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INDIVIDUAL AIR-CONDITIONERS FOR DOCTORS' CLOTHES

The paper discusses the possibility of using individual conditioners for doctors' clothes. Their use will improve the temperature conditions for the stay of medical personnel during long-term operations. To determine the most rational options for using these air conditioners, their physical models have been developed, and the advantages and disadvantages of the known options for individual conditioners for doctors' clothes have been analyzed. The paper also considers the prospects for the use of thermoelectric air conditioners.

Key words: air-conditioner for clothes, thermoelectric air-conditioner, thermal conditions, phase transition, doctor's clothes.

Introduction

General characterization of the problem. In recent years, extensive research has been pursued on the study of individual air conditioners for humans. Thus, in [1] their classification by air conditioning method and purpose was carried out. As a result of this classification, almost 20 new design features of air conditioners have been found, which can be useful in the development of air conditioners for both mass and special purposes. From the proposed classification, depending on the areas of application, individual air conditioners for doctors were identified as particularly promising. At the same time, their detailed study was not carried out in the work.

With the development of medical technology, modern methods of performing operations without incisions (radiosurgery, angiography, laparoscopy, etc.) are becoming more widespread [2]. At the same time, surgeons, nurses and technologists working with X-ray control methods are increasingly exposed to radiation hazards. To protect against radiation, medical personnel use special radiation-protective clothing [3]. With long-term use of such clothing, a problem arises that due to the lack of ventilation between the body and clothing, a significant overheating of the body occurs, which leads to increased fatigue and the inability to perform the assigned work [4].

To solve this problem, individual air conditioners are used. In [5 – 7], various options for the implementation of air conditioning are considered depending on the type of refrigeration or various design features. The most common options for providing air conditioning for medical staff are the use of phase transition and ambient air, on the basis of which real air conditioners are developed [8]. Also promising is the use of air conditioning with thermoelectric converters. This is due to the presence of a number of advantages in such converters, namely: high reliability, the ability to provide both cooling and heating, the absence of harmful refrigerants, low maintenance costs, the ability to adjust the temperature in a wide range [9]. But with all these advantages, this type of conditioning has no real application.

Analysis of the literature. Today, the problem of air conditioning of clothes is solved by various methods. In particular, the known methods are based on the use of substances with high heat capacity; on the phase transition of a liquid (evaporation of water); on the use of ambient air and on cooling and heating due to thermoelectric effects.

In [4], a project is presented, the purpose of which was to develop a cooling vest using phase change material to increase the thermal comfort of the surgeon. This air conditioner provided some improvement in temperature conditions, but all results were based only on the subjective assessments of the surveyed medical workers. In addition, the design of such a vest was imperfect due to the low cooling efficiency and the need for constant replacement of the cooled elements.

In [5], designs of radiation protective clothing were proposed in which the solution to the problem of the level of protection against radiation, rather than the efficiency of cooling, is described in more detail. Therefore, there is a need for further study of this issue.

In [10], clothes with cooling for doctors are described, based on the absorption of thermal energy as a result of the phase transition of a substance. Such clothes are designed in the form of vests with channels filled with a special liquid (water, gel, etc.). Cooling in this case is carried out by evaporation of the liquid through a special porous outer surface of the air conditioner.

In [11], the method of cooling the body by blowing it with ambient air was used. Such an air conditioner is produced in the form of overalls with channels for the passage of air, which is forced into the clothes by an electric fan.

In [12 – 14] the possibility of using thermoelectric conditioners for clothes is considered. In most cases, such air conditioners are Peltier modules located in clothes (or in special devices that are attached to clothes), which cool or heat clothes depending on the direction of the electric current.

All of these options for individual conditioners for doctors' clothes have their own advantages and disadvantages. Therefore, it is important to consider the known methods of conditioning the clothes of doctors and determine the most promising of them.

The purpose of the proposed work is to determine the most rational options for known individual air conditioners for doctors' clothes and to study the possibility of using thermoelectric air conditioners.

Known options of individual air-conditioners for doctors' clothes

The most defining feature that distinguishes individual air conditioners from each other is the type of heat or cold sources. The efficiency of air conditioners depends on them in the first place. Among the main options are: the use of *heat and cold accumulators* (*with the presence of phase transitions of substances*); use of *ambient air* (*with the presence of electric fans*); use of an *electric heater*; use of a *catalytic heater*; the use of a *compression heat pump*; and the use of a *thermoelectric heat pump.* It is also possible to combine the above sources of heat and cold [1].

