United States Patent Application Publication	20250257910
Kind Code	A1
Publication Date	August 14, 2025
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COOLING APPARATUS

Abstract

The invention provides a portable cooling vented apparatus, comprising: an array made of one or more thermoelectric cooler(s), each thermoelectric cooler (TEC) having a cold side and a hot side, the cumulative cold sides and the cumulative hot sides of all the thermoelectric cooler(s) define cold and hot sides of the array, respectively; one or more heatsinks at the hot side of the array; and at least one reservoir configured to supply liquid to the heatsink(s) with the aid of one or more liquid channel(s) connected to said reservoir and installed in the interior of the cooling apparatus in proximity to said heatsink(s); wherein the apparatus is open to the surroundings and is characterized in that the one or more liquid channels is (are) in the form of a narrow piece of wettable material in fluid communication with, or emerging from, the liquid reservoir and in contact with the heatsink.

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Family ID: **96660606**

Appl. No.: **19/053946**

Filed: **February 14, 2025**

Foreign Application Priority Data

IL	272829	Feb. 20, 2020

Related U.S. Application Data

parent WO continuation PCT/IL2023/050867 20230817 PENDING child US 19053946
parent US continuation-in-part 17890578 20220818 PENDING child US 19053946
parent WO continuation-in-part PCT/IL2021/050197 20210221 PENDING child US 17890578

Publication Classification

Int. Cl.: **F25B21/02** (20060101)

U.S. Cl.:

CPC **F25B21/02** (20130101); F25B2300/00 (20130101); F25B2321/0252 (20130101)

Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation-in-part of U.S. patent application Ser. No. 17/890,578 filed on Aug. 18, 2022, which is continuation-in-part of PCT/IL2021/050197 filed on Feb. 21, 2021, which claims the benefit of Israeli patent application No. 272829 filed on Feb. 20, 2020, the entire contents of each of which is hereby incorporated herein in its entirety. This application also is a continuation of PCT/IL2023/050867 filed on Aug. 17, 2023, which claims priority to U.S. patent application Ser. No. 17/890,578 filed on Aug. 18, 2022, the entire contents of each of which is hereby incorporated herein in its entirety.

TECHNICAL FIELD
[0002] The invention relates to the field of portable apparatuses for cooling.
BACKGROUND
[0003] Many portable cooling methods require excessive time and energy to reach a cold temperature, and even so, the cooling effect lasts a relatively short time. A reduction of the preparation time and energy consumption, as well as the increase of the cooling-period, are crucial in many cases. For example, therapeutic cooling is often performed with ice packs that take a long time to freeze and can only last until they melt. Therefore, this type of cooling results in a compromised treatment. Another example is the cooling of food by a picnic cooler that uses ice packs. A more efficient way to cool the food can extend the picnic options.
[0004] Many portable cooling products in the market are based on a bag with a pre-frozen substance, such as water or gel, while the cooling effect is obtained by a phase transition of the frozen substance back to its liquid form. The effectiveness of these cooling products fades out as the phase transition from solid to liquid is completed, and upon such completion, the “ice bag” serves as a thermal insulator that increases the temperature rather than lowering it. This is particularly problematic in the case of a medical or therapeutic usage.
[0005] There are currently no practical devices that are portable, compact, and energetically efficient, while still ensuring a prolonged cooling with no necessity for a frequent replacement of the cooling substance.
[0006] The Thermo Electric Cooler (TEC) (sometimes termed Peltier plate; these terms are used herein interchangeably) is used in the art for heating or cooling. It transfers heat through an electric component (the TEC) by applying electric current, creating a hot side and a cold side. It is known that heat can be removed from the hot side with the aid of heatsinks coupled to the hot side, e.g., in the form of plates with fins to increase surface area.
[0007] JP 2009112552 discloses a shoe having a temperature control mechanism that uses the Peltier effect to cool or heat a liquid which flows in pipes to cool a foot. WO 2014/055085 discloses a personal temperature control system which includes an article having flexible tubing for circulating a fluid whose temperature is conditioned (cooled or heated) by TEC. 2004/014169 discloses a temperature regulated clothing which is based on TEC whose hot side isn't in direct contact with fins. Rather, it is in contact with an internal heat exchanger that includes a coolant

liquid which flows to an external heat exchanger where it is cooled. JPH0884744 discloses a cooling and heating device that replaces a water bag. It uses TEC to heat or cool the water that is circulated with a pump in and out of the bag.

[0008] Self-Regulating Heating/Cooling Blanket Using the Peltier Effect, temperature controlled blanket system, (Northeastern university published article), discloses a system where the Peltier effect is used to heat or cool a blanket that is placed on a patient. In this publication, however, the heat is removed inefficiently using only heatsinks and fans, and requires the device to be connected to an electrical outlet.

[0009] Our earlier publication WO 2021/165970 shows a thermoelectric cooler that is open to the surroundings. An electric current is passed through the thermoelectric cooler from a DC power supply, to create a cold side and a hot side. Heat is drawn off from the hot side with the aid of one or more heatsink(s) coupled to the hot side. A liquid coolant is delivered to the heatsink(s) whereby the liquid evaporates, and vapors formed escape to the surrounding environment. Cooler designs and experimental results that were shown in FIGS. **1** to **10** of WO 2021/165970 are appended herein as FIGS. **1** to **10**, respectively. The present invention relates to some modifications of our earlier invention, and is exemplified in FIGS. **11**A-**11**B, **12**A-**12**B, **13**A-**13**C, **14** and **15**.

SUMMARY OF THE INVENTION

[0010] The invention relates to a portable cooling vented apparatus, comprising: [0011] an array made of one or more thermoelectric cooler(s), each thermoelectric cooler (TEC) having a cold side and a hot side, the cumulative cold sides and the cumulative hot sides of all the thermoelectric cooler(s) define cold and hot sides of the array, respectively; [0012] one or more heatsinks at the hot side of the array; and [0013] at least one reservoir configured to supply liquid to the heatsink(s) with the aid of one or more liquid channel(s) connected to said reservoir and installed in the interior of the cooling apparatus in proximity to said heatsink(s); wherein the apparatus is open to the surroundings and is characterized in that the one or more liquid channels is (are) in the form of a narrow piece of wettable material in fluid communication with, or emerging from, the liquid reservoir and in contact with the heatsink.

[0014] By “open to the surroundings” it is meant that the apparatus is vented, such that when vapors are formed in the hot side, these vapors can escape to the surroundings. The apparatus is open to the surrounding, e.g., either by leaving the hot side at least partially uncovered, by covering the hot side with a gas-permeable cover, or by otherwise incorporating a vent function in the apparatus.

[0015] For example, according to one variant of the invention, the liquid channel has one end that is immersed in a liquid tank, to enable liquid flow along the channel by capillary action. The liquid channel has a serpentine-like shape, curving in alternate directions on the heatsink. More specifically, the liquid tank is placed beneath the heatsink(s) and is adjacent to, or contiguous with at least one edge of the heatsink(s), with a liquid channel in the form of a long narrow piece of wettable material consisting of a sponge strip or a strip made of a suitable cloth, emerging from the liquid tank and lying on the face of the heatsink, curving in alternate directions on the heatsink in the spaces between the columns of fins protruding from the surface of the heatsink, such that liquid can move along said channel, from one end of the channel that is immersed in the tank, to the opposite end, by capillary action, whereby the serpentine-like liquid channel touches and wet the fins directly.

