Abstract: Systems and methods for cooling solar panels and recovering energy therefrom are disclosed. In one aspect, the system includes at least one solar panel configured to convert at least a portion of incident light into electrical energy and a pump configured to receive and regulate the flow of a working fluid. The system further includes a heat exchanger configured to receive the working fluid from the pump and circulate the working fluid in proximity to the solar panel so as to extract heat from the solar panel into the working fluid such that the working fluid undergoes a phase change from liquid to gas. The solar panel temperature control system is configured to cycle the working fluid via an Organic Rankine Cycle.
Declarations under Rule 4.17:

— as to applicant’s entitlement to apply for and be granted a patent (Rule 4.17(b))
— as to the applicant’s entitlement to claim the priority of the earlier application (Rule 4.17(in))

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SYSTEM AND METHOD FOR COOLING SOLAR PANEL AND RECOVERING ENERGY THEREFROM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/459,207, filed February 15, 2017, which is hereby incorporated by reference in its entirety.

BACKGROUND

Field

[0002] The described technology generally relates to systems and methods for cooling a solar panel, and in particular, to cooling a solar panel and recovering energy from the solar panel.

Description of the Related Technology

[0003] A solar panel is a device generally comprising semiconductor materials configured to convert at least a portion of incident light into electrical energy. Photovoltaic cells included in solar panels, along with the other materials forming the solar panel, absorb a portion of the incident solar energy onto the panel, which can result in heating up the solar panel above an optimum operating temperature. This heating of solar panels can lead to reduced efficiency of solar panels (e.g., in converting the received energy into electricity) that in turn decreases the electrical energy output from the solar panels. To cool down heated solar panels closer to the optimum operating temperature, coolant such as water, may be sprayed on the panels.

SUMMARY OF CERTAIN INVENTIVE ASPECTS

[0004] The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0005] Systems which cool solar panels via spraying a coolant or passing air or water directly onto the solar panels do not harvest energy from the coolant. Rather, the coolant (e.g., water) is cooled before being used again to cool the solar panels. Thus, the
energy transferred into the coolant is ends up being waste energy not used to generate electricity. Embodiments of the described technology solve this problem for solar cells installed on flat panels, or other configurations such as parabolic trough or dish.

[0006] In one aspect, there is provided a solar panel temperature control system, comprising: at least one solar panel configured to convert at least a portion of incident light into electrical energy; a pump configured to receive and regulate the flow of a working fluid; and a heat exchanger configured to receive the working fluid from the pump and circulate the working fluid in proximity to the solar panel so as to extract heat from the solar panel into the working fluid such that the working fluid undergoes a phase change from liquid to gas, wherein the solar panel temperature control system is configured to cycle the working fluid via an Organic Rankine Cycle.

[0007] In any of the above or below systems, the system may further comprise: an electricity generator configured to receive the working fluid from the heat exchanger and generate electricity based on the enthalpy of the working fluid; a condenser configured to receive the working fluid from the turbine-generator and circulate the working fluid in proximity to a cold source so as to extract heat from the working fluid into the cold source such that at least a portion of the working fluid undergoes a phase change from gas to liquid; and an accumulator configured to receive the working fluid from the condenser, remove excess gas from the working fluid, and supply the working fluid to the pump.

[0008] In any of the above or below systems, the organic refrigerant may have a boiling point, at an operating pressure within the heat exchanger, that is less than a standard operating temperature of the solar panel.

[0009] In any of the above or below systems, the working fluid may comprise an organic refrigerant.

[0010] In any of the above or below systems, the heat exchanger may be further configured to cool the solar panel so as to increase the efficiency of the solar panels by at least 5% compared to the combined standalone efficiency of the solar panels.

[0011] In any of the above or below systems, the pump may be further configured to regulate the flow of the working fluid to an operating pressure at which the working fluid is supplied to the heat exchanger, the operating pressure being lower than the pressure used in a refrigeration cycle.
In any of the above or below systems, the system may not include a compressor.

In any of the above or below systems, the pump may be further configured to consume less energy than is produced by the electricity generator.

In any of the above or below systems, the pump may comprise a variable speed pump configured to regulate the flow of the working fluid supplied to the heat exchanger based on the temperature of at least one of the working fluid and the solar panel.

In any of the above or below systems, the organic refrigerant may have an isentropic saturation vapor curve.

In any of the above or below systems, the heat exchanger may comprise two or more heat exchangers and the solar panel comprises two or more solar panels, each of the heat exchangers coupled to and configured to cool a corresponding one of the solar panels.

In any of the above or below systems, the overall efficiency of the solar panel temperature control system may be greater than the combined standalone efficiency of the solar panels.

In another aspect, there is provided a solar panel temperature control system, comprising: at least one solar panel configured to convert at least a portion of incident light into electrical energy; an organic refrigerant; and a heat exchanger configured to affect the temperature of the solar panel with the organic refrigerant.

In any of the above or below systems, the organic refrigerant may have a boiling point, under pressure, that is less than a standard operating temperature of the solar panel.

In any of the above or below systems, the heat exchanger may be further configured to cool the solar panels so as to increase the efficiency of the conversion of the incident light into electrical energy by at least 5% compared to the combined standalone efficiency of the solar panels.

In any of the above or below systems, the system may further comprise an electricity generator configured to receive the organic refrigerant from the heat exchanger and generate electricity based on the enthalpy of the organic refrigerant.

In any of the above or below systems, the system may not include a compressor.
In yet another aspect, there is provided solar panel system, comprising: at least one solar panel configured to convert at least a portion of incident light into electrical energy; a heat exchanger configured to move a working fluid in proximity to the solar panel so as to extract heat from the solar panel and form a heated working fluid; and an electricity generator configured to receive the heated working fluid from the heat exchanger and generate electricity.

In any of the above or below systems, the working fluid may comprise an organic refrigerant. In any of the above or below systems, the working fluid may consist essentially of, or consist of, an organic refrigerant.

In any of the above systems, the organic refrigerant may have a boiling point, under pressure, that is less than a standard operating temperature of the solar panel.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed aspects will hereinafter be described in conjunction with the appended drawings, provided to illustrate and not to limit the disclosed aspects, wherein like designations denote like elements.

FIG. 1 is a pressure-volume diagram which illustrates a power cycle in accordance with aspects of this disclosure.

FIG. 2 is a diagram illustrating a solar panel temperature control system in accordance with aspects of this disclosure.

