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PHYSICAL MODELS OF PERSONAL AIR-CONDITIONERS
(Part One)

This paper is focused on the prospects of using personal air-conditioners that are capable of saving energy resources, reducing environment thermal pollution and improving living standards. With a view to determine possible development of rational variants of air-conditioners, they have been classified according to the method and purpose of air-conditioning. From the classification more than 20 new design opportunities of air-conditioners have been found. They can be useful in the development of mass and special-purpose air-conditioners. From the analysis of these opportunities follows the promising outlook for the use of thermoelectric cooling or heating in personal air-conditioners. Such applications are defined as a promising way of wide use of thermoelectricity.

Key words: heat pump, thermoelectricity, air conditioning, physical model.

Introduction

General characterization of the problem. There is a well-known tendency to saving energy resources for the improvement of the Earth ecological state, in particular, reduction of its thermal pollution. One of important trends in this saving is reduction of energy cost for creation of comfortable conditions for human vital activity [1]. Considerable is electric energy consumption for air-conditioning of dwellings, work places and public facilities (cinema theatres, theater halls, public eating places, etc). Energy demands for air-conditioning, especially in critical weather conditions (summer period) are so great that the power of existing electric grids cannot meet them in some cases. Total air-conditioning cost in recent decades has reached $\approx 800\cdot10^9$ kW·h per year and, according to forecasts, by 2100 it will have increased by a factor of 30 [2]. In the meantime, there is no need in air-conditioning of big spaces in dwellings, industrial enterprises. In fact, for creation of such conditions it is enough to provide air-conditioning of person himself, which allows reducing energy cost by a factor of tens and hundreds.

Moreover, according to medical investigations, in many cases there is no need in air-conditioning the entire human body. To assure comfortable conditions, it is enough to act with heat or cold on certain areas of the human body [4], for instance on the head under overheat conditions or on the extremities under supercooling conditions. Moreover, it can be expected that the use of air-conditioned garment will result in considerable reduction of cold-related diseases, and creation of appropriate temperature conditions should produce curative effect with various inflammatory processes, chronic diseases of joints and other organs of the human body.

Personal air-conditioning is efficient for electric energy saving not only at elevated ambient temperatures, but also at reduced temperatures. Such air-conditioners can reduce requirements to temperature conditions of human residence. According to estimates, the use of individual air-conditioners in heating mode can save $4\cdot10^{12}$ kW·h of thermal energy per year (from the world level of energy consumption on space heating $40\cdot10^{12}$ kW·h per year) [3], which will correspond to reduction of energy consumption by about 10 %.

Personal air-conditioners allow improving the quality of life in general. This is due to the capabilities of such air-conditioners of maintaining comfortable conditions with a change of ambient temperature conditions (in wide limits) or with a change in the emission of heat from the human body depending on mechanical loads (from 100 W in a quiescent state to 1 kW, for instance, in the process of running or hard work) [5] by automatic change in person exposure to heat or cold.

The foregoing points to the importance and relevance of studies aimed at creating personal air-conditioners which, by the highest standards, can influence the conditions and life style of mankind. This will be due to transition from passive garment which has mainly performed the function of thermal insulation of the human body, to the use of active garment which responds to changes in the temperature conditions of human activity.

With regard to the above, it is important to consider methods than can achieve garment air-conditioning nowadays, and how these methods or combinations thereof can be used for solving this task. The latter comes down to studying physical models that can be used when creating such air-conditioners and their analysis with a view to find the most rational variants. Exactly this is the subject of research in this work. In so doing, of particular interest when creating optimal designs are air-conditioners which employ thermoelectric cooling and heating effects [6], which, according to investigations, at low powers of heat and cold can dominate over all other methods.

Analysis of the literature. Activities aimed at creating air-conditioned garment are already actively pursued in many countries worldwide [7 – 18]. The greatest acceptance nowadays has been gained by passive air-conditioning garment, the so-called thermal garment (thermal underwear) [19]. It retains heat (in terms of heat-insulating properties it is equivalent to two and more layers of traditional clothes) and removes humidity from the human body due to the use of synthetic textiles of complicated internal structure. As a rule, such garment is composed of three layers – the lower one absorbs and removes humidity; the middle one removes humidity outside and retains heat; the upper one protects from unfavourable weather conditions.

As to active air-conditioning, these are mainly special-purpose air-conditioners for creation of appropriate conditions that are related to professional activity under extreme temperature conditions.

In particular, works [7, 8] represent special garment for overheat protection of workers of hot shops which employs cold accumulators in the form of potassium acrylate copolymer [7] or dry ice [8]. In the former case for “charging” of accumulator the garment is soaked in water for several hours, accumulator substance absorbs the liquid which assures cooling within 8 hours, absorbing in this case up to 12.5 kJ/cm^2 per hour. Air-conditioner [8] using dry ice in garment inner lining proves cooling by circulation of cooled gas-like carbon dioxide in the space between internal jacket surface and the human body.

Works [9, 10] employ the method of human body cooling by ambient air blowing. Such air-conditioner has the form of overalls with channels for passing of air which is blown into garment by an electric fan.

Works [11 – 13] describe cooled garment for military men, sportsmen and doctors which is based on thermal energy absorption due to substance phase transition. Such garment is made as jackets, knee or elbow bandages, etc. having water-filled channels. Cooling in this case is done by water evaporation through special porous external surface of air-conditioner. The time of its continuous operation is up to 6 hours assuring temperature reduction to 15 °C from the ambient temperature (at relative air humidity 30 %).

Works [14, 15] provide insight into creation of air-conditioners heaters for supercooling protection. In particular, [14] describes a design of air heater in the form of a mask for miners working at extremely low temperatures, where air is heated by a resistive heater.

Of particular interest are works [16 – 18] which represent the results of development of thermoelectric air-conditioners. These are garment-embedded Peltier modules for garment cooling or heating depending on the electric current direction.

All above mentioned garment air-conditioning methods offer their specific advantages and, at the same time, have considerable shortcomings. Therefore, it is important to consider all modern methods used for individual air-conditioning of the human body, and to determine how these methods or combinations thereof can be used for creation of new efficient personal air-conditioners.

The purpose of this work is determination of possible modifications of personal air-conditioners, their classification and analysis for further enhancement of their quality with regard to specific operating conditions.

Classification of personal air-conditioners

In this paper, personal air-conditioners are classified according to function, the type of heat and cold source, the object of cooling or heating and garment purpose (Fig. 1).

According to function, personal air-conditioners are recognized that are used only for cooling, only for heating or for cooling and heating, as the need may be. Each of these air-conditioners differs in the type of heat or cold source.

According to the object of cooling or heating, personal air-conditioners can be classified as such that provide air-conditioning of the entire human body (overalls with individual air-conditioner) or its areas – head (air-conditioned headwear), body (air-conditioned vest), elbow or knee joints (air-conditioned bandage), loin (air-conditioned belt), abdomen (air-conditioned plate fixed on the belly), hands (air-conditioned gloves), feet (air-conditioned footwear).

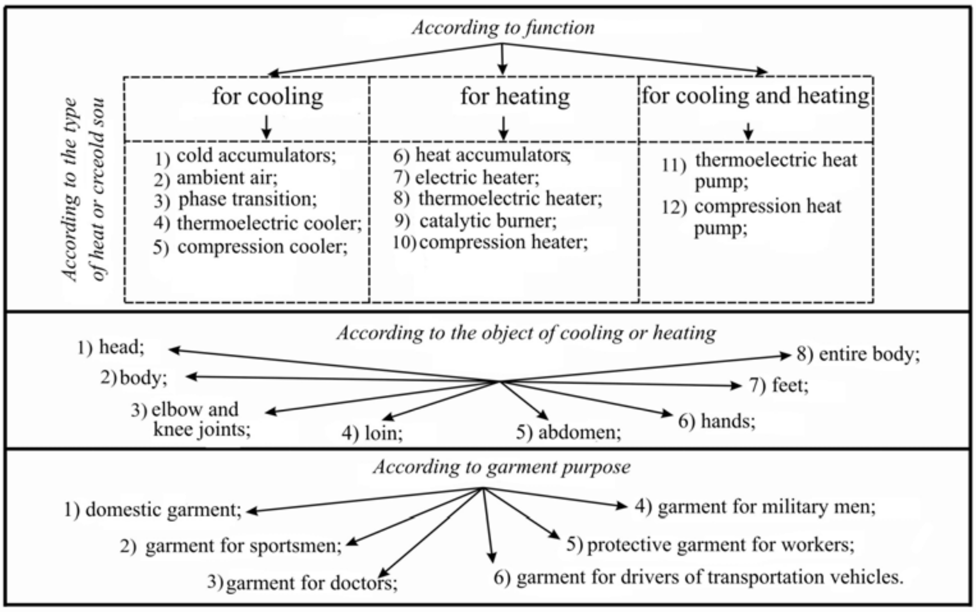

Fig. 1. Classification of personal air-conditioners for garment.