Today there are a number of companies that develop individual conditioners for doctors' clothes. Basically, these air conditioners use three types of cooling: the use of *heat and cold accumulators*; using *ambient air* and using *liquid cooling in combination with a heat pump*.

To determine the most rational options for individual conditioners for doctors' clothes, we will consider their real implementations and carry out a comparative analysis of their main parameters.

The Japanese company Kuchofuku Co. Ltd develops cooling clothing based on the intensification of heat exchange by air fans. The main product is an air-conditioned shirt. The use of such a shirt makes it possible for a long time to provide comfortable conditions for medical personnel, since the fans are connected to a lithium-ion battery pack, which can operate for up to 24 hours on a single charge, depending on the cooling mode [15]. The physical model of such clothing is shown in Fig. 1.

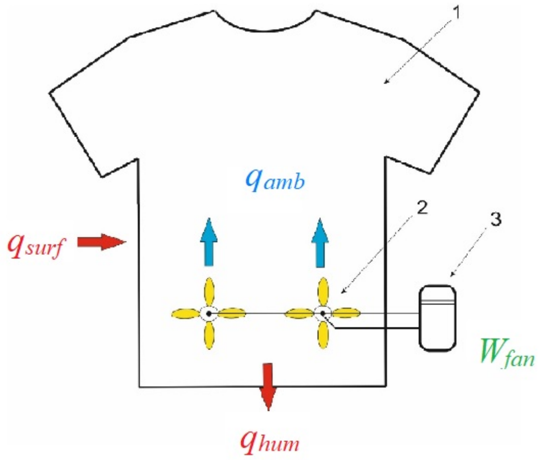

Fig. 1. Physical model of air conditioner for clothes using ambient air (fans): 1 - conditioned clothes; 2 - a system of electrically coupled fans; 3-power supply.

Where q_{hum} is the power of heat release from the human body; $q_{amb.}$ is the power of heat release from the ambient; $q_{surf.}$ is thermal power removed to the ambient; W_{fan} is power of the fan.

There are samples of special clothes for doctors, developed by the American company Coolshirt Systems. Their products are vests that are connected to special cooling systems. Further, these systems supply water with adjustable temperature to the vest to create optimal temperature conditions [16]. Such products are ideal for surgeons and medical staff while working in any operating room.

The products of the American company Polar Products are developed in a similar way. A special system for the surgeon's cooling consists of a cooling vest in which more than 15 meters of thin tubes are connected, through which the flow of cooling water passes. The system also includes a waterproof cooling tank, special couplings and insulated water pipes. For convenience, when transporting the tank, a wheeled cart is used [17]. The physical model of such variants of individual conditioners for doctors' clothes is shown in Fig. 2.

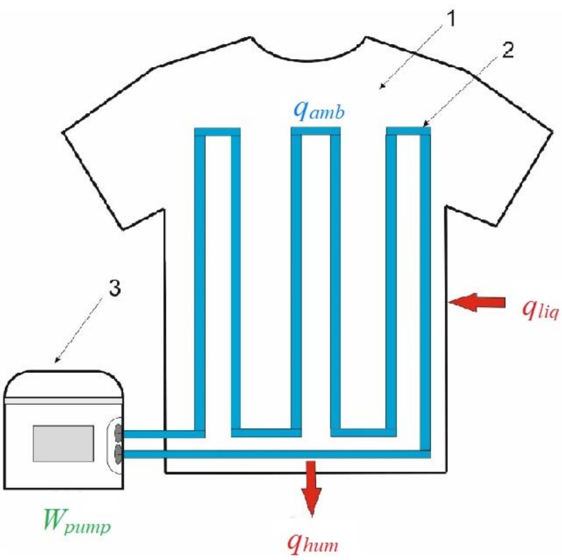

Fig. 2. Physical model of air conditioner for clothes using a circulating fluid system: 1 - conditioned clothes; 2 - a system of pipes through which chilled liquid circulates; 3 - a cooling tank with a pump.

Where q_{hum} is the power of heat release from the human body; q_{amb} is the power of heat release from the ambient; q_{liq} is thermal power removed to the ambient; W_{pump} is the power of the pump.

