

[54] **APPARATUS FOR EFFECTING
CONTINUOUS AND SIMULTANEOUS
TRANSFER OF HEAT AND MOISTURE
BETWEEN TWO AIR STREAMS**

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[58] Field of Search 165/157, 166, 57, 122, 165;
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[56]

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[57]

ABSTRACT

Apparatus for effecting continuous and simultaneous transfer of both heat and moisture between two air streams comprises a housing having therein a plurality of heat and moisture transfer surfaces statically disposed in superposed and spaced-apart relationship defining therebetween static flow paths, and means for including air from one locale through alternate ones of the flow paths to another locale and for discharging air from said another locale through the remaining flow paths to said one locale. The heat and moisture transfer surfaces are each composed of a material, such as Japanese paper, which is sufficiently heat conductive and permeable to moisture to continuously and simultaneously effect both heat and moisture exchange between the inducted and discharged air.

16 Claims, 20 Drawing Figures

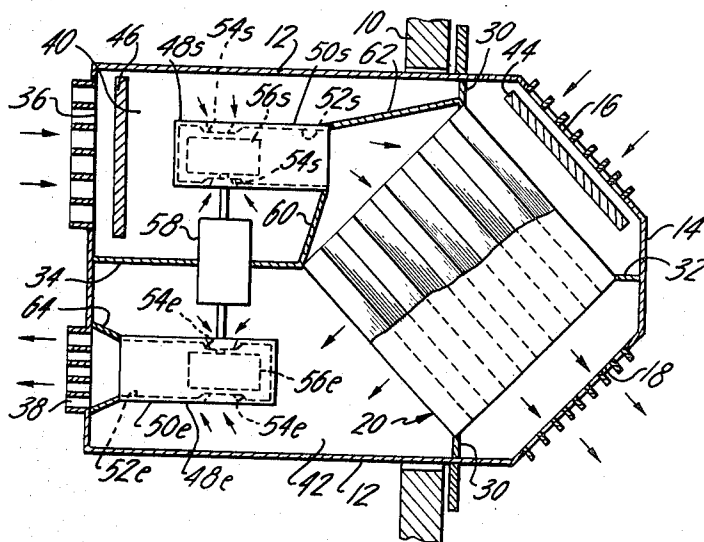


FIG. 1
PRIOR ART

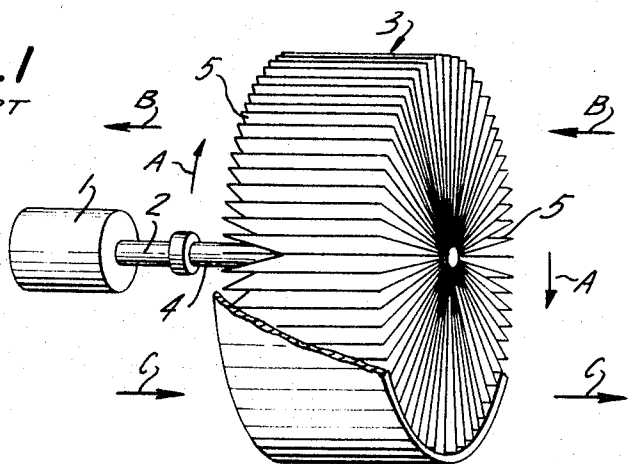


FIG. 2

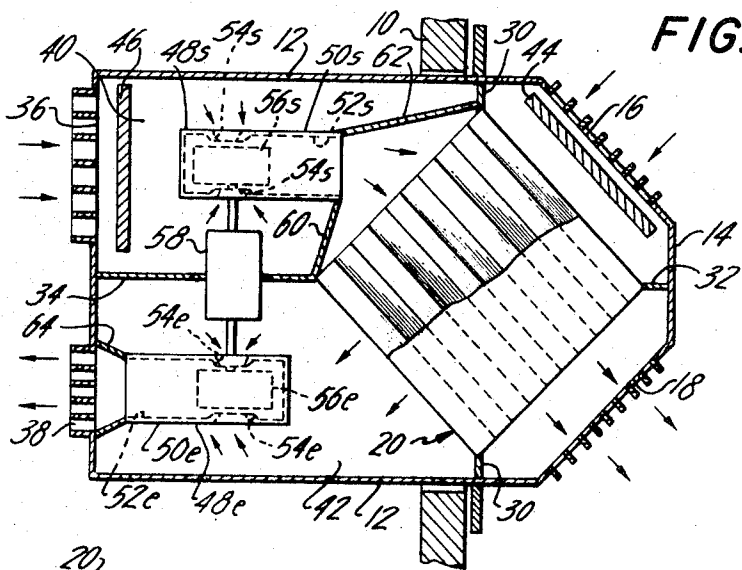


FIG. 3

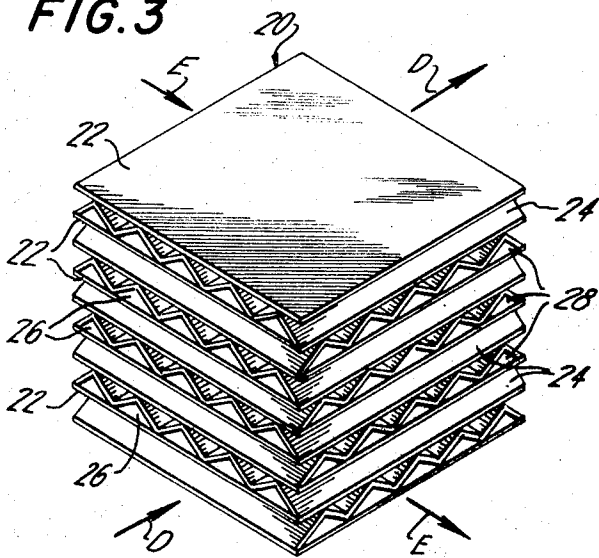
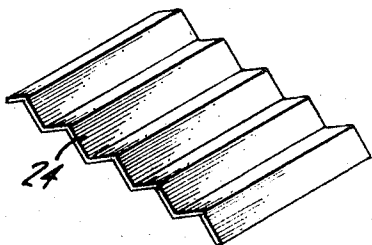


