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(54) **AUTONOMOUS GARMENT WITH ACTIVE THERMAL CONTROL AND POWERED BY SOLAR CELLS**

AUTONOMES KLEIDUNGSSTÜCK MIT AKTIVER THERMOSTEuerung UND
ENERGIEVERSorgung DURCH SOLARZELLEN

VETEMENT AUTONOME A COMMANDE THERMIQUE ACTIVE ET ALIMENTE PAR DES CELLULES
SOLAIRES

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Description

[0001] There are many patents related with this invention. Some documents are associated with heating techniques in garments: WO03059099, EP1197722, US2001047992, DE19835984, US5893991, US5643480, EP0287294, US4705935, FR2577390, US2003006229, and US4404460 that use the thermoelectric effect; FR2752363 mentioning solid and liquid fuels; US6439942 and FR2577116 describing solar arrays; US4539714 utilizes microdendritic solar energy collectors. Other documents are related with cooling procedures in garments: DE19755181 and DE19749436 describe flexible stripes; GB2352385, US6125645, US5289695, and US5111668 include appropriate materials; WO02067707, US6257011, FR2719892, and US5217408 mention forced ventilation by fans; US5438707 uses fans and compressed air; US6134714, US2002073481, US2002069448, FR2756709, US5415222, US5263336, and US3736764 use liquid refrigeration; US5755110 and DE20011331 refer heat exchanging materials; US5386823 describes a ventilated thermal suit. Furthermore, document DE19745889 includes Peltier cells and matrix resistors for cooling/warming solutions, and US5603648 specifies a safe-vest with accessories.

Field of the invention

[0002] This invention is included in the apparel segment, namely in the emerging sector known as intelligent wear (i-wear). It is related with systems and methods for automatic control of temperature in garments, not only for standard weather conditions but also for extreme environments. Furthermore, this invention also refers to special elements that provide power for those vests.

Background

[0003] The invention refers to an autonomous garment with active thermal control powered by solar cells that is designed not only for standard conditions but also for extreme weather environments. Hereafter, by "autonomous" we mean there is no need of plug in to a power line, assuring portability and energy autonomy of the garment. Furthermore, by "active thermal control" we mean the ability to produce both heat and cold in the garment and to control dynamically the internal temperature according to external conditions and user needs.

[0004] At present time there are several methods to provide temperature control of garments, which can be split in two different categories: warming and cooling. However, few patents cover both categories simultaneously.

a) Warming garments

[0005] In general, warming systems embedded in gar-

ments use the thermoelectric effect to provide heat for articles of clothing. An electric current, provided by batteries or power line, is transformed into heat in resistors embedded in garments, mainly in jackets, and in blankets. This technique is claimed in patents WO03059099, EP1197722, US2001047992, DE19835984, US5893991, US5643480, EP0287294, US4705935, FR2577390, US2003006229, and US4404460. Most of the described objects include means to maintain the produced heat, using special fabrics or geometry. Patent FR2752363 refers to a warming system powered by solid and liquid fuels, which feed an engine to produce heat. Patents US6439942 and FR257711.6 describe garments heated by means of resistors powered by solar arrays. Patent US4539714 and other references therein claim the utilization of microdendritic solar energy collectors that generate straightforward warming of pieces of clothing.

b) Cooling garments

[0006] The cooling garments already claimed have associated different techniques to produce cold: proper shape, fabrics, and special materials, natural or forced ventilation, cooling fluids or evaporation. Patents DE19755181 and DE19749436 describe a configuration with flexible stripes that allow natural ventilation. Cooling and sweat removal and evaporation by cooling in appropriate materials are described in patents GB2352385, US6125645, US5289695, and US5111668. On the other hand, forced ventilation systems are claimed in patents WO02067707, US6257011, FR2719892, and US5217408, which use small fans powered by batteries or are connected directly to power line. Patent US5438707 uses simultaneously cooling with compressed air and fans. Patents US6134714, US2002073481, US2002069448, FR2756709, US5415222, US5263336, and US3736764 describe systems with refrigeration liquids inside pipes embedded in garments, which permit the cooling by evaporation. Patent US5755110 describes a system that uses a special material to absorb heat, and patent DE20011331 claims the utilization of a textile fibre with special properties for storing and releasing available heat, depending on the needs. Finally, patent US5386823 is related with a ventilated suit with mask that is connected to a cooling device with low portability.