[0016] Another variant of the invention is a cooling apparatus comprising a liquid tank mounted above an array of TECs assembled in one or more columns and one or more tubes to supply liquid coolant from said tank to the surface of the heatsink(s), characterized in that each tube is provided with a contraction located atop of a column of TECs; with a bundle of strips made of wettable material in contact with each other, and tightly fixed in place in the interior of the contraction, extending downward from the exit of the contraction and laid out on the face of the heatsink(s) in the respective column, touching the surface of the heatsink(s) and fins protruding from the surface.

[0017] The contraction is a vertical contraction, i.e., one or more tubes is connected to a tapered section creating a vertical contraction, such that ratio of between the cross-section areas of the inlet and outlet of said tapered section is preferably in the range from 3 to 10. One or more check valves between the liquid tank and the heatsink(s) is (are) installed, to supply liquid coolant to the heatsinks in a controlled manner.
[0018] For example, a useful design of this variant comprises a single tube directed downward from the liquid tank, wherein the flow through said tube is regulated by a valve. The tube diverges into secondary tubes, each secondary tube joining a funnel-shaped element placed a top of a column of TEC; the funnel-shaped element creates a vertical contraction. The apparatus may further comprise one or more fans to facilitate evaporation from the heatsinks and heat dissipation to the surrounding.
[0019] A funnel-shaped contraction with a rectangular cross-section may be used, with a small movable plate attached to an inner wall of the narrow pipe of the contraction, such that the cross section of the narrow pipe can be adjusted by the movement of a screw that pushes the small plate, to tightly compress the strips inside the narrow pipe. The funnel-shaped contraction may contain a gasket to prevent water leakage, the gasket covering the entire inner wall where the small plate is located, and the plate itself.
[0020] The flow of liquid coolant from the tank to the heatsinks occurs by a combination of: [0021] at least one of gravitational and pressure driven flow; and a capillary flow. Thus, the cooling apparatus of the invention may further comprise one or more pumps for pushing the liquid coolant from the tank to the contraction(s).
[0022] For example, the hot side of the array may be at least partially uncovered or covered with a gas-permeable cover, such that when vapors are formed in the hot side, these vapors escape to the surroundings.
[0023] The cooling apparatus of the invention may be combined with a garment, or for use within a cooling box, a chair cushion, a helmet, or a bike handle.
[0024] Another aspect of the invention is a method of cooling using a thermoelectric cooler, comprising passing an electric current through the thermoelectric cooler from a DC source, to create a cold side and a hot side, drawing off heat from the hot side with the aid of one or more heatsink(s) coupled to the hot side, characterized in that liquid coolant is delivered to the heatsink(s) whereby said liquid evaporates and vapors formed escape to the surrounding environment, wherein the liquid coolant is delivered to the heatsinks by causing liquid to flow from a liquid tank by capillary action, or a combination of capillary flow and at least one of gravitational and pressure driven flow.
[0025] For example, the method comprises causing the liquid coolant to flow from a liquid tank to a vertical construction by gravity or with the aid of a pump, to wet a bundle of strips made of wettable material that are in contact with each other, and that are tightly fixed in place in the interior of the contraction and extend downward from the exit of the contraction and laid out on the face of the heatsink(s), touching the surface of the heatsink(s) and fins protruding from the surface.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0026] FIG. **1** illustrates in a schematic form a structure of a first embodiment of the invention shown in WO 2021/165970;
[0027] FIG. **2** illustrates in a schematic form a structure of a second embodiment of the invention shown in WO 2021/165970;
[0028] FIG. **3** illustrates in a schematic form an embodiment of the apparatus of the invention shown in WO 2021/165970, combined with a shoe;

[0029] FIG. **4** illustrates in a schematic form a structure of the Peltier array shown in WO 2021/165970;
[0030] FIG. **5** shows a cooling apparatus which includes a top main reservoir and a bottom recycling reservoir shown in WO 2021/165970;
[0031] FIG. **6** shows another cooling apparatus with a bottom recycling reservoir and a top main reservoir shown in WO 2021/165970;
[0032] FIG. **7** shows the measured ΔT between the cold side and the ambient air with and without a water spray on the heatsink shown in WO 2021/165970; and
[0033] FIG. **8** shows the measured ΔT between the cold side and the ambient air with and without a water spray on the heatsink, while a fan was used, as shown in WO 2021/165970.
[0034] FIGS. **9**A-**9**C show a cooling apparatus in which a liquid-absorbent layer soaked with liquid coolant is attached to the heatsinks to deliver the liquid to the heatsinks, as shown in WO 2021/165970.
[0035] FIG. **10** illustrates the performance of a cooling device with the aid of ΔT versus power plot, measured based on the operation of a cooling apparatus designed according to FIGS. **9**A-**9**C, as shown in WO 2021/165970.
[0036] FIGS. **11**A and **11**B show a modified cooling device of the present invention (front and side views, respectively).
[0037] FIGS. **12**A and **12**B show another variant of the cooling device of the invention (front and back views, respectively).
[0038] FIG. **13**A-**13**C show three variants of the cooling device of the present invention (front view).
[0039] FIGS. **14-15** show ΔT versus time curves, illustrating the cooling effect achieved with an experimental set-up based on the designs shown in FIGS. **13**A-**13**B, respectively.

DETAILED DESCRIPTION

[0040] The present invention provides a portable, energetically efficient, and light-weight apparatus that includes an array of (one or more) TEC units (hereinafter also referred to as “Peltier plates”). As will be discussed in more detail hereinafter, the inventors have found that the manner in which the portable Peltier-based cooling apparatuses of the prior art is used, could be improved. In one aspect, while such prior art devices use heatsinks to cool their hot side of the Peltier plates, the capability of these heatsinks to disperse heat to the environment is limited, unless large and bulky heatsinks are used, and this limitation results in a reduction in the overall mobility of the apparatus. The inventors suggest an evaporation-based use of coolant in order to further cool the heat-sinks, and significantly improve the overall efficiency of the apparatus. Moreover, the use of a coolant (such as water or any other coolant or mixture of coolants with or without solid particles dispersed in them) eliminates any necessity for pre-freezing. The addition of frozen particles to the coolant, if used, can further intensify the cooling.
[0041] In another aspect, the inventors have found that operating the Peltier plates with a low voltage, lower than the typical operating point of the Peltier plates, is advantageous. While this reduction of voltage somewhat reduces the cooling of the plates to an acceptable extent, such a reduction results in a significant improvement to the overall efficiency of the apparatus. In this respect, the inventors have found that operating close to the maximal coefficient of performance is preferable.
[0042] In view of the above structural and design differences compared to prior art apparatuses, the apparatus of the invention can operate based on a small-size and light-weight battery for a relatively longer time.
[0043] When used to cool a body part, such as for therapeutic or recreational purposes, the portable apparatus of the invention may be combined with a clothing item (such as, a shoe, a shirt, a pillow, etc.) or worn directly on a body part. The portable apparatus of the invention may also be used for other purposes, such as for cooling of food, for air conditioning, for cooling a chair in a vehicle, for