FIG. 4



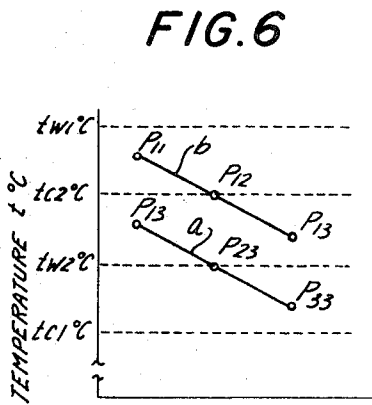
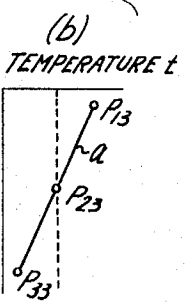
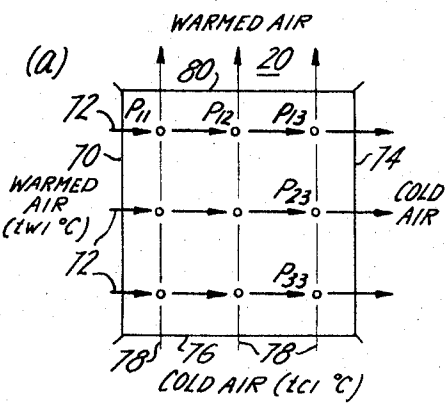
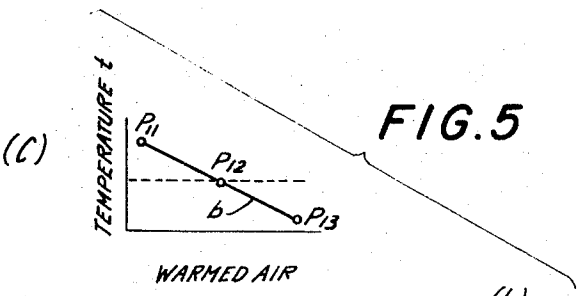
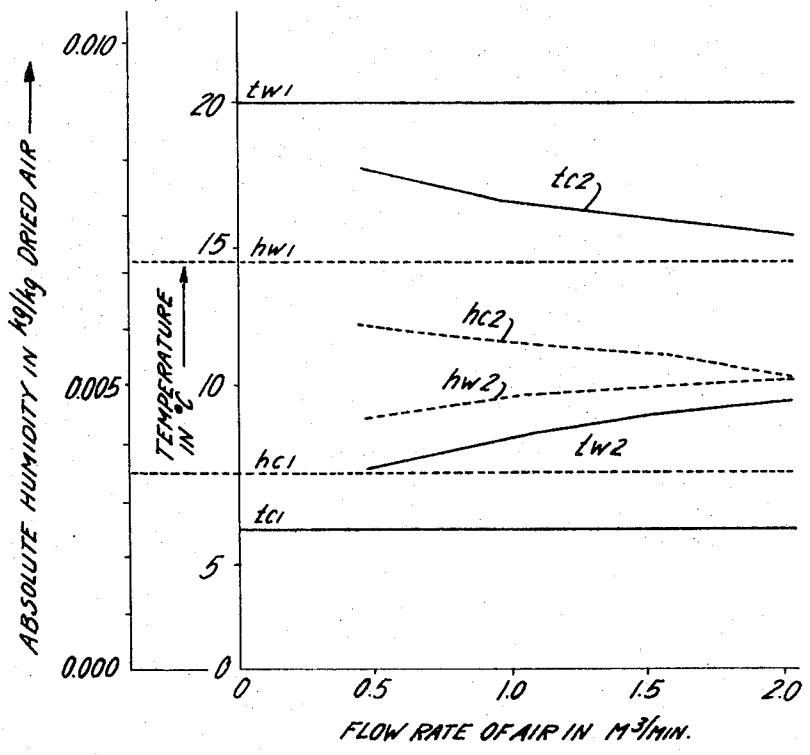