The most common type of cooling is the use of phase transition of the substance (Fig. 3). The following companies use this method: the German company E.COOLINE [18], the American company TechNiche [19], the Dutch company INUTEQ B.V [20] and the American company StacoolVEST [21]. Although the products of such companies have the same type of cooling, but the parameters of air conditioners can be quite different. First of all it depends on the working substance which will be used by conditioners, and also on the design features.

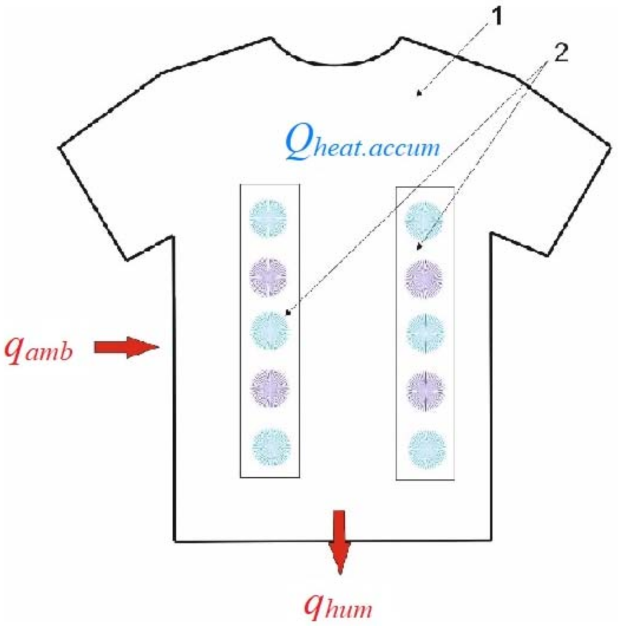

Fig. 3. Physical model of air conditioner for clothes using phase transition (cooling mode): 1 – conditioned clothes; 2 – cooling packages with a working substance (heat accumulator).

In Fig. 3: q_{hum} is the power of heat release from the human body; q_{amb} is the power of heat release from the ambient; $Q_{heat.accum}$ is the amount of heat absorbed by the working substance (heat accumulator).

Based on the products of the companies reviewed, Table 1 was created, which contains the main parameters of individual conditioners for doctors' clothes. As you can see, the parameters of various air conditioners can vary both within wide limits and in an insignificant range. One of the main parameters, the cooling temperature, in all the options presented is almost the same. That is, each air conditioner can provide approximately 10 °C cooling, which is sufficient. Despite this, there is a significant difference in weight, operating time and cost of air conditioners.

The *Coolshirt Systems* and *Polar Products* options are the most expensive, but they can still provide continuous cooling as they can be operated directly from an outlet. If necessary, there is a possibility of autonomous operation from batteries with a working time of about 6 hours. The weight of such air conditioners is not the largest, even taking into account the tubes that are located over the area of the clothing. A version of the air conditioner from Kuchofuku Co. Ltd is the most rational choice when considering cost and weight, as these figures are the smallest compared to others. At the same time, the operating time of such air conditioners is also one of the highest among those reviewed.

A wide range of phase change refrigeration air conditioners can compete with other options primarily due to cost and weight, and also due to the simplicity and reliability of the design itself. One of the significant drawbacks is the operating time, which strongly depends on environmental conditions (temperature, humidity).

Table 1

Parameters of individual air-conditioners for doctors' clothes

№	Companies that develop air-conditioners	Cooling type	Cooling type	Working time (h)	Mass (kg)	Cooling temperature (°C)	Working range (°C)	Electric components	Price ($)
1	Kuchofuku Co. Ltd (Japan) [15]	Air-conditioning using ambient air (with the availability of fans).	Body	8-24	0.5	5-10	15-35	Battery (6500 mA)	200
2	INUTEQ B.V. (Netherlands) [20]	Liquid cooling (working substance - water).	Body	8-48	0.7	5-10	20-25	-	150
3	E.COOLINE (Germany) [18]	Evaporative cooling	Body	2-24	1	Up to 12	24-32	-	150-200
4	TechNiche (USA) [19]	Liquid cooling with the use of a pump	Abdomen, chest, back	from 6	1	5-10	15-30	Power supply (12 V and 3 A)	1000
5	TechNiche (США) [19]	Cooling based on phase transition	Body	2-3	1-1.5	Up to 10	from 14	-	400
6	COOLSHIRT SYSTEMS (USA) [16]	Liquid cooling with the use of a pump.	Body	from 6	1.5-2	5-8	18-32	2A / 12B	1500
7	StacoolVEST (USA) [21]	Cooling based on phase transition	Body	1-3	2-2.5	5-10	20-30	-	190

