June 30, 1959 H. R. SCHELP 2,892,322

AIR CYCLE AIR CONDITIONING SYSTEM

Original Filed Oct. 14, 1949 2 Sheets-Sheet 1

Fig. 1.

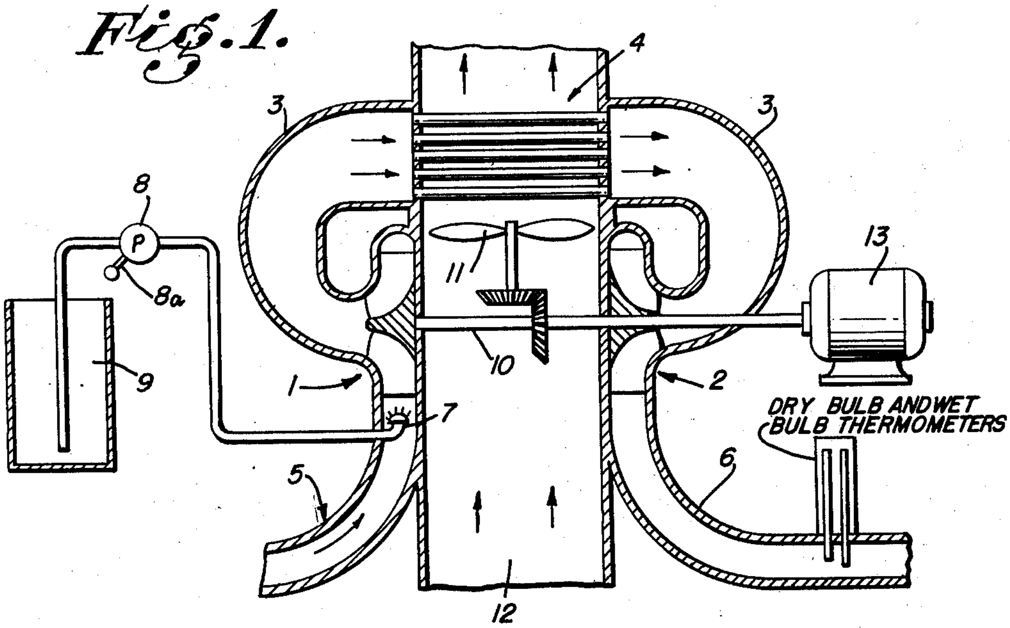

Fig. 2.

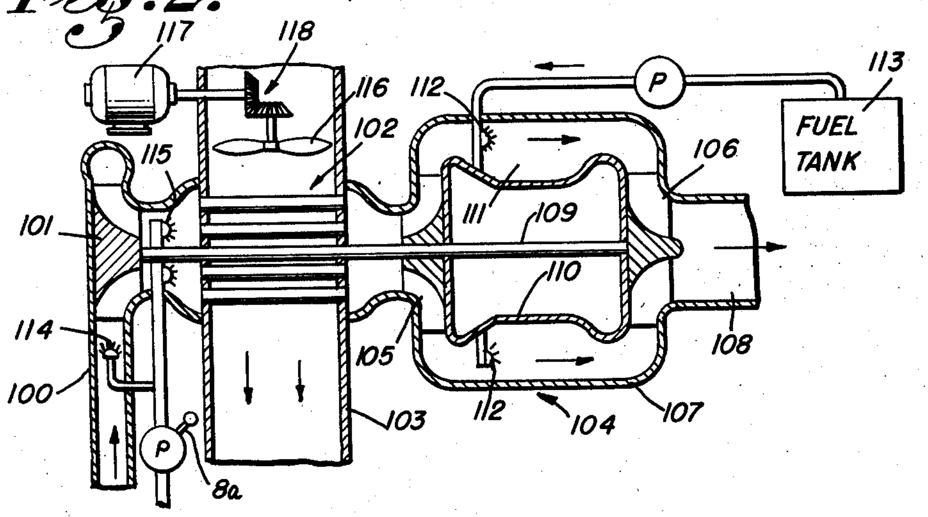

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Fig. 3.