FIG. 7



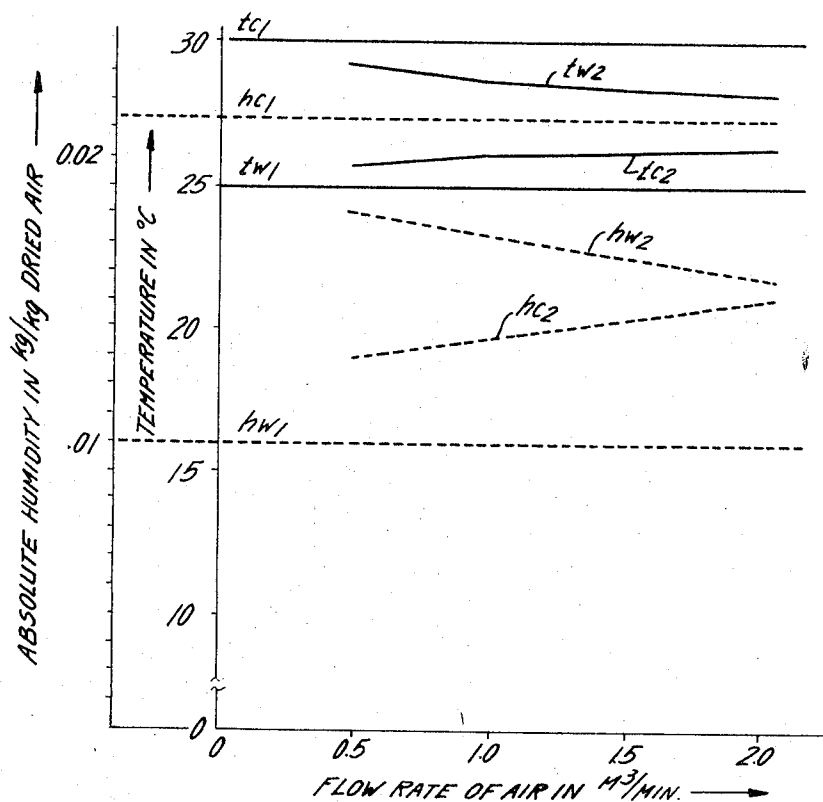


FIG. 8

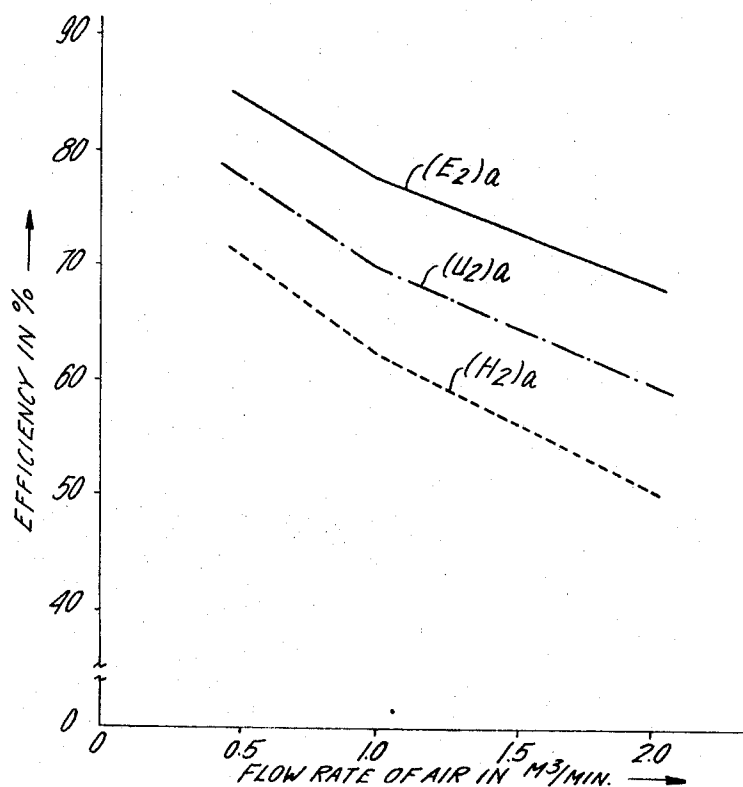
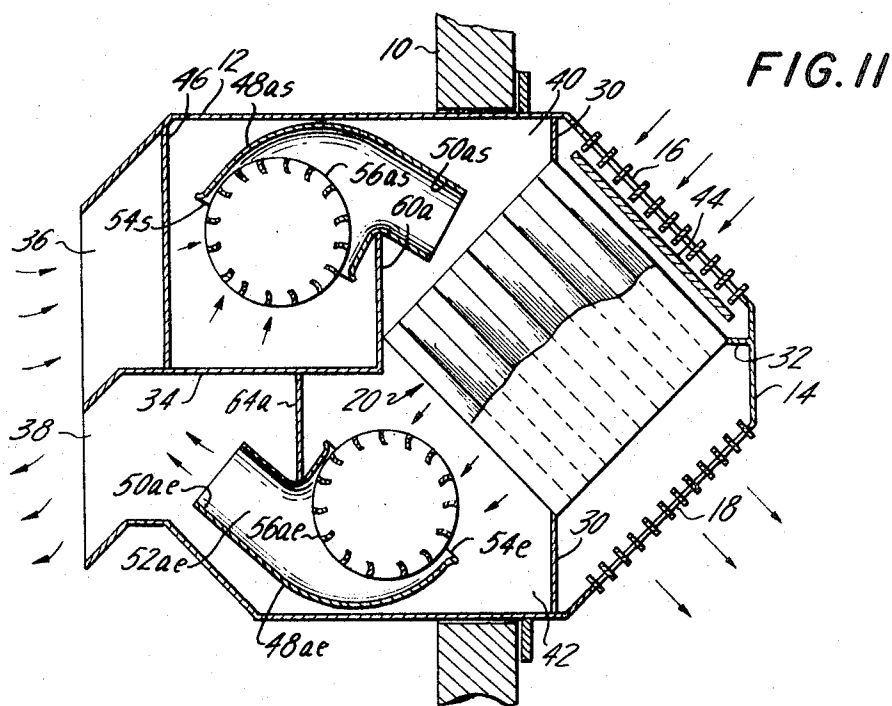
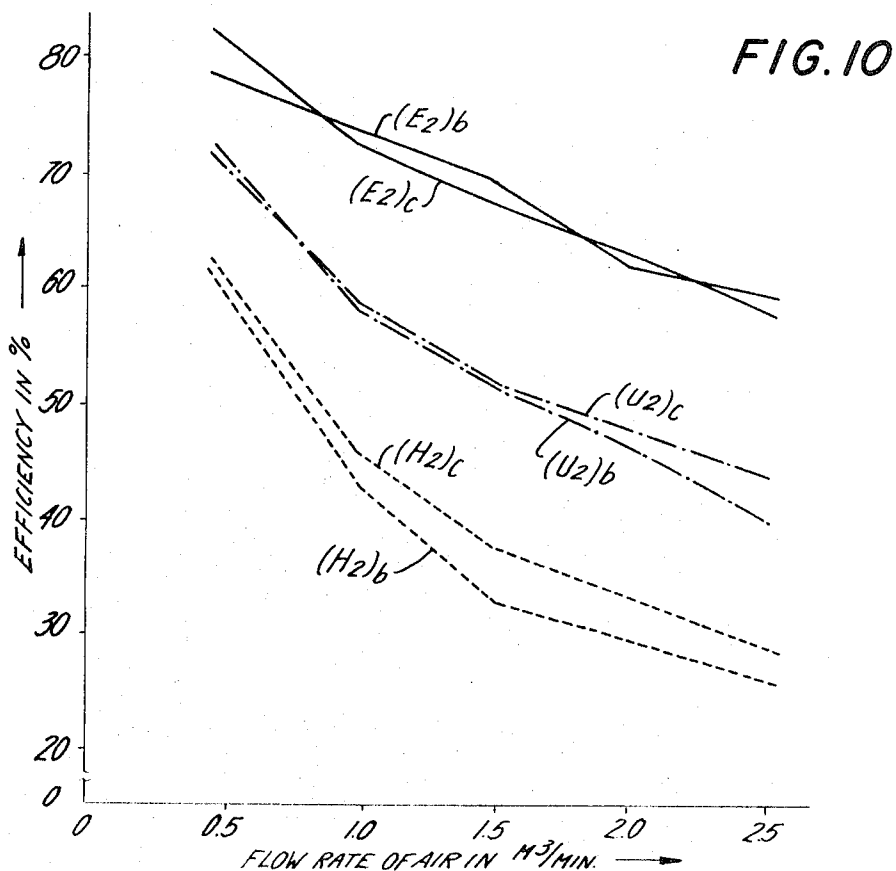


