the Invention

[02] The devices described herein relate to solar modules with photovoltaic (PV) energy output and thermal energy output.

Background of the Invention

[03] In most photovoltaic systems, about 15% to 20% of the incident energy from sunlight creates energy. For photovoltaic modules, the energy is in the form of electricity. The balance of the incident energy is dissipated as heat. One effect of this is to raise the photovoltaic module temperature. This is undesirable because photovoltaic modules produce less electricity as their temperature increases. Therefore, it is desirable to remove excess heat from photovoltaic modules and keep the photovoltaic modules and their cells near the normal operating cell temperature (NOCT).

[04] Photovoltaic Electric and Thermal Energy (PVETE) systems utilize the excess heat from the photovoltaic modules rather than just ejecting such heat to the atmosphere. Maximizing the usefulness of the thermal energy requires both maximizing the total amount of energy in the working fluid as well as maximizing the temperature of the working fluid. By maximizing the working fluid temperature, the thermodynamic utility is increased.

Brief Summary of the Invention

[05] The present invention is a method of providing a system having at least one photovoltaic module and defining a heat recapture gap below the photovoltaic module. The heat recapture gap is sized to allow for fluid flow between a first heat emissive surface and a second heat emissive surface. Resistance to convective heat transfer out of the first heat emissive surface relative to the resistance of convective heat transfer out of a light exposed surface of the photovoltaic module is reduced. Finally, heat is captured by flowing fluid through the heat recapture gap from the photovoltaic module.

[06] A further understanding of the nature and advantages of the invention will become apparent by reference to the remaining portions of the specification and drawings.

Brief Description of the Drawings

[07] Figure **1** is a perspective view of one embodiment of a minimum stress heat sink.

[08] Figure **2** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink and a back sheet formed of the same material.

[09] Figure **3** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink with a back sheet of two or more materials.

[10] Figure **4** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink joined to a continuous back sheet.

[11] Figure **5** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink joined with one continuous layer and other discontinuous layers that surround the heat sink sections.

[12] Figure **6** is a side sectional view, taken along section line **A–A** in Figure **1**, showing heat sink sections in a back sheet that surround the heat sink sections but does not continue under the heat sink segments that contact the object being cooled.

[13] Figure **7** is a bottom view of a heat sink fin row.

[14] Figure **8** is a bottom view of a segment of a heat sink showing through a back sheet.

[15] Figure **9** is an illustration of a PVETE system installed on a rooftop.

[16] Figure **10** is an illustration of a possible configuration for the radiation shield.

[17] Figure **11** is an illustration of a PVETE system with a radiation shield included.

Detailed Description of the Embodiments

[18] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed. It may be noted that, as used in the specification and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a material” may include mixtures of materials, reference to “a compound” may include multiple compounds, and the like. References cited herein are hereby incorporated by reference in their entirety, except to the extent that they conflict with teachings explicitly set forth in this specification.

[19] Specific embodiments of this invention address integrating a heat sink with the backside of a photovoltaic (PV) module. The embodiments of the present invention may also be used in conjunction with an LED display. Other embodiments of the invention add heat sinks to a large surface to augment cooling, such as integrating the heat sink into the object being cooled. One or more embodiments of the present invention can be configured to include one or more of the following features.

[20] In one embodiment of the present invention, a method is described providing a system having at least one photovoltaic module and defining a heat recapture gap below the photovoltaic module. The heat recapture gap is sized to allow for fluid flow between a first heat emissive surface and a second heat emissive surface. Resistance to convective heat transfer out of the first heat emissive surface relative to the resistance of convective heat transfer out of a light exposed surface of the photovoltaic module is reduced. Finally, heat is captured by flowing fluid through the heat recapture gap from the photovoltaic module. Optionally, the fluid that is used is air.

[21] In another embodiment, the first heat emissive surface is on an underside surface of the photovoltaic module and the second heat emissive surface is positioned to be opposing this first heat emissive surface. Optionally, the second heat emissive surface is located on a radiation shield. The second heat emissive surface has a heat emissivity equal to or greater than the first heat emissive surface. The method also

includes decreasing the second heat emissive surface radiation so that a minimal amount of this radiation reaches the photovoltaic module. Optionally, the first heat emissive surface has an emissivity in the range of 0.7 to 1.0. Optionally, the second heat emissive surface has an emissivity in the range of 0.7 to 1.0.

[22] The present invention also includes a method which forces fluid to flow between a first heat emissive surface and a second heat emissive surface. The first heat emissive surface is defined by a heat sink on an underside surface the photovoltaic module. The radiation shield, which may be integrated with the photovoltaic module, has a high emissivity surface on one side and a low emissivity surface on an opposite side, while having a directional airflow structure to preferentially direct airflow in one direction. The backside surface of the photovoltaic module has a plurality of elongated structures while its bottom layer may be integrated with a heat sink having a low stress base configuration. The heat sink, which may be coupled to a polymer layer, has a plurality of elongated members aligned in one direction that are joined by a plurality of connectors aligned in an orthogonal direction. Also, a barrier may be used to close the top end of the heat recapture gap.

[23] Although many embodiments herein use more than one high emissivity surface, embodiments using only a single high emissivity surface are not excluded. For example, such embodiments may use a heat sink without a high emissivity coating that opposes a radiation shield that does have a high emissivity surface (0.7 to 1.0). Optionally, one method comprises providing at least one photovoltaic module, wherein the module is used to define a heat recapture gap below the photovoltaic module with a heat sink on a bottom surface of the photovoltaic module that opposes a high emissivity surface having an emissivity between 0.7 and 1.0. Optionally, another method comprises providing at least one photovoltaic module, wherein the module is used to define a heat recapture gap below the photovoltaic module.

[24] In another embodiment of the present invention, a method is described providing at least one photovoltaic module. With this, heat transfer is increased through an underside of the module through use of a heat sink on the underside of the module. Also, a gap is defined between the underside of the photovoltaic module and a top

surface of an emissivity structure, wherein the gap is sized to allow for air flow between the underside of the photovoltaic module and the top surface of the emissivity structure.

[25] The present invention also deals with improving the efficiency of combined solar Photovoltaic Electric and Thermal Energy (PVETE) systems. Embodiments of this invention improve combined PVETE systems by adding heat sinks to the backside of the photovoltaic modules and optionally adding an uncommon radiation shield between the photovoltaic module with heat sinks and the roof surface. This increases both the electric and thermal energy output of the PVETE system. In the combined PVETE systems to which embodiments of this invention apply, one or more photovoltaic modules are used to produce electricity while heat from the backside of the photovoltaic modules is used as thermal energy. Common uses for the thermal energy include space heating, domestic hot water, and pool heating. By way of example only, the photovoltaic modules may be mounted to a sloping roof on a house, and the air that passes between the photovoltaic modules and the rooftop is heated and then captured for its energy. In this way, air is used to transfer heat away from the backside of the modules. Another method of improving PVETE systems involves maximizing the working fluid temperature by adding more energy into approximately the same amount of working fluid. To enhance performance of PVETE systems or to enhance the cooling of a large planar or moderately curved object in natural convection, one or more heat sinks may be added.