FIG. 3 is a diagram illustrating another example solar panel temperature control system for cooling at least one solar panel in accordance with aspects of this disclosure.

FIG. 4 illustrates one example of a heat exchanger in accordance with aspects of this disclosure.

FIG. 5 illustrates one example of a solar panel temperature control system that includes an array of heat exchangers.

DETAILED DESCRIPTION

Solar panels may have an optimum operating temperature at which electric generation is most efficient. Solar panels may include photovoltaic (PV) modules, which are typically tested at a temperature of 25°C (about 77°F), referred to as "the
standard test condition" (STC). An "optimum operating temperature" as used herein can be defined as a temperature, such as the standard test condition, above which the performance efficiency of the solar panels begins to see decreases in performance related to increasing temperatures. Depending on the ambient temperature of the environment where they are installed, the resulting temperature in solar panel(s) above the optimum operating temperature can reduce efficiency by about 10-25%. Panel manufacturers may specify a "temperature coefficient (Pmax)" as the maximum power temperature coefficient which determines how much power the panel will lose per degree Celsius the temperature rises above the optimum operating temperature 25°C. For example, the temperature coefficient of certain monocrystalline and polycrystalline PV solar panels might be -0.45% per 1 degree Celsius meaning that for every degree above 25°C, the maximum power of the solar panel falls by 0.45%.

Accordingly, the standard operating temperature of a given solar panel may be defined as the upper limit within a range of operating temperatures in which a solar panel can operate, even though the output of the solar panel within this range may include increasing operating inefficiencies as the temperature increases within this range. Contrast this definition with the aforementioned "optimum operating temperature," at or below which the solar panel operates best, and above which the efficiency of the solar panel suffers. Thus, under certain circumstance, solar panels may be heated above the optimum operating temperature, negatively affecting output efficiency, even though electricity can still be generated. For example, environmental temperatures, natural cooling (e.g., wind, rain, etc.), heat generated by the photovoltaic (PV) cells in the solar panels, etc. may all affect the operating temperature of the solar panels, contributing to a decrease in efficiency.

Solar panels can perform well in cold weather, even below freezing. However, as mentioned above, heating a solar panel above the optimum operating temperature can result in a reduction in efficiency, and therefore power output. For example, on a hot day the standard operating temperature of a solar panel temperature may exceed 75°C (167°F), far above the optimum operating temperature of 25°C in the STC design implementation. Cooling of solar panels can increase the operating efficiency of the solar panels by bringing heated or high temperature solar panels closer to or below the standard operating temperature, or even better, closer to or below the optimum operating temperature. Certain techniques for cooling panels may include
spraying water, which may be actively or passively cooled, onto the panels. However, if
the cooling water is to be recycled, it has to be collected off of the solar panels, and
because it has at that point been heated, it must be cooled before being reapplied. One
aspect of this disclosure relates to recovering a portion of the energy used to heat the
coolant, and using the recovered energy to generate electricity.

[0035] Other techniques for cooling solar panels may have drawbacks which
decrease the overall efficiency of the power generating system. For example, a
refrigeration system can in theory be used to cool the solar panels. However,
refrigeration systems are inefficient because they require a compressor to increase the
pressure of the refrigerant when run through a refrigeration cycle. Running such a
compressor will generally draw more electrical energy than is saved by increasing the
efficiency of the solar panel, leading to a net decrease in power generation. Thus, cooling
solar panels using a refrigeration cycle is generally not sufficiently energy efficient for
solar panel installations designed for power generation.

[0036] Aspects of this disclosure relate to systems and techniques which may
be used to increase the net electric energy production of solar panel systems (which may
be referred to as the "efficiency" of the system herein). Such an increase can be achieved
through different implementations, alone, or in combination with each other. For
example, some aspects relate to use of a pump and heat exchanger in an Organic Rankine
Cycle (ORC) for cooling one or more solar panel(s). Further aspects relate to using an
organic refrigerant with a heat exchanger to affect the temperature of a corresponding
solar panel. Other aspects relate to extracting energy from one or more solar panel(s) (e.g.
in the form of heat, also referred to as "waste heat"), using a heat exchanger, and
generating additional electricity from the extracted energy.

[0037] The following is provided to help further understand the general
theories behind thermodynamic cycles, including Rankine cycles and ORCs, to provide
further context for aspects of the implementations described herein:

**Thermodynamic Cycles**

[0038] Thermodynamic cycles include a series of processes (changes in state
that result in a return to the initial state) involving work and transfer of heat into and out
of a system. During the process, pressure, temperature, and other state variables of a
working fluid may change due to the heat and/or work supplied to and extracted from the
working fluid as the working fluid moves through the cycle. In passing through a thermodynamic power or heat pump cycle, the working fluid receives heat from a warm source and converts the received heat into useful work. The remaining heat (from which useful work is not or cannot be further extracted) is transferred to a cold sink, thereby acting as a heat engine (converting thermal energy to mechanical energy). In the opposite case, the cycle is reversed and work is used to move heat from a cold source to be transferred to a warm sink, acting as a heat pump.

[0039] Throughout the process in a closed loop, the system is in thermodynamic equilibrium at each point in the cycle. In the ideal case, this enables the cycle to be reversible (meaning that the change in entropy of the closed system, which is a function of the system state, is zero). In a closed loop, the net change in all system conditions is zero, because the fluid returns to its original temperature and pressure. The first law of thermodynamics applies, meaning that energy cannot be created nor destroyed. There is no net change of energy over the complete cycle. Also per the first law of thermodynamics, the net heat gain is ideally equal to the net work output over the complete cycle. Constant uninterrupted operation of the process sanctions continuous operation.

[0040] There are two primary classes of thermodynamic cycles. Power cycles convert heat gain into mechanical work. Heat pump cycles transfer heat from cool sources to warmer temperatures by applying mechanical work. FIG. 1 is a pressure-volume diagram which illustrates a power cycle to provide context for aspects of this disclosure. As shown in FIG. 1, the pressure-volume diagram 100 indicates a clockwise flow direction for power cycles, whereas a heat pump pressure-volume diagram would include a counter clockwise cycle. Similarly on temperature-entropy diagrams, the clockwise and counter clockwise flow directions respective indicate power and heat pump cycles. The illustrated flow include four processes A, B, C, and D ideally involving a change in only one parameter (pressure or volume) at each stage.

