

Protective Vest With Active and Passive Cooling Mechanisms

Field of Invention

[001] The present invention relates to a protective vest with active and passive cooling mechanisms. In one configuration, the vest is suitable for use by security and military personnel in a hot climatic region or for protection against heat in a hot environment; in another configuration, the vest is suitable for use in a cold climatic region.

Background

[002] Vests are worn by security and military personnel for body protection and for carrying a load of equipment and accessories. Such vests are made of strong, heavy duty fabrics. In use, these vests are close-fitting to the body but they restrict air flow to the chest, back and sides. These vests thus trap body heat and cause perspiration to accumulate; as a result, accumulation of body heat and sweat lead to discomfort, fatigue, dehydration and even heat stroke when the climate is hot and humid. Many attempts have been proposed to overcome these problems. For example, US Patent No. 8,397,518, assigned to Dhama Innovations Pvt Ltd, discloses a thermo-regulated apparel. An active thermo-regulated apparel allows a user to set a desired temperature and employs resistive heaters for heating and compressive coolers for cooling, or thermoelectric devices for both heating and cooling. Passive thermo-regulated apparel is capable of adding or removing heat without maintaining a desired temperature and employs chemical reactions for heating and phase change materials for cooling.

[003] Attempts to dissipate heating and cooling energy from thermoelectric devices have been unsuccessful, for example, due to the insulating properties of apparel making it difficult to transfer heat from under or through the apparel to the ambient. Other approaches of dissipating heat by natural or forced convection result in cumbersome appendages (for example, in the form of tubes for transporting fluid and pumps for compressive cooling) making them unsuitable for active donning by security and military personnel.

[004] It can thus be seen that there exists a need for another vest system with enhanced performance for security and military personnel, in hot or cold climates.

Summary

[005] The following presents a simplified summary to provide a basic understanding of the present invention. This summary is not an extensive overview of the invention, and is not intended to identify key features of the invention. Rather, it is to present some of the inventive concepts of this invention in a generalised form as a prelude to the detailed description that is to follow.

[006] The present invention seeks to provide a vest system with active and passive cooling mechanisms. In particular, this protective vest is suitable for use by a security or military personnel, in hot or cold climates.

[007] In one embodiment, the present invention provides a protective vest with active cooling mechanisms for use with a uniform incorporating passive cooling mechanisms. The protective vest is substantively described and illustrated, and as defined in the claims.

[008] In another embodiment, the present invention provides a vest system for a security or military personnel. The vest system is substantively as described and illustrated, and as defined in the claims.

[009] In yet another embodiment, the present invention provides an enhanced method of transmitting cool or warm energy from a thermoelectric module to a user of the protective vest. This method is substantively as described and illustrated, and as defined in the claims.

Brief Description of the Drawings

[0010] This invention will be described by way of non-limiting embodiments of the present invention, with reference to the accompanying drawings, in which:

[0011] FIG. 1A illustrates a protective vest with frontal active cooling mechanisms according to an embodiment of the present invention, whilst FIG. 1B illustrates the use of

the protective vest over an apparel or a security/military uniform having passive cooling mechanisms;

[0012] FIG. 2 illustrates a protective vest with active cooling mechanisms disposed at the back region according to another embodiment of the present invention in use with an apparel or a security/military uniform having passive cooling mechanisms;

[0013] FIG. 3A illustrates a portion of the above protective vest with the active cooling mechanisms shown in a first configuration; FIG. 3B illustrates an exploded view of the active cooling mechanisms shown in FIG. 3A, whilst FIG. 3C illustrates a sectional view along a heat pipe of the active cooling mechanisms; and FIG. 3D illustrates an exploded view of FIG. 3C;

[0014] FIG. 4A illustrates the above protective vest with the active cooling mechanisms shown in a second configuration in use with an apparel or a security/military uniform having passive cooling mechanisms; FIG. 4B shows the active cooling mechanisms shown in FIG. 4A;

[0015] FIG. 5A illustrates a uniform for use with the above protective vest; FIG. 5B illustrates a closed-up view of passive cooling mechanisms at a front portion of the uniform; FIG. 5C illustrates a closed-up of the passive cooling mechanisms at a sleeve of the uniform; FIG. 5D illustrates a section view of the material of the uniform when it is dry, whilst FIGs. 5E and 5F illustrate expansion of the material when the material is wet;

[0016] FIG. 6A illustrates a setup for testing fabrics of the above uniform; and FIG. 6B illustrates a setup for observing the above passive cooling mechanisms; and

[0017] FIG. 7 illustrates a control system for the above active cooling mechanisms.