c) Garments with both warming and cooling systems

[0007] Although there are many patents and other documents related with cooling and heating systems and methods, to our own knowledge only one uses both techniques in the same garment: patent DE19745889 illustrates garments with Peltier elements for cooling and matrix resistors for heating that are connected to an electricity source, namely power line, friction wheel, propeller driven generator or batteries.

d) Other applications

[0008] The major number of documents refers to heat or cold generation but some garments include accessories for other applications. Patent US5603648 describes a safe-vest with several accessories, namely optical fibres and LEDs powered by solar cells, resistors powered by batteries to provide heat, and other signalling and survival gadgets. This solution is especially useful in rescue missions and other risky assignments. Patent US 5148002 mentions sensors for monitoring internal and external environmental conditions and physiological parameters, namely body temperature.

e) Power autonomy

[0009] Most autonomous systems available on the market generate either heat or cold, and do not have both solutions embedded in the same garment. The large majority of the systems must be connected continuously to the power line even though some smaller articles of clothing include batteries to provide some energy autonomy. Thus, systems connected to power lines are neither portable nor autonomous, and solutions with batteries have low autonomy. Therefore, autonomous pieces of clothing need large and heavy batteries or must utilize very low power, preventing the addition of thermal control units, mainly cooling solutions, where the thermal cycle efficiency is lower.

[0010] Some small pieces of clothing use solar cells or energy collectors to provide power to feed resistors, which are used to warm articles of clothing.

f) Temperature automatic control

[0011] There are several methods to control the temperature inside garments but almost all of them use a passive approach. The most common solutions release heat or cool continuously, such as fans, even though some methods include mechanisms to control heating and cooling fluxes, like orientation of flexible stripes. Nevertheless, more effective methods utilize thermostats to regulate temperature, switching thermal devices on and off to control heating or cooling flows. So far, these control units do not require sophisticated algorithms because they are only used to turn a thermal source on or off. However, the development of systems with active thermal control allows a more efficient management of heat and cold inside garments.

g) Conclusion

[0012] Presently there are many solutions and methods to include heat or cold production in garments, which is evident due to the large number of patents and other published documents. However, these solutions have in common several limitations.

[0013] The most important constraint in garments with

thermal control is related with power generation, because either the systems generate significant amount of power but are not portable, or they are autonomous but the power generated is rather small.

[0014] The large majority of available systems include either cooling or warming units but do not provide both solutions in the same piece of clothing, mainly due to power limitations.

[0015] The inclusion of both cooling and warming devices in the garment requires a much more efficient management of thermal control.

[0016] All the systems and methods claimed so far do not provide simultaneously the following characteristics: power autonomy, automatic control of temperature, cooling and heating cycles, and portability.

Summary of the invention

[0017] The present invention reduces limitations both in portability and autonomy, and allows warming and cooling thermal cycles in the same piece of clothing. One of the main goals of this invention is to solve these limitations without a significant increase in weight. Furthermore, it foresees a more efficient way to manage temperature distribution and power resources.

[0018] A standard application in garments includes the following units: solar cells, batteries, cooling device, warming device, active thermal controller, wiring grid, and auxiliary gadgets.

[0019] Solar cells are assembled in a flexible substrate and can include special filters or optical parts. Solar cells use flexible substrates made of inexpensive silicon beads sandwiched between two thin layers of metal foil embedded in a plastic cover. The metallic sheets give the material physical strength and act as electrical contacts. Furthermore, the wavelength that provides maximum optical-to-electric energy efficiency can be shifted to match different radiation sources. Thus, not only solar radiation but also from other sources can be used; namely fluorescent lamps and flames.