cooling a motorcycle vest, motorcycle handlebars or any other uses.
[0044] The Peltier plates in the array may be connected in parallel, in series, or in a combination of series and parallel. Each plate in the array has a cold side and a hot side. One or more heatsinks are attached to the hot side of the array to assist in the heat dissipation. Coolant (such as water or any other flowing medium that can go through phase transition) is spilled on the heatsinks to facilitate an accelerated heat dissipation. The coolant may be spilled using one or more of liquid drippers, nozzle sprays, or any other mechanism capable of dispensing liquid on the heatsinks (for the sake of brevity, all will be referred hereinafter as “drippers”). The coolant evaporates and thus contributes to the cooling of the hot sides of the Peltier plates, thereby facilitating the cooling effect of the apparatus.
[0045] FIG. **1** (corresponding to FIG. **1** of WO 2021/165970) is a general-schematic view of a cooling apparatus **100** according to one embodiment of the invention described in WO 2021/165970). A series of Peltier plates **105** are arranged in a two-dimensional array form, and are electrically connected in parallel, in series, or in a combination of series and parallel. The plates also connected mechanically by flexible strips, discrete wires to provide higher strength. Alternatively, single or several flexible TECs, which are currently being developed in various places, may be used instead of the rigid ones to add to the flexibility. In case more than one TEC is used, heat dissipating layer **120** may be added to diffuse the cold environment between the TEC-s. Layer **120** may also be used to allow a different touch or feel of the cold side. A liquid impermeable layer **125** (such as fabric or any other medium that is impermeable to coolant) may also be used to mechanically connect the plates and separate between the hot (wet) sides and the cold (dry) sides of the array. The fact that each of the plates **105** is of relatively small dimensions (typically from a few square millimeters and up to hundreds of square millimeters) enables the user a flexibility to adapt the cooling surface **120** of the array to the surface of the cooled region. In some embodiments, each of the Peltier plates may be reduced even to a 1×1 micron size, which is the smallest Peltier plates currently known in the art. The collection of all the cooling sides **105***c* of the Peltier plates **105**, together with the heat dissipating layer **120** forms, in combination, a roughly unified cooling surface. In order to provide an improved temperature distribution on the cooled object, while compensating for the gaps between the plates **105**, the cooling layer **120** may be made of a thermal-conducting layer (for example, carbon fiber, strengthened carbon, simple cloth, etc.). A series of heatsinks **107** are attached to the hot sides **105***h* of the Peltier plates **105**. Alternatively, a series of discrete heatsinks **107** may be used, each being attached separately to a single or several hot sides **105***h* of a Peltier plates **105**.
[0046] One or more liquid drippers (or nozzles) **111** are provided to wet the heatsinks **107** with coolant. The coolant evaporates on the heatsink, thereby it accelerates the heat dissipation and the total cooling of the series of hot surfaces of the Peltier plates, thus facilitating the cooling effect of the entire apparatus **100**. The one or more liquid drippers **111** are connected to a liquid channel **106** which is connected to a main reservoir (in this case a top main reservoir) **113**, i.e., a container that contains the coolant substance. In one embodiment, the liquid channel **106** includes a valve **109** that is configured to enable or disable the flow of the coolant to the liquid drippers **111**. The number of liquid drippers **111** may vary. There may be one liquid dripper **111** per each plate **105**, there may be several liquid drippers **111** per each plate **105**, or there may be one liquid dripper per several of plates **105**.
[0047] The term “liquid channel” refers herein to any mechanism for carrying out a liquid flow, such as a tube, an open channel, or similar.
[0048] Throughout this application, similar reference numbers appearing in the various embodiments relate to components of similar functionalities, respectively.
[0049] In the embodiment of FIG. **1**, the main reservoir **113** is located at the top of the apparatus **100**. In another embodiment 300 shown in FIG. **2** (corresponding to FIG. **2** of WO 2021/165970), the main reservoir **313** is located at the bottom of the apparatus. Pump **319** is used to raise the

liquid towards drippers **311**. For a sake of brevity, the additional components whose function is similar to those of FIG. **1**, will not be discussed in more details.

[0050] FIG. **5** (corresponding to FIG. **5** of WO 2021/165970) shows a cooling apparatus **500** which includes a top main reservoir **513** and a bottom recycling reservoir **514**. Apparatus **500** is similar to the apparatus **100** of FIG. **1**, however, with two reservoirs. Excessive coolant which is dropped over the heatsinks and not evaporated is accumulated within the bottom recycling reservoir **514** for recycling. One or more check valves **516** are repeatedly opened to allow the recycled coolant to flow back into the top main reservoir **513**.

[0051] FIG. **6** (corresponding to FIG. **6** of WO 2021/165970) shows a cooling apparatus **600** with a bottom recycling reservoir **614** and a top main reservoir **613**. The apparatus further includes a compact pump **619**. Pump **619** is substantially made of two components: a ferromagnetic core **618**, an electric coil **617**, an upper check valve **616***a* and a lower check valve **616***b*. The ferromagnetic core may be made, for example, of iron. Ferromagnetic core **618** has a diameter somewhat smaller than the internal diameter of liquid channel **615**, and is located within the liquid channel (in contact with the recycled coolant). When electric current flows through coil **617**, core **618** is pushed up, thereby also pushing the recycled liquid, that opens both check valves **616***a* and **616***b* (that are normally closed, and are configured to open upon a flow of liquid (in this case in the up direction). When the current is off, core **618** sinks down to rest on the lower check valve and both check valves **616***a* and **616***b* close.

[0052] As will be discussed in more details hereinafter with respect to FIG. **3** (corresponding to FIG. **3** of WO 2021/165970), when the apparatus is combined with a garment article which covers the hot side (such as a shoe), ventilation holes may be provided in the garment such that the evaporated coolant is removed from the apparatus (such as **310** in the shoe shown in FIG. **3**) while improving the overall efficiency of the heat removal. Another option is to condense the coolant that is evaporated and recycle it.

[0053] FIG. **2** (corresponding to FIG. **2** of WO 2021/165970) shows an embodiment 300 with a bottom reservoir. The embodiment 300 is essentially identical to the embodiment 100 of FIG. **1**, however, while in the embodiment of FIG. **1** the reservoir **113** is positioned at the top of the apparatus, in the embodiment of FIG. **2** the reservoir **313** is positioned at the bottom, while pump **319** is used to raise the coolant into liquid channel **306**, and spray or drizzle (or dispense in any other way) it via one or more of the nozzles **311**.

[0054] The embodiments of FIGS. **1** and **2** (corresponding to FIGS. **1** and **2** of WO 2021/165970) preferably recycle the coolant, in order to save weight and coolant volume. In the embodiment of FIG. **1**, a pump (not shown) may be used to lift the excess of coolant that was not evaporated and drained into a lower reservoir (also not shown) to the top reservoir **113**. In the embodiment of FIG. **2**, the pump **319** lifts the coolant towards the nozzles **311**, from which the liquid goes back down by gravity, thus completing the recycling process. In some embodiments, the user's movement assists in raising the liquid up with a further assistance of one or more check valves, replacing the pump. For example, the pressure applied by the user's foot may assist in pumping the coolant upwards towards the nozzles. Other random motions may also raise the liquid through the check valves.