[0018] One or more specific and alternative embodiments of the present invention will now be described with reference to the attached drawings. It shall be apparent to one skilled in the art, however, that this invention may be practised without such specific details. Some of the details may not be described at length so as not to obscure the invention. For ease of reference, common reference numerals or series of numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0019] FIG. 1A shows a protective vest 100 with active cooling mechanisms 200 disposed in a front region corresponding to a chest area of a user according to an embodiment of the present invention. FIG. 1B shows a use of the protective vest 100 over an apparel or a security/military uniform 1000 having passive cooling mechanisms 2000. FIG. 2 shows a protective vest 100a with active cooling mechanisms 200 disposed in a back region according to another embodiment. In FIGs. 1A, 1B and 2, the protective vest 100, 100a is cut to visually show two of the active cooling mechanisms whilst the other two active cooling mechanisms are disposed inside the protective vest. Needless to say, a protective vest 100b of the present invention may include active cooling mechanisms 200 disposed in both the front and back regions.

[0020] The protective vest 100, 100a, 100b will be described for use by a user in a hot climatic region or environment; the vest for use in cold climates will require inverting the active cooling mechanisms without changing the working principle underlying the vest for use in hot climates. The protective vest 100, 100a, 100b is made up of a front panel 110 to cover substantially a front torso portion of a user, a back panel 120 substantially in size with the front panel 110 and two shoulder straps 130 joining the front and back panels. Preferably, the shoulder straps 130 fit over the shoulder regions of the user and are adjustable. Preferably, the front and back panels 110, 120 are adjustably joined by two or more side straps 140; the shoulder and side straps may employ the Velcro fastening mechanism for quick donning, doffing or adjustment. In addition or alternatively, a hem region may be adjustable by use of a draw string. As will be seen FIG. 3A, a cool spreader 150 is attached to an inside of the front or back panel or both panels like a lining. Each edge or part of each edge around the cool spreader 150 is not attached to an associated edge of the front or back panel so as to form openings or vents 155 into a space between the cool spreader 150 and inside surface of the front panel 110 or back panel 120 of the

protective vest 100, 100a, 100b. Alternatively or in addition, the vents 155 are also provided as slit openings on the front panel 110, rear panel 120 or sides.

[0021] In one embodiment, the active cooling mechanisms 200 are supported by the cool spreader 150. Alternatively, the active cooling mechanisms 200 are supported on a hot spreader 160 which is attached to an inside face of the front panel or back panel. It is also possible that the active cooling mechanisms 200 are supported by both the cool and hot spreaders. Means 157 for removably attaching the cool spreader 150 and hot spreader 160 to the inside face of the front or back panel include: Velco fasteners, snap-on fasteners, buttons and button holes; and so on. With these removable fasteners 157, the entire active cooling mechanisms 200 can be easily removed, for example, when the protective vest 100, 100a, 100b requires washing or the active cooling mechanisms 200 require repair or replacement. It is also possible that the hot spreader 160 is integrally formed into the front panel 110 and/or back panel 120 of the protective vest 100, 100a, 100b. It is also possible that the cool spreader 150 or the hot spreader 160 is made from a unitary piece or composed of multiple component pieces.