Rankine Cycle

[0041] A Rankine cycle is one of many common thermodynamic cycles. The Rankine cycle is a thermodynamic power cycle primarily used to convert heat gain into work output. The heat is generally supplied to a closed loop system. The Rankine cycle often refers to a steam cycle as typically used in power plants. Utility scale thermal
power plants typically use water and steam as the working fluid in a Rankine cycle and provide an estimated 85% of electricity produced globally today. In a Rankine cycle, three things generally happen to generate work output:

[0042] 1. Heat is added at a temperature greater than that of the working fluid to alter the fluid's characteristics (e.g., boiling the working fluid);

[0043] 2. A certain amount of energy from heat gained in step 1 is used to perform work (e.g., generate power); and

[0044] 3. The balance of the heat not used to performed work is removed at a temperature that is lower than the temperature of the working fluid to condense the working fluid.

[0045] The amount of power that can be produced by a Rankine cycle is a function of the temperature difference between the heat source and the cold sink. More mechanical power can be efficiently extracted out of heat energy with a higher temperature difference. Low inlet temperature of steam turbines (as contrasted with high combustion temperatures in gas turbines) is one of the reasons why the Rankine cycle is practical to recover rejected waste heat in gas turbine plants. Cold sinks used in these power plants can be rivers, cooling towers or the sea. The Rankine cycle power plant efficiency is limited by the lower practical temperature of the working fluid on the cold side.

[0046] The working fluid used in the Rankine cycle is generally processed in a continuous closed loop. In certain implementations, such as in a power plant, water vapor is produced by the plant cooling systems when cooling the working fluid. Exhaust heat is produced from the cooling system in cooling the working fluid.

[0047] Typically, for non-solar utility scale power plants, water is used for the working fluid, because the operating temperatures and differentials in these power plant cycles are high enough to provide the phase changes between liquid water and steam. However, because water requires such a high temperature or temperature swing, it may not be efficient to use it in certain relatively lower temperature or temperature differential applications which nonetheless produce external heat, for potential power generation. For example, a solar power application does not have a high enough temperature to substantially vaporize liquid water into steam. Similarly, there are numerous applications (e.g., low grade waste heat recovery systems) in which the operating temperature is not sufficient to vaporize water. Therefore, in certain applications, a refrigerant, or high

-8-
molecular mass fluid typically known as organic fluid, can be used in an ORC system to cool the heat source and generate supplementary electricity.

**Organic Rankine Cycle (ORC)**

[0048] This disclosure relates to the use of an ORC for the recovery of waste heat at low/medium temperatures (e.g., at temperatures below the boiling point of water), and particularly to the use of an ORC to cool a solar panel system. For example, in the solar panel implementation, the ORC may be used to cool solar panels to within a defined range of temperatures within which the solar panel can be operated more efficiently. Depending on the implementation, the low temperature heat discharged in several industrial applications cannot be recovered with a traditional bottom steam cycle. However, using an ORC as described in this disclosure, this waste heat can be converted into electrical energy. The choice of the fluid used as the working fluid for the ORC may be important for a performance of the cycle because the thermophysical properties of the selected working fluid may be related to the operating temperatures of the particular implementation.

[0049] ORC may use an organic fluid as the working fluid in place of water and steam. ORC efficiency may be lower than a non-organic Rankine cycle due to the lower temperature of operation. However, ORC may still be practical for heat energy recovery because of the low cost required to gather heat and the broad opportunities for low-grade waste heat recovery. An organic fluid as described herein may refer to an organic compound of low boiling point, such as a high molecular mass fluid (e.g., higher than the molecular mass of water) with a boiling point (liquid-vapor phase change) at a low temperature compared to that of the liquid water-steam phase change. The organic fluid for the ORC cycle may be selected based upon its particular boiling point relative to the standard operating temperature of the heat source (e.g., solar panel(s)) used to vaporize the working fluid. That is, the boiling point may be selected to be lower than the standard operating temperature of the heat source such that the working fluid can be vaporized effectively by the heat source during standard operating conditions.

[0050] The boiling point of the working fluid may depend upon the state of the working fluid. For example, while the boiling point of the working fluid may be defined at atmospheric temperatures, the relevant boiling point of the working fluid is the boiling point at the pressure experienced by the working fluid when exposed to the heat
source. For example, since the working fluid should be vaporized by the heat source in an ORC, the boiling point of the working fluid may be less than the standard operating temperature of the heat source, as defined further herein. Other factors that may weigh into the selection of the working fluid include the lower threshold temperatures and pressures of the application. The organic fluid selected may also be selected to be economical, nontoxic, nonflammable, environmentally safe (low Global Warming Potential), and/or stable. The fluid may allow a high utilization of the available energy from the lower temperature heat source. The freezing point of the fluid may be lower than the lowest temperature of the cycle.

[0051] The proper selection of a working fluid allows ORC heat recovery from moderate temperature sources such as industrial waste heat or solar panel(s) which may have a standard operating temperature of 70-90°C. However, solar panel(s) designed to operate in specific environments (e.g., cold environments where a standard operating temperature of 70-90°C may not occur) can be developed to have a standard operating temperature outside of the 70-90°C range. In general, the standard operating temperature of a solar panel, as used herein, is the upper limit within a range of temperatures within which the solar panel can operate to some extent, even with inefficiencies, which is at and above the optimum operating temperature. Thus, in certain embodiments, the standard operating temperature from which it is desirable to cool the solar panel(s) may depend on the particular design of the solar panel(s) and the corresponding optimum operating temperature thereof. Traditional water-based heat recovery systems cannot effectively generate electricity within these operating temperatures. By using organic fluid as a working fluid, the low-temperature "low-grade waste heat" can be converted into practical work typically used to generate electricity. The characteristics and working principles of the ORC may be similar to those of a traditional, non-organic Rankine cycle, such as described generically above with reference to FIG. 1.

[0052] In an ideal ORC, expansion is isentropic and the evaporation and condensation processes are isobaric. However, in real world implementations, irreversibilities such as heat loss lower the overall efficiency of the ORC.

[0053] ORC technology has many possible may implementations including a solar panel implementation and other solar applications such as parabolic trough concentrated solar thermal, where the ORC technology can be used in lieu of the usual
steam Rankine cycle. ORC allows power generation at lower capacities and with a lower collector temperature, and hence the possibility for low-cost, small scale decentralized concentrating solar power (CSP) units.