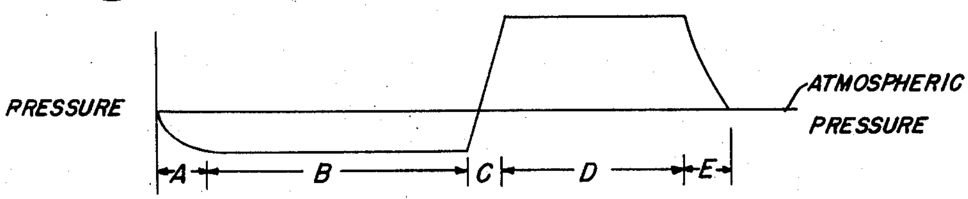
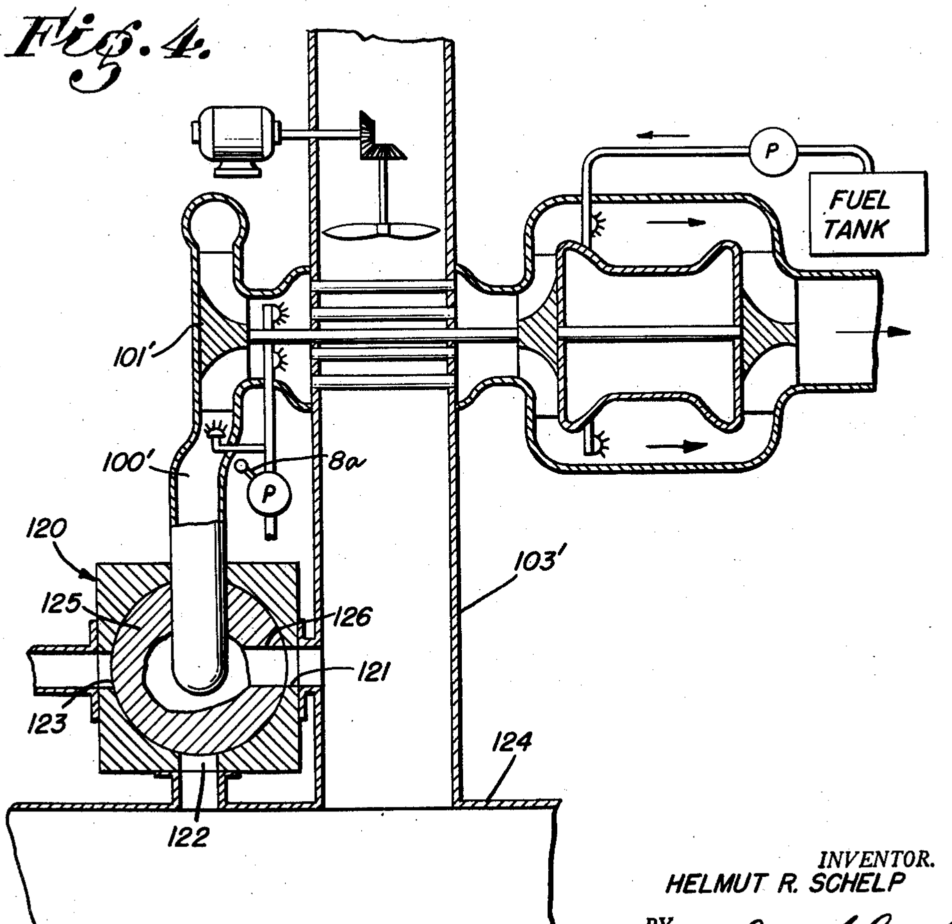


Fig. 4.



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AIR CYCLE AIR CONDITIONING SYSTEM

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Original application October 14, 1949, Serial No. 121,436, now Patent No. 2,730,874, dated January 17, 1956. Divided and this application December 12, 1955, Serial No. 552,337

3 Claims. (Cl. 62—314)

This is a divisional application based on Figs. 1, 7, 7*a* and 8 of my copending application, Serial No. 121,436, filed October 14, 1949, for Air Conditioner Employing an Expansion Evaporation Air Cycle, now issued as Patent No. 2,730,874.

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without the payment to me of any royalty thereon.

The present invention relates to a system of air conditioning including a working air cycle which takes advantage of expansion for initial cooling of the working air and which further takes advantage of evaporative cooling as the working air passes through a heat exchanger to avoid any appreciable temperature increase of the working air during the heat transfer phase.