[0020] The utilization of batteries in the garment is convenient not only to store energy but also to provide power stabilization, namely when power transients occur in the solar cells. New technologies allow the development of ultrathin flexible batteries, and their series and parallel association increase the power storage to more than 200Wh/kg. Moreover, thin batteries are easily shaped so that weight distribution in the garment is possible and substrate flexibility allows ergonomic profiles.

[0021] The devices utilized to produce cooling use different techniques. Peltier cells are made from two dissimilar metals and the application of a DC voltage to a closed circuit gives rise to a temperature change at the junction of the two metals. Peltier cells do not have moving parts, are lightweight, and can be used in any orientation. Furthermore, they may be stacked to achieve greater temperature differential. Miniaturized compressed cooling machines with coefficient of perform-

ance (COP) ~4 are available. Thus, vapor compression cycles are very efficient systems providing a cooling process to garments. Additionally, the utilization of thin flexible pipes allows a proper distribution of thermal flow across the piece of clothing.

[0022] The most effective method to provide heat to the garment is the conversion of electrical energy in heat by means of resistors. Wiring, high flexibility, and weightless of electrical resistors make them the more suitable elements to generate heat inside the garment.

[0023] The proper thermal control in the garment is better obtained with active units, mainly because on/off systems are not effective in complex systems that use both cooling and heating cycles. On the other hand, the active thermal control proposed in this document uses not only parameters from those cycles but also from human body activity, external environment, and preset conditions. Thus, thermal control units can use sophisticated algorithms.

[0024] Wiring is an important issue for assembling procedures. Although solar cells, batteries, resistors, and pipes have high flexibility it is fundamental to study stress and fatigue in some of the junctions of the garment, namely those related with the human articulations.

[0025] As there is some power available in the garments, they can include auxiliary plugs to feed external devices, namely laptops, mobile phones, audio readers, and other low power electronic devices. Although none of these portable devices forms part of the invention.

Detailed description of the invention

[0026] The presented invention refers to an autonomous garment with active thermal control and powered by solar cells.

[0027] Fig.1 represents a piece of clothing that includes several units for powering, warming, cooling, and controlling the whole system.

[0028] Fig.2 shows, as an example, a clothing uniform with the illustration of solar cells on the surface.

[0029] In a simple configuration, the system includes one or several pieces of clothing, solar cells (1), batteries (2), resistor circuits (3), refrigeration units (4), and an automatic thermal controller (6). Alternatively or together with the resistors and cooling units, Peltier cells (5), which can be used for heating and cooling. As Peltier cells are able to produce or remove heat in the same unit just by changing the current direction on the cell, garment versatility can be increased. The solar cells convert electromagnetic radiation in electric power, which is used to feed the electric devices. The distribution of resistors and refrigerating pipes (7) is adjusted according to human body needs, in order to produce or remove heat in the garment. The thermal unit assures that temperature inside the garment is maintained in the selected range, which can be function of metabolic activity, weather conditions, breathable fabrics properties, and pre-selected values defined by the user. Furthermore, a specific algo-

rithm surveys the thermal control unit and manages heating and cooling production in the garment. The batteries have two different purposes in the system. On one hand, they are used to stabilize power consumption if there is a strong variation in the electric power production. On the other hand, the batteries are used to store energy and provide extra power to increase autonomy, namely when radiation level is low or no longer available.

a) Solar cells

[0030] The solar cells absorb radiation and convert it in electricity, which is supplied to the devices under control. The generated power can also be stored in the batteries. The solar cells are the outer active layer of the garment, must be flexible, and have to have low bending stress with time. Moreover, solar cells shall have good wiring properties.

[0031] Solar cells have to be covered with an optical external layer to prevent weathering degradation. This layer shall be thin, flexible, and transparent to visible radiation.

[0032] The global power efficiency of the solar cells shall be higher than 10%, in order to provide enough energy to the thermal units. This value is the state-of-the-art efficiency for flexible solar cells.