[0022] FIG. 3A shows an inside portion of the protective vest 100, 100a, 100b with four groups of active cooling mechanisms 200 being arranged according to a first configuration. The active cooling mechanisms 200 are shown mounted on the cool spreader 150 with a thermal insulator 250 separating the cool spreader 150 from the hot spreader 160; however, the hot spreader 160 on top of FIG. 3A is omitted for clearer illustration. FIG. 3B shows an exploded view of the active cooling mechanisms 200 including the cool spreader 150, thermal insulator 250 and hot spreader 160. As seen in FIGs. 3A and 3B, each group of the active cooling mechanisms 200 includes a thermoelectric junction module (TEM) 210, a heat pipe 230, a heat sink 240, the thermal insulator 250 and a blower 270. Each of the thermoelectric junction module (TEM) 210 has a cool junction 215 and a hot junction 220, which are seen more clearly in FIG. 3C. As can be seen in FIG. 3A, a proximate end of each of the heat pipe 230 is attached to the hot junction 220 of the associated TEM, whilst a heat sink 240 is attached to a distal end of the heat pipe 230. Adjacent to each of the heat sink 240, the associated blower 270 is arranged to direct airflows over the heat sink 240 and the air exiting from the vents 155 carries away the heat generated at the hot junction 220. In one embodiment, each of the cold junction and hot junction are attached directly to the cool spreader 150 and hot spreader 160, respectively; the heat pipe 230 is connected to

the TEM 210 via a mount 225 and screws 227 for easy assembly and disassembly, as seen more clearly in FIG. 3D. The thermal insulator 250 has apertures, for example, to fit over the TEMs 210 and blowers 270 but the face in contact with or adjacent to the hot spreader 160 is sculptured and channels thus formed define plenums 260 for air flow; in this way, air is also caused to flow over the mounts 225, heat pipes 230 and hot spreader 160 to remove heat generated at the hot junctions 220. Preferably, the heat insulator 250 is made of a thermal foam. The plenum openings near the heat sinks 240 are large in cross section and serve as air outlets 262, whilst air plenum openings away from the air outlets 262 are relatively smaller in cross section and serve as air inlets 264; the air flowing from the outlets 262 is directed to the vents 155 and is expelled out of the protective vest 100, 100a, 100b. The thermal insulator 250 thus has thicknesses at various points ranging from about 1 mm to about 5 mm. Preferably, the plenums 260 have a depth of substantially about 3 mm where possible. The face of the heat insulator 250 on the same side as the cold junction can also be sculptured so as to reduce the thickness and bulk of the heat insulator, thus allowing it to be more flexible.

[0023] For the present invention to perform as designed (in respect of thermal efficiency), the heat pipe 230, heat sink 240 and blower 270 of each group of the cooling mechanisms 200 are selected to dissipate a thermal power of substantially twice a thermal power at the hot junction 220. In one embodiment, the blower 270 includes a micro-fan, micro-blower or a piezoelectric blower, preferably of a centrifugal type.

[0024] FIG. 4A shows a protective vest 100c with four groups of active cooling mechanisms 200 arranged according to a second configuration. As in the above, the protective vest 100c is in use with the uniform 1000 having passive cooling mechanisms 2000. In FIG. 4A only two of the active cooling mechanisms 200 are made visible for illustration. The second configuration, as shown in FIG. 4B, is different from the first configuration in that the air outlets 262 are all directed to the sides of the user. As seen in FIG. 4B, the insulator 250a has a central, wide plenum 266. In use, the central, wide plenum 266 is often substantially vertical when the user is sitting or standing; by making optimal use of natural hot air rising in the central, wide plenum 266, air is sucked by the blowers 270 and discharged laterally through the side vents 155.

[0025] Materials of the cool spreader and hot spreader: Preferably, the cool and hot spreaders 150, 160 are made of a highly thermal conductive yet flexible material. For example, the cool and/or hot spreader can be selected from the following:

- a) thermal conductive tapes;
- b) woven or non-woven fabric of fine metal meshes;
- c) metalized fabrics;
- d) fabrics weaved, knitted or stitched with thermal conductive threads or yarns;
- e) fabrics printed with thermal conductive ink; or
- f) thermal conductive felts.