An object of the invention is to provide a system of air conditioning in which a working air path includes an expansion device near the air inlet, water sprays before, within or after the expansion device, a heat exchanger after the expansion device and a suction device after the heat exchanger to maintain a partial vacuum between the expansion and suction devices, and in which a conditioning air path includes the heat exchanger, suitable ducting and means to cause movement of conditioning air in desired volume for proper ventilation and cooling of a room or other space.

Another object of the invention is to provide a system of air conditioning in which a working air path includes an expansion turbine near the air inlet, water sprays before the expansion turbine, a heat exchanger after the expansion turbine and a suction blower deriving a part of its power requirements from the expansion turbine and acting to draw the working air through the expansion turbine and heat exchanger and to maintain sub-atmospheric pressure between the expansion turbine and suction blower, and in which a conditioning air path includes the heat exchanger, suitable ducting and means to cause movement of conditioning air in desired volume for proper ventilation and cooling of a room or other space.

Fig. 1 is a schematic diagram in central cross-section of an air conditioner in one preferred form of the invention;

Fig. 2 is a schematic diagram in cross-section of an air conditioner employing two expansion turbines and a coupled air compressor;

Fig. 3 is a gas pressure diagram to show the relative pressure values through the apparatus of Fig. 2; and

Fig. 4 is a schematic diagram in cross-section of an air conditioner similar to that of Fig. 2 but including an air selector valve at the inlet side of the first expansion turbine.

In general the systems disclosed include two separate air flow paths, namely the working air flow path and

the conditioning air flow path. The working air flow enters the apparatus at atmospheric pressure but by reason of a suction device near the air outlet the pressure within the apparatus is below atmosphere. Thus the system used may be termed an expansion evaporation vacuum air cycle, because the working air path is at a partial vacuum during a substantial portion thereof. By providing an expansion device such as an expansion turbine near the inlet end of the working air path, a pressure drop thereacross causes the air to be expanded and cooled because of the loss of kinetic energy and at the same time the energy given up by the air may perform useful work in driving the expansion turbine. Before, during or after the air expansion phase, water or other liquid is sprayed into the working air in the form of a fine mist and the intimate contact of air and water provides further cooling of the air by evaporative cooling. As the working air proceeds through a heat exchanger to provide for cooling of the conditioning air it becomes progressively warmer. Each increment of temperature increase causes further evaporation of water or other liquid evaporant and this action in turn extracts heat from the working air, thus tending to maintain the working air temperature constant through the heat exchange phase of the air cycle. Some additional moisture is evaporated in passing through the suction device, thus reducing the power consumed thereby. Just enough water or liquid is sprayed into the working air to result in complete saturation thereof by the time the air flow is leaving the suction device. Any excess will increase the mass of flowing air and cause the suction device near the outlet end of the working air path to consume more power in drawing a vacuum. By the same token water or liquid sprayed into the working air before it enters the expansion turbine will result in more power output from the turbine and will also permit more time of contact between the air and liquid to provide for more efficient cycle operation.

In Fig. 1 there is shown a preferred air cycle system wherein the working air path includes an expansion turbine **1** and a suction blower **2** connected by conduits **3** and a heat exchanger **4**. The working air flow enters the apparatus by a conduit **5** and leaves by a conduit **6**, from which it is discharged to the atmosphere. The working air entering at conduit **5** will ordinarily be from the free atmosphere or from the room being air conditioned. Upstream of expansion turbine **1** is a water spray nozzle **7** connected to a pump **8** and a supply of water **9**. The turbine **1** and blower or compressor **2** are interconnected by a drive shaft **10** from which power may be taken to drive a fan **11** for moving the conditioning air flow through duct **12** on its way to the room being air conditioned or cooled. As the air in duct **12** moves in the direction of the arrows it passes around the tubes of heat exchanger **4**, which are normally at a lower temperature than the conditioning air flow. Thus the conditioning air becomes cooled and also loses some of its moisture content by condensation on the cold tubes of the heat exchanger. The drive shaft extends outside the air conditioning apparatus for connection with a prime mover or motor **13**. The motor supplies power to assist in driving the fan **11** and the blower **2**, although it should be understood that some power is derived from the expansion turbine **1**.