Depending on the spheres of application of air-conditioned garment they are classified as air-conditioners for domestic garment (creation of comfortable conditions in everyday life and on holidays), for sportsmen (garment abstracting heat during extreme physical loads), for doctors (for instance, protective garment for surgeons during long-term surgical interventions or operations in garment protecting against harmful radiation), for drivers of transportation vehicles (pilots, cosmonauts, drivers of automobiles and motorcycles), for military men (for instance, air-conditioner for armour vests that will assure comfortable conditions for combat mission performance under various climatic conditions), for workers (for instance, garment for protection against long-term exposure to elevated temperatures at metallurgical plants or, on the contrary, for protection of workers against low temperatures in the North).

The key attribute which distinguishes one air-conditioner from another is the type of heat or cold sources. They primarily govern the operating efficiency of air-conditioners. So, let us consider classification of personal air-conditioners by the types of heat and cold sources.

Classification of physical models of personal air-conditioners

Analysis of the literature testifies that the problem of creation of personal air-conditioners that would combine the basic advantages of known methods of heat and cold production is still poorly understood. We first discuss all possible combinations of heat and cold sources which provide air-conditioning. This is an exhaustive list of physical models of air-conditioners. Their modifications are given in Table. Here: 1 – heat or cold accumulators (12 in particular, using substance phase transition); 2 – ambient air; 3 – electric heater; 4 – catalytic heater; 5 – compression heat pump; 6 – thermoelectric heat pump.

Table

Modifications of physical models of personal air-conditioners

	1	2	3	4	5	6	1.2
1.3	1.4	1.5	1.6	2.3	2.4	2.5	2.6
3.4	3.5	3.6	4.5	4.6	5.6	1.2.3	1.2.4
1.2.5	1.2.6	1.3.4	1.3.5	1.3.6	1.4.5	1.4.6	1.5.6
2.3.4	2.3.5	2.3.6	2.4.5	2.4.6	2.5.6	3.4.5	3.4.6
3.5.6	4.5.6	1.2.3.4	1.2.3.5	1.2.3.6	1.2.4.5	1.2.4.6	1.2.5.6
1.3.4.5	1.3.4.6	1.3.5.6	1.4.5.6	2.3.4.5	2.3.4.6	2.3.5.6	2.4.5.6
3.4.5.6	1.2.3.4.5	1.2.3.4.6	1.2.3.5.6	1.2.4.5.6	1.3.4.5.6	2.3.4.5.6	1.2.3.4.5.6

- already in use;
- promising;
- use is unreasonable.

The Table comprises known modifications of air-conditioners (13 physical models, preferably the simplest, with one type of heat or cold source), as well as those which are unreasonable to be used now (28 models). Nevertheless, it enables us to single out new physical models of air-conditioners that can be promising for practical use.

We first discuss physical models of known air-conditioners. They are numbered according to Table.

Physical models of known personal air-conditioners

Physical models with heat or cold accumulators

One of the simplest methods of cooling or heating is the use of cold or heat accumulators, respectively [7, 8]. The operating principle of such air-conditioners is based on the use of high heat capacity substances which gradually release or absorb human heat flux.

Physical models of personal air-conditioner with heat or cold accumulator are represented in Fig. 2.

In cooling mode (Fig. 2*a*) heat accumulator absorbs the amount of heat equal to:

$$Q_{accum.} = V \cdot \rho \cdot C \cdot \left(T_2 - T_1\right) \cdot t\,, \qquad (1)$$

where $Q_{accum.}$ is thermal energy absorbed by heat accumulator (J), V is volume of heat accumulator (m^3), ρ is its density (kg/m^3), C is specific heat capacity ($W/kg \cdot K$), $\left(T_2 - T_1\right)$ is the difference between final T_2 and initial T_1 temperatures of heat accumulator substance, t is time of accumulator discharge (sec) from temperature T_1 to T_2.

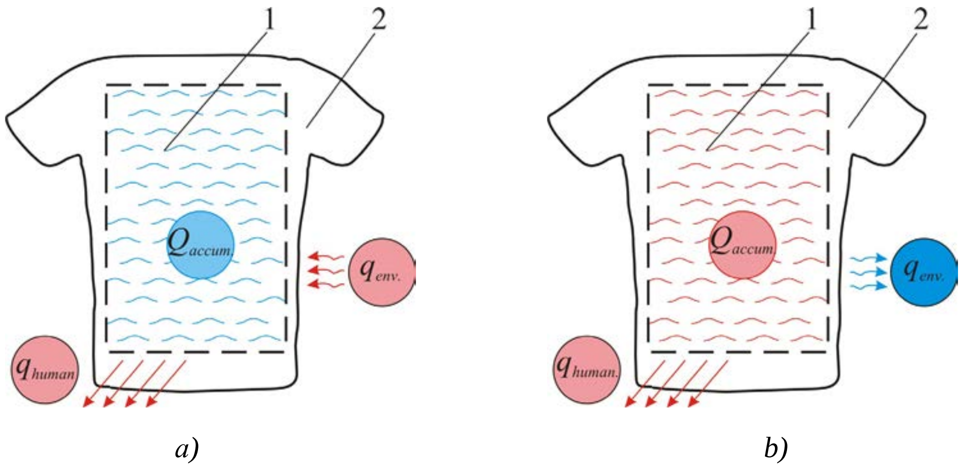

Fig. 2. Physical model of personal air-conditioner with heat or cold accumulator: 1 is vessel with heat accumulator, 2 is air-conditioned garment, a) cooling mode, b) heating mode.

In this case heat balance equation will be of the form:

$$Q_{accum.} = (q_{human.} + q_{env.}) \cdot t\,, \qquad (2)$$

where $q_{human.}$ is heat release from human body (W), $q_{env.}$ is power of heat release from the environment (W), for instance, thermal radiation from heated objects, t is time of accumulator discharge (sec) from temperature T_2 to T_1.

In heating mode (Fig. 2*b*), heat balance equation will be of the form:

$$Q_{accum.} = (q_{env.} - q_{human.}) \cdot t\,. \qquad (3)$$

From (2), (3) it is clear that normal heat exchange from human body can be assured within time t which depends on the parameters of heat accumulator and power of heat release from human body $q_{human.}$ and environment $q_{env.}$

The disadvantage of such air-conditioning circuit is the need for permanent replacement ("charging") of accumulator which makes impossible its long-term use.

A variety of air-conditioners using heat accumulators are coolers with substance phase transition [11 – 13]. The working substance here (liquid, dry ice) is evaporated, absorbing therewith thermal energy. Such air-conditioning scheme is more efficient than the previous variant, but it has its weak points, namely the absence of possibility of garment heating, strong dependence on ambient conditions, in particular, humidity and air temperature.

Thermal energy $Q_{ph.tr.}$ (J), removed to environment by such air-conditioner will be equal to:

$$Q_{ph.tr.} = L \cdot V \cdot \rho, \tag{4}$$

where L is specific heat of evaporation (J/kg), V is the volume of substance which is evaporated (m^3), ρ is its density (kg/m^3).

In this case heat balance equation will be of the form:

$$Q_{accum.} = (q_{human.} + q_{env.}) \cdot t, \tag{5}$$

where t is time of full evaporation of substance.

As is seen from (5), an essential deficiency of such air-conditioner model is the need for permanent replacement of working substance which renders impossible its long-term use.

Physical model using thermal energy of ambient air

A common method employed only for cooling of human body is the use of heat exchange with the environment [9, 10] (Fig. 3). In this case the prerequisite for human body cooling is that the ambient temperature must be lower than the body temperature. Moreover, such air-conditioning scheme involves the electric fan which consumes certain power $W_{fan.}$, and, accordingly, its power supply.