[0054] FIG. 2 is a diagram illustrating a solar panel temperature control system 200 in accordance with aspects of this disclosure. As used herein, the term "solar panel temperature control system" can refer to a system that provides the benefits associated with controlling (e.g., cooling) the solar panels and/or the energy recovery and additional electricity generation by using the waste heat from a solar panel system. Thus, in the present example, the solar panel system 200 may be configured to employ an ORC for cooling a heat source, such as one or more solar panel(s) and/or, in some embodiments, generating electricity using "waste heat" extracted from the solar panel into a working fluid.

[0055] The system 200 can include a pump 205, a heat exchanger 210 (e.g., an evaporator), a turbine-generator 215, a condenser 220, and a solar panel 230. Although FIG. 2 is discussed in connection with a solar panel 230, this disclosure is not limited thereto, and in other embodiments, the solar panel 230 may be replaced by another heat source for which cooling the heat source is desirable. For example, the heat source may include a gas turbine plant or another industrial process that generates waste heat.

[0056] Returning to FIG. 2, the working fluid is pumped via pump 205 as a liquid to the heat exchanger 210 which receives heat from the solar panel 230. The pump 205 may be any suitable device configured to receive, increase the pressure of, and/or otherwise regulate the flow of the working fluid within at least some portion(s) of system 200. The working fluid may comprise an organic refrigerant. The heat exchanger 210 may be configured to receive the working fluid from the pump 205 and circulate the working fluid in proximity to the solar panel 230 so as to extract and transfer heat from the solar panel 230 into the working fluid. The heat exchanger 210 can be any suitable device that transfers heat from the solar panel 230 such that the working fluid at least partially undergoes a phase change from liquid to gas. The efficiency of the system will increase, for example, as the temperature of the working fluid increases, as in when the amount of working fluid converted into a gas is increased. This may be accomplished via the selection of the working fluid with desirable characteristics as described below.

[0057] After the working fluid is at least partially evaporated by the heat exchanger 210, it is then passed through the turbine-generator 215 (also referred to
simply as a turbine) where the working fluid exhausts pressure as the turbine-generator 215 extracts energy from the working fluid. The turbine-generator 215 may be any suitable electricity generator configured to receive a working fluid (e.g., from the heat exchanger 210) and generate electricity based on the enthalpy of the working fluid. For example, the turbine-generator 215 may be configured to generate electricity using the internal energy, pressure and/or volume of the working fluid. Depending on the embodiment, the turbine-generator 215 may be any suitable electricity generator, embodied as a turbo-expander, turbo-generator, steam turbine, scroll turbine, etc., and any related components to generate electricity.

[0058] The working fluid can be provided to the condenser 220, or a heat sink, where the working fluid drops in temperature and re-condenses, for example, before being fed back into the pump 205. The condenser 220 may be any suitable device configured to receive, cool and condense a working fluid such that at least a portion of the working fluid undergoes a partial or complete phase change from gas to liquid. For example, the condenser 220 can be configured to receive the working fluid from the turbine-generator 215, circulate the working fluid in proximity to a cold source so as to extract heat from the working fluid into the cold source, such that at least a portion of the working fluid undergoes a phase change from gas to liquid. The condenser 220 can be configured to supply the working fluid to the pump 205.

[0059] In certain implementations, the turbo-generator 215 uses medium-to-high-temperature thermal oil to preheat and vaporize (e.g., further vaporize) the organic working fluid received from the heat exchanger 210. The organic fluid vapor rotates the turbine of the turbine-generator 215, which is directly coupled to additional electricity-generating components, resulting in, for example, clean, reliable electric power. The exhaust vapor from the turbine-generator 215 may flow through a regenerator (not illustrated), where the regenerator heats the working fluid which is then provided to the condenser 220 and condensed and cooled. The working fluid is then pumped again, via the pump 205 into the heat exchanger 210, thus completing the closed-cycle operation.

[0060] The system shown in FIG. 2 may be adapted to cool the solar panel by circulating the working fluid using different types of cycles. However, as described above, a refrigeration cycle often requires a compressor that requires more power than a pump, and thus may consume more electricity than can be gained in extracting energy recovered by the heat transferred into the working fluid. Accordingly, some aspects of
this disclosure relate to the implementation of systems that can be implemented within non-refrigeration cycles that don't require a high energy compressor. In order to operate within a non-refrigeration cycle, in certain embodiments, the pump 205 may be configured to regulate the flow of the working fluid at an operating pressure at which the working fluid is supplied to the heat exchanger, for example, the operating pressure being lower than the pressure used in a refrigeration cycle. For example, the system of FIG. 2 can facilitate the use of organic fluids (such as an organic refrigerant), which may be used in an ORC. An ORC can be run using a pump (e.g., the pump 205 of FIG. 2) that consumes considerably less energy than a compressor. Accordingly, certain solar panel cooling systems may not include a compressor, thereby decreasing the energy consumption of the cooling system.

[0061] In certain implementations, the energy used by the pump 205 may be less than the additional energy generated by the increase in efficiency of a solar panel cooled with the organic fluid. For example, a system similar to that shown in FIG. 2 may be implemented with a pump and heat exchanger(s), to cool and improve efficiency of the solar panel(s), resulting in increased power generation, with or without the electricity generator. In other embodiments, the pump 205 may consume less energy than is generated by the electricity generator 215. Thus, the system 200 can provide increased overall power generation for example, with an ORC cycle using the organic fluid, than a similar system using only solar panel(s) without additional cooling and/or power-generating components, or a solar power system that uses a refrigeration cycle.

Working Fluid Characteristics

[0062] There are options available for the selection of a working fluid for use in the low-grade waste heat recovery and/or ORC electricity generation systems described herein. Suitable working fluids are currently being developed and brought to market in larger numbers. Refrigerants, which are organic fluids, historically had characteristics making them undesirable for environmental reasons. Recently developed fluids are designed with these challenges in mind, and are therefore much more appealing from an environmental standpoint. Some of the new fluids have better characteristics for low-grade waste heat recovery. Selection of the proper working fluid can be particularly important in lower temperature cycles because heat transfer inefficiencies are closely
related to the temperature differences, operating conditions, and thermodynamic characteristics of the fluid.

[0063] For solar panel embodiments, the locations at which solar panels are likely to be deployed have vastly different temperature profiles, and may require the selection of different fluid, and/or blends of fluids. Certain fluid characteristics which may be important in selecting and evaluating a working fluid for use in the described technology include:

[0064] a) Isentropic saturation vapor curve. Since one aspect of the described ORC technique focuses on the recovery of low-grade heat power, a superheated approach like the traditional Rankine cycle may not be appropriate. Therefore, a lower amount of superheating at the exhaust of the heat exchanger 220 is desirable. Thus, "wet" fluids (e.g., fluids that are in a two-phase state at the end of the expansion) are not ideal.