The thermal conductive tapes may be made from alumina or graphite with fabric or fiberglass backings; these thermal conductive tapes are often supplied with pressure sensitive adhesive for easy application. Fabrics of fine metal meshes, metalized fabrics, fabrics weaved, knitted or stitched with thermal conductive threads or yarns, and fabrics printed with thermal conductive ink form a network of highly conductive metallic particles to conduct heat energy for dissipation over a large area. In addition, parts of the front and back panels 110, 120 of the protective vest 100, 100a, 100b, 100c may be weaved, knitted or stitched with thermal conductive threads to integrally form the hot spreader 160. When thermal conductive threads are weaved, knitted, stitched or sewed into/onto the hot or cold spreader, the fabric has to remain planar or flat; otherwise, the fabric may be wrinkled and the wrinkles tend to cause air pockets, which lead to an increase in thermal resistance. Thermal conductive felts have some upstanding fibres or filaments that are thermally conductive; together, the thermal conductive fibres or filaments conduct and dissipate heat energy over a large area. In the following description, the spreading of heat by the cool spreaders 150 and hot spreaders 160 across the fabric is referred to as the x- and y- directions, whilst the z-direction is in the thickness direction of the fabric.

[0026] Materials of the uniform: FIG. 5A shows the uniform 1000 for use with the above protective vest 100, 100a, 100b, 100c. The uniform 1000 worn under the protective vest is made from cotton fibres 1010 and synthetic fibres 1020 (such as, rayon, polyester, nylon, spandex, etc.) interspersed with thermal conductive fibres 1030. In another embodiment, super absorbent polymer (SAP) 1040, phase change materials (PCM) 1050 and highly absorbent phase change composites (PCC) 1055 are embedded interstitially by the cotton and synthetic fibres; these SAP, PCM and PCC materials may appear as deposits; it is also possible that the SAP, PCM and PCC materials 1040, 1050, 1055 are printed, deposited by

dyeing, rolling, calendaring, and so on, with pre-treatments and post-treatments to enhance adhesion to the materials of the uniform 1000. These SAP, PCM, PCC and thermal conductive materials constitute the passive cooling mechanisms 2000 of the present invention. Preferably, areas located at the front, back and sides have higher concentrations of thermal conductive materials than SAP, PCM and PCC materials, whilst at the sleeves or hem region there are higher concentrations of SAP, PCM and PCC than thermal conductive material. FIGs. 5B and 5C illustrate providing patterned concentrations of SAP, PCM, PCC and thermal conductive materials in two separate regions in the uniform 1000.

[0027] From the above figures, a reader will appreciate that the cool spreader 150 provides a large area to spread cool energy from the cold junctions 215 of the TEM 210 to the chest or back of the user. Similarly, the hot spreader 160 provides a large area for the heat energy from the hot junction 220 and heat pipes 230 to dissipate by conduction whilst heat energy from the heat sinks 240 is removed by forced convection by airflow from the blowers 270. At the same time, the passive cooling mechanisms 2000 in the uniform cooperate synergistically with the active cooling mechanisms 200 deployed in the protective vest 100, 100a, 100b, 100c in spreading cool energy or warm energy to the torso area of a user. When the protective vest is worn, body heat naturally causes perspiration. The base material, such as cotton absorbs sweat; the SAP fibres or SAP deposits enhance absorption of sweat; the drawing of sweat from the user helps to dissipate heat from the chest or back region. The SAP fibres and cotton fibres 1010 also help to release the absorbed sweat by wicking and evaporating sweat in regions away from the chest and back. At the same time, sweat wets the PCM and PCC materials and the resulting endothermic heat of solution of the PCM, PCC is felt as a drop in temperature. The wetted SAP, PCM and PCC materials also expand and stretch the fabric in the x-, y- and z-directions. Stretching of the fabric in the x- and y-directions enhances permeability of the fabric and this effect is felt by higher evaporation of sweat. Stretching in the z-direction enhances thermal contact points between the skin of the user and the cool spreader 150, for example by reducing air gaps, and this effect is felt as cool energy is conducted from the cool junctions 215 of the TEM. The stretching of the PCM 1050, PCC 1055 is illustrated in FIGs. 5D-5E. At the same time, the weaving, knitting, stitching or sewing of the thermal conductive yarns or threads enhances thermal conductivity in the z-direction through the thickness of the fabric. The combination of thermal conductive and SAP, PCM and PCC materials in the fabric of the uniform 1000 all add up synergistically to transmit cool energy from the cold junctions 215