The apparatus or system of Fig. 1 operates on what may be termed an expansion evaporation air cycle. The air flow in conduit **5**, which is at atmospheric pressure whether it comes from the free atmosphere or from the conditioned room, acts to rotate the impeller of expansion turbine **1** and thus gives up some of its heat energy thereby cooling down. The exhaust side of turbine **1** is at a negative pressure because of the suction fan or blower **2**, and therefore the working air entering at **5** exerts a driving effect on the turbine impeller. Before entering the turbine, the working air picks up moisture in passing the spray nozzle **7**, whereby its mass is increased for greater energy output from the turbine **1**. The air carrying excess water over that required for saturation enters the heat exchanger tubes at a temperature determined by the energy extracted in going through the turbine. Also a small temperature decrease may be due to evaporating moisture while moving from the turbine to the heat exchanger. In passing through the heat exchanger the working air becomes warmed up by heat transfer through the tube walls but any increase in temperature enables the working air to evaporate more water thus tending to lower the air temperature. The result is that the tendency to warm up the air by heat transfer is balanced out by loss of heat by evaporation of more water, since as is well known the moisture content of saturated air increases with increase in temperature. The temperature of air entering the heat exchanger is accordingly maintained through the exchanger by reason of the evaporative cooling effect. Now the air which is still supersaturated flows to the compressor **2** where work is done on the air tending to increase its temperature. It is now capable of evaporating still more moisture and its temperature rise through the compressor is held to a minimum and the work required of the compressor is minimized to some extent. The reason for this is obvious when it is realized that increase in temperature of a working medium, such as a gas or fluid, always means that work is being done to bring about the temperature rise. The water flowing to spray nozzle **7** may come from a reservoir **9** and be pumped by any type of pump **8**. The pressure of the water may be regulated by the pump in order to deliver a controlled volume of water to the working air flow. The ideal situation, and that which dictates the rate of water flow through the spray nozzle **7**, is one where the working air leaving the blower or compressor **2** is saturated but carries no excess moisture. In keeping with the foregoing I have shown a regulating handle *8a* for the pump P so that it may be adjusted to deliver an amount of water just sufficient to produce total saturation of the working air, as indicated by the thermometric means disposed downstream from the heat exchanger **4**. Any increase in moisture content over this ideal amount will tend to increase the power consumption of the blower **2** and also cause needless consumption of water. In passing through the blower **2** the pressure of the working air is boosted to slightly above atmospheric and then the air is discharged by conduit **6** to the ambient atmosphere. From the above explanation it will be seen that the cooling of the working air through the apparatus is due to extraction of heat energy in the expansion turbine **1** and to the extraction of heat energy by evaporation of moisture from the water sprayed through the nozzle **7**. The room conditioning air passing along duct **12** is cooled and dehumidified by passage over the relatively cold tubes of heat exchanger **4** before being conducted to the room or space to be conditioned. If the working air supply is taken from the conditioned space so that it will be cooler and dryer than outside air, then it may be desirable to take most of the conditioning air from the ambient atmosphere. The term air conditioning in the present description implies the cooling and dehumidifying of controlled quantities of air and conducting the air to a room, cabin or space to be air conditioned for increasing the comfort conditions in enclosed spaces during hot weather or to control the air conditions for the benefit of specific processes or manufacturing operations being carried out in enclosed spaces.

The aircycle system as illustrated in Fig. 2 is similar in some respects to that of Fig. 1 but embodies a special type of suction blower drive making use of the working air flow. The working air flow enters the apparatus by the suction pipe or conduit **100** and then passes through the expansion turbine **101**, where a temperature drop in the air occurs. The air then passes through the heat exchanger **102** mounted in the main air duct **103**, and then flows into a self-contained unit **104** combining both a compressor **105** and a combustion gas turbine **106**. The unit **104** is enclosed in a cylindrical housing **107** having an open outlet end **108** for the free discharge of the working air and combustion gases therefrom. A drive shaft **109** connects together the low pressure expansion turbine **101**, the compressor **105** and the high pressure combustion turbine **106**, whereby power derived from the two turbine components may be used to drive the compressor or blower **105**. Between the outer wall **107** and inner wall **110** of the compressor-turbine unit **104** there is provided an annular combustion chamber **111** wherein is located fuel spray nozzles **112** supplied with liquid fuel from a fuel tank **113**. In the air intake conduit **100** is a water spray nozzle **114** and after the expansion turbine, that is downstream thereof and directed into the heat exchanger **102** are other water spray nozzles **115**. The spray nozzles **114** and **115** are fed with water by a variable pump P having a regulating lever **8***a*. In order to maintain conditioning air flow in the main air duct **103** there is provided a fan **116** driven by a motor **117** and bevel gearing **118**.