[0055] FIG. **3** (corresponding to FIG. **3** of WO 2021/165970) schematically shows a side view of a shoe which is integrated with a cooling apparatus **300** such as shown in FIG. **2**. The apparatus **300** cools down the lower part of a wearer's leg (the Achilles tendon, the ankle, and the foot). The shoe **400** contains a series of Peltier plates **305** with their cold side facing the leg, and one or more check valves **403**. Check valve **403** allows coolant to drain into the lower reservoir **313**. When the leg is lifted up, the spring **402** lowers the pressure in the lower reservoir **313**. This facilitates the entry of the drained liquid through the check valve **403**. A check valve **404** is opened when the foot is down allowing the liquid to go up into the nozzles **311**. The shoe **400** does not need an electrical pump for its operation, as each step of the user applies a force on the bottom section of the shoe, which causes a dose of liquid to flow from reservoir **313** upward through liquid channel **306** towards liquid drippers **311** (only one liquid dripper **311** is shown, for the sake of brevity). The liquid is sprayed to cool the heatsink **307** and excessive of it falls downwards. Additional elements, such as a control unit, a switch, and a pump may also be included within the shoe **400** (but are not shown, for the sake of brevity). The battery is also not indicated, as it may be included within the shoe, or external to the shoe or can be used in combination with solar panels. Ventilation holes **310** are provided such that at least a portion of the evaporated coolant is removed from the apparatus while improving the overall efficiency of the heat removal. The coolant can be added through the sealable opening **405**.

[0056] FIG. **4** (corresponding to FIG. **4** of WO 2021/165970) illustrates a structure of TECs array, according to an embodiment of the invention. The exemplary array **200** has 25 Peltier plates **202**.sub.1,1 to **202**.sub.5,5 that are arranged in rows and columns. Each of the series of the plates **202** is mechanically connected with a coolant liquid impermeable fabric **225** (or any other medium that is impermeable to the coolant). The impermeable fabric **225** can be connected at any place between the Peltier plates, but placing it between the wet (hot) side of the plate and the dry (cold) side can serve two purposes: separating the hot and the cold sides, and separating the wet and the dry sides. Alternatively, separate thermal insulator and coolant impermeable materials may be used. Each of the Peltier plates **202** is connected to a battery or a power supply via positive and negative lines **208** and **210**, respectively. The Peltier plates may be connected either in a parallel form, in a serial form, or a combination of serial and parallel connections. The example of FIG. **4** shows a combined connection in which the plates in each row are connected in series, while all the 5 rows are connected in parallel. Preferably, the exact type of electrical connection which is selected is the one which optimizes the energy consumption and cooling. The structure of all the connected plates forms a roughly unified cooling array. The cooling array may contain an ON/OFF switch (not shown), and optionally also a cooling regulator or control system (not shown), such as a potentiometer, for regulating the level of cooling by adjustment of the DC voltage that is applied on the plates or several batteries, that can be switched ‘on’ or ‘off’ so that the number of batteries that are ‘on’ determine the voltage level on the Peltier plates.

[0057] As noted above, the present apparatus is designed to provide a prolonged cooling. It is known that the coefficient of performance (COP) of Peltier plates has a maximum at some low power, i.e. low voltage and current (the exact values of which depends on the type of the plate). The COP is the ratio between amount of heat transferred by the Peltier plates and the energy consumption of the plate. Other prior art cooling devices (either stationary or portable) tend to use a much higher power and low COP so that the cooling rate will be maximal regardless of the COP efficiency. In this invention, however, the tendency is to use a relatively low power (low voltage and current) and to be closer to the COP maximal value. This provides higher energetic efficiency and longer working time. The cooling rate can still be rather high due to the evaporation of the coolant that adds to the cooling rate.

[0058] It is expected that with a battery having dimensions similar to those of a conventional portable phone, the apparatus may provide a cooling temperature which is more than 10° C. lower than the ambient temperature, and this cooling may be provided to a duration up several hours.

[0059] It should be noted that the one or more of the containers (top or bottom) may be located external to the apparatus. Moreover, the array may include one or more Peltier plates. For the sake of brevity, the term “array” is used herein even when only one Peltier plate is included within the array.

[0060] In some alternatives, the type of heatsinks and liquid channels may vary. For example, the heatsink may be in a form of a wet fabric, where coolant is dripped on the fabric. In another alternative, the tubing may partially or entirely pass through internal liquid channels within the heatsinks. This can eliminate the need for external drippers as the liquid oozes/seeps out of the pores in the heatsinks.

[0061] Another embodiment is using TECs that only have a wet cloth as a heat sink, or a solid heat sink that is made with pores into which liquid can enter and from which liquid can evaporate.
[0062] As explained above, the cooling device is designed to benefit from a phase transition of a liquid coolant delivered at the hot side of the TEC array. When the liquid coolant is supplied to the hot side of the TEC array, it removes heat, transforming into vapors (the quantity of heat removed is known as latent heat of evaporation). The cooling device of the invention is configured to enable the escape of these vapors, such that the heat generated is released away from the device, dissipating in the environment.
[0063] Suitable liquid coolants include, in addition of course to water, a mixture of water and isopropyl alcohol or ethylene glycol or any other substance or combination of substances that undergo liquid to vapor phase transition at temperatures close to room temperature. Latent heat of water at 28° C. is 2434.6 KJ/kg, the latent heat of ethylene glycol at the same temperature is 1057 KJ/kg and the latent heat of isopropyl alcohol at this temperature is 748.8 KJ/kg. The mixture of each of these alcohols with water creates a heat of vaporization (latent heat) that is between the corresponding two numbers. The advantage in mixing them comes from the increase in the rate of evaporation.
[0064] FIGS. **9**A-**9**C (corresponding to FIGS. **9**A-**9**C of WO 2021/165970) illustrate another approach to the supply of the liquid coolant to the hot side of the TEC array, namely, an alternative to a design consisting of main tubing and drippers which drip the coolant onto the hot side, shown in previous drawings. FIG. **9**A is a top view of the cold dry side of the TEC array, consisting of six TECs arranged in two parallel rows, electrically connected to a power source. A top view of the hot side of the TEC array is illustrated in FIG. **9**B, showing the heatsinks deployed on the hot side of the TECs. The liquid coolant is supplied to the heatsinks with the aid of a liquid-absorbing layer attached to the heatsinks (e.g., a porous material whose pores can be filled up with the liquid coolant, for example, a sponge soaked up with the liquid coolant). FIG. **9**C shows a side view of a cooling device **900** based on the "sponge" variant of the invention. Numerals **905**, **905***c* and **905***h* indicate the thermoelectric modulus and its cold and hot sides, respectively. Heatsinks **907** (e.g., made of a plate with fins or pins, e.g., an aluminum plate, or any other geometry that allows an increase in the surface area and allows contact with a liquid) are placed on the hot side **905***h*, partially surrounded by the liquid absorbing layer **915**, which is about 0.01 to 100 mm thick, depending on the intended use of the cooling device. Liquid impermeable layer **925**, e.g., made of nylon or other flexible that is impermeable to the coolant liquid used, prevents coolant liquid occupying the pores of layer **915** from crossing into the TEC array zone. Note that heat dissipating layer **920** is provided in the spaces between each individual TECs. It is seen that heatsinks **907** extend above the surface of the liquid absorbing layer **915**, reaching a liquid permeable cover **916**, to let vapors, generated in the cooling device upon evaporation of the liquid coolant, escape. For example, the ventilation function is achieved with cover **916** in the form of a net, or a sheet made of nylon mesh or a plastic cover or other materials with ventilation holes uniformly distributed over the sheet.
[0065] Another aspect of the invention is a method of cooling using a thermoelectric cooler, comprising passing an electric current through the thermoelectric cooler from a DC power source, to create a cold side and a hot side, drawing off heat from the hot side with the aid of one or more heatsink(s) coupled to the hot side (e.g., heatsinks in the form of a plate with fins or pins), wherein the cold side and hot side are separated by a liquid impermeable layer, characterized in that a liquid coolant is delivered to the heatsink(s), whereby said liquid evaporates and vapors formed escape to the surrounding environment (for example, through openings provided in a cover applied onto said heatsinks, or by partially or fully exposing the heatsinks to the surrounding environment).
[0066] Suitable TECs are usually square or rectangular in shape with length and width in the ranges of 10 to 40 mm and 10 to 40 mm, e.g., of 15 to 30 mm and 15 to 30 mm, respectively, including TECs of low quality, namely, high resistivity TECs, e.g., of 0.00375 to 0.00625 ohm/mm.sup.2, for

example, of 1.95 ohm for 20 mm×20 mm TEC (nominal resistance). Either a single or a multistage TEC may be used.