[26] Some embodiments of this invention provide integrating the heat sink with the backside of the object to be cooled. This may be accomplished in many ways. First, the heat sink may be integrated with the protective back cover or sheet. Second, the heat sink may be integrated by including the heat sink features, for example, extended surfaces, into the object itself. Next, the heat sink may be integrated with a layer or coating that comprises the back surface of the object. Last, the heat sink may be integrated with the surface of an object where the surface is made from the same material as the bulk of the object. Some of these objects may comprise active electronic or electrical layers covered by a protective layer or coating on the backside. Such covers may be to protect the inner layers or components from abrasion, scratches, or the environment. Other large planar objects to be cooled may have no

active electrical components inside but they may still benefit from cooling, such as the seats of outdoor furniture or other objects exposed to sunlight, ducts carrying hot fluids, or heated chamber walls. For these and other types of objects, there may be benefit to integrating the heat sink with the object being cooled. The heat sink may be combined with the cover if present, or it may be formed out of the primary material of the object itself. Possible benefits include improved manufacturability, lower cost, and improved thermal performance. Potential applications of integrating a heat sink with an electrical object to be cooled would be the integration of a heat sink with a photovoltaic module or an LED display.

[27] The back sheet of a photovoltaic module or LED display is desirably flexible enough so the module can expand and contract freely during thermal cycles without mechanically stressing the internal components. The cells in photovoltaic modules, especially silicon or other cells, may be brittle and especially susceptible to being stressed or cracked. Heat sinks may be mounted to the back of a finished photovoltaic module by joining with an adhesive. In this use of a heat sink, it is necessary to allow the module to expand and contract relatively freely so the heat sink does not significantly increase stress and strain in the module and cause damage. One way to accomplish this is with a "Low Stress-Inducing Heat Sink" previously described by, Carbone, et. al. in PCT Application Publication No. WO 2010/118183 filed on April 7, 2010 and incorporated herein by reference for all purposes. In that disclosure, a low stress-inducing heat sink is described as a heat sink having fins which are held together in a non-rigid manner.

[28] The heat sink shown in Figure **1** transfers heat to the surroundings primarily by convection and radiation from fins **1**. Heat may also be transferred from other heat sink structures such as fin interconnecting features **2**. In addition, to maximize cooling performance, all paths for heat transfer from the module to the environment should have minimum thermal resistance. One of these heat transfer paths goes through area **5** that leads from the cells, through the back of the module between fins and any other heat sink structures to the air; this area **5** between fins transfers heat to the environment by both convection, shown schematically as **3**, and radiation, shown schematically as **4**. To minimize heat transfer resistance from the cells to the environment, area **5** between

heat sink features should be kept as open as possible; there should be no heat sink base or structure in this type of area.

[29] To facilitate a description of thermal radiation heat transfer resistance for purposes of this description, it is first assumed that the surface to be cooled has a higher temperature than its environment. Examples of this are a photovoltaic module in sunlight and an LED display during operation. Therefore, to minimize radiation resistance from the surface of the heat sink, the heat sink material should have maximum emissivity in the thermal radiation wavelengths, broadly defined in this context as those wavelengths emitted by a black or grey surface with a temperature in the range of 20°C to 160°C.

[30] The back sheet of a photovoltaic module typically covers the back of the module and serves to protect the cells and their connections from the environment, and to electrically insulate the cells and connections from other objects. The back cover or sheet of a photovoltaic module or LED display has similar functions. The back sheet is desirably flexible to allow thermal expansion and contraction of the module without subjecting the cells to stress and strain high enough to cause damage.

[31] Protective measures for the inner parts of a photovoltaic module are concerned mainly with blocking ultraviolet (UV) light and retarding moisture from entering the module. This may be accomplished by coupling a polymer layer to the heat sink. Materials such as fluoropolymers, for example, Tedlar ® or Kynar®, are commonly used in this application. For electrical insulation, a layer of polyester such as polyethylene terephthalate (PET) is typically used. Normally, layers of Tedlar-PET-Tedlar are laminated into a composite sheet, and then this sheet is used to cover the back of the module. Alternatively, layers of Kynar®-PET-Kynar® may be used. This composite sheet provides a barrier to both UV light and moisture. The PET layer functions largely as an electrical insulator while the fluoropolymer layer, which faces the interior of the module, primarily functions to keep UV light that enters the front of the module from reaching the PET layer. It also acts as a second moisture retarding layer. Finally, two-layer composite sheets of PET-Tedlar® or PET-Kynar® can be used, especially when the PET layer has UV stabilizers added. In these cases, the PET layer generally faces the interior of the module. Immediately under these composite back sheets is an

encapsulant layer such as ethylene vinyl acetate (EVA). The photovoltaic cells would then be located immediately under the encapsulant layer.

[32] Figure **2** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink and back sheet formed of the same material. One method to integrate a heat sink and a back sheet is to fabricate the fins **1** and a continuous sheet **6** of the same material. These may be formed at the same time, such as in a one-shot molding process, or formed in steps, such as in a two-shot molding process, or formed separately and joined. Fin interconnecting features **2** may be constructed of the same or a different material and may be formed or joined at any point in the process. If the same material is used for the fins and back sheet material, the material is desirably sufficiently thermally conductive for the fins to augment heat transfer and sufficiently electrically insulating to isolate the cells and interconnections electrically. In addition, the material should be weather resistant so as to survive outdoors for the life of the photovoltaic module (generally 20 to 25 years), or an additional material would need to be added as a coating or treatment to increase weather resistance. For example, a polymer or elastomer that has been enhanced to increase thermal conductivity may be used. In all cases, the material used for the fin interconnecting features **2** and the continuous sheet **6** should have an elastic modulus and geometry so as to allow thermal expansion and contraction of the module to occur with low stress and strain.

[33] Figure **3** is a side sectional view, taken along section line **A–A** in Figure **1**, showing the heat sink with a back sheet of two or more materials. In this embodiment, fins **1** with fin interconnecting features **2** are shown as well as added layer(s) **7**, which is a different material to the first layer **6**. The additional layer(s) **7** may be added to the fin/back sheet unit that was previously joined in Figure **2**, or the additional layer(s) **7** may be formed onto the fin/back sheet assembly. For the example of polymers or elastomers, as was introduced above, any additional layer(s) **7** may be formed in a variety of ways, such as molded, cast, or extruded separately and then joined, or may be formed in place with the heat sink structure during subsequent fabrication steps. The final layer stack-up should be flexible enough to allow thermal cycling

[34] Another method of integrating heat sinks into the back of a photovoltaic module is to join the heat sink with one or more sheets of one or more materials that may be

different from each other as well as different from the heat sink material. Figure **4** is a side sectional view, taken along section line **A–A** in Figure **1**, showing a heat sink joined to a continuous back sheet. Fins 1 with fin interconnecting features **2** are shown. Additionally, layer **8**, layer **9** and layer **10** represent different materials from one another, which further differ from the heat sink material. This embodiment may be fabricated either by a multiple-step forming process, such as in a two-shot molding process, or by attaching the components after forming.

[35] The heat sink has a low stress base configuration which may be integrated with a bottom layer of the photovoltaic module. To illustrate possible material stack-ups, the following series of examples will consider the integration of a heat sink with a typical multi-layer photovoltaic module back sheet. For example, one possible configuration may be to use layer **8**, layer **9** and layer **10** of Tedlar®-PET-Tedlar®, respectively. Another possibility may be Kynar®-PET-Kynar®. Also, for each of these cases, the innermost layer, or layer **8**, may be eliminated, resulting in PET-Tedlar® or PET-Kynar®. In general, one or more layers such as layer **8**, layer **9** and layer **10** may be used for protection from the weather and electrical insulation. Note that alternate constructions are possible.