FIG. 9



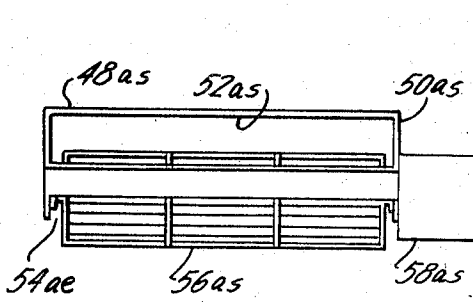


FIG. 12

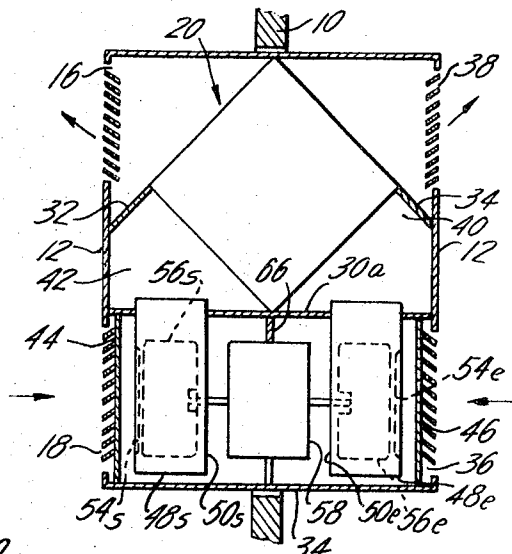


FIG. 13

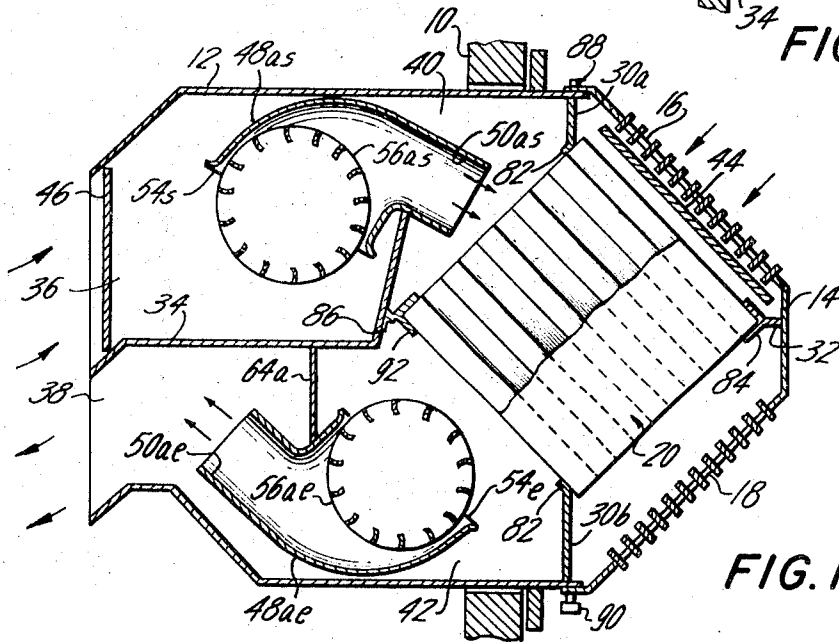


FIG. 14

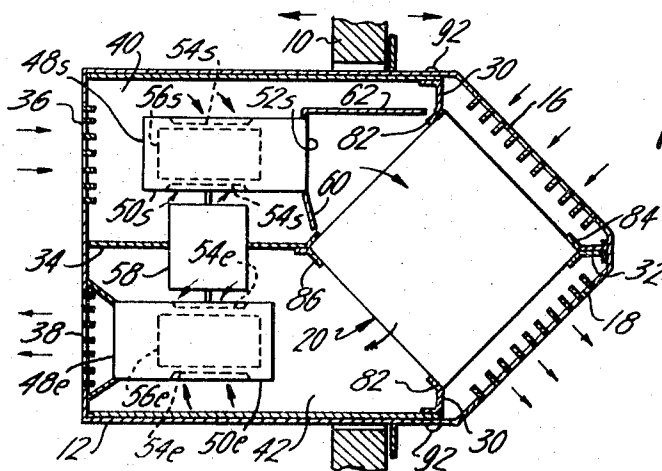
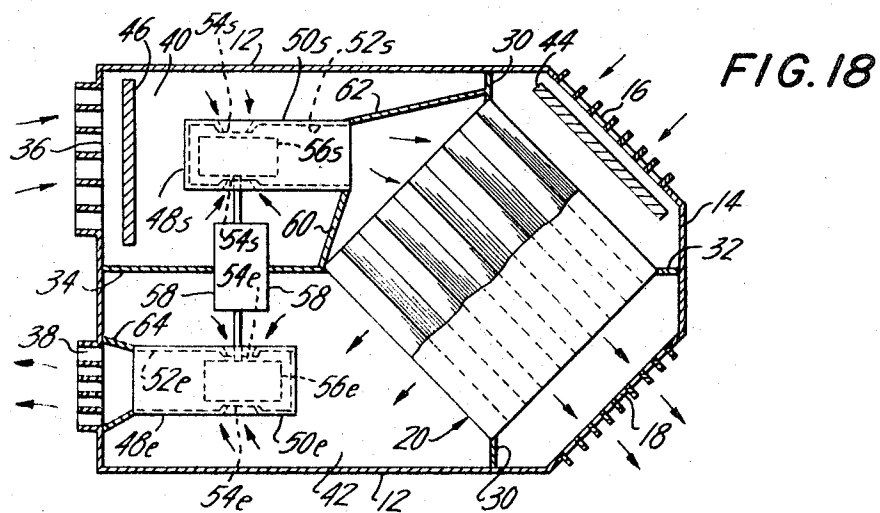
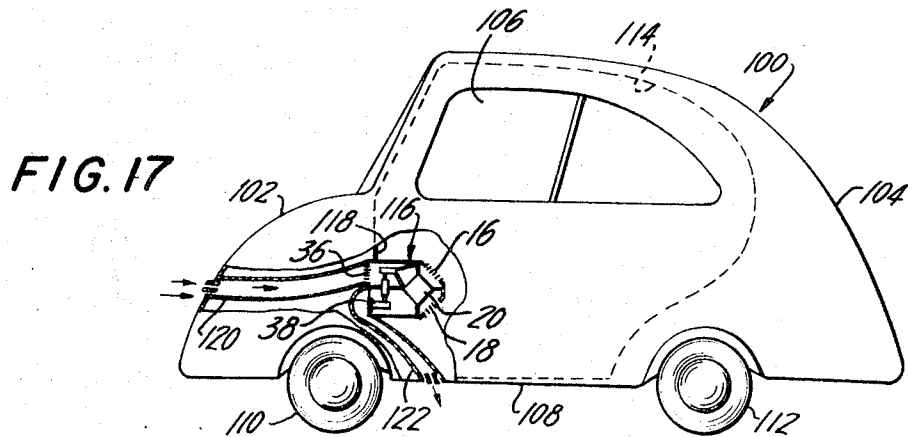
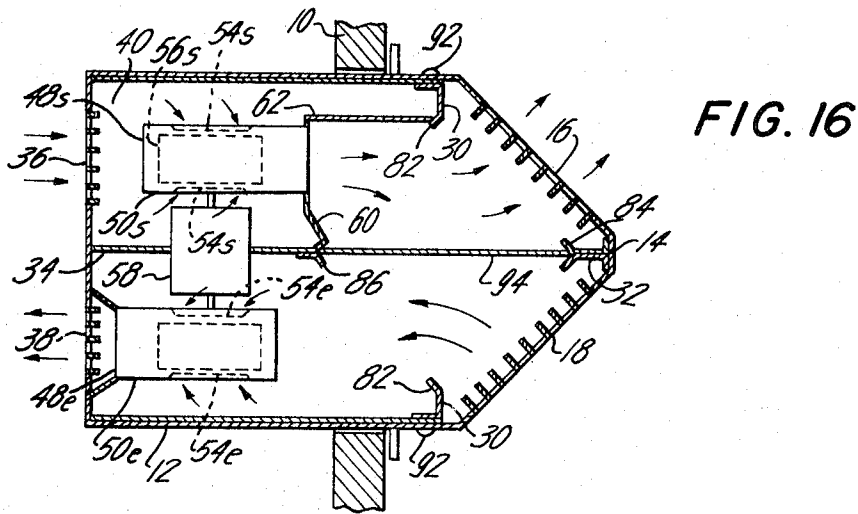


FIG. 15



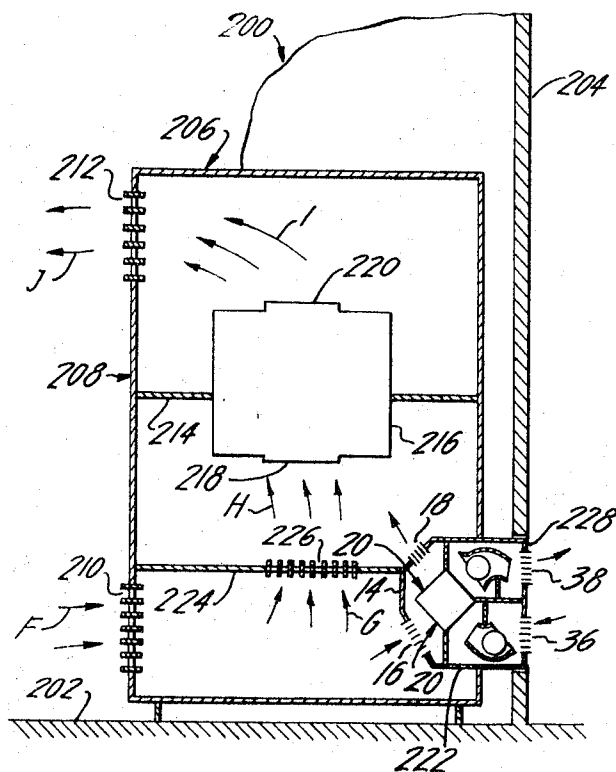


FIG. 19

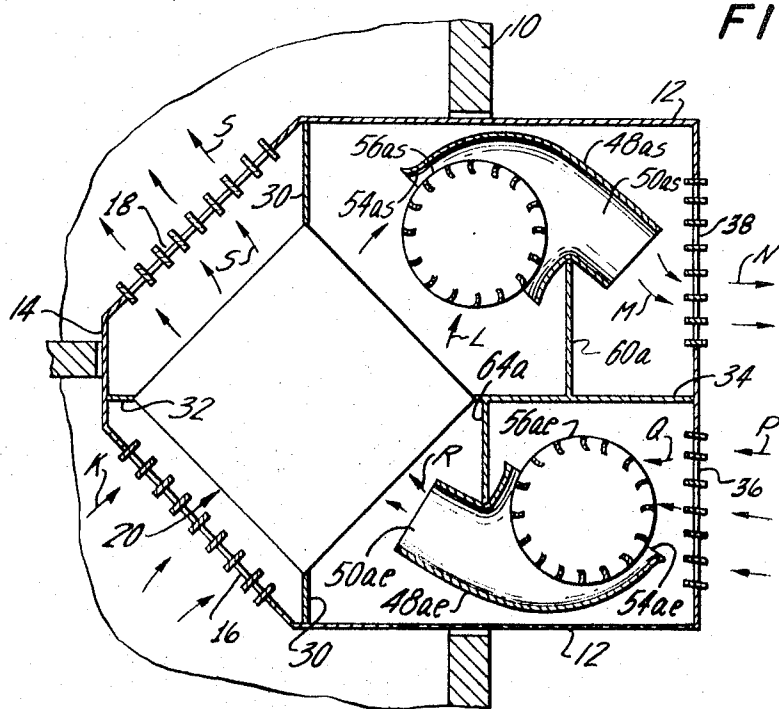


FIG. 20

APPARATUS FOR EFFECTING CONTINUOUS AND SIMULTANEOUS TRANSFER OF HEAT AND MOISTURE BETWEEN TWO AIR STREAMS

BACKGROUND OF THE INVENTION

This invention relates to a ventilating device including a heat exchanger for exhausting, as an exhaust stream, air from a room externally of the room simultaneously with the suction of the open air, as a suction stream, into the room while effecting heat exchange between the exhaust and suction streams. The invention also concerns an air conditioning system incorporating such a ventilating device.