[0065] b) Low freezing point, high stability temperature. Unlike water, organic fluids usually suffer chemical deteriorations and decomposition at higher temperatures. The maximum heat source temperature is thus limited by the chemical stability of the working fluid. The freezing point should be lower than the lowest temperature in the cycle.

[0066] c) High heat of vaporization and density. A fluid with a high latent heat and density will absorb more energy from the source in the heat exchanger 210 and thus reduce the required flow rate, the size of the facility, and the pump consumption. This leads to lower energy consumption in running the pump 205 and also can reduce the wear of the components in the system 300, leading to a longer life cycle.

[0067] d) Other important characteristics for the working fluid which may be considered include: low environmental impact (e.g., ozone depletion potential and global warming potential), safety (e.g., non-corrosive, non-flammable, and non-toxic), good availability and low cost, and acceptable pressures and operating range.

[0068] According to certain embodiments, the molecular mass of the working fluid is greater than that of water. The molecular mass of the working fluid may also be selected to reduce the rotation speed of the turbine, lower the pressures within the closed system, and reduce or eliminate erosion of the metal parts and/or blades within the closed system.

[0069] In certain embodiments, the working fluid may be selected to have a boiling point in the range of about -18°C (0°F) to about 66°C (150°F) at the operational
pressure of the working fluid when within the heat exchanger. However, the boiling point of the working fluid may be below about -18°C (0°F) or above about 66°C (150°F), depending on the implementation. In certain implementations, the operational pressure of the working fluid within the heat exchanger may range between 50 psi and 150 psi, or higher. In certain implementations, the boiling point of the working fluid, under pressure (i.e. within the operating pressure of the working fluid within the heat exchanger), may be less than the standard operating temperature of the solar panel. Thus, the boiling point of the working fluid may be selected based on such that the boiling point of the working fluid when under the expected range of pressures when passing through the heat exchanger, allows for the working fluid to at least partially undergo a phase change from liquid to gas, when encountering solar panel temperatures at or above the standard operating temperature.

[0070] Depending on the implementation, the standard operating temperature for a given solar panel may be within the range of about -18°C (0°F) to about 93°C (200°F). However, in many embodiments, the standard operating temperature of a solar panel may be in the range of about 21-77°C (70-170°F). The standard operating temperature of 21-77°C (70-170°F) may comprise the range of temperatures at which the solar panels can operate, but within which the efficiency of the solar panel's electricity generation is increased compared to standalone solar panel(s) which are not cooled. Thus, the working fluid may be selected to have a boiling point that is less than the standard operating temperature of the solar panel. In one embodiment, the working fluid may have a boiling point of about -4°F at atmospheric conditions.

[0071] Evaluating ORC cycles requires analyzing the equations of mass and energy balance, heat transfer, pressure drop, efficiency, and other variables. ORC simulation models will be either steady-state or dynamic. Another important piece of ORC modeling is the addition of the organic fluid thermodynamic properties to a database. The properties for new or particularly unreleased fluids are not commonly available and must be generated to be included, as needed. Multi-parameter equations of state are be preferred, using properties databases, available for simulation models.

Refrigerants

[0072] Refrigerants are organic fluids which may be composed of organic substance(s) or a blend of substances, usually fluid, which may be designed for use in a
heat pump and/or refrigeration cycles. In many applications, the refrigerant transitions from a liquid to gas and back to liquid as it moves completely through the process cycle. As discussed above, an ideal refrigerant would have favorable thermodynamic properties, be non-corrosive, safe, non-toxic and nonflammable. The ideal refrigerant would also not cause ozone depletion or climate change.

[0073] Certain thermodynamic properties which may be important for fluid selection for low-grade waste heat recovery include a low boiling point below the target temperature (e.g., the operating temperature at which the heat source is desired to be cooled), high heat of vaporization, moderate density as a liquid compared to relatively high density in gaseous form, and a high critical temperature. Boiling point and gas density are both functions of pressure, so proper selection of refrigerants can result in better suitability for each particular application by appropriate consideration of operating pressures.

[0074] The organic refrigerants which may be suitable for the described ORC solar panel cooling system may include fluorine-based organic refrigerants, and preferably, without chlorine, to avoid chlorine radicals and their corresponding environmental pitfalls. For example, saturated organic refrigerants, such as Hydro-Fluoro Carbon based compositions may be implemented. Unsaturated organic refrigerants such as Hydro-Fluoro-Olefin-based compositions may be implemented. One such example is DR-14 (from The Chemours Company), which is a Hydro-Fluoro-Olefin-based fluid with no ozone depletion potentials and low global warming potentials. DR-14 remains chemically stable at least up to the maximum temperature tested of 250°C, and thus can be implemented within low grade temperature heat recovery systems. The thermodynamic cycle performance of DR-14 over a range of conditions representative of potential applications was evaluated by the manufacturer through computational modeling and compared to HFC-134a and HFC-245fa. DR-14, along with DR-12 and DR-2 could enable more environmentally sustainable heat pump platforms for the utilization of abundantly available low temperature heat to meet heating duties at higher temperatures and with higher energy efficiencies than incumbent working fluids.

**Example Embodiment of ORC Solar Panel Installation**

[0075] **FIG. 3** is a diagram illustrating an example solar panel temperature control system 300 for cooling at least one solar panel in accordance with aspects of this
disclosure. System 300 can enhance performance of one or more solar panel(s) by cooling the heated panel(s), to increase panel efficiency, and/or converting energy removed from the heated panel into electrical energy. The solar panel temperature control system 300 includes a plurality of heat exchangers 305, configured in parallel and/or in series, a plurality of isolation valves 310, a turbine 315, a condenser 320, an accumulator 325, and a pump 330. The common components in FIG. 3 can function substantially similar to those described in similar terms with respect to FIG. 2. Although not illustrated, one or more of each of a fluid temperature sensor, a pressure sensor, a flow sensor, a solar panel temperature sensor, and a voltage sensor may be installed into the system 300 to provide feedback to a control system for controlling the system 300 (e.g., controlling the flow of the working fluid via pump 330).