[0067] A satisfactory cooling efficiency was measured when operating at voltages and currents of 0.5 V to 2 V, and 0.1 Amp to 0.5 Amp, respectively, with a fairly cheap, low quality (high resistivity) TEC; the resulting power consumption was usually about 0.05 to 1 Watt per a single TEC plate of 20×20 mm.

[0068] For example, we used an array of six TEC plates of 20×20 mm arranged in two parallel rows (three plates in each row). The rows were 10 mm spaced apart. The distance between the edges of a pair of adjacent TEC plates in a row was 10 mm. We glued a 21 mm×21 mm heatsinks with pins of 15.2 mm to the TECs and used the extra 1 mm margin to glue a vinyl tablecloth which served two purposes: (a) it was a water barrier that made sure that the cold side is dry; (b) it provided a structural base connecting the array. The vapors generated during operation were allowed to flow to the surrounding air without any restrictions.

[0069] As pointed out above, the liquid coolant can be delivered to the heatsinks by supplying the liquid coolant to a liquid-absorbing layer attached to said heatsinks, e.g., a sponge or a cloth soaked up with the liquid. Alternatively, the liquid coolant is delivered to the heatsinks by causing one or more liquid streams to flow in one or more tubes equipped with drippers/sprayers/nozzles directed to said heatsinks, or directed to the liquid-absorbing layer attached to said heatsinks, or by directly incorporating the liquid coolant into the heatsink (e.g., tubes installed internally within the heatsink, such that liquid coolant emerges from within the heatsinks, e.g., in the form of drops which undergo evaporation).

[0070] Another variant of the cooling device is based on using a liquid tank for delivering liquid to the heatsink through a liquid channel provided by a long narrow piece of wettable material with good liquid holding capacity and good liquid mobility, that is attached to the heatsink. This variant of the invention benefits from a combination of a liquid tank, that can supply liquid continuously to the heatsink, and the use of liquid-absorbing material in contact with the heatsink, that can wet the heatsink directly. In the description that follows, we refer to water as an example of the liquid that can be used, but aqueous mixtures are also meant to be included.

[0071] One design of the cooling device according to the variant set forth above is illustrated in FIGS. **11**A and **11**B. FIG. **11**A shows heatsink **1**, consisting of a plate (e.g., with the shape of a quadrangle such as a rectangle or a square, made of aluminum) with a plurality of fins **2** protruding from one face of the plate. The geometry shown in FIG. **11**A is based on deploying the fins in rows and columns over one face of the plate, to cover about 30 to 70% of total area of the face of the plate **1**. Water is held in, and supplied from, tank **4** that is adjacent to, or contiguous with at least one edge of heatsink **1**, with a water channel in the form of a long narrow piece of wettable material with good water holding capacity and water mobility, e.g., a sponge strip, or a strip made of a suitable cloth (akin to clothes used in the manufacture of wet wipes), emerging from tank **4** and lying on the face of plate **1**. For example, by capillary action, water moves along channel **3**, from one end of the channel that is immersed in tank **4**, to the opposite end. Water channel **3** has an appropriate geometry to maximize the contact of the water passing therethrough with the heatsink and at the same time maximize water evaporation to the surroundings.

[0072] For example, in FIG. **11**A, water channel **3** has a serpentine-like shape, e.g., it rests on the surface of the heatsink and curves in alternate directions, in the spaces between the columns of the fins. Water channel **3** can touch and wet fins **2** directly, such that the contact of water channel **3** and heatsink **1** result in evaporation of water to the open atmosphere. Other useful geometries include a tree-like shape, i.e., with branches made of the wettable material distributed over the surface of the heatsink.

[0073] FIG. **11**B is a schematic side view of the cooling device. It is seen that water tank **4** is placed beneath heatsink **1**. The TEC **5** is attached to one face of the heatsink **1**, whereas fins **2** and water channel **3** are provided on the opposite face of the heatsink **1**. Water channel **3** is deployed in the spaces between the columns of fins, creating the serpentine-like shape that is seen in FIG. **11**A.

[0074] As pointed out above, water channel **3** consists of a long, narrow piece of wettable material (good water mobility) with good water holding capacity. For example, the total length of the piece(s) of wettable material lying on the heatsink is at least twofold (e.g., threefold) longer than the side of the heatsink; the width of the piece(s) of the wettable material preferably does not exceed the height of the fins disposed on the heatsink; the thickness of the piece(s) of the wettable material preferably does not exceed the spacing between adjacent fins; the water holding capacity is at least two times, e.g., three times, the dry weight; and good water mobility indicates that the liquid channel enables capillary rise of water.

[0075] By way of example, when the area of the heatsink is roughly 4 cm.sup.2, the length of the water channel could be roughly from 4 cm to 13 cm, with width of 1 to 10 mm. The volume of water tank **3** is from 3 ml to 30 ml.

[0076] Thus, according to a preferred variant of the invention, there is provided a portable cooling apparatus comprising a liquid channel in the form of a narrow piece of wettable material emerging from the liquid reservoir and in contact with the heatsink. That is, the liquid channel has one end that is immersed in the liquid tank, to enable liquid flow along the channel by capillary action onto and along the heatsink.

[0077] FIGS. **12**A and **12**B show a modification of the cooling device of FIGS. **11**A and **11**B, i.e., with greater number of components as compared to the configuration of FIG. **11**, i.e., two water tanks **4** and the three heatsinks **1**. A heatsink with the TEC **5** attached to one of its faces is placed between two other heatsinks (i.e., the same plates with fins protruding from one of their faces, but without TEC being glued to the opposite face, as shown in FIG. **12**B). That is, each of two opposing sides of the central square-shaped heatsink (the one equipped with a TEC) is aligned with a side of an adjacent heatsink. The set-up consisting of the three heatsinks can be assembled with the aid of flexible aluminium wires **6**, glued or attached with a heat conducting material very close to the edges (top and bottom, respectively) of the square plates to join the three heatsinks. Akin to the design of FIG. **11**, a sponge strip **3** rests on one face of the heatsink (the one with fins **2** deployed thereon), curving in alternate directions to create a serpentine-shaped path for the water to flow through and contact with the heatsink to maximize water evaporation. The experimental results reported below indicate the devices of FIGS. **11** and **12** both achieve good cooling effect.