[36] Figure **5** is a side sectional view, taken along section line **A–A** in Figure **1**, showing the heat sink joined with one continuous layer and other discontinuous layers that surround the heat sink sections. Layer **13** is continuous but layer **11** and layer **12** are penetrated by the heat sink. Such a configuration may be fabricated by starting with fins **1** and any other structures joined to a continuous layer **13.** Then one or more layers such as layer **11** and layer **12** may be formed or joined with the assembly. In addition, a structure can be used as shown in Figure **6.** Figure **6** is a side sectional view, taken along section line **A–A** in Figure **1**, showing the heat sink sections in a back sheet that surround the heat sink sections but does not continue under the heat sink segments that contact the object being cooled. Optionally, the stack-up of layer **14**, layer **15** and layer **16** can all be penetrated by the heat sink.

[37] Two distinctions can be made when incorporating a heat sink with a photovoltaic module back sheet. The first distinguishing design feature is the arrangement of material under the fins of the heat sink as opposed to the arrangement of material

between the fins. Three options are shown in Table **1** as Type 1 (resulting structure has the same back sheet material(s) under and between fins), Type 2 (resulting structure has thinner back sheet material(s) under the fins than between the fins) and Type 3 (resulting structure has no back sheet material under the fins). The second distinguishing design feature is the manner of how the fins of the heat sink are connected to each other before being joined with a back sheet. Referring to Table **1**, these possibilities include Type A (fins independent of each other before joining with a back sheet), Type B (fins in small groups before joining with a back sheet) and Type C (fins in larger groups before joining with a back sheet).

Table **1** below shows a matrix of completed structure designs and possible fabrication options and methods.

	Fins independent of each other before joining (fins held together only through back sheet and module after joining) *Type A*	**Fins are in small groups before joining** (mechanical features interconnect fin groups rigidly before joining with back sheet) *Type B*	**Fins are in larger groups before joining** (mechanical features interconnect fin groups flexibly before joining with back sheet) *Type C*
Resulting structure has the same back sheet material(s) under and between fins *Type 1*	May be formed by joining individual fins to completed back sheet	May be formed by joining fin groups to completed back sheet	May be formed by joining groups of interconnected fins to completed back sheet
Resulting structure has thinner back sheet material(s) under the fins than between the fins *Type 2*	May be formed by joining individual fins to continuous back sheet; additional material would then be added between fins	May be formed by joining fin groups to continuous back sheet; add additional material between fins and interconnection structures	May be formed by joining fin groups to continuous back sheet; add additional material between fins and interconnection structures

Resulting structure has no back sheet material under the fins *Type 3*	May be formed by retaining fins in place and forming back sheet around them; may require larger fin base and some Tedlar® on top of pin base for structural integrity	May be formed by retaining fin groups in place and forming back sheet around them; struts aid mechanical strength to keep fins from breaking out of back sheet	Mechanical features interconnect fins flexibly and back sheet is formed or assembled around them

Table 1: Structure Designs and Possible Fabrication Options

[38] In Table **1**, an example of Type 1 is the heat sink joined to the complete back sheet stack-up. The joining may be accomplished by adding a new material to adhere the heat sinks to the back sheet, or by heat staking or welding the bottom of the heat sink to the back sheet, or by another method. This would result in a structure very similar to that produced when using adhesive to attach the heat sink to the back of a finished photovoltaic module. In Type 1A, the fins are separate before being joined to the back sheet, and after the assembly is completed the fins are interconnected only through the back sheet and module. In Types 1B and 1C, the fins are connected by inter-fin connections into groups of two or more before being attached to the back sheet. It is a Type 1B design if the inter-fin connection is relatively rigid. In a specific embodiment, the fin group is desirably small so photovoltaic module stress and strain are kept low during thermal cycles.

[39] In another specific embodiment, the inter-fin connections will be flexible enough such that any stress and strain induced in the photovoltaic modules by thermal cycles will not damage the modules. Figure **1** shows one embodiment of a heat sink that can be used for all of the example drawings in this document. By way of example only, the heat sink used in this example is approximately five inches by five inches in area, and the fin interconnecting features **2** collectively are flexible to create a Type C heat sink. The fin interconnecting features **2** are arranged geometrically so that the structure flexes easily in the plane of the photovoltaic module and does not exert sufficient stress

or strain on the photovoltaic module to cause damage, premature ageing or failure. Figure **7** is a bottom view of a heat sink fin row and depicts the fins **1** and fin interconnecting features **2**. In this embodiment, the fins are in one or a few rows, interconnected with flexible mechanical interconnect features that span a significant portion of the length or width of the back sheet.

[40] In a Type 2 structure, as described in Table **1**, and referring to Figure **5**, the bottom layer **13** would be continuous on the surface that faces the photovoltaic module. There may be an additional layer **11** and/or layer **12** in area **5** between fins **1** and fin interconnecting features **2**. This may ease the fabrication process as well as enhance the protection as it comprises a continuous layer as a barrier. The continuous layer may be a single material, such as Tedlar® or PET, or may be a composite layer, such as a PET-Tedlar®.

[41] In a Type 3 structure, as described in Table **1**, the back sheet material would exist solely between the fins. Referring to Figure **6,** the back sheet material may or may not exist under the fin interconnecting features **2.** Figure **6** shows the heat sink sections in a back sheet that surround the heat sink sections, but the back sheet material does not continue under the heat sink segments that contact the object being cooled.

[42] Figure **8** is a bottom view of a segment of the heat sink showing through a back sheet. In this embodiment, fins **1** and the fin interconnecting features **2** as well as area **5** is visible with the back sheet surrounding the visible base areas of heat sink.

[43] **Enhanced Thermal Power Generation**

[44] In yet another embodiment of the present invention, devices and systems can be configured to increase the amount of heat that goes into the working fluid being utilized by a PVETE system, while keeping the amount of working fluid substantially the same as in prior art systems. Therefore, both the amount of energy in the working fluid, and the temperature of the working fluid are increased.

[45] In normal operation of a PVETE system, heat is transferred from both the front and back of the photovoltaic module. Heat transferred from the front of the photovoltaic module is lost to the environment, and heat from the back of the photovoltaic module largely can be captured by the system for use as thermal energy. Heat transfer from

the front of the photovoltaic module is by natural convection, possibly aided by wind, and thermal radiation. Heat transfer from the back of the photovoltaic module is by convection and thermal radiation.

[46] Referring now to Figure **9**, one embodiment of the present invention increases the amount of heat being preferentially directed toward at least one surface of a photovoltaic module **100**. Although other techniques are not excluded, embodiments of this invention use heat sinks to reduce the resistance to convective heat transfer out of the first heat emissive surface, defined by the backside of the photovoltaic module. This approach increases the proportion of heat transferred out the backside of the photovoltaic module resulting in more thermal energy going into the working fluid to be made available for thermal energy use. Figure **9** shows heated air **102** being directed at duct **104** toward a heat capture unit **106**. The entire system may be mounted on an angled roof with roof surface **108**. The roof surface may include tiles made of clay or slate, shingles made of asphalt or wood, metal panels made of steel or aluminum, or other commercially available roof surface materials.