[0076] Each of the heat exchangers 305 may be configured to circulate a working fluid in proximity to a corresponding solar panel. Each corresponding solar panel is not illustrated, but can be easily understand with reference to the heat exchanger 210 and corresponding solar panel 230 in FIG. 2. For example, each of the heat exchangers 305 may be configured to receive the working fluid from the pump 330 and circulate the working fluid in proximity to the solar panel so as to extract heat from the solar panel into the working fluid such that the working fluid undergoes a phase change from liquid to gas. Depending on the embodiment, there may be more or fewer isolation valves 310 than illustrated in FIG. 3. It will be understood that the general aspects of the systems described herein can be provided with different quantities of components. For example, one or more pumps may flow fluid through one or more heat exchangers, which may each correspond with one or more solar panels, and vice versa. Thus, a single solar panel need not correspond with a single heat exchanger, etc.

[0077] In certain implementations, the turbine 315 may comprise a micro turbine/generator combo. The turbine 315 may be configured to receive the working fluid from the heat exchanger 305 and generate electricity based on the enthalpy of the working fluid. The condenser 320 may be configured to receive the working fluid from the turbine 315, circulate the working fluid in proximity to a cold source (not illustrated) so as to extract heat from the working fluid into the cold source such that the working fluid undergoes a phase change from gas to liquid, and supply the working fluid to the pump 330 via the accumulator 325. The accumulator 325 may be configured to remove
excess gas from the working fluid before the working fluid is supplied to the pump 330, such that gas is prevented from reaching the pump 330.

[0078] The pump 330 may be configured to pump and regulate flow of a cooled working fluid to the heat exchanger 305 and solar panel via a heat collector piping. The heated working fluid leaving the heat exchanger 305 is then transported to the turbine 315, which may comprise a turboexpander like a micro-turbine, scroll turbine, Tesla Disc turbine, Stirling engine or similar device where energy of the fluid is first converted into mechanical energy and then into electrical energy. The working fluid leaving the turbine 315 may be cooled by the condenser 320 (such as a water radiator) before returning the cooled working fluid to the pump 330 for circulating to the heat exchanger 305 again.

[0079] The pump 330 may be configured to regulate the flow and/or increase the pressure of the working fluid to an operating pressure at which the working fluid is supplied to the heat exchanger. For example, the operating pressure may be lower than the pressure used in a refrigeration cycle. By employing an operating pressure that is lower than the pressure for a typical refrigeration cycle, the pump 330 may consume less energy that is required by a compressor to achieve pressures required for a refrigeration cycle. Thus, less energy is lost in pressurizing the working fluid. In one embodiment, the pump 330 consumes less energy than is produced by the turbine 315, thereby enabling the system to have net positive energy production.

[0080] In some implementations, the pump 330 may include a variable speed pump configured to adjust the pressure of the working fluid supplied to the heat exchanger based on the temperature of the working fluid. The variable speed pump may be configured to adjust the amount of heat exchanged between the solar panel and the working fluid by controlling the flow of the working fluid. For example, an increase in the flow of the working fluid may result in greater heat exchange. The variable speed pump may also maintain the flow below a certain threshold level to ensure a sufficient amount of vaporization of the working fluid.

[0081] By way of example, one embodiment of the described technology cools a solar panel by pumping a cool working fluid through the panel then collecting a hot working fluid for converting energy of the hot fluid into mechanical energy then into electrical energy. Thus, the performance (e.g., the efficiency of converting incident light into electrical energy) of the solar panel(s) can be increased by maintaining the actual
panel temperature closer to the solar panel's optimum operating temperature and/or by harvesting electrical energy from the working fluid used to cool the panel. That is, the described solar panel temperature control system may increase the overall system efficiency by at least two mechanisms: i) increasing the efficiency of the solar panel(s) by cooling the solar panel(s) to a more efficient operating temperature (e.g., below the standard operating temperature, and closer to or below the optimum operating temperature as defined herein) and/or ii) generating additional electricity from the heated working fluid using an electricity generator. Depending on the embodiment, either or both of these mechanisms may increase the efficiency of the overall solar panel temperature control system. This efficiency is increased, relative to the standalone performance efficiency of the same standalone system with the same solar panel(s), but without the cooling features, and/or without additional harvested electrical energy from the heated working fluid.

[0082] Depending on the embodiment, efficiencies of the solar panel temperature control system can be improved. For example, the efficiency of the solar panel(s), solely by cooling, can be increased by about 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, or 10%, or any range therebetween. In some embodiments, the solar panel efficiency can be increased by about 5-10%. In some embodiments, the solar panel efficiency can be increased by at least 5%. Theoretical increases in efficiency are available up to about 20%, which falls just below the 25% solar panel efficiency loss due to high temperature conditions.

[0083] System efficiency improvements solely based upon the additional harvested energy can be about 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, or any range therebetween. In some embodiments, the system efficiency can be increased by about 5-15%, or more narrowly, 10-15%. In some embodiments, the system efficiency can be increased by at least 5%, and in some embodiments, at least 10%, and in some embodiments, about 5-15%, and in some embodiments, about 10-15%. Theoretical increases in efficiency are possible up to about 25% or more.

[0084] Thus, the overall increase in efficiency realized by embodiments that include both the solar panel cooling and heat recovery aspects of the solar panel temperature control system may be at least about 1%. In certain embodiments, the overall increase in efficiency may be greater than 1%, for example, about 2%, 3%, 4%, 5%, 9%, 15%, 20%, 25%, or greater. In some embodiments, the overall system
efficiency can be increased by at least 5%, and in some embodiments, at least 10%, at least 15%, at least 20%, or at least 25%, and in some embodiments, about 5-25%, about 10-20%, about 10-15%, or about 15-20%. In certain applications, it may be desirable to achieve an increase in the overall efficiency of the solar panel temperature control system of at least 5% such that the costs of installation and maintaining the improved system is economical.

[0085] Thus, the overall efficiency of the solar panel temperature control system may be greater than the combined standalone efficiency of a standalone solar panel(s) system due to cooling of the panel(s), and/or the generation of electricity by the electricity generator 315 based on the enthalpy of the heated working fluid. That is, the power generation of the system, for example, due to improved performance of the solar panels when cooled and/or additional power generated by capturing waste-heat, is greater than the amount of power generated by the same solar panel(s) without the inclusion of the cooling system and/or electricity generator.