[0078] Another design that is based on a combined gravitational and capillary flow of water through a fabric/sponge strip, to supply water from a reservoir located above the TEC array to the heatsink(s), is shown in FIGS. **13**A-**13**C. It is based on a liquid channel having a tree-like shape that was mentioned above (or more precisely, inverse tree-like shape), i.e., with branches made of, e.g., fabric/sponge strips, spread over the surface of the heatsink.

[0079] An array based on six TEC plates assembled in two parallel rows (three plates in each row) is shown in FIGS. **13**A-**13**C. The hot face of the array, i.e., six heatsinks **1** with the fins deployed thereon, is shown; the opposite face, with the TEC, is not shown. The array can be assembled as previously described hereinabove. Water is supplied from reservoir **6** mounted above the array, and the flow is regulated through tube **11** by valve **5**. In view of the geometry of the assembly of TECs, the water flow is divided into three separate streams, with the aid of a splitter **10**. Splitter **10** serves a useful purpose in the specific design shown in FIGS. **13**A-**13**C but is not mandatory. Splitter **10** can be of the same design of element **3**, described below in detail. When splitter **10** is used, tubes **12** filled with a spongy material extend from its bottom to deliver the water to a set of elements **3** described below.

[0080] Numeral **3** indicates a vertically positioned funnel-shaped duct, i.e., tapered pipe, creating a gradual contraction. Hereinafter, for the sake of brevity, the element is named “contraction **3**”. The cross section of the contraction may be rectangular or circular. By way of example, when the area of a heatsink is roughly 4 cm.sup.2, and a rectangular contraction is used, then the dimensions of contraction **3**, through which water is delivered to the heatsink are as follows: the wide inlet

opening at the top, receiving the incoming water, is from 5 to 20 mm long and 6 mm wide, and the ratio between the cross-section area of the inlet opening at the top and the cross-section area of the narrow outlet opening at the bottom of contraction **3** is from 3 to 10, e.g., 3-7, e.g., around 5.
[0081] A bundle of strips made of wettable material, e.g., cloth with good water capacity and mobility as previously defined, is pressed against the inner walls of the narrow section of construction **3** such that the strips are intimately touching each other and therefore water supplied to contraction **3** is equally distributed between the strips.
[0082] A vertical funnel-shaped contraction may be provided by a tapered section (e.g., cylindrical, or rectangular) joined, at its small side, to a pipe with cross section area S**1**.
[0083] Optionally, a second pipe with cross section area S**2** (S**1**<S**2**) is attached to the large side of the tapered section.
[0084] For example, when a funnel-shaped contraction with a rectangular cross-section is used, then a small movable plate is attached to an inner wall of the narrow pipe of the contraction, and the cross section of the narrow pipe, S**1**, is adjusted by the movement of a screw that pushes the small plate, to tightly compress the strips inside the funnel. A sealing to prevent water leakage is achieved by applying a gasket that covers the entire inner wall where the small plate is located, and the plate itself.
[0085] The individual fabric/cloth strips **2** extend downward from the bottom of contraction **3** and are laid out on the surface of the heatsink **1**, covering the spaces between the fins protruding from the heatsink, in good contact with the fins to maximize wetting of and heat removal from the fins. The strips can be fastened to the lower edges of the heatsinks or hanged loosely.
[0086] A liquid (either as drops, a slow flow of a stream, or as short jet) moves from valve **5**, either through splitter **10** via tube **12** filled with a spongy material to contraction **3**, or directly to contraction **3**, where it spreads evenly between the individual fabric/sponge strips **2**. The flow is restricted because of the contraction created by element **3**. But such flow restriction does not affect the efficiency of the cooling generated by the device, provided that the maximal rate of liquid evaporating from the heatsink **1** and the fabric/sponge strips **2** is smaller than the minimal flow rate of liquid supplied through element **3**, such that there is continuous supply of coolant to the heatsinks. One or more receptacles **4** are placed at the bottom of the cooling device, beneath the heatsinks, to collect water that may drip from the fabric/sponge strips, in case that the amount of water delivered from valve **5** exceeds the amount that can be removed by evaporation.
[0087] FIG. **13**B shows a modification of the cooling device of FIG. **13**A, with installation of fans **7**. The fans blow air on the wet heatsink and accelerate the rate of evaporation, as shown by the experimental results reported below.
[0088] FIG. **13**C shows another modification of the cooling device of FIG. **13**A, with an addition of a control loop. An actuated (electrical) valve **5** is positioned upstream to contraction **3** and responds to signals from thermocouples **8** that measure the temperature at the heatsink **1** (and/or on the cold side of the TECs). The actuated valve is opened and closed based on the temperature measured on the heatsinks **1** or the TECs.
[0089] Accordingly, another aspect of the invention is a cooling device as described above, characterized in that a liquid tank is mounted above an array of TECs assembled in one or more columns, with one or more tubes to supply liquid from said tank to the heatsink(s) at the hot side of said array, wherein each tube is provided with a contraction installed atop of a column of TECs; with a bundle of strips made of wettable material in contact with each other, and tightly fixed in place in the interior of the contraction, extending downward from the outlet opening of the contraction and laid out on the face of the heatsink(s) in the respective column, touching the surface of the heatsink(s) and fins protruding from the surface.
[0090] The experimental results reported below indicate the devices of FIGS. **13**A-**13**C achieve good cooling effect. For example, for a TEC of 10×10 to 25×25 mm in area, equipped with heatsink whose area is 1.5 to 2 times larger, aided by a tiny fan with air delivery of 10 to 50 l/min,

and with power consumption of not more than 0.25 Watt to the fan, and from 0.25 to 1 Watt to the TEC, and one drop of water supplied every one to five minutes, temperature reduction of not less than 10° C., e.g., >15° C., was achieved (temperature went down from 24 to 7° C., namely a reduction of 17° C., with a total power consumption of not more than 0.7 Watts for 15×15 mm TEC).

[0091] The invention also relates to a method of cooling using a thermoelectric cooler, comprising passing an electric current through the thermoelectric cooler from a DC power supply, to create a cold side and a hot side, drawing off heat from the hot side with the aid of one or more heatsink(s) coupled to the hot side, characterized in that liquid coolant is delivered to the heatsink(s) whereby said liquid evaporates and vapors formed escape to the surrounding environment (for example, through openings provided in a cover applied onto said heatsinks, or by partially or fully exposing the heatsinks to the surrounding environment), wherein the liquid coolant is delivered to the heatsinks by causing liquid to flow from a liquid tank by capillary action, or a combination of capillary flow and at least one of gravitational and pressure driven flow.

EXAMPLES

Example 1

[0092] A system with a top reservoir of 20 ml was prepared. The system dripped water at flow rate of 1.8 ml/min on a row of 3 heatsinks that were connected to 3 TECs. The water was collected at a lower reservoir from which it was recycled back to the top reservoir. Three 20 mm×20 mm×3.6 mm TECs were of model FPH1-7104NC, produced by Qinhuangdao Fulianjing Electronic Co., Ltd, China. Three 21 mm×21 mm×15.2 mm heatsinks of model H/S HO-HB-1106, produced by Antou Resource Inc., China, were supported on vinyl sheet. The three TECs were connected in series to a DC source which supplied 1.8 Volts and 0.19 Ampere-0.6 Volts on each TEC, or 0.114 Watts on each TEC. The temperature on the cold side of one of the TECs was measured. It was assured that the temperature remained stable for at least 20 minutes. The experiment was repeated with and without a fan. For the experiment with the fan, one fan was used, that faced the heatsink of the one TEC whose cold side temperature was measured. The fan drew a 5.25 Volts and 53 milli Ampere (0.278 Watt).