[47] Heat sinks that can be added to the back of the photovoltaic module generally include any of those described herein or in PCT Application Publication No. WO 2010/118183, filed on April 7, 2010 and fully incorporated herein by reference for all purposes. By way of example only, the heat sinks utilize material of modest thermal conductivity, have a plurality of elongated structures such as pin fins **110**, and employ a low stress-inducing base. In addition, the heat sinks can be further optimized for certain applications by changing the form of the fins. In some PVETE systems, a device is used to guarantee working fluid flow. By non-limiting example, the device may be a convection device or a fan. In such systems, the fins **110** should have a higher cross-sectional area (may be made slightly thicker) than would be optimal for a natural convection or “open rack” system. This will keep fin efficiency high, maximizing heat transfer from the photovoltaic module and maximizing the final temperature of the working fluid. Some embodiments may have a barrier **120** to close the top end of the heat recapture gap **180** to prevent loss of heat.

[48] Referring now to Figure **10**, an additional feature of an embodiment of the invention is to add a radiation shield **150** between the photovoltaic module **100** with heat

sinks and the roof surface **108**. This radiation shield **150** will be unlike a traditional radiation shield which normally has a low emissivity. In one preferred embodiment, the radiation shield **150** will have a radiation shield high emissivity side **152** facing the photovoltaic module and a radiation shield low emissivity side **154** facing the roof. High emissivity can be described as in the range of about 0.7 to 1.0 while low emissivity can be described as 0 to about 0.1. The emissivity of a material (usually written ε or e) is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. A true black body would have an $\varepsilon = 1$ while any real object would have $\varepsilon < 1$. Emissivity is a dimensionless quantity. The radiation shield **150** will typically always be cooler than the photovoltaic module **100** when the system is operating near steady state, so even if the emissivity of the radiation shield **150** is as high, or is slightly higher than the back of the photovoltaic module **100**, the net radiation heat transfer will be from the photovoltaic module **100** to the radiation shield **150**. This will cause radiation from the photovoltaic module **100** with heat sinks to be absorbed by the radiation shield **150** and then largely transferred to the working fluid through convection. This can be aided by folding or otherwise shaping the radiation shield **150** to increase its surface area for convection while increasing re-radiation from the sheet to itself, and thereby avoiding an increase in the net radiation exiting the radiation shield **150**. It is beneficial to make the radiation shield **150** thin because a lower mass will allow the temperatures to increase as high as possible.

[49] Optionally, the radiation shield **150** may be further enhanced by extended surfaces on the side of the radiation shield that face the photovoltaic module such that the extended surfaces or fins protrude into the air stream. Energy re-radiates itself rather than radiating back to the photovoltaic module/heat sink assembly. Thus, the net thermal radiation emission remains low as surface area for convection increases. Further, this increases the area for convection, minimizing the temperature of the radiation shield, and reducing radiation from the radiation shield back to the photovoltaic module, thereby assisting to keep photovoltaic module temperatures low and maximizing the energy ending up in the air stream.

[50] Referring now to Figure **11**, in roof PVETE systems **170**, the radiation shield low emissivity side **154**, which faces the roof, will reduce heat transfer to the roof surface **108**. It is desirable to have the living space cool and to keep the energy available to the thermal energy system. However, when heat is desired in the living space, it will be delivered by the thermal energy system rather than conducted through the attic.

[51] It may be desirable to add holes, vents, louvers, or other openings, potentially with a labyrinthine path, to the radiation shield **150**. In this way, these openings allow a small amount of air to be drawn through and flow between the radiation shield **150** and the roof surface **108,** thus reducing the temperature underneath. However, optimally, these holes in the radiation shield **150** should not allow thermal radiation to pass directly from the photovoltaic module **100** to the roof surface **108**.

[52] Figure **11** also shows that there is a heat recapture gap **180** between a first heat emissivity surface defined by the underside surface of the photovoltaic module or the heat sink **110** with fins (emitting thermal radiation **182**), and a second heat emissivity surface defined by radiation shield **150** (emitting thermal radiation **184**). Fluid such as air can flow naturally or be forced into the heat recapture gap **180** where it is heated between the opposing emissivity surfaces. Some embodiments can include a plurality of photovoltaic modules **100** with an opposing radiation shield **150**. Optionally, some embodiments may integrate the radiation shield **150** to be part of the photovoltaic module **100**. Further, the second heat emissive surface may have a heat emissivity equal to or greater than the first heat emissive surface.

[53] Roof PVETE systems **170** as described above may direct the air that is the working fluid into a living space for heating. If this is done, there may be a problem with Indoor Air Quality (AIQ) in that the air may pick up chemical odors from the roofing material. Contamination of the air may be reduced by sealing the edges of the radiation shield **150** to the connection rails **190** for the photovoltaic modules that run parallel to the airflow direction. Such connection rails **190** are common for attaching the photovoltaic modules **100**. These connection rails **190** may be located at the ends, in the center or randomly spaced throughout the radiation shield. The shape of connection rails **190** may be a cylindrical rod or another shape so long as the contour does not significantly impede the airflow through the gap. The radiation shield **150** may

be sealed with an adhesive, caulk, or tape to these connection rails **190** which seal the air that is the working fluid away from the roofing surface **108**.

[54] The radiation shield **150** may be fabricated from a thin material such as metal, for example, aluminum foil, or another thin sheet material. In one embodiment, the radiation shield high emissivity side **152** facing the photovoltaic module may have its emissivity increased by applying a coating to the surface. Appropriate coatings include but are not limited to anodization, black anodization, paint, or any other coating that increases emissivity and has long life. In one nonlimiting example, a high emissivity coating is available under the tradename Duracon from Materials Technology Corporation of Monroe CT. Although other embodiments are not excluded, high emissivity coatings typically comprise a refractory pigment, a high emissivity additive and a binder/suspension agent. Typical refractory pigments include zirconia, zirconia silicate, aluminum oxide, aluminum silicate, silicon oxide, etc. The high emissivity additive is typically a transition metal oxide such as chromium oxide, cobalt oxide, ferrous oxide, and/or nickel oxide (NiO). In some coatings, the refractory pigment and the high emissivity additive are the same material. The binder/suspension agent acts like a high temperature glue and is typically an aqueous solution or suspension of silicates or phosphates.

[55] The radiation shield low emissivity side **154**, which faces the roof, should be as shiny as is practical to minimize its emissivity. Emissivity less than 0.1 can be achieved with an aluminum foil surface.

[56] Embodiments of the radiation shield **150** may include all or some of the following:

a. High emissivity on the side that faces the photovoltaic module.
b. Low emissivity on the side that faces the roof.
c. Folding or extended surfaces on the side of the radiation shield that faces the photovoltaic module such that it re-radiates energy to itself rather than back to the photovoltaic module/heat sink assembly. This may result in the net thermal radiation emission remaining low as surface area for convection increases.
d. Holes, vents, louvers, or other openings, potentially with a labyrinthine path, to allow some air flow from between the radiation shield and the roof.

e. Openings that do not allow radiation to go directly to the roof.

[57] After adding one or more of the features described herein to a PVETE system **170** and using air as the working fluid, for the same airflow, there will be more energy in the air, and therefore, for the same flow rate, the air will be at a higher temperature.

[58] Table **2** compares two design cases. Case 1 details data with no heat sink on the photovoltaic module while Case 2 has heat sinks added to the photovoltaic module. The following set of parameters are used to compare the two cases:

a. solar irradiance = 1000 W/m^2,
b. energy removed as electricity or reflected from front of photovoltaic module = 20%,
c. ambient air temperature = 30°C,
d. average temperature of objects behind module = 30°C, and
e. average temperature of area in front of photovoltaic module for radiation calculation = 10°C.