Thermoelectric air-conditioners for doctors' clothes

As noted above, thermoelectric conditioners for doctors' clothes have no real use in practice. At the same time, work is underway to make it possible to manufacture various design options for such air conditioners. It follows from the analysis of the literature that only three possible variants of thermoelectric air conditioners for doctors' clothes are mainly considered. All of them differ in the arrangement of thermoelectric converters - in a special backpack behind clothes, over the entire surface of clothes and in a device that acts only on the corresponding part of the human body. To further determine the advantages and disadvantages of each of the options, we will consider them in more detail based on known works.

Option A

The arrangement of thermoelectric converters in a special backpack behind clothes was studied in [22]. The air conditioner belongs to a surgical suit that provides a high degree of cooling and sterility. It includes a hood and vest that are loosely attached to the user's head and body, respectively. The hood has a large visor through which the user can see freely. The body is located above the user's head and under the hood. At the same time, it carries a significant part of the weight of the hood and is supported above the user's head by means of vertically extended support rods that are connected to the backpack. The casing houses a fan and a thermoelectric module. An exhaust fan is part of the backpack and forces air to be drawn in through the filter and then flow past the user's face. A fan in the backpack draws air downward around the user's upper body and expels it out of the vest through a filter.

This air conditioner is quite difficult to implement. At the same time, it is inappropriate to use it together with radiation-protective clothing. First, it is quite large, which is a significant disadvantage, as it is an additional burden on the surgeon, who already wears heavy radiation-protective clothing. Secondly, the cooling in this embodiment occurs from the outside of the user, which is inefficient for the torso, which is under clothing. The latter problem is solved by supplying cooled air from the backpack directly under the clothes, using a system of special channels. But at the same time it is necessary to understand the complexity of such a design in the implementation.

Option B

The next possibility of realizing a thermoelectric air conditioner for doctors' clothes is the use of thermoelectric converters, which are placed directly in the clothes. The physical model of this option is shown in Fig. 4. Where q_{hum} is the power of heat release from the human body; q_{amb} is the power of heat release from the ambient; q_x is thermal power absorbed on the cold side of thermoelectric converter; $W_{t/e}$ is the power supplied to thermoelectric module.

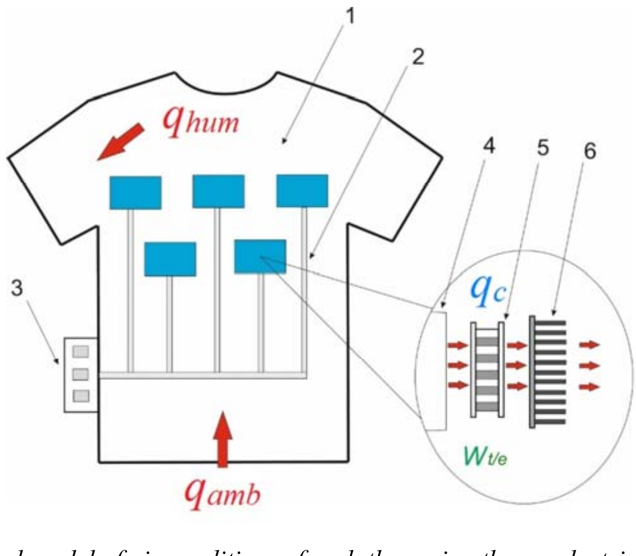

Fig. 4. Physical model of air conditioner for clothes using thermoelectric modules located on the area of conditioned clothes (cooling mode): 1 – conditioned clothes; 2 – electric connections; 3 – power supply; 4 – element for providing thermal contact; 5 – thermoelectric module; 6 – air heat exchanger.

The cooling system contains several thermoelectric modules, which are located in the area required by the user. They are then electrically connected to a DC power supply. On the cold side, the thermoelectric module is connected to the element to ensure thermal contact, and on the hot side - to the air heat exchanger to dissipate unnecessary heat into the environment.