Thermal power $q_{air.}$ (*W*) removed to the environment by such air-conditioner will be equal to:

$$q_{air.}(W_{fan.}, T_1) = G(W_{fan.}) \cdot \rho \cdot C \cdot (T_2 - T_1), \tag{6}$$

where G is air flow rate (m^3/sec) which is a function of fan power $W_{fan.}$, ρ is air density (kg/m^3), C is specific heat of air ($W/kg \cdot K$), $(T_2 - T_1)$ is the difference between air-conditioner outlet temperature T_2 and inlet temperature T_1.

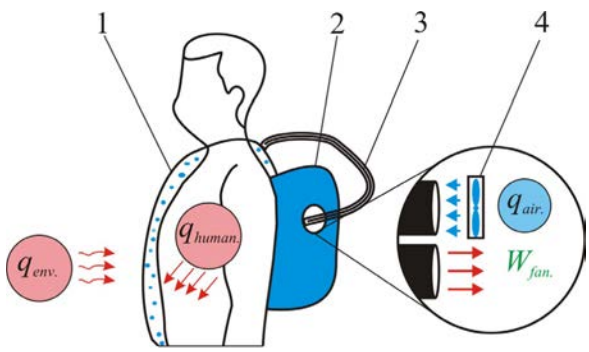

Fig. 3. Physical model of personal air-conditioner using heat-exchange with the environment: 1 – garment with air passage channels, 2 – air-conditioner unit comprising an electric fan 4 with power supply, 3 – channels for air change.

Heat balance equation in this case can be written as follows:

$$q_{air.} = q_{human.} + q_{env.}. \tag{7}$$

The shortcomings of this air conditioning method are low efficiency, absence of the possibility of heating, strong dependence on the environmental conditions, the need for electric power supply.

Physical model using the Joule effect

A simple method of garment heating is the use of electric resistive heaters [14, 15] (Fig. 4). Such air-conditioner comprises a garment-embedded heater in the form of current-carrying conductor and an electric power supply with control unit. Despite its simplicity, such air-conditioner has its weak points, namely absence of the possibility of cooling and the need for permanent charge of power supply (electric accumulator).

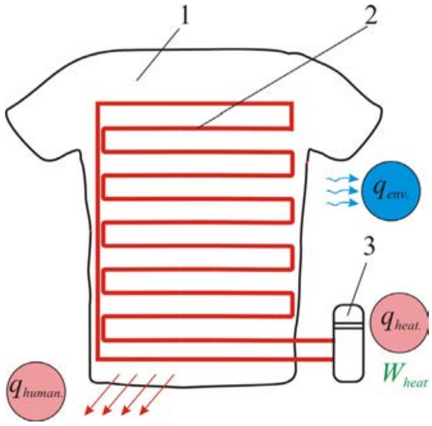

Fig. 4. Physical model of personal air-conditioner using the Joule effect:
1 – air - conditioned garment, 2 – electric heater, 3 – power supply.

Thermal power $q_{heat.}$ (W) release by such heater will be equal to:

$$q_{heat.} = I^2 \cdot r, \tag{8}$$

where I is current strength (A), r is electric resistance of the heater (Ω).

Heat balance equation will be of the form:

$$q_{heat.} = q_{env.} - q_{human}. \tag{9}$$

The efficiency of such heater is close to unity, as long as almost all spent electric power $W_{human.}$ is converted into thermal flux q_{human}.

Physical model with catalytic fuel combustion

Another method of garment heating is the use of gas catalytic combustion in a burner [20]. The operating principle of such air-conditioner-heater lies in heat release with flameless oxidation (combustion) of gas mixture in the presence of a catalyst. The air heated in this way gets through the system of channels into garment, heating it. Gas combustion products are removed to the environment.

Thermal energy $Q_{g.f.}$ (*J*) released with fuel combustion will be equal to:

$$Q_{г.п.} = g \cdot m, \tag{10}$$

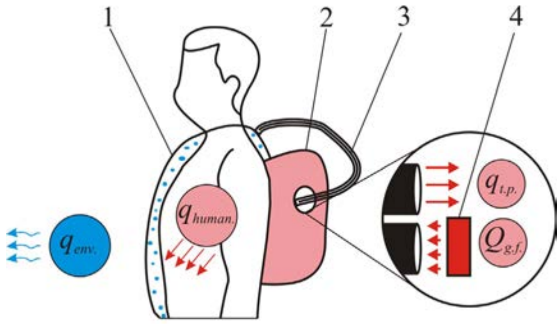

*Fig. 5. Physical model of personal air-conditioner with catalytic gas combustion:
1 – garment with heated air passage channels 3, 2 – container with burner 4.*

where g is specific heat of fuel combustion (J/kg), m is fuel weight (kg).

Heat balance equation will be of the form:

$$Q_{g.f.} = (q_{env.} - q_{human.} + q_{t.p.}) \cdot t\,, \tag{11}$$

where $q_{t.p.}$ is thermal power (W) which is released to environment with fuel combustion products and spent air.

This method of garment air-conditioning offers the advantages of a relatively low need for heat source (petrol, spirit), its weak point is absence of the possibility of garment cooling.

Physical model with compression heat pump

The operation of compression heat pumps is based on a refrigeration cycle [21]. A simple vapour cycle of mechanical refrigerating machine is realized by means of four members forming a closed cooling loop, namely compressor, condenser, throttle valve and evaporator or cooler (Fig. 6). Vapor from the evaporator comes to compressor and is compressed, owing to which its temperature is rising. On leaving the compressor, vapour that has high temperature and pressure comes to condenser where it is cooled and condensed. Liquid from the condenser passes through throttle valve. As long as boiling (saturation) temperature for this pressure proves to be lower than liquid temperature, it starts to boil violently; in the process, part of the liquid is evaporated and the temperature of the rest is lowered to equilibrium saturation temperature (the heat of the liquid is spent on its conversion to vapour). In this way, the necessary garment areas are cooled or heated. The disadvantages of this air-conditioning method include the demand for charging of compressor electric power supply (storage battery), the presence of coolant (specifically, freone, which is rather toxic), weight-size parameters, as well as noisy work.

Thermal power $q_{cool.}$ (W) taken off on the cold side of compressor cooler (cooling capacity) is determined by the relation:

$$q_{cool.} = q_{heat.} - W_{compr}\,, \tag{12}$$

where $q_{heat.}$ is thermal power (W) removed from the hot side to the environment, $W_{compr.}$ is electric power (W) spent by compressor.

To provide for heat balance in cooling mode:

$$q_{cool.} = q_{env.} + q_{human}\,. \tag{13}$$

In heating mode (13) will be rewritten as:

$$q_{heat.} = q_{env.} - q_{human.}\,. \tag{14}$$

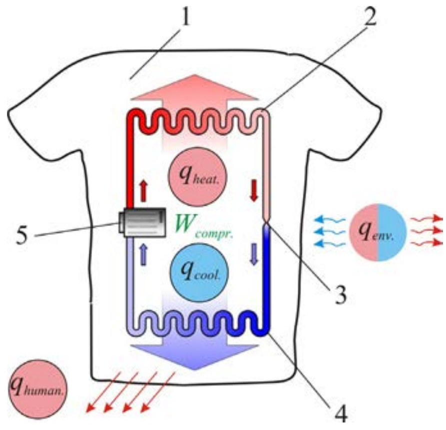

Fig. 6. Physical model of personal air-conditioner with compression heat pump: 1 – garment, 2 – evaporator, 3 – throttle valve, 4 – condenser, 5 – compressor.

It is worth mentioning that despite their disadvantages, compression heat pumps have high value of energy conversion efficiency factor (coefficient of performance at a level of 3).

Physical model with thermoelectric heat pump

A convenient method of garment cooling or heating is the use of thermoelectric heat pumps based on the Peltier effect [16 – 18] (Fig. 7). Depending on the electric current direction such air-conditioner can be used both for cooling and heating.