[0033] Solar cells cover as much as possible of the outer layer of the garment to maximize available area. However, special human articulations, such as shoulder, elbow, and knee, can damage solar cells so that high bending joints in the garment shall not be covered with solar cells. Special wiring is used to interconnect solar cells in an overall grid and the electric bus connector that provides power distribution and signal control to all devices.

b) Batteries

[0034] Batteries store energy supplied by the solar cells or a power line. The main functions for batteries are energy storage and power stabilization.

[0035] The batteries must be thin, lightweight, flexible, rechargeable, and must have low bending stress with time. The state-of-the-art flexible batteries allow up to 200Wh/kg, which allow autonomy of 3 hours for minimum warming and cooling thermal requirements. The batteries layer is embedded in the garment and has the same bending constraints as the solar cells. Batteries are connected to the electric bus connector that provides power distribution and signal control to all devices.

c) Warming cycles

[0036] The garment has two different systems to provide heat. The utilization of resistors is the most efficient method to warm articles of clothing. The second system includes Peltier cells.

[0037] Resistors must be thin, flexible, and lightweight.

Furthermore, they must have low bending stress with time and good wiring connectors. The wiring grid and resistors distribution in the garment are selected to provide appropriate heat flow inside the garment. Furthermore, several sectors of resistors can provide heat independently of each other, which allow unbalanced distribution of energy if required. For example, this technique allows differentiating energy distribution in chest, arms, and legs. Resistors layers are embedded in the garment and can also be impregnated directly in fabrics.

[0038] Peltier cells are used both for warming and cooling purposes and are also embedded in the garment. This property makes them useful for areas of the garment that are subject to high thermal inertia. However, as they are heavier than resistors, Peltier cells are properly distributed to balance weight in the piece of clothing.

[0039] Resistors and Peltier cells are connected to the electric bus connector that provides power distribution and signal control to all devices.

d) Cooling cycles

[0040] The utilization of miniaturized cooling cycles with high COP is a proper solution to provide a cooling system to the garment. The utilization of thin flexible pipes permits an efficient distribution of temperature inside the garment: The utilization of different tube diameters and pipe distribution allocates unbalanced cool distribution, using different fluid flow and valves in the pipes.

[0041] The cooling cycle systems are connected to the electric bus connector that provides power distribution and signal control to all devices.

e) Temperature controller

[0042] simple thermostat devices used so far to control temperature in garments are useful but inefficient for more advanced systems because a simple on/off control type is inappropriate. Thus, a programmable microcontroller is used. The management of temperature includes several important inputs such as sensors signals, user defined settings, feedback conditions, and device performance monitoring values.

[0043] The utilization of temperature sensors (e.g. thermocouples) monitoring garment temperature, external environment conditions, and body temperature of the user provides useful information.

[0044] A model describing production and distribution of heat flow on the human body is included. The heat flow level is function of physiological parameters, e.g. body activity, and weather conditions.

[0045] A special algorithm is developed to process all information related with sensors, devices status, body activity model, weather parameters, and preset conditions. The algorithm is run in the microcontroller unit surveying and analysing temperatures within the garment, controlling heat and cool production, and preserving thermal preset comfort conditions. The microcontroller is con-

nected to the electric bus connector that provides power distribution and signal to control the garment, managing all devices and accessories.

5 f) Other applications

[0046] The power generated in the garment can be used for other purposes not forming part of the invention, in particular to provide energy to small appliances like laptops, audio readers, positioning systems, mobile phones, digital cameras, signalling and warning devices. The small appliances are connected to the electric bus connector that provides power distribution all devices.

15 g) Conclusion

[0047] This invention is unique in the following characteristics:

- 20 1. Includes both warming and cooling cycles in the garment, and provides the automatic thermal control.
2. Solar cells are used to power both cooling and heating units.
- 25 3. The garment can use other spectral sources than solar energy, namely optical radiation of fires.

[0048] All the claimed systems so far do not provide simultaneously the following characteristics: power autonomy, automatic control of temperature, cooling and heating cycles, and portability. The cooling garments currently available do not use solar cells to provide power to the system. The two available systems that include solar cells for heating purposes claim to utilize solar radiation only. All the solutions that provide temperature control at the present time use either warming or cooling devices, but do not include both solutions in the same piece of clothing.