The operation of the system of Fig. 2 is a little more involved than the previously described systems. The working air flow first picks up some moisture at the nozzle **114** and then delivers energy to the expansion turbine **101**, whereby a substantial temperature drop in the working air occurs. The air then picks up more moisture at the nozzles **115** and passes through the heat exchanger **102** to cool the tubes thereof. As in the other forms of the invention the excess moisture carried over beyond that required to lower the air temperature to the wet bulb level is useful in maintaining a lower air temperature through the heat exchanger since a rise in air temperature enables the evaporation of more moisture and a corresponding tendency to lower air temperature. The air now passes to the compressor **105** which functions to maintain air flow through the expansion turbine **101** and heat exchanger **102**, as well as to deliver compressed air to combustion chamber **111**. Here the fuel from the fuel spray nozzles **112** burns with the consequent rapid expansion of air and gases and as a result of the flow of hot gases from the combustion chamber, the turbine **106** is rotated for the delivery of power to the compressor **105**. It is understood that the expansion turbine **101** produces power for the compressor operation also but its power output will be smaller than that of the combustion turbine **106**. The conditioning air flow through the duct **103** in the direction of the arrows is cooled and dehumidified in passing over the tubes of the heat exchanger **102** before flowing to the room to be air conditioned.

Attention is further directed to Fig. 3 to show the comparative pressure changes through the air cycle system of Fig. 2. Considering the horizontal base line as atmospheric pressure, the pressure curve first covers part A where pressure is decreasing below atmospheric pressure from the inlet to the outlet of expansion turbine **101**. This below atmosphere is produced by the suction effect of compressor **105**, and is maintained as the working air passes through the tubes of heat exchanger **102**, that is part B of the pressure curve. Over part C of the pressure curve the air goes from the negative pressure level to a comparatively high positive pressure level in passing through the compressor **105**. This level is maintained fairly constant throughout the combustion chamber **111**, as shown by part D of the curve, but in delivering power to turbine 106 the pressure is brought back to an atmospheric level for discharge from the turbine tail pipe 108. This pressure drop during power delivery is shown by part E of the pressure curve. The system as shown and described in compact and adapted for many special applications, either large or small in requirements.

The system of Fig. 4 is essentially a duplicate of that shown in Fig 2 but further includes a selector valve 120 for providing three possible variations in the character of the intake air for the expansion turbine 101'. The valve 120 has three inlet openings 121, 122 and 123 connected by conduits to the main air duct 103', to the room 124 and to the outside atmosphere respectively. A rotary element 125 in the valve has a radial passage 126 adapted to be connected to the valve openings 121, 122 or 123 and also in continuous communication with the air supply conduit 100' extending to the expansion turbine 101'. The mode of operation of the system is the same as for Fig. 2 but it is now possible to select within limits the air admitted to the working air cycle. If the outside air is comparatively dry and not too hot, the air may then be admitted at valve port 123 for best results and cycle efficiency. However if the outside air is both hot and humid it may be preferable to select the valve port 122, whereby return air from the room 124 may be used in the working air cycle for best effect. When the cooling load is especially severe, the valve port 121 may be selected in order to take the working air directly from the conditioning air duct 103'. The inlet air to the expansion evaporation air cycle will now be as cold and as dry as any available in the apparatus shown and the cooling effect on the heat exchanger will therefore be at a maximum. The rotary element or plug 125 of the air selector valve 120 may be turned by any convenient means, such as a stem and handle projecting from the side opposite to the inlet end of the air supply conduit 100'.