[59] The following set of parameters are used for typical photovoltaic module and installation characteristics:

a. emissivity for front of module = 0.9,
b. emissivity for back of module = 0.9,
c. convection coefficient, h, from front (top) of module = 4 $W/m^2°K$, and
d. convection coefficient, h, from back (bottom) of module = 2.5 $W/m^2°K$.

[60] A photovoltaic module of area 1 m^2 is considered to compare two cases. For Case 1, the back of the photovoltaic module is a conventional flat surface. For Case 2, heat sinks are attached on the back of the photovoltaic module. For the purposes of this analysis, assume the resulting product hA for the back of the module changes from 2.5 to 10 after the heat sinks are added which is a reasonable improvement when adding heat sinks to a surface.

[61]

	Case 1: no heat sinks on module	Case 2: with heat sinks added to module	Improvement in operation with heat sinks in place
heat convected from front of module (W)	139	103	

heat radiated from front of module (W)	339	271	
total heat transfer from front of module	477	374	
heat convected from back of module (W)	87	258	Δ = 171 Watts or 197% increase
heat radiated from back of module (W)	236	168	
assume half of radiated heat ends up in air stream	118	84	
total heat from back of module (W)	323	426	32% increase
total of heat convected plus half radiated	205	342	67% increase
Module Temperature (°C)	65	56	9°C improvement

Table 2: Heat Sink Designs Cases

[62] The following observations can be made from this analysis using Table **2**:

a. The photovoltaic module is running 9°C cooler in Case 2. For a photovoltaic module with a temperature power coefficient of 0.5 %/°C units, Case 2 will therefore produce 4.5% more electricity from the photovoltaic module(s).

b. Approximately 100 Watts or 22% less energy is leaving the front of the photovoltaic module in Case 2. This occurs because the resistance to heat transfer out the back of the photovoltaic module has been reduced by the heat sinks, and therefore more heat flows out the back of the photovoltaic module in Case 2.

c. More heat is available out the back of the photovoltaic module in Case 2. The above analysis shows 171 Watts (258 Watts – 87 Watts) more thermal energy is transferred into the air by convection.

d. The radiation effect is not as straightforward to assess, as the surfaces will re-radiate back and forth to each other.

   - Analysis A: Assume all of the radiation from the back of the photovoltaic module (with or without heat sinks) ends up in the air stream; this will result in a reduction of 68 Watts (236 Watts – 168

Watts) of energy radiated from the back of the photovoltaic module going into the air stream.

- Analysis B: Assume that half of the radiation from the back of the module ends up in the air stream; this will result in a reduction of 34 Watts (118 Watts – 84 Watts) of energy radiated from the back of the photovoltaic module going into the air stream.

e. The bounds of the increase in thermal energy into the air stream can be approximately bounded by Analysis A and Analysis B:

- Analysis A: assuming all of radiation ends up in air stream, energy put into the air stream increases from 323 Watts to 426 Watts, a 32% increase.
- Analysis B: assuming half of the radiation ends up in the air stream, energy put into the air stream increases from 205 Watts to 342 Watts, a 67% increase.

[63] Therefore, adding heat sinks to the back of the photovoltaic module(s) in a PVETE system described earlier increases the energy put into the air stream by approximately 1/3 to 2/3 (or 32% and 67%). The use of the uncommon radiation shield described previously will further improve the amount of energy going into the air stream.

[64] While the specification has been described in detail with respect to specific embodiments of the invention, it will be appreciated that those skilled in the art, upon attaining an understanding of the foregoing, may readily conceive of alterations to, variations of, and equivalents to these embodiments. These and other modifications and variations to the present invention may be practiced by those of ordinary skill in the art, without departing from the spirit and scope of the present invention, which is more particularly set forth in the appended claims. Furthermore, those of ordinary skill in the art will appreciate that the foregoing description is by way of example only, and is not intended to limit the invention. Thus, it is intended that the present subject matter covers such modifications and variations as come within the scope of the appended claims and their equivalents.

Claims

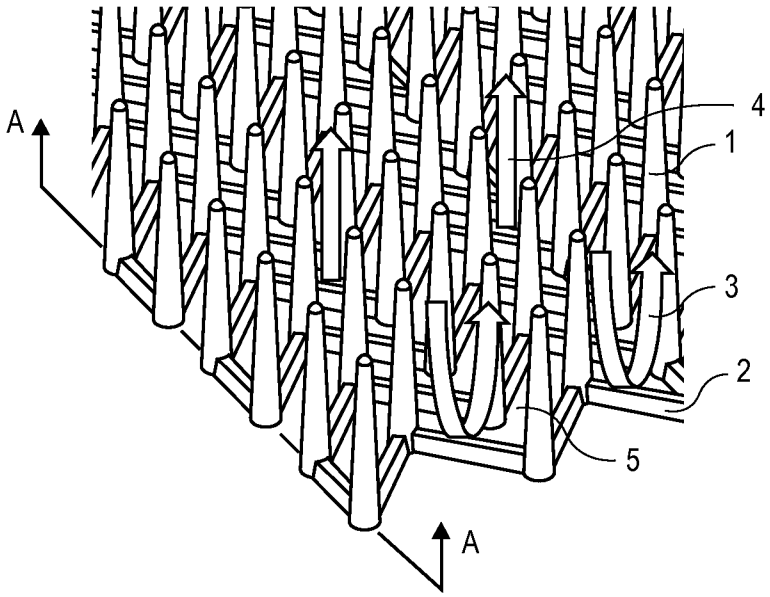
The invention claimed is:

1. A method comprising the steps of:
   providing a system having at least one photovoltaic module and defining a heat recapture gap below the photovoltaic module, wherein the heat recapture gap is sized to allow for fluid flow between a first heat emissive surface and a second heat emissive surface;
   reducing resistance to convective heat transfer out the first heat emissive surface, relative to resistance to convective heat transfer out a light exposed surface of the photovoltaic module; and
   capturing heat from the photovoltaic module by flowing fluid through the heat recapture gap.
2. The method of claim 1 wherein the fluid is air.
3. The method of claim 1 wherein the first heat emissive surface is on an underside surface of the photovoltaic module.
4. The method of claim 1 wherein the second heat emissive surface is positioned to be opposing the first heat emissive surface.
5. The method of claim 1 wherein the second heat emissive surface is located on a radiation shield.
6. The method of claim 1 wherein the second heat emissive surface has a heat emissivity equal to or greater than the first heat emissive surface.
7. The method of claim 5 further comprising the step of extending surfaces on a side of the radiation shield such that the extended surfaces protrude into the air stream.
8. The method of claim 1 further comprising the step of forcing the fluid to flow between the first heat emissive surface and the second heat emissive surface.
9. The method of claim 1 wherein the first heat emissive surface is defined by a heat sink integrated on an underside surface of the photovoltaic module.