of the TEMs 210 in 3-D patterns to the user's chest or back; at the same time, the heat pipes 230, heat sinks 240 and blowers 270 help to actively remove heat from the hot junctions 220 of TEMs and aided by the hot spreader 160 passively dissipating heat away in 3-D patterns from the chest or back region of the user. Likewise, the combination of thermal conductive and SAP, PCM and PCC materials in the fabric of the uniform 1000 all add up synergistically to transmit warm energy from the hot junctions 220 of the TEMs 210 in 3-D patterns to the user's chest or back.

[0028] Fabrics of the uniform 1000 were tested using a Permetest setup 3000 shown in FIG. 6 and evaluated according to a modified standard under ISO 11092. As shown in FIG. 6, the tester 3000 includes a test chamber 3100 and a fan 3200 at a downstream position to suck air through the test chamber and to cause a controllable airflow over a measuring head 3300. Fabrics of the uniform 1000 were placed on the measuring head and the measuring head was then connected to the test chamber to expose the fabric of the uniform inside the test chamber. Upstream from the measuring head, a temperature sensor 3110 and a relative humidity sensor 3120 are used to monitor the environment conditions inside the test chamber. The measuring head 3300 has an external thermal insulation 3310 and an internal metallic body 3320. A heating element 3321 and a temperature sensor 3322 are embedded in the metallic body 3320, whilst a tubing 3340 carries water to wet the fabrics at the measuring head 3300.

[0029] After quantitative testing of the fabrics in the above tester 3000, some of the fabrics were put through an environmental chamber tester 4000 in which the climatic conditions in using the uniform 1000 are simulated. As shown in FIG. 6B, the tester 4000 includes an insulated environment chamber 4100 in which the environmental temperature and humidity are controlled. Outside the environment chamber, a thermal camera 4200 monitors the temperature of the uniform through a view port. From the tests, it was observed that the passive cooling mechanisms involve cyclic wetting of the fabric followed by evaporative cooling; such cyclic wetting of the fabric and evaporative cooling was called regenerative cooling. It was also observed that as thermal resistance at the fabric was lower (in variation with concentration of thermal conductive yarns/threads), cooling increased as indicated by lower temperature monitored by the thermal camera.

[0030] Performance of the above active cooling mechanisms 200 is further enhanced by using a micro-controller 280, an ambient temperature sensor 290, a micro-climate temperature sensor 292 and a body temperature sensor 294. FIG. 7 shows the use of the micro-controller 280 and the three temperature sensors. The micro-climate temperature sensor 292 detects the temperature inside the protective vest or between the protective vest and uniform 1000. Preferably, the body temperature sensor 294 is located near the neck just behind the collar bone. In one embodiment, power to the TEM 210 and blower 270 is pulse-width modulated (PWM) by the micro-controller 280; this attempts to extend duration of power usage from a portable battery worn inside the protective vest. The micro-controller 280 is also controlled by an adaptive algorithm 285 to maximise efficiency, for example, by responding to the micro-climate temperature sensor 292, to the body temperature sensor 294 which adapts to physiological needs of the user, and to the ambient temperature sensor 290 as it senses variations of the ambient. With the adaptive algorithm 285, the duty cycle of operating the TEM 210, speed of the blower, and power supplied to the TEM 210 (all determine the rate of cooling) and the sequence of operation of the active cooling mechanisms become controllable. This results in low power consumption and high efficiency in operating the active cooling mechanisms 200. This entails optimum use of battery power; in other words, the battery size can be comparatively small or there is little need for additional, standby batteries.