The disadvantage of this air conditioning option is primarily associated with the removal of excess heat, since for high cooling efficiency it is assumed to use a thermoelectric air conditioner under radiation protective clothing. In this case, unnecessary heat from the hot surface of the module will not be dissipated into the environment, which negatively affects the overall cooling effect. In this case, the use of thermoelectric air conditioning on top of radiation-protective clothing will also lose in cooling efficiency. It is impractical to change the design of the radiation-protective clothing. For example, if you make extra holes in such clothes, you can solve the problem of removing excess heat. But it should be understood that this will reduce the ability of such clothing to perform its basic functions, namely the protection of medical personnel from radiation.

Option C

The third option of thermoelectric air conditioning is to create a special air conditioner that will cool only the relevant part of the human body. First of all, this means conditioning the head or neck.

Figs. 5 and 6 show physical models of thermoelectric device for cooling the neck and head of a person, respectively. Where q_{hum} is the power of heat release from human body; q_{amb} is the power of heat release from the ambient; q_c is thermal power absorbed on the cold side of thermoelectric converter; $W_{t/e}$ is the power supplied to thermoelectric module.

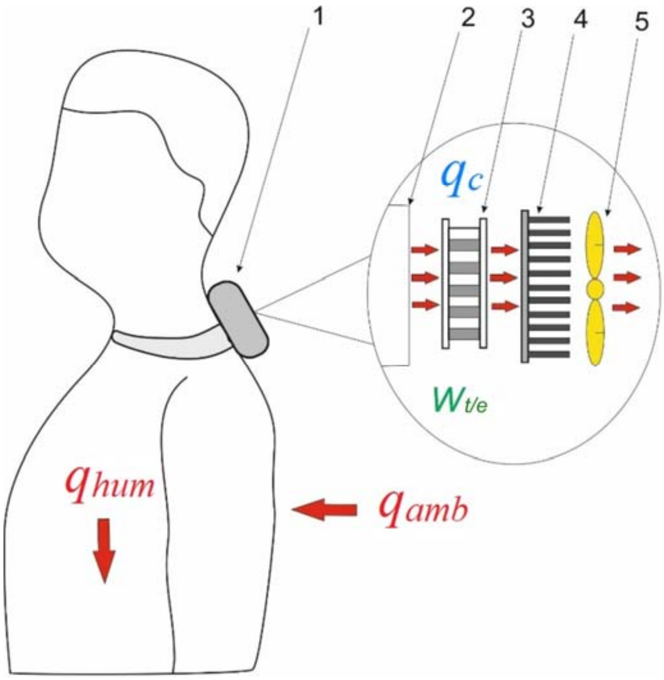

Fig. 5. Physical model of air conditioner for clothes using thermoelectric device with a directed action on neck area (cooling mode): 1 – thermoelectric device; 2 – element for providing thermal contact; 3 – thermoelectric module; 4 – air heat exchanger; 5 – fan.

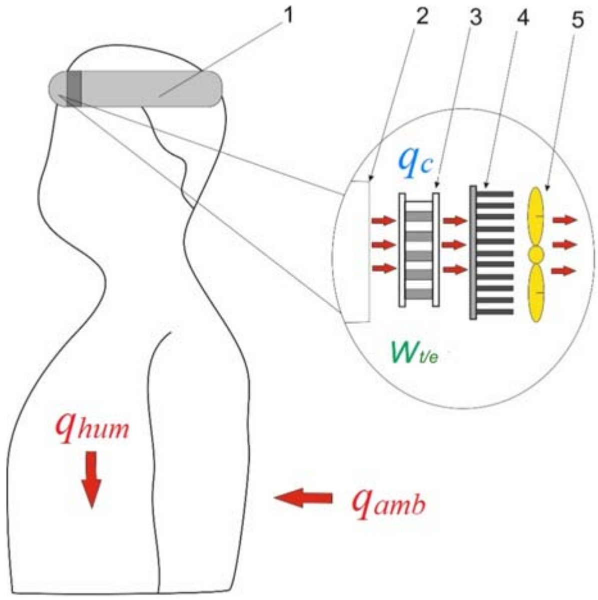

Fig. 6. Physical model of air conditioner for clothes using thermoelectric device with a directed action on head area (cooling mode): 1 – thermoelectric device; 2 – element for providing thermal contact; 3 – thermoelectric module; 4 – air heat exchanger; 5 – fan.