[0049] This invention, which simultaneously provides warming and cooling active thermal control, can be applied in a wide range of weather conditions and included in different clothing types, namely jackets and uniforms (Fig. 1 and Fig. 2). The system can also work without solar radiation if another radiation source is present, namely artificial illumination (e.g. lamps). A particular useful situation is provided by fire radiation, which can be converted in electricity and used to cool fireman suits.

[0050] Pieces of clothing can include sensors monitoring the external weather conditions, communications and positioning devices, and luminous and sonorous signalling apparatus. These types of sensors and gadgets are particularly important in extreme conditions and sparsely inhabited areas, namely deserts, Polar Regions, and mountains.

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Claims

1. An autonomous garment with active thermal control and powered by solar cells, comprising solar cells (1), batteries (2), resistors (3), Peltier cells (5), microcontroller (6), electric bus connector, thermal sensors, and plugs, **characterized by** further comprising a refrigeration unit (4) pipes (7); and
 - Includes both warming and cooling units in the garment, and provides the automatic thermal control.
 - Solar cells used to power both cooling and heating units, which can use other spectral sources than solar energy.
2. The system of claim 1, wherein solar cells, connected to an electric bus connector, are on the outer shell of the garment and include optical parts, protection layer, and filters with appropriate geometry optimized for solar spectrum or other.
3. The system of claim 1, wherein batteries, embedded in the garment, are connected to the electric bus connector.
4. The system of claim 1, wherein a set of resistors, embedded in the garment and connected to the electric bus connector, is properly distributed in the garment for delivery of heat.
5. The system of claim 1, wherein Peltier cells, embedded in the garment and connected to the electric bus connector, are properly distributed in the garment to produce heat and cold.
6. The system of claim 1, wherein the refrigerating unit, connected to the electric bus connector, includes pipes properly distributed in the garment for delivery of cooling.
7. The system of claim 1, **characterized by** including at least one mechanism among thermal sensors, luminous and sonorous signaling appliances, positioning systems, and power plugs, connected to the electric bus connector.
8. The system of claim 1, **characterized by** including a microcontroller connected to all the electric devices, via the electric bus connector, for the active thermal control of the garment.
9. The system of claims 1 and 8, wherein the microcontroller includes means to display data and software to control the thermal parameters.
10. The apparatus of an autonomous garment with active thermal control and solar cells adapted to con-

vert fire radiation in electric power according to claim 1, specially developed for uniform applications, e.g. for fireman.

Patentansprüche

1. Die Erfindung betrifft ein selbständiges Kleidungsstück mit thermisch aktivierter Kontrolle und, dass durch Solarzellen angetrieben ist, enthaltend Solarzellen (1), Akkumulatoren (2), Widerstände (3), Peltier-Elemente (5), Mikrokontroller (6), ein elektrischer Busanschlussstecker, Thermosensoren und Stecker, **dadurch gekennzeichnet, dass** im Kleidungsstück ein Kältesatz (4), Röhre (7), und sowohl Kälte-, als auch Heizelemente enthalten sind und damit die automatische Temperaturkontrolle gewährleistet wird. Die Solarzellen, die die Kälte- und die Heizelemente antreiben, können außer Sonnenstrahlung auch andere spektrale Strahlung benutzen.
2. Das System nach Anspruch 1, worin die Solarzellen, die an den elektrischen Busanschlusssteckern verknüpft und im Außenschicht des Kleidungsstückes sind, optische Elemente, Schutzschicht und Filter mit geeigneter, optimierter Geometrie für die Sonnenstrahlung oder für andere Strahlungen enthalten.
3. Das System nach Anspruch 1, worin die Akkumulatoren, die im Kleidungsstück eingebaut sind, an einem elektrischen Busanschlussstecker verknüpft sind.
4. Das System nach Anspruch 1, worin eine Reihe von Widerständen, die im Kleidungsstück eingebaut und an dem elektrischen Busanschlussstecker verknüpft sind, durch das ganze Kleidungsstück verteilt sind und dadurch die Wärme liefern.
5. Das System nach Anspruch 1, worin die Peltier-Elemente, die im Kleidungsstück eingebaut und an den elektrischen Busanschlussstecker verknüpft sind, durch das ganze Kleidungsstück verteilt sind und dadurch Wärme oder Kälte erzeugen.
6. Das System nach Anspruch 1, worin, um die Kälte zu liefern, der Kältesatz, der an den elektrischen Busanschlussstecker verknüpft ist, Röhre, die durch das ganze Kleidungsstück verteilt sind, enthält.
7. Das System nach Anspruch 1, **dadurch gekennzeichnet, dass** an den elektrischen Busanschlussstecker, mindestens ein Thermosensor, eine leuchtende oder klingende Signalleitung, ein Lokalisierungssystem oder ein Netzstecker verknüpft ist.
8. Das System nach Anspruch 1, **dadurch gekenn-**