[0086] It will be readily understood that, even though the solar panels in FIG. 3 are not shown, the heat exchanger 305 may be fitted below or in an adjacent area to the solar panels and are connected to the pump 330 for transporting the cool working fluid to the solar panel. The working fluid can be transported through system 300 (FIG. 3) and system 200 (FIG. 2) via any suitable piping for transporting working fluid.

[0087] FIG. 4 illustrates one example of a heat exchanger 400 in accordance with aspects of this disclosure. Heat exchanger 400 is an embodiment of heat exchangers 210 and 305 in FIGS. 2 and 3, respectively.

[0088] The heat exchanger 400 may include ports 410 to act as a respective inlet and outlet for transporting working fluid through heat collector piping 415 extending through a body 420 of heat exchanger 400. Piping 415 can include one or more bends, or otherwise wrap through the body 420 to provide increased surface area and improved heat transfer from a corresponding proximate solar panel. The heat exchanger 400 can include a hydraulic valve 425 corresponding to each of ports 410, to provide selective fluid communication therethrough. The heat exchanger 400 can include sensors, such as a combined pressure-temperature indicator on either side of valve 425 for first determining pressure and temperature and then regulating the flow and heat exchange of the system to improve efficiency.
[0089] The heat collector piping 415 can comprise any suitable configuration for a heat exchanger. For example, a low-pressure copper tubing used for drinking water can be used, for example, with dimensions: ½" tube size, 5/8" OD, 0.028" thickness and 0.569" ID. The heat collector piping may be modified with a fin configuration for reducing length of the piping. In one example, the pump can produce the fluid with 70 psi pressure having flow rate of about 0.06 gpm. The heat collector piping 415 can be configured for compatibility with various working fluids, such as various organic fluids.

[0090] The working fluid can be flowed to and from the ports 410 of heat exchanger 400 with other system piping that is similar to the heat collector piping 415 of heat exchanger 400. For example, with reference again to FIGS. 2 and 3, system piping 240, 340, respectively, can extend between the various components shown. In some embodiments, the components shown may be integrally formed, or immediately adjacent, without needing system piping. The heat collector and/or system piping may be insulated to improve efficiency by retaining energy in the hot working fluid going to the turbo-expander. For the system piping, a medium pressure copper tubing for drinking water can be used with dimensions: ½" tube size, 5/8" OD, 0.04" thickness and 0.545" ID. Other tubing such as aluminum and PEX tubing, or high-density polyethylene (HDPE) may be used.

[0091] As described above, the systems herein can include sensors of various types. For example, a combined pressure-temperature indicator may be installed prior to the electricity generator to measure the pressure and temperature, and a flow controller may regulate the flow according to the pressure. The fluid leaving the electricity generator can be regulated by a flow controller, before entering into for the condenser further cooling by cold water and ice. The flow controllers with low flow panel mount and a protective case may be used.

[0092] The cool working fluid leaving the condenser can be measured by a combined pressure-temperature indicator, and the pressure and/or temperature of the working fluid can be adjusted before entering into the pump again.

[0093] FIG. 5 illustrates one example of a solar panel temperature control system 500 that includes an array of heat exchangers 510. The heat exchangers 510 can be similar to those shown in FIGS. 2-4, and otherwise described herein. The system 500 can include a solar panel corresponding to each heat exchanger 510. The system 500 can include electricity generator 550, condenser 530, accumulator 520, and pump 540, and
piping, gauging, and sensors as shown. The system 500 can operate similarly to systems
200 and 300 (FIGS. 2 and 3) in parallel and series configurations.

[0094] In some implementations, the system may comprise a parabolic trough or dish. The solar cells may be arranged to line a parabolic trough and may be covered with a reflective film or coating that absorbs the energy from sunlight at a wavelength that the module can convert and reflects or concentrates the rest onto the additional heat collector installed in front of the trough as in a classic concentrated solar thermal collector with a mirror, like a parabolic trough or dish. The working fluid absorbs heat from the back of the trough or dish as in the flat panel case and then is further heated as it flows into the collector installed in front of the trough or dish. This may increase the electrical energy generated at the turbine due to the increased enthalpy of the working fluid.

[0095] In one embodiment, a system for enhancing performance of a solar panel or an array of solar panels by cooling the heated solar cells and converting energy from the heated panel into electrical energy; the system comprising: a pump pumped a cool working fluid to the solar panel via a heat collector piping with a pressure-temperature indicator and a valve in the middle; a device, adapted to receive a hot working fluid leaving the solar panel via an insulated piping for extracting energy and converting into mechanical energy before converting into electrical energy, wherein the insulated water radiator piping collected the hot working fluid, equipped with a pressure-temperature indicator for measuring pressure and temperature and also equipped with a flow controller and a flow controller for measuring flow of the fluid entering and leaving the micro-turbine, respectively, a heat exchanger received the hot working fluid from the piping for cooling the fluid using cold matter before returning the cool working fluid to the pump, wherein pressure and temperature of the fluid before entering the pump is measured by using pressure-temperature indicator for pressure and temperature while pressure is regulated by a valve.

[0096] The systems described herein, or modifications thereof, can be implemented to provide various methods.

[0097] For example, a method of removing heat from a solar panel can include: providing at least one solar panel; circulating a working fluid proximate to the solar panel; and extracting heat from the solar panel via an Organic Rankine Cycle. The method can further include generating electricity based upon the enthalpy of the working
fluid. The extracting heat step can include cooling the solar panels so as to increase the efficiency of the solar panels by at least 5% compared to the combined standalone efficiency of the solar panels. The circulating step can include regulating the flow of the working fluid to an operating pressure being lower than the pressure used in a refrigeration cycle.

[0098] For example, another method can include: providing at least one solar panel; and affecting the temperature of the solar panel with an organic refrigerant. The affecting the temperature step can include cooling the solar panel so as to increase the efficiency of the solar panels by at least 5% compared to the combined standalone efficiency of the solar panels. The method can further include generating electricity based upon the enthalpy of the organic refrigerant.

[0099] For example, another method can include: providing at least one solar panel; moving a working fluid proximate to the solar panel; extracting heat from the solar panel and forming a heated working fluid from the working fluid; and generating electricity from the working fluid. The generating electricity step can include flowing the heated working fluid to an electricity generator and exhausting pressure from the working fluid.

[0100] For purposes of this disclosure, certain aspects, advantages, and novel features are described herein. Not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the disclosure may be embodied or carried out in a manner that achieves one advantage or a group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

[0101] As used herein, the term "plurality" denotes two or more. For example, a plurality of components indicates two or more components. The phrase "based on" does not mean "based only on," unless expressly specified otherwise. In other words, the phrase "based on" describes both "based only on" and "based at least on."