The thermoelectric device consists of a heat dissipation element that fits around the user's neck. The thermoelectric module, operating at low current and low voltage, is thermally connected on one side to the rear surface of the element, and on the other to an air heat exchanger. The presence of a fan allows efficient heat dissipation to the environment. A battery can be used to power the thermoelectric module.

The work [23] studied a thermoelectric device that corresponds to this option. The invention is a self-contained device that can be sized to fit the user's neck or forehead (or other body part) to provide cooling or heating. The device operates in a dry state, that is, without the need for any external coolant. It includes a thermal contact element that absorbs or dissipates heat. The surface of this element is directed towards the user and is pressed against the corresponding area of the human body. The Peltier thermoelectric module is in thermal contact with the surface of this element. The device preferably includes a power supply from a low voltage battery, a fan and the corresponding electronic circuits, and also provides temperature control on the element that absorbs / dissipates heat to select the operating mode. There is also an air heat exchanger, which allows you to effectively dissipate unnecessary heat. The device operates at low voltage and low current, but achieves a fairly efficient operation. The electronic circuits that are housed in this invention control the precise degree of heating or cooling and make compensatory changes, if necessary, in the power supply to reach a user-selected temperature. In cooling mode, the thermoelectric device will dissipate heat, thus cooling the user. The fan diverts heat flow from the air heat exchanger, which, in turn, leads to greater cooling of the surface returned to the user. As a result, effective cooling of the corresponding area of the human body is achieved.

Another variant of head cooling was studied in [24]. The invention relates to a new and useful personal protective system, such as the type of system used to provide a sterile barrier between medical staff and the patient. In this case, the system can operate in cooling mode, which is realized through the use of a cooling strip located in the headdress. Such a strip includes Peltier thermoelectric modules that are attached to a flexible strip. There are also conductors, which are built into a flexible tape, through which current is supplied to thermoelectric modules. The presence of two sensors allows you to control the surface temperatures of the modules. The use of radiators and fans provides greater cooling efficiency. The modules and fans are powered by the battery. If necessary, the cooling strip can be placed not only in the hat, but also in other possible clothing options.

In [25], a personal heat control device is considered. The invention has many application aspects. It can be a stand-alone device or integrated into an accessory. One of the options for its use is to cool the human head. The device is made in the form of a helmet and contains thermoelectric modules, which are attached to the user's head thanks to an elastic band. At the same time, the cooling surfaces of the modules are directed towards the user's head, and the heating surfaces are directed away from the head. The heat pipes are thermally connected to the hot side of the modules at one end and to the heatsink at the other. They provide heat transfer from one place to another with minimal losses. The design of the device also provides a place for one or more power sources. Current is supplied to thermoelectric modules through electrical conductors, which can travel the same path as heat pipes.

The use of option C as thermoelectric cooling allows solving the problems that arose in the previous two options. At the same time, the cooling efficiency will be less, but still sufficient to ensure optimal conditions for the stay of medical personnel.

In general, the development of a thermoelectric air conditioner for doctors' clothes is very promising. All variants of such air conditioners considered in the work have their own advantages and disadvantages. To cool medical personnel who use radiation-protective clothing, it is most appropriate to choose a thermoelectric conditioner for clothing with conditioning only a certain part of the human body. At the same time, solving some of the described shortcomings of options A and B will allow to obtain air conditioners that will be on a par with the known individual air conditioners, or even outweigh them.

Conclusions

1. The use of liquid-cooled air conditioners is the most rational for the development of a self-contained and efficient air conditioning system that can be used by medical personnel in any operating room. This is achieved due to continuous running time and low cooling temperature. At the same time, their price is higher than the other options considered. Therefore, it is rational to use air conditioners based on phase transitions and air conditioners with air cooling, which are less efficient in air conditioning, but win in price.
2. Among the thermoelectric conditioners for doctors' clothes, the most expedient from the point of view of general efficiency is option C. Such a conditioner allows solving the shortcomings related to the mass and removal of excess heat from the hot side of the thermoelectric module.
3. It is also expedient to study thermoelectric air conditioners, which are presented by options A and B. Today, their efficiency is not high enough, but solving these problems will allow such air conditioners to compete with other individual air conditioners, or even outperform them.

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