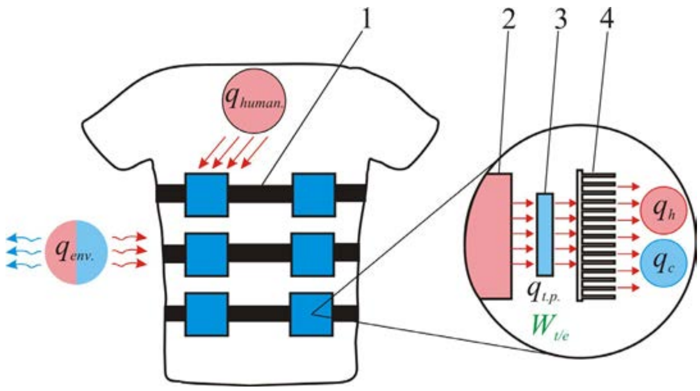

Fig. 7. Physical model of personal air-conditioner with thermoelectric heat pump: 1 – garment with fastener system, 2 – member assuring thermal contact of thermoelectric energy converter 3 to garment, 4 – air heat exchanger.

In cooling mode, thermal power q_c (W) absorbed on the cold side of thermoelectric converter is equal to:

$$q_c = \Pi \cdot I - \frac{1}{2} \cdot I^2 \cdot r - \mathrm{K} \cdot \Delta T \,, \tag{15}$$

where Π is the Peltier coefficient (V), K is full thermal conductivity (W/K), ΔT is temperature difference on thermoelectric converter (K).

Heat balance is given below:

$$q_c = q_{env.} + q_{human.} \,. \tag{16}$$

For heating mode, thermal power q_h (W) released on the hot side of thermoelectric converter is equal to:

$$q_h = \Pi \cdot I + \frac{1}{2} \cdot I^2 \cdot r - \mathrm{K} \cdot \Delta T \,. \tag{17}$$

Heat balance in heating mode is given below:

$$q_h = q_{env.} - q_{human} \,. \tag{18}$$

This air-conditioning method offers the advantages of high efficiency, reliability, low weight-size parameters, environmental friendliness (absence of harmful coolants) and noise-free operation. The shortcoming includes the demand for permanent charging of electric accumulators.

Model 1.2

Fig. 8 represents a physical model of personal air-conditioner which is a combination of the above models using thermal energy of the ambient air (item 2) and heat accumulators (item 1).

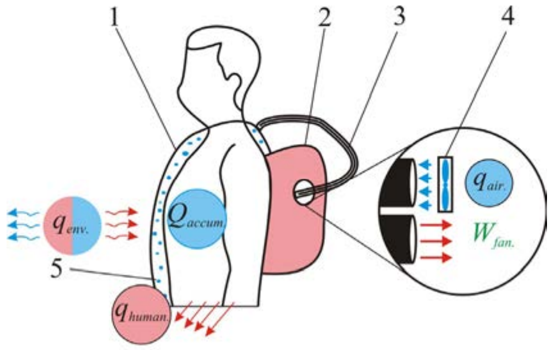

*Fig. 8. 1 – garment with air passage channels 3,
2 – container with a fan 4, 5 – vessel with heat accumulator.*

This method of garment air-conditioning offers the advantage of increased cooling efficiency due to the use of two sources of cold. Its shortcomings include absence of the possibility of garment heating and the demand for permanent charging of fan electric supply and replacement of heat accumulator (water, dry ice, etc).

Model 1.3

Fig. 9 represents a physical model of personal air-conditioner which is a combination of models using the Joule effect (item 3) and heat accumulators (item 1).

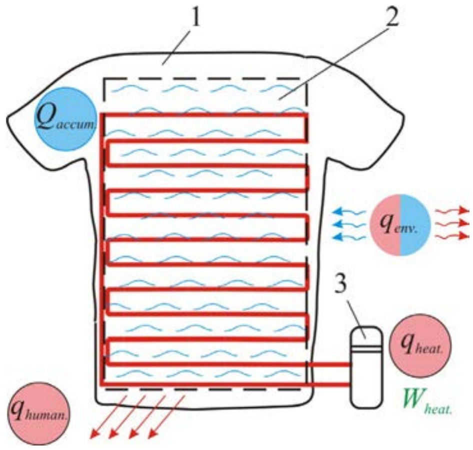

*Fig. 9. 1 – air-conditioned garment, 2 – vessel with heat
accumulator, 3 – electric heater.*

The advantages of this garment air-conditioning method include both cooling (by thermal energy absorption at substance phase transition) and heating (by heat release at current flow through conductor) capabilities. The shortcoming is the demand for permanent charging of heater electric supply and replacement of heat accumulator (water, dry ice, etc).

Model 2.3

Another physical model of personal air-conditioner which already finds practical implementation is depicted in Fig. 10. It combines the models using thermal energy of ambient air (item 2) and thermal action of the Joule effect (item 3).

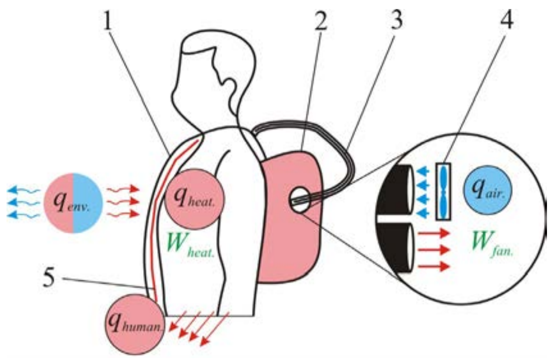

Fig. 10. 1 – garment with air passage channels 3, 2 – container with a fan 4, 5 – electric heater.

The advantages of this garment air-conditioning method include both cooling (by absorption of thermal energy at blowing of human body with a lower temperature ambient air), and heating (by heat release at current flow through conductor) capabilities. The shortcoming is the demand for permanent charging of heater and fan electric supply.

Model 2.4

Fig. 11 represents a physical model of personal air-conditioner which combines the use of thermal energy of ambient air (item 2) and thermal action with catalytic fuel combustion (item 4).

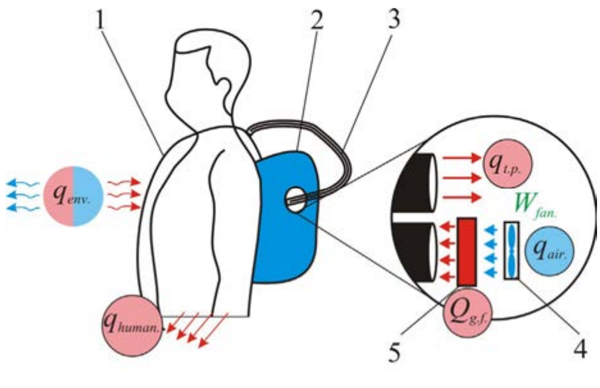

Fig. 11. 1 – garment with air passage channels 3, 2 – container with a fan 4 and gas burner 5.

The advantage of this air-conditioner is both cooling (by absorption of thermal energy at blowing of human body with a lower temperature ambient air) and heating (thermal energy release at catalytic fuel combustion) capabilities. The shortcomings include the demand for permanent charging of fan electric supply and replacement of fuel in catalytic heater).

Model 2.5

Fig. 12 represents a physical model which combines the use of thermal energy of ambient air (item 2) and compression heat pump (item 5).

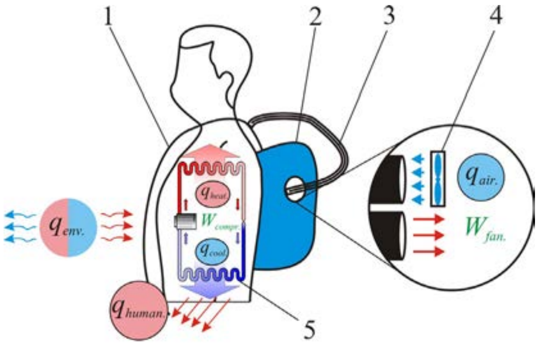

Fig. 12. 1 – garment with air passage channels 3,
2 – container with a fan 4, 5 – compression heat pump.

This model offers the advantages of both cooling (by operation of compression heat pump and absorption of thermal energy at blowing of human body with a lower temperature ambient air) and heating (thermal energy release with a reverse cycle of compression heat pump) capabilities. Its shortcomings include the demand for permanent charging of the fan and compressor power supply, the presence of harmful coolants (for instance, freon).

Model 2.6

Fig. 13 represents a physical model of personal air-conditioner which combines the use of thermal energy of ambient air (item 2) and thermoelectric heat pump (item 5).