[0102] Conditional language, such as "can," "could," "might," or "may," unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements, and/or steps are in any way required for one or more embodiments or that one or more
embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements, and/or steps are included or are to be performed in any particular embodiment.

[0103] Conjunctive language such as the phrase "at least one of X, Y, and Z," unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be either X, Y, or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require the presence of at least one of X, at least one of Y, and at least one of Z.

[0104] Language of degree used herein, such as the terms "approximately," "about," "generally," and "substantially" as used herein represent a value, amount, or characteristic close to the stated value, amount, or characteristic that still performs a desired function or achieves a desired result. For example, the terms "approximately", "about", "generally," and "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount. As another example, in certain embodiments, the terms "generally parallel" and "substantially parallel" refer to a value, amount, or characteristic that departs from exactly parallel by less than or equal to 15 degrees, 10 degrees, 5 degrees, 3 degrees, 1 degree, or 0.1 degree.

[0105] The scope of the present disclosure is not intended to be limited by the specific disclosures of preferred embodiments in this section or elsewhere in this specification, and may be defined by claims as presented in this section or elsewhere in this specification or as presented in the future. The language of the claims is to be interpreted broadly based on the language employed in the claims and not limited to the examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive.

[0106] The previous description of the disclosed implementations is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these implementations will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the scope of the invention. For example, it will be appreciated that one of ordinary skill in the art will be able to employ a number corresponding alternative and equivalent structural details, such as equivalent ways of fastening, mounting, coupling, or engaging tool components, equivalent mechanisms for producing
particular actuation motions, and equivalent mechanisms for delivering electrical energy. Thus, the present invention is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.
WHAT IS CLAIMED IS:

1. A solar panel temperature control system, comprising:
   at least one solar panel configured to convert at least a portion of incident
   light into electrical energy;
   a pump configured to receive and regulate the flow of a working fluid; and
   a heat exchanger configured to receive the working fluid from the pump
   and circulate the working fluid in proximity to the solar panel so as to extract heat
   from the solar panel into the working fluid such that the working fluid undergoes
   a phase change from liquid to gas,
   wherein the solar panel temperature control system is configured to cycle
   the working fluid via an Organic Rankine Cycle.

2. The system of Claim 1, further comprising:
   an electricity generator configured to receive the working fluid from the
   heat exchanger and generate electricity based on the enthalpy of the working
   fluid;
   a condenser configured to receive the working fluid from the turbine-generator
   and circulate the working fluid in proximity to a cold source so as to
   extract heat from the working fluid into the cold source such that at least a portion
   of the working fluid undergoes a phase change from gas to liquid; and
   an accumulator configured to receive the working fluid from the
   condenser.

3. The system of Claim 2, wherein the organic refrigerant has a boiling point,
   at an operating pressure within the heat exchanger, that is less than a standard operating
   temperature of the solar panel.

4. The system of Claim 3, wherein the working fluid comprises an organic
   refrigerant.

5. The system of Claim 4, wherein the heat exchanger is further configured to
   cool the solar panel so as to increase the efficiency of the solar panels by at least 5%
   compared to the combined standalone efficiency of the solar panels.
6. The system of Claim 5, wherein the pump is further configured to regulate the flow of the working fluid to an operating pressure at which the working fluid is supplied to the heat exchanger, the operating pressure being lower than the pressure used in a refrigeration cycle.

7. The system of Claim 6, wherein the system does not include a compressor.

8. The system of Claim 7, wherein the pump is further configured to consume less energy than is produced by the electricity generator.

9. The system of Claim 8, wherein the pump comprises a variable speed pump configured to regulate the flow of the working fluid supplied to the heat exchanger based on the temperature of at least one of the working fluid and the solar panel.

10. The system of Claim 9, wherein the organic refrigerant has an isentropic saturation vapor curve.

11. The system of Claim 10, wherein the heat exchanger comprises two or more heat exchangers and the solar panel comprises two or more solar panels, each of the heat exchangers coupled to and configured to cool a corresponding one of the solar panels.

12. The system of Claim 11, wherein the overall efficiency of the solar panel temperature control system is greater than the combined standalone efficiency of the solar panels.

13. A solar panel temperature control system, comprising:

   at least one solar panel configured to convert at least a portion of incident light into electrical energy;
   an organic refrigerant; and
   a heat exchanger configured to affect the temperature of the solar panel with the organic refrigerant.

14. The system of Claim 13, wherein the organic refrigerant has a boiling point, under pressure, that is less than a standard operating temperature of the solar panel.
15. The system of Claim 14, wherein the heat exchanger is further configured to cool the solar panels so as to increase the efficiency of the conversion of the incident light into electrical energy by at least 5% compared to the combined standalone efficiency of the solar panels.

16. The system of Claim 15, further comprising:
   an electricity generator configured to receive the organic refrigerant from the heat exchanger and generate electricity based on the enthalpy of the organic refrigerant.

17. The system of Claim 16, wherein the system does not include a compressor.

18. A solar panel system, comprising:
   at least one solar panel configured to convert at least a portion of incident light into electrical energy;
   a heat exchanger configured to move a working fluid in proximity to the solar panel so as to extract heat from the solar panel and form a heated working fluid; and
   an electricity generator configured to receive the heated working fluid from the heat exchanger and generate electricity.

19. The solar panel system of Claim 18, wherein the working fluid comprises an organic refrigerant.

20. The solar panel system of Claim 19, wherein the organic refrigerant has a boiling point, under pressure, that is less than a standard operating temperature of the solar panel.
FIG. 1
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

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<th>IPC</th>
<th>CPC</th>
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According to International Patent Classification (IPC) or to both national classification and TPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

See Search History document

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

See Search History document

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>US 2009/0126364 A1 (Mills, D. et al) 2009.05.21; figure 2; paragraphs [0037]-[0040], [0404]-[0407]</td>
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<td>Y</td>
<td>DE 202006017581 U1 (Brueckner, J. et al) 2007.03.01; figure 2; page 2, paragraph 3; page 4, paragraph 3; page 7, paragraph 2</td>
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*Further documents are listed in the continuation of Box C.*

See patent family annex.

**Date of the actual completion of the international search**

10 April 2018 (10.04.2018)

**Date of mailing of the international search report**

26 APR 2018

**Name and mailing address of the ISA/**

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