As previously explained the water spray nozzles located upstream, within or downstream of the expansion device should supply just enough water to the working air to result in complete saturation of the air by the time the working air flows from the suction blower, compressor or other suction device into the atmosphere or in the case of the apparatus of Figs. 2 and 4 by the time the working air flows from the air compressor into the combustion chamber. The reasons for this have been stated at some length above. This desirable result may be obtained by temperature determination in the working air stream leaving the blower or compressor and precise adjustment of the water flow rate in accordance therewith. For example in Fig. 1 the blower discharge outlet may have installed therein a dry-bulb thermometer and a wet-bulb thermometer. With operating conditions steady the water spray pressure is increased slowly to increase the flow of water through the water spray nozzle 7 until the dry-bulb temperature decreases to the level of the wet-bulb temperature. At this point of adjustment the working air leaving the blower 2 will be staurated but will carry no excess moisture. Another method is to use only the dry-bulb thermometer and slowly increase the flow of water through the spray nozzle 7 until the dry-bulb temperature recedes to a minimum level. When further increase in the rate of water flow causes no further decrease in dry-bulb temperature, then the operator may be sure that the working air leaving the blower is completely saturated. By careful adjustment of the flow of water through the spray nozzle or nozzles this minimum dry-bulb temperature, which should equal the wet-bulb temperature, may be held within fairly close limits. These same control methods and devices may be used in all embodiments of the invention, that is by temperature adjustment of the working air leaving the blower, compressor or other suction producing device.

I claim:

1. In an air cycle air conditioning system, an expansion turbine including an air inlet for working air at atmospheric pressure and an air outlet to discharge said working air at a pressure below atmosphere after passing through said expansion turbine, nozzle means for introducing a fine spray of water into the working air which flows into the inlet of said turbine, a heat exchanger connected to said air outlet and providing a path for said working air after leaving said expansion turbine, an air compressor for maintaining said working air at a pressure below atmosphere between said expansion turbine and said compressor and including an air inlet for the working air leaving said heat exchanger and an air discharge outlet, a combustion chamber receiving compressed air from said air discharge outlet and having mounted therein fuel supply nozzles for spraying liquid fuel into said chamber whereby the combustion of said fuel causes volume expansion of said working air with the evolution of heat, a second expansion turbine having its inlet connected to the outlet of said combustion chamber and including an exhaust outlet leading to the free atmosphere, a power transmission means extending from both of said expansion turbines to said air compressor, duct means to conduct conditioning air through said heat exchanger along a path separate from the working air path but in heat exchange relation with respect thereto, and means to maintain a flow of said conditioning air.

2. In an air cycle air conditioning system, an expansion turbine including an air inlet for working air at atmospheric pressure and an air outlet to discharge said working air at a pressure below atmosphere after passing through said expansion turbine, nozzle means for introducing a fine spray of water into the working air which enters said expansion turbine for evaporative cooling of said working air, a heat exchanger connected to said air outlet and providing a path for said working air after leaving said expansion turbine, an air compressor for maintaining said working air at a pressure below atmosphere between said expansion turbine and said compressor and including an air inlet for the working air leaving said heat exchanger and an air discharge outlet, means to regulate the flow of water through said nozzle means whereby the moisture content of the working air issuing from said air discharge outlet is capable of regulation to obtain total saturation, a combustion chamber receiving compressed air from said air discharge outlet and having mounted therein fuel supply nozzles for spraying liquid fuel into said chamber whereby the combustion of said fuel causes volume expansion of said working air with the evolution of heat, a second expansion turbine having its inlet connected to the outlet of said combustion chamber and including an exhaust outlet leading to the free atmosphere, a power transmimssion means extending from both of said expansion turbines to said air compressor, duct means to conduct conditioning air through said heat exchanger along a path separate from the working air path but in heat exchange relation with respect thereto, and means to maintain a flow of said conditioning air.

3. In an air cycle air conditioning system, an expansion device including an air inlet for working air and an air outlet to discharge said working air at a reduced temperature and at a pressure below atmosphere after passing through said expansion device, nozzle means for introducing a fine spray of water into the working air for evaporative cooling thereof, a heat exchanger connected to said air outlet and providing a path for said working air after leaving said expansion device, a compression device for maintaining the working air at said pressure below atmosphere and including an air inlet for the working air leaving said heat exchanger and an air discharge outlet open to the atmosphere, means to regulate the flow of water through said nozzle means whereby the moisture content of the working air issuing from said air discharge outlet is capable of regulation to obtain total saturation, duct means to conduct conditioning air through said heat exchanger along a path separate from the working path

but in heat exchange relation with respect thereto, means to maintain a flow of said conditioning air, and a three-way selector valve connected to said air inlet of the expansion device and including three alternative inlet passages connected to the outside atmosphere, to the room being air conditioned and to the duct means carrying conditioning air into said room.

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