Upon air conditioning rooms in buildings, it is generally desirable to comfortably and healthily air condition the rooms by introducing a quantity of outside open air into the rooms. However if too much the open air is introduced into the room, the introduced air can vary the room temperature. As a result, an airconditioning equipment involved is undesirably increased in operating costs. Therefore it has been previously practiced to cool or warm the room through the utilization of an air conditioner for effecting the suction of the air simultaneously with the exhaust of the room air in combination with a heat exchanger for warming or cooling the suction stream with the exhaust stream to approximate both the streams to each other in temperature for the purpose of saving costs at which the air conditioner is operated. The conventional type of such ventilating devices has comprised the multi-vane rotary impeller having the heat accumulating and moisture absorbing properties and bridging the suction and exhaust streams, resulting in the disadvantages that they are complicated and troublesome to be manufactured.

Lately motor vehicles have tended to be provided with a cooling device in addition to the warming device. If either of the warming and cooling devices is in operation while the associated windows are kept shut to isolate the interior of the vehicle from the exterior thereof, then air in the vehicle will have been contaminated within a short time interval because the vehicle interior has such a small volume. This has led to the necessity of sometimes opening the windows or introducing the surrounding fresh air into the vehicle interior through an air intake involved for the purpose of ventilation. Due to the small capabilities of the warming and cooling devices, the effects exhibited by the devices could not be much expected when the open air was introduced too much into the vehicle.

Further in the conventional type of air conditioning equipment for warming or cooling the room while the open air is continuously introduced into the latter, such has been disadvantageous in that the intake of the open air in a large amount causes a decrease in warming or cooling effect leading to an increase in operation costs of the equipment.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide a new and improved ventilating device having a heat exchanger for exhausting, as an exhaust stream, air in a room externally of the room simultaneously with the suction of the open air, as a suction stream, into the room while continuously and simultaneously effecting temperature and humidity exchanges between the exhaust and suction streams with a simple construction capable of being easily manufactured at low costs.

It is another object of the invention to provide a new and improved ventilating device for use in a motor vehicle to ventilate the interior thereof without deteriorating the cooling or warming effect.

It is still another object of the invention to provide a new and improved airconditioning equipment for effectively ventilating rooms without deteriorating the effect thereof.

The invention accomplishes these objects by the provision of a ventilating device with a heat exchanger, comprising a box-shaped housing including a suction port and an exhaust port facing each of the interior and exterior of the associated room, a plurality of partitions within the housing for forming a suction passage and an exhaust passage extending within the

housing from the associated suction to the exhaust port, a suction fan disposed in the suction passage to form a suction stream along the suction passage, an exhaust fan disposed in the exhaust passage to form an exhaust stream along the exhaust passage, and a heat exchanger, characterized in that the suction passage intersects the exhaust passage, and that the heat exchanger is positioned at the intersection of the suction and exhaust passages and includes a plurality of laminations of a material thermally conductive and permeable to moisture and superposed on one another at predetermined equal intervals, and means within gaps formed between the laminations for passing the suction stream through alternate ones of the gaps and for passing the exhaust stream through the remaining gaps.

The suction and exhaust fans each may be preferably either a centrifugal fan or a cross flow fan.

The laminations of the heat exchanger may be advantageously of a Japanese paper.

The housing may conveniently comprise a front decorated panel facing the interior of the room and having disposed thereon the suction and exhaust ports, the front panel detachably closing the associated end of the housing, a support member attached to the interior surface of the front panel, and support means disposed in the housing to cooperate with the support member on the front panel to removably support the heat exchanger. In this arrangement the support member and means may engage an isolating plate rather than the heat exchanger to isolate the suction passage from the exhaust passage without the passages intersecting each other for purpose of ventilation alone.

The ventilating device may also be installed in a motor vehicle to ventilate the interior of the vehicle without deteriorating the cooling or warming effect.

Further the ventilating device may be operatively associated with an air conditioning equipment such that the suction stream resulting from the open air is supplied to the equipment while the exhaust stream from the associated room is partly exhausted through the ventilating device with no decrease in efficiency of the latter.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a fragmental perspective view of a heat exchanger for use with a ventilating device constructed in accordance with the principles of the prior art with parts broken away to illustrate the internal structure thereof;

FIG. 2 is an elevational view, partly in section of a ventilating device with a heat exchanger constructed in accordance with the principles of the invention with parts broken away, and with parts illustrated in phantom;

FIG. 3 is a perspective view of the essential part of the heat exchanger shown in FIG. 2;

FIG. 4 is a perspective view of one portion of the heat exchanger shown in FIG. 3;

FIG. 5a is a schematic plan view of air streams flowing through the heat exchanger shown in FIG. 3;

FIGS. 5b and c are graphs illustrating the temperature distributions on the discharge side of the air streams shown in FIG. 5a;

FIG. 6 is a graph plotting the temperature distributions shown in FIG. 5b and c in a common temperature unit for comparison purpose;

FIG. 7 is a graph plotting a temperature and an absolute humidity on the discharge side of the suction stream against a flow rate of air for one embodiment of the invention in one mode of operation;

FIG. 8 is a graph similar to FIG. 7 but illustrating the embodiment in another mode of operation;

FIG. 9 is a graph plotting a flow rate of air against efficiencies of exchange as to the temperature, humidity and total

heat calculated on the basis of the data shown in FIGS. 7 and 8;

FIG. 10 is a graph similar to FIG. 9 but illustrating another embodiment of the invention;

FIG. 11 is an elevational view, partly in section of a modification of the invention with parts broken away;

FIG. 12 is a front elevational view of the fan shown in FIG. 11;

FIGS. 13, 14 and 15 are views of different modifications of the invention;

FIG. 16 is an elevational view, partly in section of the device shown in FIG. 15 and put in a particular mode of operation;

FIG. 17 is a schematic elevational view of a motor vehicle incorporating the invention with parts broken away to illustrate the manner in which the ventilating device of the invention is installed therein;

FIG. 18 is a view illustrating the details of the ventilating device shown in FIG. 17;

FIG. 19 is an elevational view, partly in section of an air-conditioning equipment constructed in accordance with the principles of the invention with parts cut away; and

FIG. 20 is a view illustrating the details of the ventilating device shown in FIG. 19.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and FIG. 1 in particular there is illustrated a heat exchanger of the conventional construction used in ventilating devices. The arrangement illustrated comprises a driving electric motor 1 including a driving shaft 2, and a main body 3 of the heat exchanger including a rotary shaft 4 operatively connected to the driving motor shaft 2 and a plurality of radial vanes 5 secured in substantially equal angular intervals on the rotary shaft 4. The vanes 5 are formed of any suitable material having heat accumulating and moisture absorbing properties. The main body 3 of the heat exchange is encircled by a cylindrical wind channel or tunnel 6 (only one thereof illustrated in FIG. 1).