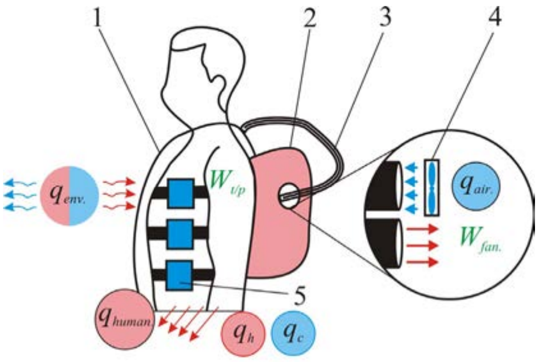

Fig. 13. 1 – garment with air passage channels 3,
2 – container with a fan 4, 5 – thermoelectric heat pump.

The advantages of this garment air-conditioning method include both cooling (by using thermoelectric heat pump and by absorption of thermal energy at blowing of the human body with a lower temperature ambient air) and heating (thermal energy release at thermoelectric heating) capabilities. The shortcomings include the demand for permanent charging of the fan and thermoelectric power converters electric supply.

New physical models of personal air-conditioners

As is shown in Table 1, 23 physical models of personal air-conditioners have been selected that hold promise for further studies. These models are combinations of known methods of heat and cold production that have been discussed in the previous section. Consider them in more detail.

Model 1.4

Fig. 14 represents a physical model of personal air-conditioner which combines catalytic heater (item 4) with heat accumulator (item 1). This model allows enhancing the functionality of garment air-conditioning, namely to provide for garment cooling (by thermal energy absorption at phase transition of substance contained in a vessel with heat accumulator) or heating (heating of air that gets into garment channels due to catalytic combustion of gas). Its shortcoming is the demand for permanent replacement of heat accumulator and fuel in the heater.

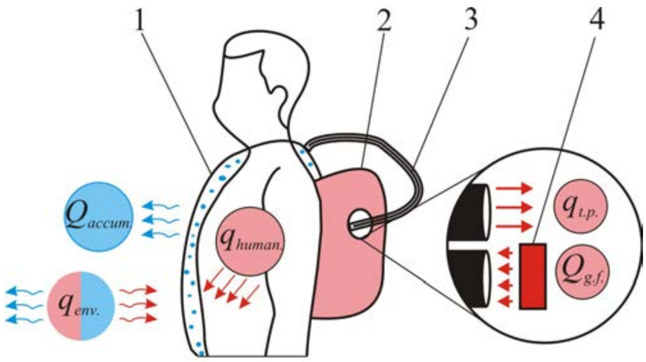

Fig. 14: 1 – vessel with heat accumulator, 2 – container with gas burner 4, 3 – heated air passage channels.

Model 1.5

Fig. 15 represents a physical model of personal air-conditioner which combines compression heat pump (item 5) with heat accumulator (item 1). The use of such air-conditioning method makes it possible to increase garment cooling efficiency through combination of mechanical cooling by compression refrigeration machine with cooling by substance phase transition. Another advantage of this garment air-conditioning method is the possibility of its use in heating mode (through the reverse cycle of compression refrigeration machine). Its shortcoming is the need for permanent charging of compressor power supply, the demand for heat accumulator replacement and the presence of harmful coolants.

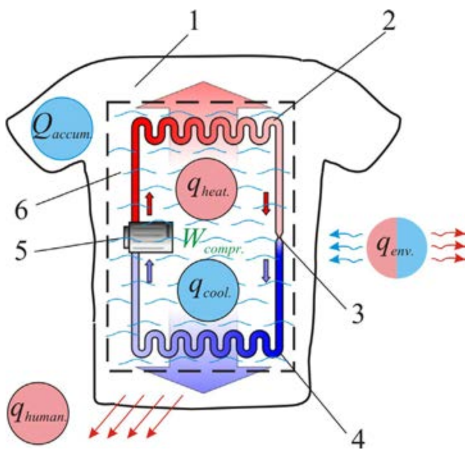

Fig. 15: 1 – garment, 2 – evaporator, 3 – throttle valve, 4 – condenser, 5 – compressor, 6 – vessel with heat accumulator.

Model 1.6

Fig. 16 represents a physical model which combines thermoelectric heat pump (item 6) with heat accumulator (item 1). Its use allows increasing garment cooling efficiency through combination of the Peltier thermoelectric effect with cooling by substance phase transition. It can be also used in heating mode due to thermoelectric power converters. Its shortcoming is the need for permanent charging of thermoelectric modules power supply and the demand for heat accumulator replacement.

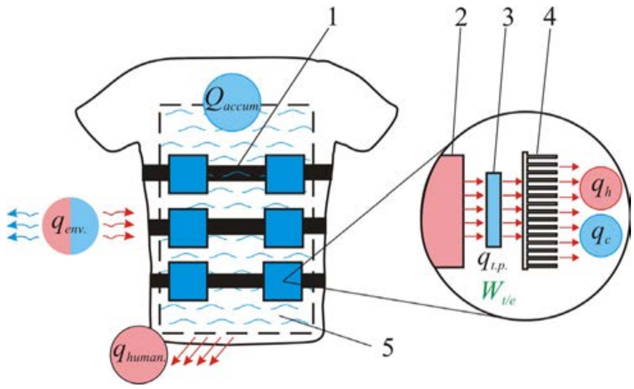

Fig. 16: 1 – garment with fastener system, 2 – member providing for thermal contact of thermoelectric energy converter 3 to garment, 4 – air heat exchanger, 5 – vessel with heat accumulator.

Model 3.5

Fig. 17 represents a physical model of personal air-conditioner which combines compression heat pump (item 5) with electric heater (item 3). The advantages of this garment air-conditioning method include both cooling (mechanical cooling by compression refrigeration machine) and heating (compression heat pump and the Joule effect in current-carrying conductor) capabilities; efficiency increase in heating mode due to the use of two heating modes. The shortcomings include the need for permanent charging of compressor and heater power supply, the presence of harmful coolants.

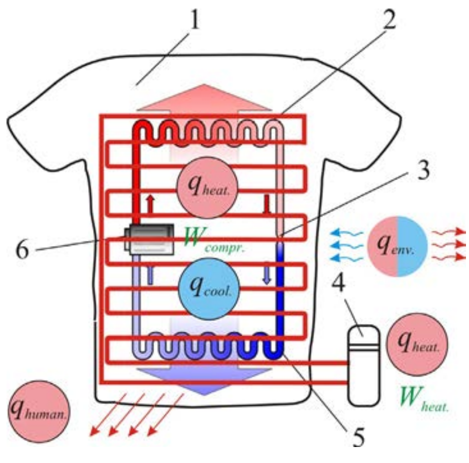

Fig. 17: 1 – garment, 2 – evaporator, 3 – throttle valve, 4 – condenser, 5 – compressor, 6 – electric heater.

Model 3.6

Fig. 18 represents a physical model which combines thermoelectric heat pump (item 6) with electric heater (item 3). The advantages of this model include both cooling (thermoelectric Peltier effect) and heating (thermoelectric heat pump and the Joule effect in current-carrying conductor) capabilities; efficiency increase in heating mode due to the use of two heating methods. The shortcoming is the need for permanent charging of thermoelectric converters and heater power supply.

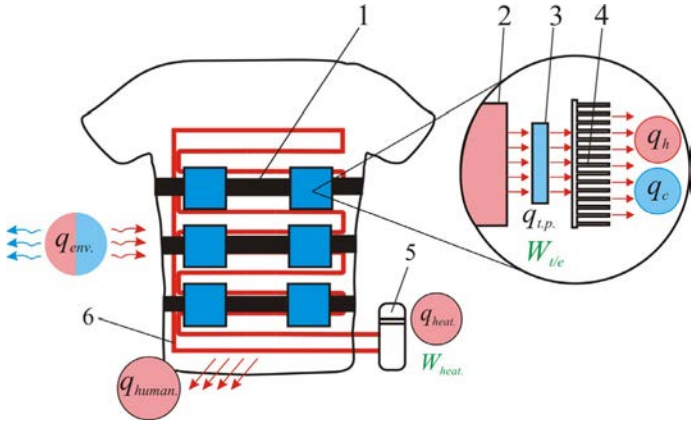

Fig. 18: 1 – garment with fastener system, 2 – member providing for thermal contact of thermoelectric energy converter 3 to garment, 4 – air heat exchanger, 5 – electric heater.