10. The method of claim 5 wherein the radiation shield has a high emissivity surface on one side and a low emissivity surface on an opposite side.
11. The method of claim 5 wherein the radiation shield has a directional airflow structure to preferentially direct air flow in one direction.
12. The method of claim 1 wherein a backside of a surface of the photovoltaic module has a plurality of elongated structures.
13. The method of claim 9 wherein the heat sink has a low stress base configuration.
14. The method of claim 13 wherein the low stress base is integrated with a bottom layer of the photovoltaic module.
15. The method of claim 9 wherein the heat sink has a plurality of elongated members aligned in one direction that are joined by a plurality of connectors aligned in an orthogonal direction.
16. The method of claim 15 further comprising the step of using a polymer layer coupled to the heat sink.
17. The method of claim 1 further comprising the step of using a barrier to close a top end of the heat recapture gap.
18. The method of claim 1 wherein the radiation shield is integrated with the photovoltaic module.
19. A system formed according to any of the preceding claims.
20. A method comprising the steps of:
providing at least one photovoltaic module;
increasing heat transfer through an underside of the module through use of a heat sink on the underside of the module; and defining a gap between the underside of the photovoltaic module and a top surface of an emissivity structure,
wherein the gap is sized to allow for air flow between the underside of the photovoltaic module and the top surface of the emissivity structure.
21. A method comprising the step of:
providing at least one photovoltaic module, wherein the module is used to define a heat recapture gap below the photovoltaic module.

22. A method comprising the steps of:

providing at least one photovoltaic module, wherein the module is used to define a heat recapture gap below the photovoltaic module with a heat sink on a bottom surface of the photovoltaic module that opposes a high emissivity surface having an emissivity between 0.7 and 1.0.