In operation, the motor 1 is driven to rotate the main exchanger body 3 in the direction of the arrow A illustrated in FIG. 1. On the other hand the suction stream is adapted to pass through the region of the upper half of the rotating main body 3 in the direction of the arrows A shown in FIG. 1, while the exhaust stream is adapted to pass through the region of the lower half thereof in the direction of the arrows C shown in FIG. 1. Under these circumstances, those vanes 5 located in the region of the lower half of the main exchanger body 3 are warmed or cooled and humidified or dehumidified, as the case may be, with the exhaust stream while they are successively moved to the region of the upper half of the main body 3 as the latter is rotated in the direction of the arrow A. Those vanes 5 reaching the region of the upper half of the main exchanger body 3 are operated to warm or cool and humidify or dehumidify the suction stream until the latter stream approximates the state of air within the associated room. As a result, temperature and humidity exchanges are effected between the suction and exhaust stream by the medium of the rotating vanes 5. That is the total heat exchange is effected between both streams.

The heat exchanger as shown in FIG. 1 has been satisfactorily operated to some extent as the ventilating device for effecting the total heat exchange between the suction and exhaust streams for practical purposes. However heat exchangers such as shown in FIG. 1 include a rotary portion leading to various disadvantages. For example, that rotary portion is complicated in construction while being troublesome and expensive to be manufactured. Also the rotary portion has been permitted to be only formed into a circular cross section which is, in turn, accompanied by a circular or nearly circular cross section of the resulting device. Therefore the entire device could not be formed into an elongated shape giving a smart appearance.

The invention contemplates to eliminate the disadvantages of the conventional devices as above described.

Referring now to FIG. 2 of the drawings there is illustrated one embodiment constructed in accordance with the ventilating device of the invention. The ventilating device illustrated is attached to one wall 10 of the associated room by having its box-shaped housing 12 extending through and fixed to wall 10. The housing 12 includes a front decorated panel 14 of angled shape rigidly secured to that end portion thereof near to the room and provided on the upper portion with a suction port 16 and on the lower portion with an exhaust port 18. A combined heat-moisture transfer means comprises a heat exchanger 20 having a vertical diagonal portion thereof sealed through a vertical partition 30 extending across the above-mentioned end portion of the housing 12 and a horizontal diagonal portion fixed at both ends to a horizontal partition 32 secured to the inner surface of the front panel 14 and to a horizontal partition 34 opposite to the partition 32. The partition 34 terminates on the inner surface of a rear panel 36 closing the other end of the housing 12. The rear panel is exposed to the open air and provided on the upper and lower portions with a suction port 36 and an exhaust port 38 respectively. All the ports are rectangular and horizontally positioned and all the partitions along with the heat exchanger form a suction passage 40 and an exhaust or discharge passage 42 extending within the housing 12 from the outdoor suction port 36 to the indoor exhaust port 18 and from the indoor suction port 16 to the outdoor exhaust port 38 respectively. Thus both the passages intersect each other and open into a common heat-exchange area in the region of the heat exchanger 20. The suction passage 40 and the associated ports 18 and 36 comprise an air exhaust system for exhausting air contained within the room to the outside whereas the exhaust passage 42 and the associated ports 16 and 38 comprise an air induction system for inducing outside air into the room.

A filter 44 for cleaning air is disposed adjacent the indoor suction port 16 within the housing 12 to fully cover that port and another filter 46 for cleaning air is disposed adjacent the outdoor suction port 36 within the housing 12 to fully cover that port. Then a suction and an exhaust fans generally designated by the reference numerals 48s and e respectively are disposed in the suction and exhaust passages 40 and 42 respectively so as to have their axes of rotation coaxial to each other with discharge ends thereof directed downstream of the respective passages. The fans 48s and e are shown here as being of the centrifugal type and identical in construction to each other. Therefore one of the fans, in this case, the suction fan 48s will now be described in detail. The components of the exhaust or discharge fan 48e are designated by the same reference numerals denoting the corresponding components of the suction fan 48s with the suffix "e" in place of the suffix "s" and need not be described.

The suction fan 48s comprises a casing 50s open at one end to provide a discharge opening 52s, a pair of opposite inflow openings 54s disposed on the periphery of the casing 50s, an impeller 56s within the casing including a plurality of strip-shaped radial vanes 56s formed into a cylindrical configuration about their rotary shaft (not shown). Only one of the vanes 56s is illustrated in FIG. 2.

As shown in FIG. 2, the suction and exhaust fans 48s and e are operatively connected to a common electric motor 58 sealed through the horizontal partition 34. Specifically, the motor 58 includes a driving shaft 60 having connected to both ends thereof the rotary shafts of the vanes 56s and e respectively. The suction fan 48s has its discharge opening 52s communicating with the inflow side of the heat exchanger 20 through a space defined by partitions 60 and 62 extending from that discharge opening 52s to a pair of the adjacent corner edges of the heat exchanger 20 while the exhaust fan 48e has its discharge opening 52e communicating with the outdoor exhaust port 38 through a space defined by partitions 64 and 66 extending from that discharge opening 52e to the outdoor exhaust port 38.

In operation, the electric motor 58 is driven to rotate the fans 48s and e. Then the suction fan 48s sucks the open air or primary air into the suction passage 40 through the outdoor

suction port 36 to form a suction stream. After having been cleaned by the air filter 46 the suction flows through the inflow and discharge opening 54s and 52s respectively of the suction fan 48s into the heat exchanger 20. Simultaneously the exhaust fan 48e is operative to introduce air in the room or the secondary air into the exhaust passage 42 through the indoor suction port 16 to form an exhaust stream. The exhaust stream is cleaned by the filter 44 and flows into the heat exchanger 20. After the suction and exhaust streams have passed through the heat exchanger 20, in the manner as will be fully described hereinafter, the suction stream or primary air is introduced into the room through the indoor exhaust port 18 while the exhaust stream or secondary air is exhausted into the atmosphere along the exhaust passage 42 through the inflow and discharge openings 54e and 52e respectively of the exhaust fan 48e. In FIG. 2 the arrows shows the directions of the respective streams. As a result, the room is ventilated.

Referring now to FIG. 3, it is seen that the combined heat-moisture transfer means comprises a plurality of heat and moisture transfer surfaces or heat-exchange surfaces composed of flat partitions or laminations 22 in the form of squares superposed on one another at predetermined, substantially equal intervals to form gaps or flow paths therebetween and one undulated spacer member 24 disposed in each of the gaps to be sandwiched between the adjacent laminations 22 thereby to form a multi-layer stack. Alternate ones of the undulated spacer members 24 have their wave crests substantially parallel to one side of the laminations 22 to form air channels 26 between the associated laminations. The remaining spacers 24 have their wave crests substantially parallel to the adjacent side of the laminations 22 to form air channels 28 between the associated laminations. In the example illustrated the air channels 26 are intersected substantially perpendicularly with the air channels 28. For example the uppermost spacer 24 forms the air channels 26 substantially parallel to the righthand side as fully viewed in FIG. 3 of the stack between the uppermost and succeeding laminations 22 to permit an air current flowing in the direction of the arrows D shown in FIG. 3 to pass therethrough but to prevent an air current flowing in the direction of the arrows E shown in FIG. 3 from passing therethrough. Similarly the lowermost spacer 24 forms the air channels 28 substantially parallel to the lefthand side as fully viewed in FIG. 3 of the stack between the lowermost and succeeding laminations 22 to permit the air current flowing in the direction of the arrows E to pass therethrough but to prevent the air current flowing in the direction of the arrows D from passing therethrough. Therefore it will be appreciated at the air currents flowing in the direction of the arrows D and E are completely isolated from each other within the heat exchangers. It is to be noted that in the arrangement of FIG. 2, both the passages 40 and 42 communicated with the air channels 26 and 28 respectively and therefore that both the passages 40 and 42 intersect each other on the region of the heat exchanger 20 without communicating with each other by virtue of the above-mentioned structure of the heat exchanger 20 cooperating to the partitions 30, 32 and 34.