Model 4.5

Fig. 19 represents a physical model of personal air-conditioner (item 5) with a catalytic heater (item 4). The advantages of this model include cooling (mechanical cooling by compression refrigeration machine) and heating (compression heat pump and catalytic fuel combustion) capabilities; efficiency increase in heating mode due to the use of two heating methods. The shortcomings include the need for permanent charging of compressor power supply, the demand for fuel replacement in the heater and the presence of harmful coolants.

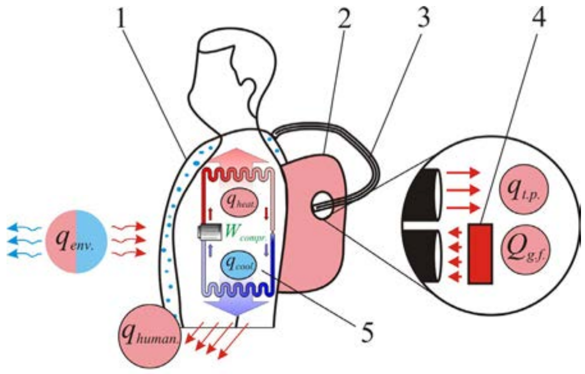

Fig. 19: 1 – garment, 2 – container with gas burner 4, 3 – heated air passage channels, 5 – compression heat pump.

Model 4.6

Fig. 20 represents a physical model which combines thermoelectric heat pump (item 6) with a catalytic burner (item 4). The advantages of this model include both cooling (cooling due to the Peltier effect) and heating(heat release due to catalytic fuel combustion, thermoelectric heating due to the Peltier effect) capabilities; efficiency increase in heating mode due to the use of two heating methods. The shortcomings include the need for permanent charging of thermoelectric converters power supply, the demand for replacement of fuel in the heater.

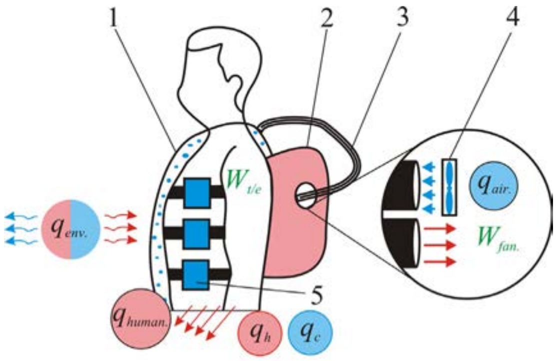

Fig. 20: 1 – garment with channels 3, 2 – unit with a catalytic burner 4, 5 – thermoelectric heat pump.

Model 1.2.3

Fig. 21 represents a physical model of personal air-conditioner which combines ambient air blowing (item 2), heat accumulator (item 1) with electric heater (item 3). Its advantages include cooling (heat absorption at substance phase transition, blowing with lower temperature ambient air) and heating (heat release according to the Joule effect in current-carrying conductor) capabilities. The shortcomings include the need for permanent charging of heater and fan power supply and the demand for heat accumulator replacement.

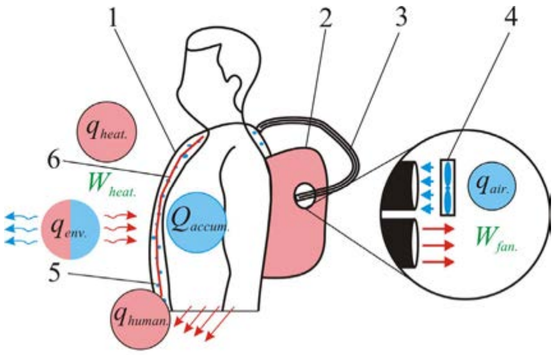

Fig. 21: 1 – garment with air passage channels 3, 2 – air-conditioning unit comprising an electric fan 4 with power supply, 5 – vessel with heat accumulator, 6 – electric heater.

Model 1.2.4

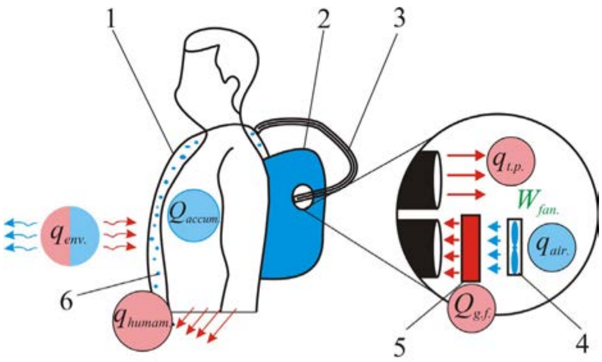

Fig. 22: 1 – garment with air passage channels 3, 2 – air-conditioning unit comprising an electric fan 4, 5 – catalytic burner, 6 – vessel with heat accumulator.

Fig. 22 represents a physical model of personal air-conditioner which combines ambient air blowing (item 2), heat accumulator (item 1) with a catalytic burner (item 4). The advantages of this garment air-conditioning method include cooling (heat absorption at substance phase transition, blowing with lower temperature ambient air) and heating (heat release due to catalytic fuel combustion combined with forced fanning) capabilities. The shortcomings include the need for permanent replacement of heat accumulator and fuel in the heater and the demand for electric fan power supply.

Model 1.2.5

Fig. 23 represents a physical model which combines compression heat pump (item 5), heat accumulator (item 1) and ambient air blowing (item 2). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with ambient air blowing) and heating (compression heat pump) capabilities; efficiency increase in cooling mode due to the use of two methods of heat extraction. The shortcomings include the need for permanent charging of compressor power supply, the demand for heat accumulator replacement and the presence of harmful coolants.

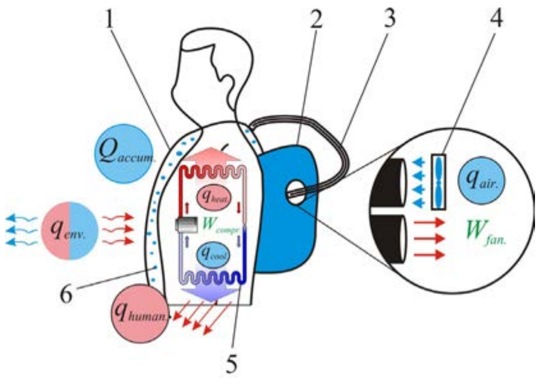

Fig. 23: 1 – garment with air passage channels 3, 2 – unit comprising an electric fan 4, 5 – compression heat pump, 6 – vessel with heat accumulator.

Model 1.2.6

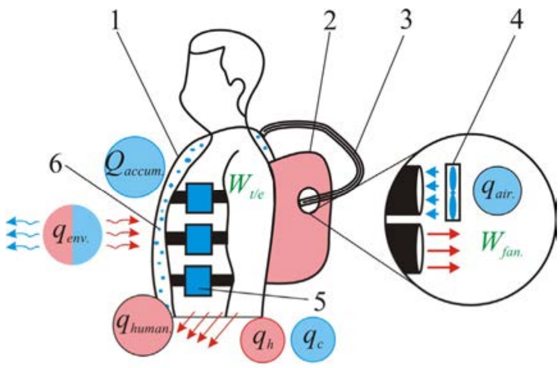

Fig. 24: 1 – garment with air passage channels 3, 2 – unit comprising an electric fan 4, 5 – compression heat pump, 6 – vessel with heat accumulator.

Fig. 24 represents a physical model which combines thermoelectric heat pump (item 6), heat accumulator (item 1) and ambient air blowing (item 2). Its advantages include both cooling (cooling due to the Peltier effect combined with ambient air blowing) and heating (thermoelectric heating) capabilities; efficiency increase in cooling mode due to the use of two methods of heat extraction.

The shortcomings include the need for permanent charging of thermoelectric converters power supply and the demand for heat accumulator replacement.