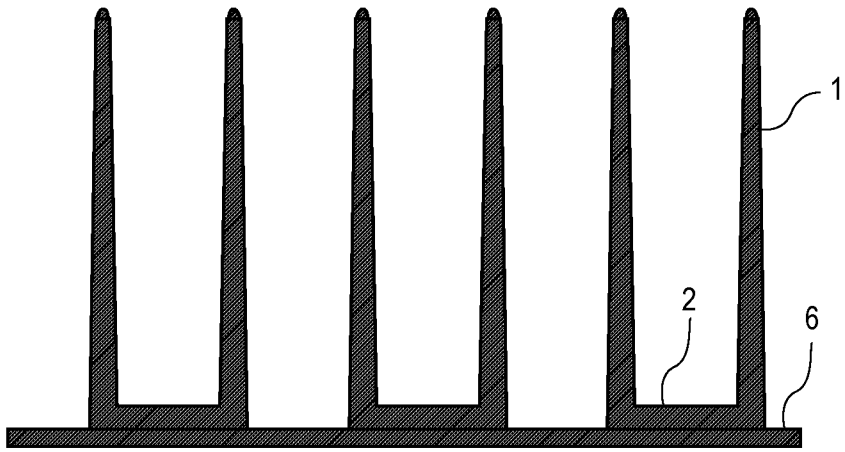


FIG. 2

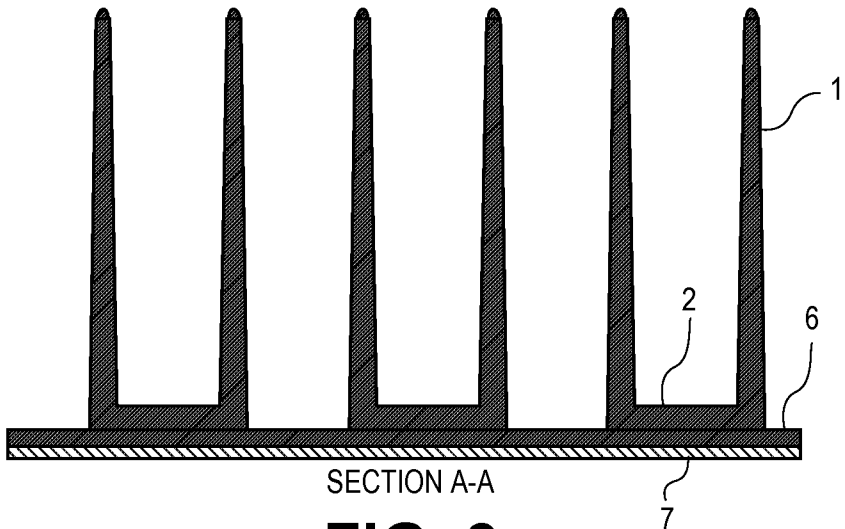


FIG. 3

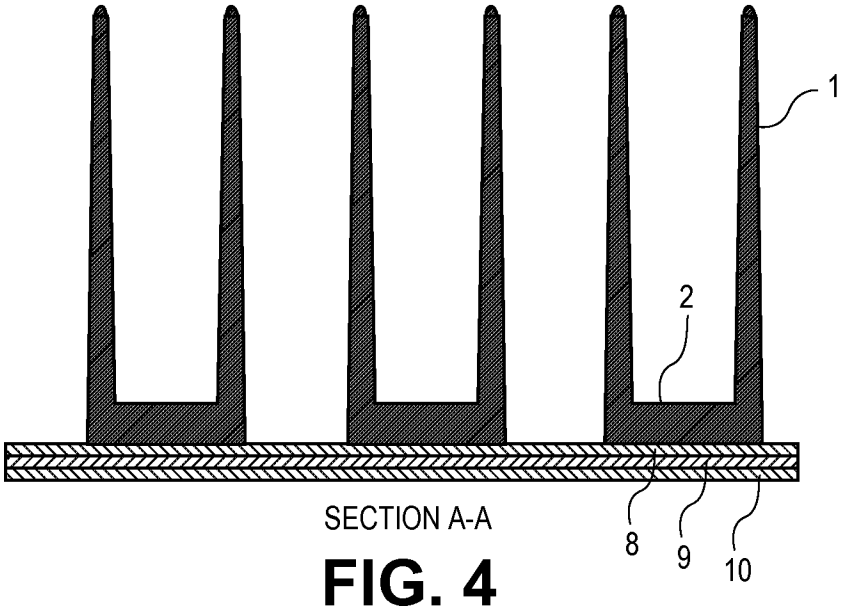


FIG. 4

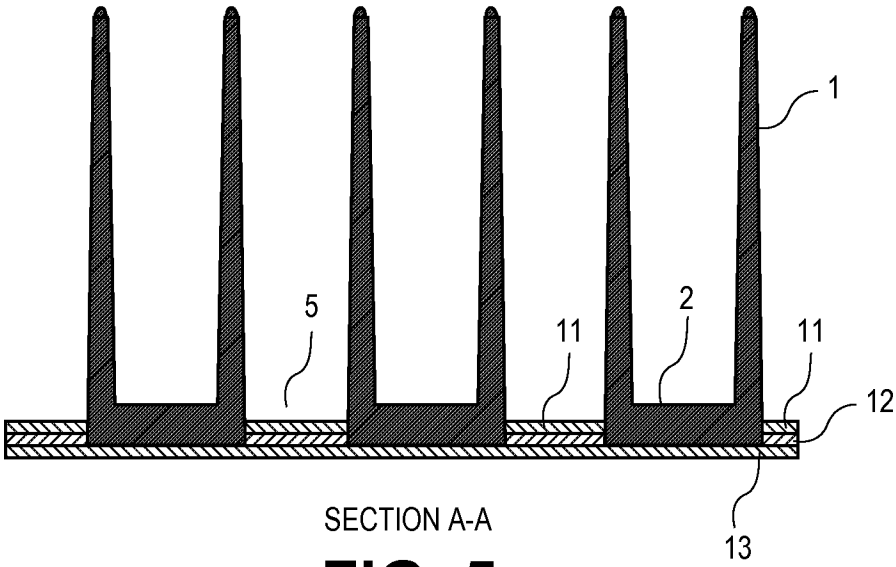


FIG. 5

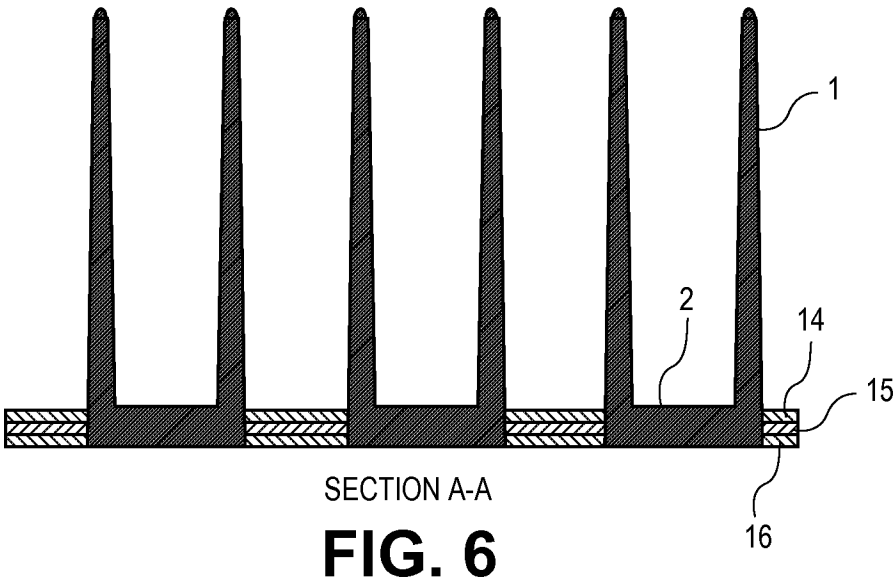


FIG. 6

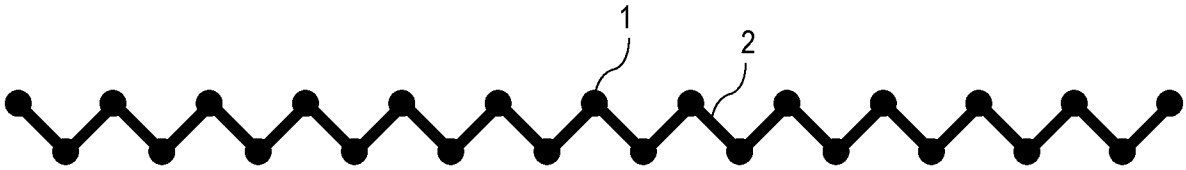