The laminations should be formed of any suitable material which is sufficiently thermally conductive and permeable to moisture to enable both heat and moisture transfer therethrough, for example Japanese paper. The undulated spacer 24 is shown in FIG. 4 as having a triangular waveform. However it is to be understood that the spacer 24 may be undulated into a sawtoothed or sinusoidal or any other desired waveform.

The operation of the heat exchanger 20 will now be described in more detail with reference to FIGS. 5a, b and c. In FIG. 5a the heat exchanger 20 is diagrammatically shown at block 20 and the warmed air or the secondary air forming the exhaust stream enters the heat exchanger 20 on its inflow side 70 to form exhaust currents 72 along the air channels 26 or 28 on the spacers 24 and leaves the heat exchanger 20 through its discharge side 74. Similarly the primary air or the cold air

forming the suction stream enters the heat exchanger 60 on its inflow side 76 perpendicular to the inflow side 70 for the secondary air to form suction current 78 and leave the heat exchanger 20 through its discharge side 80. Thereby the temperature exchange is effected between the exhaust and suction currents. In this event, the warmed or secondary air has a temperature distribution as shown at curve *a* in FIG. 5b wherein a temperature *t* is plotted against a distance measured from one end of the discharge side 74 therealong and P_{13} , P_{23} and P_{33} typically represent imaginary intersections of the exhaust currents 72 and that suction current 78 nearest to the discharge side 74 for the exhaust currents 72 as shown in FIG. 5a. From FIG. 5b, it is seen that the temperatures at points P_{13} and P_{33} are maximum and minimum respectively with the mean temperature equal to the temperature at point P_{23} . The primary or cold air has a temperature distribution as shown at curve *b* in FIG. 5c similar to FIG. 5b. Points P_{11} , P_{12} and P_{13} typically represent imaginary intersections of the suction currents 78 and that exhaust current 72 nearest to the discharge side 80 for the suction current. As in the warmed exhaust currents the temperatures at points P_{11} and P_{13} of the cold currents are maximum and minimum respectively with the mean temperature equal to the temperature at point P_{12} .

For comparison purpose, curves *a* and *b* as shown in FIGS. 5b and c are illustrated together in FIG. 6 wherein t_{w1} and t_{w2} designate the maximum temperature on the inflow side and the mean temperature in the discharge side of the secondary or exhaust current in degrees Centigrade and t_{c1} and t_{c2} represent the maximum temperature on the inflow side and the mean temperature in the discharge side of the primary or suction current in degrees Centigrade. From FIG. 6 it is seen that the maximum temperature of the exhaust currents 72 on the discharge side (which corresponds to the temperature at P_{13}) is approximately equal to the minimum temperature of the suction currents 78 on the discharge side (which corresponds to the temperature at P_{13}). Accordingly the mean temperature of the suction currents on the discharge side or at P_{12} is appreciably higher than that of the exhaust currents on the same side or at P_{23} .

As previously described, the laminations 22 of the heat exchanger 20 are also permeable to moisture so that the moisture contained in the exhaust currents 72 is transferred to the suction currents 78 until the exhaust and suction currents have the respective distributions of humidity and strictly, the absolute humidity similar to the temperature distributions as above described. Therefore the suction currents are appreciably higher in mean humidity on the discharge side than the exhaust currents which is accompanied by the mean enthalpy on the discharge side appreciably higher in the suction currents 78 than in the exhaust currents 72.

By using the t_{w1} , t_{w2} , t_{c1} and t_{c2} as above defined, the heat exchanger 20 has an efficiency of temperature exchange E_1 for the suction currents expressed by the equation

$$E_1 = (t_{w1} - t_{w2}) / (t_{w1} - t_{c1})$$

Similarly an efficiency of temperature exchange E_2 for the exhaust currents is expressed by the equation

$$E_2 = (t_{c2} - t_{c1}) / (t_{w1} - t_{c1})$$

Also the heat exchanger 20 has efficiencies of humidity exchanges H_1 and H_2 for the suction and exhaust currents expressed respectively by the equations

$$H_1 = (h_{w1} - h_{w2}) / (h_{w1} - h_{c1})$$

and

$$H_2 = (h_{c2} - h_{c1}) / (h_{w1} - h_{c1})$$

where

h_{w1} = humidity on inflow side of exhaust current

h_{w2} = mean humidity on discharge side of exhaust current

h_{c1} = humidity on inflow side of suction current

and

h_{c2} = mean humidity on discharge side of suction current.

Further the efficiencies of total heat exchange U_1 and U_2 for the suction and exhaust currents taking into account of both their temperature and humidity exchanges are expressed respectively by the equations

$$U_1 = (U_{w1} - U_{w2}) / (U_{w1} - U_{c1})$$

and

$$U_2 = (U_{c2} - U_{c1}) / (U_{w1} - U_{c1})$$

where

U_{w1} = enthalpy on inflow side of exhaust current

U_{w2} = mean enthalpy on discharge side of exhaust current

U_{c1} = enthalpy on inflow side of suction current

and

U_{c2} = mean enthalpy on discharge side of suction current.

As an example, partitions or laminations such as shown at 22 in FIG. 3 were into 110 mm long squares of a Japanese paper having a thickness or a basis weight of 70 grams per square centimeter and including 3 percent by weight of a synthetic fibrous material. On the other hand, spacers such as shown at 24 in FIG. 3 were formed of a Kraft paper having a thickness or a basis weight of 120 grams per square centimeter such that they were undulated into triangular waveforms having a peak-to-peak amplitude of about 1.8 millimeters and a wavelength of about 2.1 millimeters. Then the laminations alternating the undulated spacers superposed one another to form a stacks of 110 layers having the overall height of 220 millimeters and a spacing of about 18 millimeters between each pair of adjacent laminations. Then the stacks each were formed into a unitary structure by any suitable means (not shown) to provide a heat exchangers.

The heat exchanger thus produced was put under the operating conditions that the associated room was to be maintained at a temperature t_{w1} of 20° C at a relative humidity h_{w1} of 50 percent or an absolute humidity of 0.0072 kg/kg kilogram per each kilogram of dried air in the open air having a temperature t_{c1} of 5° C and a relative humidity h_{c1} of 65 percent or an absolute humidity of 0.0035 kg/kg kilogram per each kilogram of dried air as during the winter season requiring to heat the room. Then the exhaust stream from the room and the suction stream from the open air passed through the heat exchanger in the manner as above described in conjunction with FIG. 4 while both the streams varied in flow rate but they were continuously equal in flow rate to each other. Under these circumstances the temperature t_{w2} and humidity h_{w2} on the discharge side of the exhaust streams were measured as were the temperature t_{c2} and humidity h_{c2} on the discharge side of the suction stream. The mean values of the respective parameters determined by the measurements are plotted in FIG. 7 wherein the axis of abscissas represents a flow rate of air in m³/min of either of the exhaust and suction streams and the axis of ordinates represents an absolute humidity in kg/kg dried air or a temperature in °C.

Also the heat exchanger were put in under the operating conditions that the room was to be maintained at a temperature t_{w1} of 25° C and at a relative humidity h_{w1} of 50 percent or an absolute humidity of 0.01 kg/kg dried air in the open air having a temperature t_{c1} of 30° C and a relative humidity h_{c1} of 50 percent or an absolute humidity of 0.01 kg/kg dried air as during the summer season requiring to cool the room. Under these conditions the measurements as above described were repeated to provide the mean values of the various parameters as plotted in FIG. 8.