Model 1.3.5

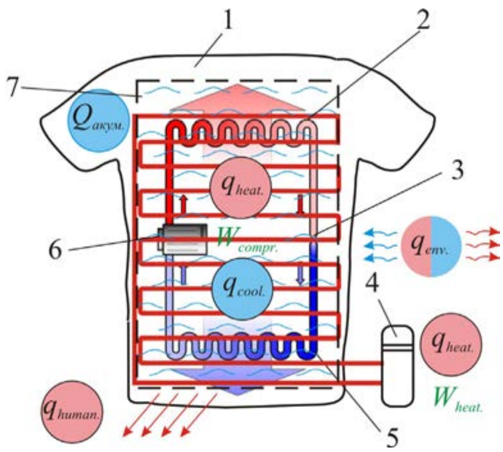

Fig. 25: 1 – garment, 2 – evaporator, 3 – throttle, 4 – electric heater, 5 – condenser, 6 – compressor, 7 – heat accumulator.

Fig. 25 represents a physical model which combines compression heat pump (item 5), heat accumulator (item 1) and electric heater (item 3). The advantages of this method include both cooling (mechanical cooling by compression refrigeration machine combined with heat absorption at substance phase transition) and heating (compression heat pump and electric heater) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating methods. The shortcomings include the need for permanent charging of compressor and heater power supply, the demand for heat accumulator replacement and the presence of harmful coolants.

Model 1.3.6

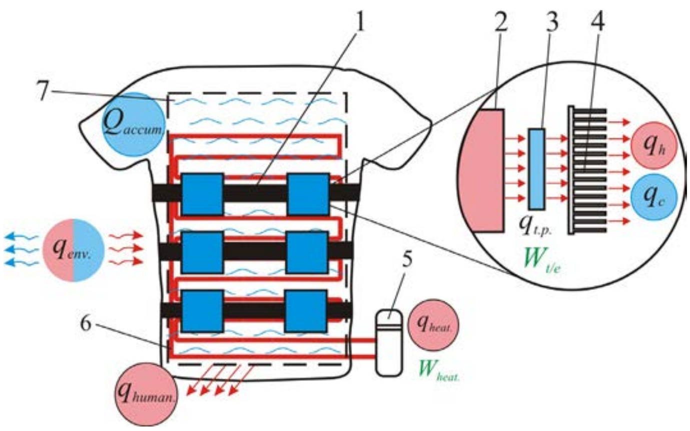

Fig. 26: 1 – garment with fastener system, 2 – member providing for thermal contact of thermoelectric energy converter 3 to garment, 4 – air heat exchanger, 6 – electric heater with power supply 5, 7 – vessel with heat accumulator.

Fig. 26 represents a physical model which combines thermoelectric heat pump (item 6), heat accumulator (item 1) and electric heater (item 3). The advantages of this garment air-conditioning method include both cooling (cooling due to the Peltier effect combined with heat absorption at substance phase transition) and heating (the Peltier effect and electric heater) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of thermoelectric converters and heater power supply, the demand for heat accumulator replacement.

Model 1.4.5

Fig. 27 represents a physical model which combines compression heat pump (item 5), heat accumulator (item 1) and a catalytic heater (item 4). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with heat absorption at substance phase transition) and heating (heat release due to catalytic fuel combustion, heating by compression heat pump) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor power supply, the demand for replacement of heat accumulator and fuel in the heater, the presence of harmful coolants.

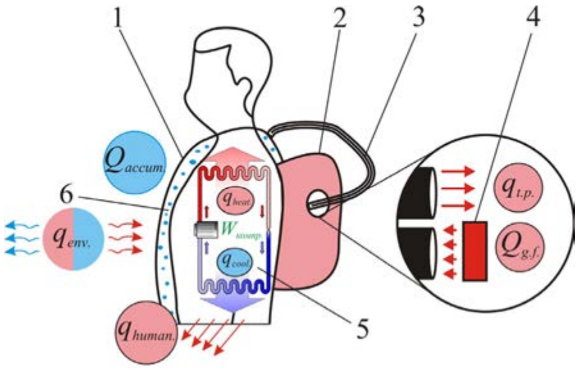

Fig. 27: 1 – garment with air passage channels 3, 2 – unit comprising a catalytic burner 4 with power supply, 5 – compression heat pump, 6 – vessel with heat accumulator.

Model 1.4.6

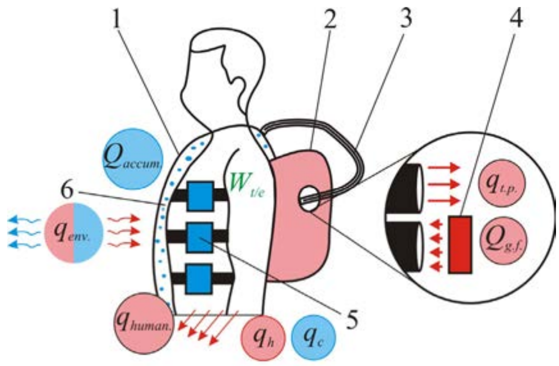

Fig. 28: 1 – garment with channels 3, 2 – unit with a catalytic burner 4, 5 – thermoelectric heat pump, 6 – vessel with heat accumulator.

Fig. 28 represents a physical model which combines thermoelectric heat pump (item 6), heat accumulator (item 1) with a catalytic burner (item 4). Its advantages include both cooling (cooling due to the Peltier effect combined with heat absorption at substance phase transition) and heating (heat release due to catalytic fuel combustion, thermoelectric heating due to the Peltier effect) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor power supply, the demand for replacement of heat accumulator and fuel in the heater, the presence of harmful coolants.

Model 2.3.5

Fig. 29 represents a physical model which combines compression heat pump (item 5), electric heater (item 3) with ambient air blowing (item 2). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with cooled ambient air blowing) and heating (by compression heat pump combined with heat release in current-carrying conductor due to the Joule effect) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor and heater power supply, the presence of harmful coolants.

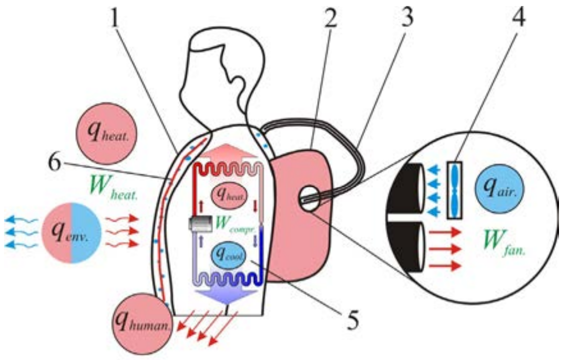

Fig. 29: 1 – garment with air passage channels 3, 2 – unit comprising an electric fan 4 with power supply, 5 – compression heat pump, 6 – electric heater.

Model 2.3.6

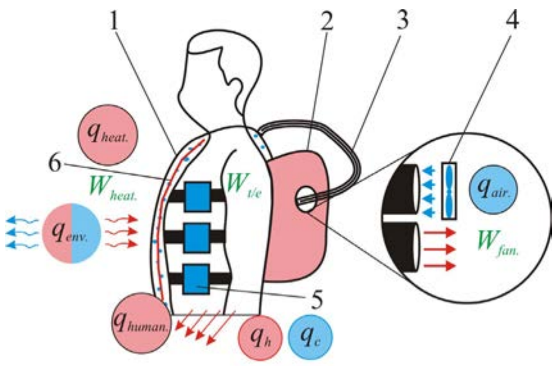

Fig. 30: 1 – garment with channels 3, 2 – unit comprising and electric fan 4 with power supply, 5 – thermoelectric heat pump, 6 – electric heater.

Fig. 30 represents a physical model which combines thermoelectric heat pump (item 6), electric heater (item 3) with ambient air blowing (item 2). Its advantages include both cooling (cooling due to the Peltier effect combined with cooled ambient air blowing) and heating (heating due to the Peltier effect combined with heat release in current-carrying conductor due to the Joule effect) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of thermoelectric converters and heater power supply.

Model 2.4.5

Fig. 31 represents a physical model which combines compression heat pump (item 5), a catalytic burner (item 4) with ambient air blowing (item 2). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with cooled ambient air blowing) and heating (by compression heat pump combined with heat release due to catalytic fuel combustion) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor and heater power supply, the demand for fuel replacement in the burner, the presence of harmful coolants.