zeichnet, dass, um das Kleidungsstück thermoaktiviertes zu kontrollieren, ein Mikrokontroller, durch einen elektrischen Busanschlussstecker, an alle elektrischen Einheiten verknüpft ist, enthält.

9. Das System nach Ansprüche 1 und 8, worin der Mikrokontroller ein Datenbildschirm und Software, um den thermischen Parametern zu kontrollieren, umfasst.
10. Das Apparat des autonomen Kleidungsstückes mit thermisch aktivierter Kontrolle und Solarzellen, die, nach Anspruch 1, zur Umwandlung von Feuerstrahlung in elektrische Leistung geeignet ist, insbesondere zur Anwendungen in Uniformen, z. B. für die Feuerwehrmänner.

Revendications

1. Un vêtement autonome ayant un contrôle thermique actif et propulsé par des cellules solaires, constitué par des cellules solaires (1), des batteries (2), des résistances (3), des cellules Peltier (5), un microcontrôleur (6), un connecteur électrique de bus, des détecteurs thermiques et des prises de courant, **caractérisé en ce qu'il** comprend également une unité de réfrigération(4) et des tuyaux (7) ; et

- Inclut des unités de chauffage et de réfrigération à l'intérieur du vêtement, et est pourvu d'un contrôle thermique automatique ;
- Des cellulaires solaires utilisées pour propulser les unités de chauffage et de réfrigération, pouvant utiliser des sources spectrales autres que l'énergie solaire.

2. Le système selon la revendication 1, dans lequel des cellules solaires, connectées à un connecteur électrique de bus, se situent sur l'enveloppe extérieure du vêtement et comprennent des pièces optiques, une couche de protection et des filtres ayant une géométrie appropriée optimisée pour un spectre solaire ou autre.
3. Le système selon la revendication 1, dans lequel des batteries, intégrées dans le vêtement, sont connectées au connecteur électrique de bus.
4. Le système selon la revendication 1, dans lequel un ensemble de résistances, intégré dans le vêtement et connecté au connecteur électrique de bus, est distribué de manière appropriée dans le vêtement pour le transfert de chaleur.
5. Le système selon la revendication 1, dans lequel des cellules Peltier, intégrées dans le vêtement et connectées au connecteur électrique de bus, sont dis-

tribuées de manière appropriée dans le vêtement pour la production de chaleur et de froid.

6. Le système selon la revendication 1, dans lequel l'unité de réfrigération, connectée au connecteur électrique de bus, comprend des tuyaux distribués de manière appropriée dans le vêtement pour le transfert de froid.
7. Le système selon la revendication 1, **caractérisé en ce qu'il** comprend au moins un mécanisme parmi des détecteurs thermiques, des dispositifs de signalisation lumineux et sonores, des systèmes de positionnement et des prises de courant, connectés au connecteur électrique de bus.
8. Le système selon la revendication 1, **caractérisé en ce qu'il** comprend un microcontrôleur connecté à tous les dispositifs électriques, à travers le connecteur électrique de bus, pour le contrôle thermique actif du vêtement.
9. Le système selon les revendications 1 et 8, dans lequel le microcontrôleur comprend un moyen pour la visualisation de données et un logiciel pour contrôler les paramètres thermiques.
10. L'appareil d'un vêtement autonome ayant un contrôle thermique actif et des cellules solaires adaptées pour transformer le rayonnement provoqué par les incendies en énergie électrique selon la revendication 1, développé spécialement pour être utilisé avec les uniformes, par exemple pour les pompiers.