[0031] The above protective vest 100, 100a, 100b, 100c in use with the uniform 1000 provides a new micro-climatic system for a security or military personnel. Evidently, the protective vest of the present invention is light-weight and compact, and devoid of any cumbersome accessories and auxiliary equipment. This gives the user unimpeded degrees of movement. Furthermore maintenance and logistic issues such as the needs for reactivation of both the active and passive cooling mechanisms are not required for this vest system; in addition, the above protective vest does not suffer from bacteria growth and performance reduction due to ambient conditions. The ease of replacement of the active cooling mechanisms 200 for repair and maintenance also allows the ease of adapting the active cooling mechanisms to a different vest rather than designing a vest to fit the cooling system. In addition, the active and passive cooling mechanisms can operate independently, although optimal heat dissipation performance comes from the synergy of combining the active and passive cooling mechanisms.

[0032] While specific embodiments have been described and illustrated, it is understood that many changes, modifications, variations and combinations thereof could be made to the present invention without departing from the scope of the present invention. For example, the protective vests 100, 100a, 100b may be used at a smelting plant where people are protected against heat radiation. In another example, the entire active cooling mechanisms together with the cool and hot spreaders is inverted inside the vest by changing the terminal polarity so that the protective vest 100, 100a, 100b becomes usable in cold climates. It is also possible that the protective vest can be upgraded to provide additional protection against bullets or explosive blasts.

CLAIMS:

1. A protective vest comprising:
 - a front panel to cover substantially a torso region of a user;
 - a back panel substantially matching the front cover;
 - two shoulder straps;
 - two or more side straps to adjustably connect the front and back panels to fit the protective vest on a user;
 - a cold spreader and a hot spreader attached to the front panel or the back panel or to both the front and back panels such that part of the attachment at each of the front or back panel has a vent or a plurality of vents leading to a space in between the cold and hot spreaders;
 - a thermoelectric module (TEM) with a cold junction being mounted on the cold spreader whilst a hot junction is mounted on the hot spreader; and
 - a thermal insulation separating the cold spreader from parts associated with the hot junction, wherein the thermal insulation is sculptured to form plenums through which air in contact with the parts associated with the hot junction is moved by a blower and exhausted through the vent or plurality of vents.
2. The protective vest according to claim 1, further comprising a heat pipe, with a proximal end of the heat pipe being connected to the hot junction and a distal end is connected to a heat sink.
3. The protective vest according to claim 2, wherein the hot junction, heat pipe, heat sink and blower are disposed in the plenums.
4. The protective vest according to claim 2, wherein the heat pipe, heat sink and blower have a thermal heat dissipation power twice the power generated at the hot junction.
5. The protective vest according to claim 2, further comprising a micro-controller, a micro-climate temperature sensor disposed inside the protective vest, a body temperature sensor and an ambient temperature sensor.

6. The protective vest according to claim 5, wherein the TEM is operated by pulse width modulation (PWM) signal from the micro-controller and by an adaptive control algorithm.
7. The protective vest according to claim 6, wherein the adaptive control algorithm is operated to adjust the duty cycle and rate of cooling of the TEM, speed of the blower or sequence of operation.
8. The protective vest according to any one of the preceding claims is used together with a uniform with materials of the uniform incorporating passive cooling mechanisms.
9. A vest system for a security or military personnel comprising:
 - a protective vest with active cooling mechanisms according to any one of claims 1-7; and
 - a uniform having passive cooling mechanisms incorporated into materials of the uniform.
10. The vest system according to claim 9, wherein the passive cooling mechanisms comprise thermal conductive threads interspersed with base materials of the uniform.
11. A method for transmitting cool energy from a thermoelectric module constituted in a protective vest according to any one of claims 1-8, the method comprising:
 - attaching a cold junction of the thermoelectric module onto a cool spreader;
 - disposing the cold spreader onto a uniform of a personnel wearing the protective vest ; and
 - wetting part of the uniform with sweat from the personnel and allowing the part of the uniform materials to expand cyclically, thereby giving rise to cyclic regenerative cooling at the uniform.
12. A method for transmitting warm energy from a thermoelectric module constituted in a protective vest according to any one of claims 1-8, the method comprising:
 - attaching a hot junction of the thermoelectric module onto a hot spreader;
 - disposing the hot spreader onto a uniform of a personnel wearing the protective vest; and

wetting part of the uniform with sweat from the personnel and allowing the part of the uniform materials to expand cyclically, thereby giving rise to cyclic regenerative heat transfer at the uniform.