FIG. 7

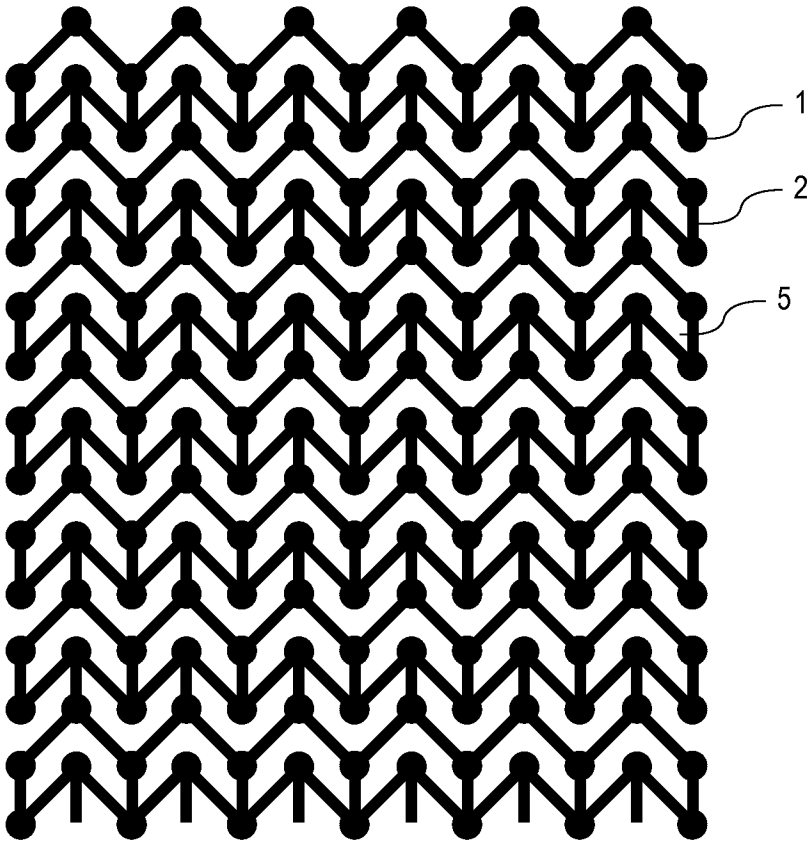


FIG. 8

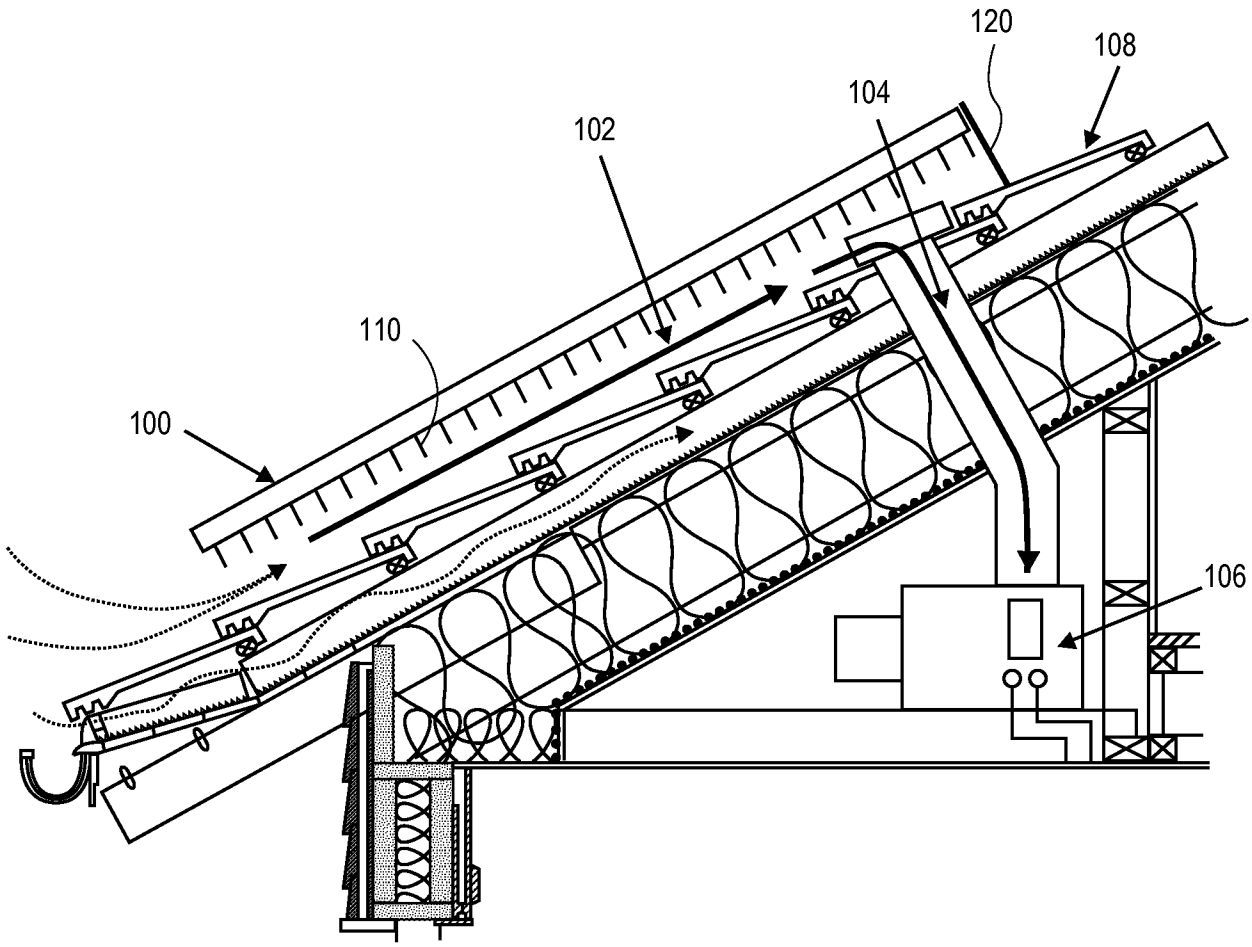


FIG. 9

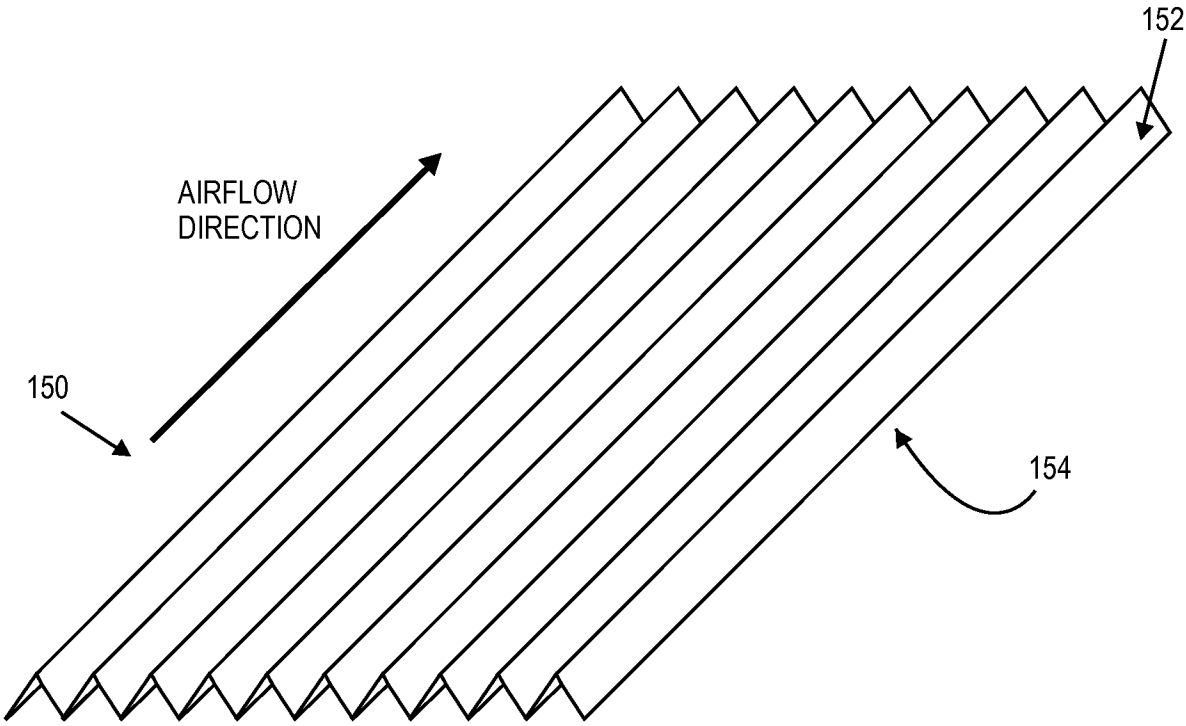

152
AIRFLOW
DIRECTION
150
154

FIG. 10

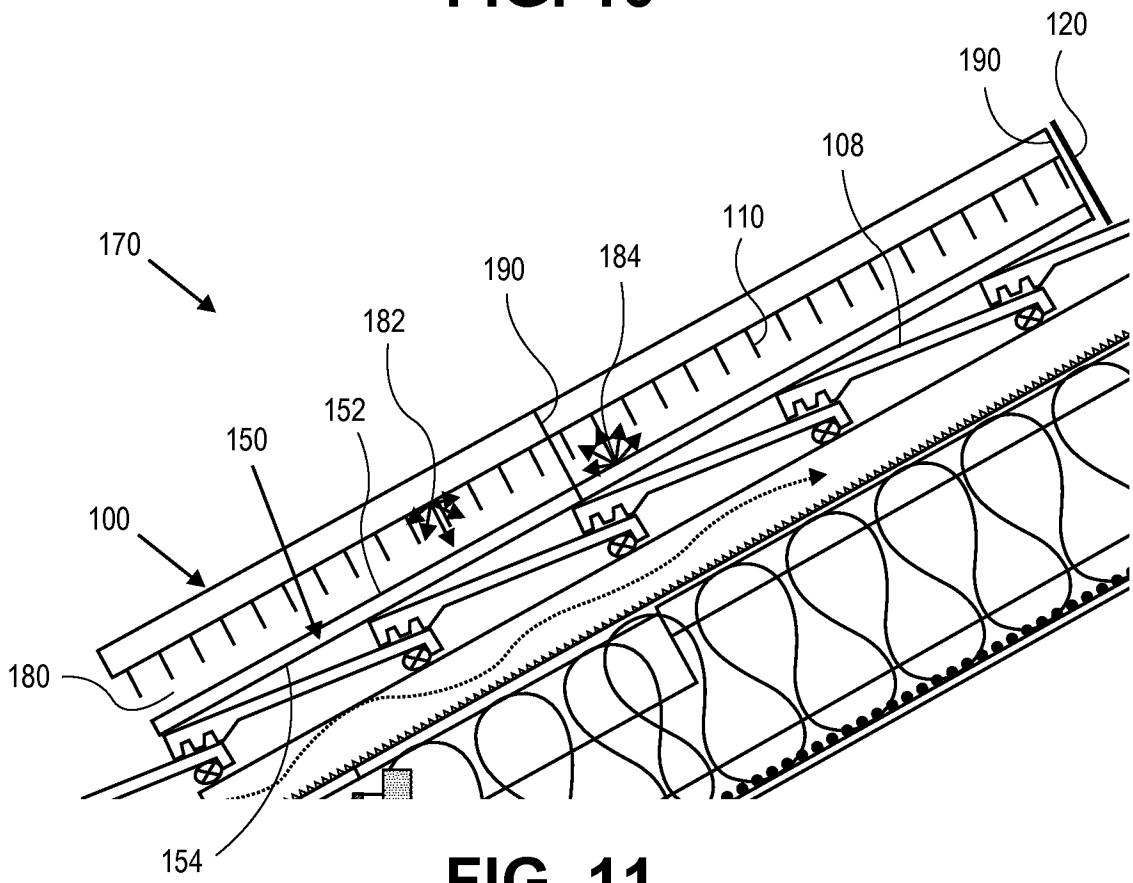

120
190
108
110
170
190
184
182
152
150
100
180
154

FIG. 11