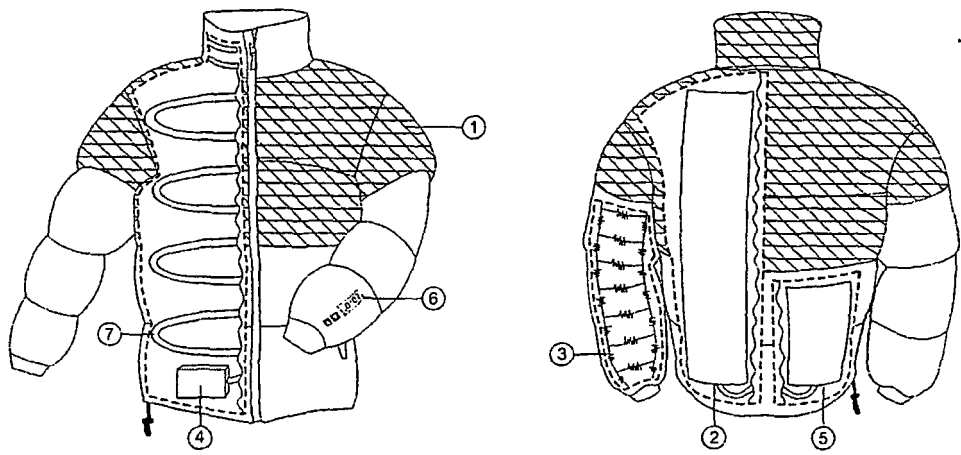


Figure 1

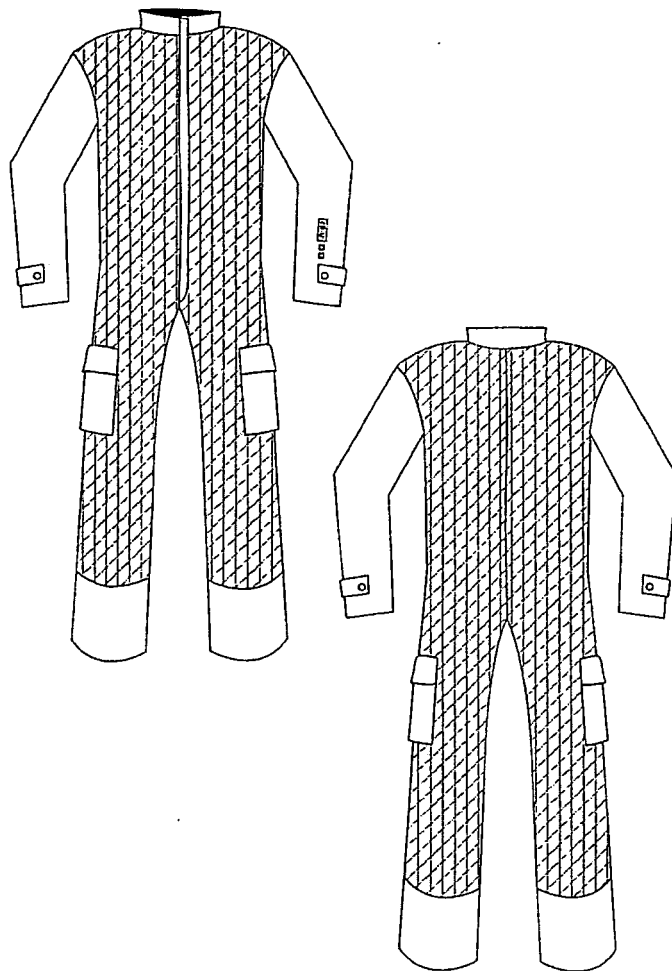


Figure 2

REFERENCES CITED IN THE DESCRIPTION

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