[0093] FIG. **7** is a bar diagram showing the measured ΔT between the cold side and the ambient air with and without a water spray on the heatsink. FIG. **8** is a bar diagram showing the measured ΔT between the cold side and the ambient air with and without a water spray on the heatsink, while a fan (as mentioned above) was used. The results of the experiments clearly indicate the beneficial effect gained from the evaporation of the liquid applied onto the hot side, i.e., an improved cooling.

Example 2

[0094] A single 20 mm×20 mm×3.6 mm TEC of model FPH1-7104NC, produced by Qinhuangdao Fulianjing Electronic Co., Ltd, China was glued to a single 21 mm×21 mm×15.2 mm heatsinks of model H/S HO-HB-1106, produced by Antou Resource Inc., China. The glue used was PRIMA-SOLDER™ (EG8020) produced by AI Technology, Inc. The sides of heatsink were partially covered with an absorbent cloth (Sano sushi cleaning cloths), by sewing it to the pins of the heatsink. The lower part of the cloth, which extended beyond the heatsink, was immersed in small puddle of water (1 ml, this amount of water reservoir was more than sufficient for the whole experiment). The water soaked by the cloth provided a continuous supply of liquid coolant throughout the experiment. The TEC was connected to a DC power source which was set on 0.7 Volts and 0.15 Ampere. The TEC cooled its colder side and its temperature was allowed to stabilize for 20 minutes. The stable temperature was recorded. The power supply was then set on 0.9 Volts and 0.21 Ampere and again the new temperature of the cold side of the TEC was recorded after 20 minutes. Similarly, the power supply was set on 1.2 Volts and 0.33 Ampere and the stable temperature of the cold side of the TEC was recorded. The results are shown in FIG. **10**, as ΔT versus power plot (ΔT being the temperature difference between the cold side and ambient temperature).

Examples 3A and 3B

[0095] Devices were assembled based on the configurations shown in FIGS. **11** and **12** and were tested to determine their efficiency (Examples 3A and 3B, respectively).

[0096] As water reservoir, a tank with a shape of rectangular parallelepiped made of plastic was used (a single tank in the device of Example 3A, two tanks positioned one next to each other in Example 3B). The volume of each tank was 9 ml. Each tank had a 1 mm wide 6 mm long opening through which a strip of cloth of about 6 mm wide and roughly 200 mm long was passed (commercially available from Sano, Israel, multi-use cleaning cloth). Four of the six inner walls of the tank were covered by the cloth, such that the corners of the tank had a cloth touching them or placed very close to them, to enable an efficient drain off the water held in the tank.

[0097] A heatsink consisting of 20 mm×20 mm×9 mm anodized aluminium plate was used (purchased from Mouser Electronics). The fins protruding from one face of the aluminium plate were 6.5 mm high. The space between fins s located in adjacent columns was 3 mm. A 15×15 mm TEC (purchased from Mouser Electronics) was glued (PRIMA-SOLDER™ (EG8050) purchased from AiTechnology) to the opposite face of the aluminium plate.

[0098] The device that was assembled and tested in Example 3A consisted of a single heatsink placed atop of a single water tank. In the device that was assembled and tested in Example 3B, the heatsink with the TEC attached to one of its faces was placed between two other heatsinks (i.e., the same anodized aluminium plates with fins protruding from one of their faces, but without TEC being glued to the opposite face, as shown in FIGS. **12**A and **12**B). That is, the opposing 20 mm sides of the central heatsink (the one with the TEC) are aligned with a 20 mm side of an adjacent heatsink. The set-up consisting of the three heatsinks was assembled with the aid of two 0.0403″ aluminium wires, that were glued very close the edges (top and bottom, respectively) of the square heatsinks plates using the same thermal glue, to join the three pieces. There was a 4 mm separation between edges of the central heatsink and edges of the adjacent heatsinks.

[0099] The cloth running from the opening in the top of the tank was formed into a serpentine-like shape, curving in alternate directions over the heatsink(s), as shown in FIGS. **11**A and **12**A, so that at least one side of every fin was in contact with the cloth. The tank was filled with water; water flow by capillary action occurred, from the tank through the cloth to the heatsink.

[0100] Then, the TEC was connected to a power source, and the temperature was measured. Water evaporated from the sponge attached to the heatsink and from the continuously wetted heatsink to the ambient environment. The room was at 25° C. and at a voltage of 0.5 V and 1.15 Amp, the temperature of the cold side of the TEC went down to 12° C. and 8° C., for Examples 3A and 3B, respectively, and remained stable for the duration of the experiment (77 minutes).

Example 4

[0101] An experiment was conducted to test the efficiency of a design akin to the one shown in FIG. **13**A. The experimental was assembled as follows.

[0102] Three square heatsinks were used. One with 20 mm long side, the other two with 25 mm long side. Both heatsinks were 9 mm thick, and both were made of anodized aluminium, with fins protruding from one face of the aluminium plate at 6.5 mm high. The space between adjacent fins was ˜2 mm. The 20×20 mm heatsink was Model HSB07-202009, and the 25×25 mm heatsink was purchased from Mauser. The three heatsinks were assembled in a row, with the 20×20 mm.sup.2 heatsink in the middle.

[0103] Three TECs (15×15×3.4 mm in size), manufactured by CUI Devices Model CP85134H, were used. Each TEC was glued on the smooth face of a respective heatsink as described earlier.

[0104] Water was supplied manually to three tiny funnel-shaped contractions mounted above the heatsinks(s), at a rate of about one drop per minute, by dripping into the funnels. The funnel had a rectangular cross section: at the top opening, the dimensions were 20 mm×6 mm, at the bottom 4 mm×6 mm, and the length of the funnel was 20 mm. Strips were pressed against the inner walls of the narrow section, extending downward. Each strip was made of a wettable cloth of about 6 mm wide and roughly 50 mm long (commercially available from Sano, Israel, multi-use cleaning cloth). The strips were arranged in the pattern shown in FIGS. **13**A-**13**C, i.e., the strips were laid out on the surface of the heatsink to occupy the spaces between the fins. The strips extended down to the bottom of the heatsinks, with their edges merely dangling at the bottom. Owing to the slow rate of water supply, no dripping was observed from the strips, as they were never wet enough to drip. Receptacles, like receptacles **4** shown in FIGS. **13**A-**13**C, were therefore not mounted in the experimental set-up.

[0105] The strips were soaked with water before the experiment started, and the first drop was added about 20 minutes after the experiment had begun. The TECs were connected to a power supply and a DC voltage was applied on the TECs.

[0106] The results of the experiment are shown in FIG. **14** as ΔT (temperature change relative to room temperature, which was 25° C.) versus time curves. Four curves are plotted: two decreasing curves and two roughly monotonic/slightly increasing curves. A decreasing curve shows the reduction at temperature measured at the cold side of a TEC; the lowermost curve represents the TEC that was attached to the larger heatsink. The two roughly monotonic/slightly increasing curves represent the temperatures at the (small and large) heatsinks and have very little difference between them. The voltage marked on the graph in FIG. **14** represents the voltage over three TECs, namely the voltage on a single TEC was a third of that indicated on the graph. During the experiment, voltage applied on the TEC was increased periodically and each time was held for thirty minutes, to determine that the reduced temperature is maintained during this time interval. The experiment was stopped after the voltage was increased to 1.1 V and current 1.0 Amp (0.37 V and 0.33 Amp on a single TEC).