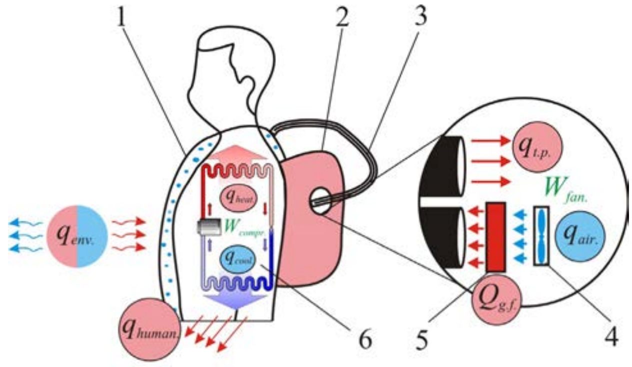

Fig. 31: 1 – garment with air passage channels 3,
2 – unit comprising an electric fan 4 with power supply,
5 – catalytic heater, 6 – compression heat pump.

Model 2.4.6

Fig. 32 represents a physical model which combines thermoelectric heat pump (item 6), a catalytic burner (item 4) with ambient air blowing (item 2). Its advantages include both cooling (due to the Peltier effect combined with cooled ambient air blowing) and heating (by compression heat pump combined with heat release due to catalytic fuel combustion) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of thermoelectric converters and heater power supply, the demand for fuel replacement in the burner.

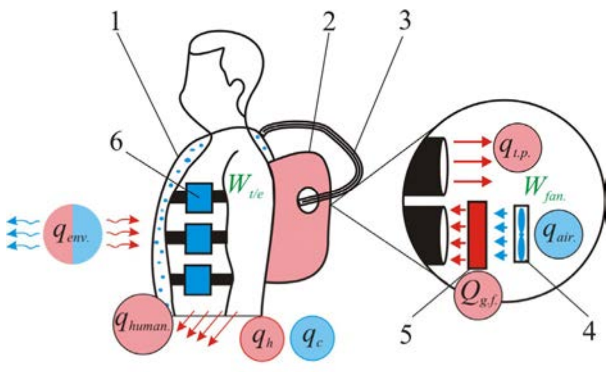

Fig. 32: 1 – garment with air passage channels 3, 2 – unit
comprising an electric fan 4 with power supply, 5 – catalytic heater,
6 – thermoelectric heat pump.

Model 1.2.3.5

Fig. 33 represents a physical model which combines compression heat pump (item 5), electric heater (item 3), heat accumulator (item 1) with ambient air blowing (item 2). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with cooled ambient air blowing and substance phase transition) and heating (by compression heat pump combined with heat release in current-carrying conductor due to the Joule effect) capabilities;

efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor and heater power supply, the demand for heat accumulator replacement, the presence of harmful coolants.

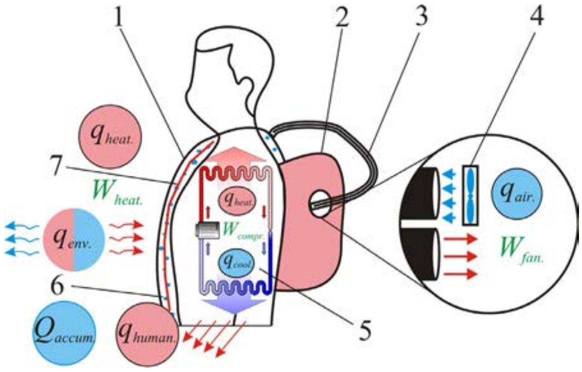

Fig. 33: 1 – garment with air passage channels 3, 2 – unit comprising an electric fan 4 with power supply, 5 – compression heat pump, 6 – vessel with heat accumulator, 7 – electric heater.

Model 1.2.3.6

Fig. 34 represents a physical model which combines thermoelectric heat pump (item 6), electric heater (item 3), heat accumulator (item 1) with ambient air blowing (item 2). Its advantages include both cooling (cooling due to the Peltier effect combined with cooled air blowing and substance phase transition) and heating (heating to to the Peltier effect combined with heatv release in current-carrying conductor) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of thermoelectric converters and heater power supply, the demand for replacement of heat accumulator, the presence of harmful coolants.

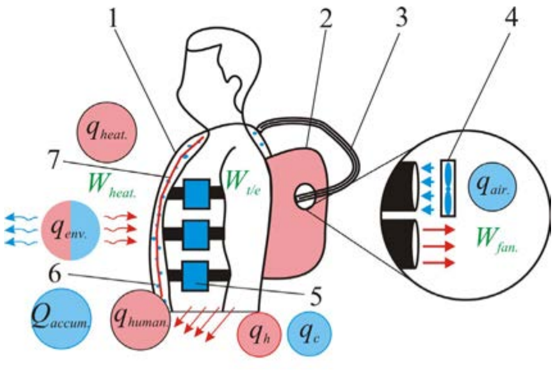

Fig. 34: 1 – garment with air passage channels 3, 2 – unit comprising and electric fan 4 with power supply, 5 – thermoelectric haet pump, 6 – vessel with heat accumulator, 7 – electric heater.

Model 1.2.4.5

Fig. 35 represents a physical model which combines compression heat pump (item 5), a catalytic burner (item 4), heat accumulator (item 1) with ambient air blowing (item 2). Its advantages include both cooling (mechanical cooling by compression refrigeration machine combined with cooled air blowing and substance phase transition) and heating (by compression heat pump combined with heat release due to catalytic fuel combustion) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of compressor power supply, the demand for replacement of heat accumulator and fuel in the heater, the presence of harmful coolants.

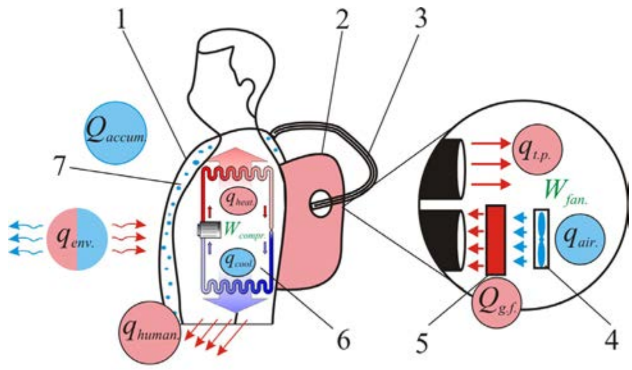

Fig. 35: 1 – garment with air passage channels 3, 2 – unit comprising an electric fan 4 with power supply, 5 – catalytic heater, 6 – compression heat pump, 7 – vessel with heat accumulator.

Model 1.2.4.6

Fig. 36 represents a physical model which combines thermoelectric heat pump (item 6), catalytic burner (item 4), heat accumulator (item 1) with ambient air blowing (item 2). Its advantages include both cooling (cooling due to the Peltier effect combined with cooled ambient air blowing and substance phase transition) and heating (heating due to the Peltier effect combined with heat release due to catalytic fuel combustion) capabilities; efficiency increase in cooling and heating modes due to the use of two cooling or heating modes. The shortcomings include the need for permanent charging of thermoelectric converters power supply, the demand for replacement of heat accumulator and fuel in the heater.

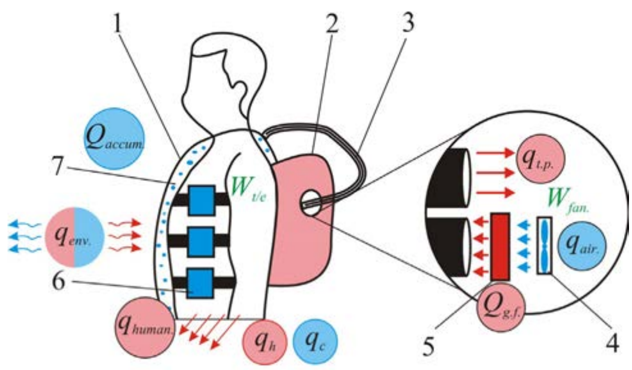

Fig. 36: 1 – garment with channels 3, 2 – unit comprising and electric fan 4 with power supply, 5 – catalytic heater, 6 – thermoelectric heat pump, 7 – vessel with heat accumulator.

The analysis of the above described physical models of personal air-conditioners for garment has proved their advantages which makes promising their further study. The results of investigations of such air-conditioners will be presented in the second part of this work.

Conclusions

1. The features of physical models of personal air-condioners for garment have been analyzed and their detailed classification has been developed.

2. 63 variants of physical models of personal air-conditioners for garment have been proposed, of which only 12 have been studied to date.
3. Analysis of physical models of air-conditioners for garment has enabled us to single out 23 combinations of models that are promising for investigation and practical implementation.

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