[0107] At these conditions, temperature decreases of 11 and 12 degrees below room temperature were achieved for the small (20 mm) and large (25 mm) heatsinks, respectively.

Example 5

[0108] An experiment was conducted to test the efficiency of a design akin to the one shown in FIG. **13**B, i.e., fan-assisted cooling.

[0109] The experimental set-up was assembled as described in Example 4, but this time only one type of heatsink was used, i.e., the small one, in which the length of side was 20 mm. As to the fans, two 17×17×3 mm tiny fans, manufactured by Sunon Inc., Taiwan; Model: UF3H3-710, were used. The rated voltage of such tiny fun is 3V DC, with air delivery of 16.27 l/min and a rated current of 37 mA (rated power: 0.1 Watts).

[0110] Three TECs were glued on the smooth surfaces of three respective heatsinks as previously described, and the so-formed structures were mounted in a row. The two TECs positioned at the ends of the row received air from the fan(s), while the third, which was in the middle, had no fan, but was roughly 5 mm away from them (the distance between the edges of adjacent heatsinks), meaning that it received some residual wind.

[0111] The experimental protocol was as described in Example 4. The results of the experiment are shown in FIG. **15** as ΔT (temperature change relative to room temperature, which was 25° C.) versus time curves. Six curves are plotted: three decreasing curves showing the reduction at temperature measured at the cold side of each of the three TECs, and three roughly monotonic/slightly increasing curves representing temperatures measured at the heatsinks. It is seen that one of the decreasing curves exhibits a slightly slower rate of temperature reduction; it corresponds to the middle TEC which did not benefit from a direct action of a fan. Correspondingly, the middle heatsink showed slightly higher temperatures over the experiment.

[0112] Voltage was increased roughly as described in Example 4. The last recorded conditions show a power of 1.1 V and 1.06 Amp which induce temperature reduction of 19° C. on the TECs with the fans and a temperature reduction of about 16° C. on the TEC without the fan. The room temperature was 25 C (meaning that the reduction of 19° C. represents a temperature of 6° C.).

Claims

1. A portable cooling vented apparatus, comprising: an array made of one or more thermoelectric cooler(s), each thermoelectric cooler (TEC) having a cold side and a hot side, the cumulative cold sides and the cumulative hot sides of all the thermoelectric cooler(s) define cold and hot sides of the array, respectively; one or more heatsinks at the hot side of the array; and at least one reservoir configured to supply liquid to the heatsink(s) with the aid of one or more liquid channel(s) connected to said reservoir and installed in the interior of the cooling apparatus in proximity to said heatsink(s); wherein the apparatus is open to the surroundings and is characterized in that the one or more liquid channels is (are) in the form of a narrow piece of wettable material in fluid communication with, or emerging from, the liquid reservoir and in contact with the heatsink.
2. A cooling apparatus according to claim 1, wherein the liquid channel has one end that is immersed in a liquid tank, to enable liquid flow along the channel by capillary action.
3. A cooling apparatus according to claim 1, er **2**, wherein the liquid channel has a serpentine-like shape, curving in alternate directions on the heatsink.
4. A cooling apparatus according to claim 3, wherein the liquid tank is placed beneath the heatsink(s) and is adjacent to, or contiguous with at least one edge of the heatsink(s), with a liquid channel in the form of a long narrow piece of wettable material consisting of a sponge strip or a strip made of a suitable cloth, emerging from the liquid tank and lying on the face of the heatsink, curving in alternate directions on the heatsink in the spaces between the columns of fins protruding from the surface of the heatsink, such that liquid can move along said channel, from one end of the channel that is immersed in the tank, to the opposite end, by capillary action, whereby the serpentine-like liquid channel touches and wets the fins directly.
5. A cooling apparatus according to claim 1, comprising a liquid tank mounted above an array of TECs assembled in one or more columns and one or more tubes to supply liquid coolant from said tank to the surface of the heatsink(s), characterized in that each tube is provided with a contraction located atop of a column of TECs; with a bundle of strips made of wettable material in contact with each other, and tightly fixed in place in the interior of the contraction, extending downward from the exit of the contraction and laid out on the face of the heatsink(s) in the respective column, touching the surface of the heatsink(s) and fins protruding from the surface.
6. A cooling apparatus according to claim 5, wherein the one or more tubes is connected to a tapered section creating a vertical contraction, such that the ratio of between the cross-section areas of the inlet and outlet openings of said tapered section is in the range from 3 to 10.
7. A cooling apparatus according to claim 5, further comprising one or more check valves between the liquid tank and the heatsink(s), to supply liquid coolant to the heatsinks in a controlled manner.
8. A cooling apparatus according to claim 5, comprising a funnel-shaped contraction with a rectangular cross-section, with a small movable plate attached to an inner wall of the narrow pipe of the contraction, such that the cross section of the narrow pipe can be adjusted by the movement of a screw that pushes the small plate, to tightly compress the strips inside the narrow pipe.
9. A cooling apparatus according claim 8, wherein the funnel-shaped contraction contains a gasket to prevent water leakage, the gasket covering the entire inner wall where the small plate is located, and the plate itself.
10. A cooling apparatus according to claim 5, comprising a single tube directed downward from the liquid tank, wherein the flow through said tube is regulated by a valve, said tube diverging into secondary tubes, each secondary tube joining a funnel-shaped element placed a top of a column of TEC, said funnel-shaped element creating a vertical contraction.
11. A cooling apparatus according to claim 5, further comprising one or more fans to facilitate evaporation and heat dissipation to the surrounding.
12. A cooling apparatus according to claim 5, further comprising one or more pumps for pushing

the liquid coolant from the tank to the contraction(s).

13. A cooling apparatus according to claim 5, wherein a flow of liquid coolant from the tank to the heatsinks is a combination of: at least one of gravitational and pressure driven flow; and a capillary flow.

14. A cooling apparatus according to claim 1, wherein the hot side is at least partially uncovered or covered with a gas-permeable cover, such that when vapors are formed in the hot side, these vapors escape to the surroundings.

15. A portable cooling apparatus according to claim 1, combined with a garment, or for use within a cooling box, a chair cushion, a helmet, or a bike handle.

16. A method of cooling using a thermoelectric cooler, comprising passing an electric current through the thermoelectric cooler from a DC source, to create a cold side and a hot side, drawing off heat from the hot side with the aid of one or more heatsink(s) coupled to the hot side, characterized in that liquid coolant is delivered to the heatsink(s) whereby said liquid evaporates and vapors formed escape to the surrounding environment, wherein the liquid coolant is delivered to the heatsinks by causing liquid to flow from a liquid tank by capillary action, or a combination of capillary flow and at least one of gravitational and pressure driven flow.

17. A method according to claim 16, wherein the liquid coolant is delivered to the heatsinks by causing liquid to flow from a liquid tank by a combination of capillary flow and at least one of gravitational and pressure driven flow.

18. A method according to claim 17, comprising causing the liquid coolant to flow from a liquid tank to a vertical contraction by gravity or with the aid of a pump, to wet a bundle of strips made of wettable material that are in contact with each other, and that are tightly fixed in place in the interior of the contraction and extend downward from the exit of the contraction and laid out on the face of the heatsink(s), touching the surface of the heatsink(s) and fins protruding from the surface.