From FIGS. 7 and 8 it is seen that with the abovementioned heat exchanger used to effect the total heat exchange between the exhaust and suction streams for the ventilating device of FIG. 2, the suction stream is supplied to the associated room while it is maintained in this state substantially equal to the air state within the room both under the heating conditions during the winter season and under the cooling conditions during the summer season.

On the basis of the data as shown in FIGS. 7 and 8 the efficiencies of temperature exchange $(E_2)_a$, humidity exchange $(H_2)_a$ and total heat exchange $(U_2)_a$ of the suction streams were calculated so that their figures remained substantially unchanged between the heating conditions during the winter season and the cooling conditions during the summer season as shown in FIG. 9 wherein the axis of abscissas represents a flow rate of air in m³/min and the axis of ordinates represents an efficiency of each parameter in percent. Also curves are labelled the same reference characters representing the corresponding parameters as in FIGS. 7 and 8.

Further heat exchangers such as shown in FIG. 3 were formed of a Japanese paper including 60 percent by weight of a synthetic fibrous material for use with sliding screens and Kent paper. That is, the Japanese paper was cut into squares having one side 105 millimeters long to form laminations such as shown at 22 in FIG. 3 and the Kent paper was formed into undulated spacers such as shown at 24 in FIG. 3. Then the laminations and spacers thus formed were assembled into a unitary structure including a stack of 144 layers having the overall length of 325 millimeters and a spacing of from 2.0 to 2.3 mm formed between each pair of adjacent laminations as previously described.

The measurements as above described in conjunction with FIGS. 7 and 8 were repeated to obtain the efficiencies of temperature exchange E_2 , humidity exchange H_2 and total heat exchange U_2 as shown in FIG. 10. While FIG. 10 is similar to FIG. 9 it is noted that the various efficiencies are plotted against the flow rate of air under two different sets of operating conditions. More specifically, curves labelled the reference characters $(E_2)_b$, $(H_2)_b$ and $(U_2)_b$ were obtained with a difference between temperatures on the inflow sides of the exhaust and suction streams ranging from 7° to 12° C and with a difference in absolute humidity on the inflow sides of both the streams ranging from 0.03 to 0.049 kg/kg dried air. If such differences in temperature and humidity range from 20° to 25° C and from 0.0084 to 0.0123 kg/kg dried air respectively the respective efficiencies are expressed at curves $(E_2)_c$, $(H_2)_c$ and $(U_2)_c$.

From FIG. 10 it is seen that the efficiencies of temperature exchange E_2 , humidity exchange H_2 and total exchange U_2 are not much affected by both differences between the temperatures on the inflow sides of the exhaust and suction streams and a difference between the humidities on the same and rather greatly change with a flow rate of each stream. For example FIG. 10 indicates that for a flow rate of about 0.5 m³/min, the efficiencies of temperature exchange E_2 , humidity exchange H_2 and total heat exchange U_2 are as high as about 80 percent, about 60 percent and about 70 percent respectively whereas with the flow rate increased to about 2.5 m³/min, those efficiencies all decrease as much as by 20 to 30 percent.

While the heat exchanger has been shown in FIG. 3 as being of a square cross section it is to be understood that it may be of any desired shape. For example, the laminations and spacers may be rhombic or circular while the exhaust channels intersect the suction channels at the corresponding angle other than right angles. Also if desired, the undulated spacer may change in waveform. For example, they may be undulated into sawtoothed, sinusoidal rectangular waveform or any other desired waveform.

Referring to FIG. 11 wherein like reference numerals designate the components identical or corresponding to those shown in FIG. 2, there is illustrated a modification of the invention having a cross flow type fan substituting each of the centrifugal fans as shown in FIG. 2. As shown in FIG. 11, a cross flow type suction fan 48a s and a line flow type exhaust fan 48a e are disposed in the suction and exhaust passageways 40 and 42 respectively so as to direct their discharge openings 52a s and a e to the heat exchange 20 and the outdoor exhaust port 38 respectively.

Both the fans are identical in construction to each other and only one of the fans for example, the suction fan 48a s, will now be described with reference to FIG. 12. The line flow type fan 48a s comprises a casing 50a s having the form of a curved hollow cylinder open at both ends one of which provides a discharge opening 52a s in the form of a laterally elongated rectangle. Rotatably disposed at the other end of the casing 50a s is an impeller 56a s formed into a cylinder having a plurality of strip-shaped vanes disposed at predetermined equal angular intervals about its axis of rotation. One half of the impeller 56a s projects beyond the open end of the casing 50a s providing an inflow opening 54a s in the form of a laterally elongated rectangle. As shown in FIG. 12, an electric motor 58a s is secured to one side of the casing 50a s to drive the impeller 56a s. The components of the exhaust fan 48a e are

designated by the same reference numerals denoting the corresponding components of the fan 48a s with the suffix e in place of the suffix s.

Since the cross flow type fans 48a s and a e include their own motors 58a s and a e, the common motor 58 as shown in FIG. 2 is omitted from the arrangement of FIG. 11. Further the partitions 60, 64 and 66 connected to the fans are omitted and support plates 60a and 64a are fixed to the partition 34 to support the respective fans 48a s and e s. In other respects the arrangement is substantially identical to that shown in FIG. 2.

FIG. 13, wherein like reference numerals designate the components identical or corresponding to those shown in FIG. 2, shows another modification of the invention capable of maintaining the primary or suction stream substantially equal in flow rate to the secondary or exhaust stream. In FIG. 13, the housing 16 is of a rectangular cross section and extends through and is fixed to the wall 10 at its position where it has been rotated from its position as illustrated in FIG. 2 by an angle of 90°. All the components are disposed in bilateral symmetry with respect to the central plane of the wall 10. For example, the indoor and outdoor exhaust ports 18 and 38 are disposed in opposite relationship on the upper portions of the opposite panels of the housing 12 and a pair of centrifugal fans 48s and e are disposed in opposite relationship on the lower portion of the housing 12 and include the respective inflow openings 54s and e facing the outdoor and indoor suction ports 36 and 16 opposing to each other. The suction and exhaust fans 48s and e are sealed through a partition 30a extending across the interior of the housing 12 and their discharge openings 52s and e are open toward the heat exchanger 20. Therefore the exhaust stream from the room passes through the exhaust fan 48e and then to the heat exchanger 20 whereas the same first passes through the heat exchanger 20 and then through the exhaust fan 48e in the arrangement of FIG. 2. In other respect the arrangement substantially identical to that shown in FIG. 2.

The arrangement of FIG. 13 is particularly advantageous in that the disposition of the suction and exhaust fans having the same capability on the inflow sides of the heat exchanger, ensures that the primary and secondary streams pass at an equal flow rate and therefore at an equal speed through the heat exchanger to increase the efficiency of total heat exchange to the order of 70 percent to provide excellent means for thermally isolating the interior of the room from the open air. Further due to its symmetric construction, the resulting device is simple and compact in construction and inexpensive to manufacture.

If desired, the heat exchanger 20 may be detachably disposed in the housing 12 as shown in FIGS. 14 and 15 wherein like reference numerals designate the components identical or corresponding to those shown in FIGS. 2 and 11.

The arrangement of FIG. 14 is identical to that shown in FIG. 11 excepting that the heat exchanger 20 is detachably disposed in the housing 12. More specifically the heat exchanger 20 has its vertical diagonal portion detachably supported to tilted ends 82 of a pair of vertical partitions b disposed in opposite relationship to that portion and its horizontal diagonal portion sandwiched at the opposite corner edges between a pair of opposite angle brackets 84 and 86 fixed to the partition 32 secured to the front panel 14 and to the support plate 60a for the suction fan 48s respectively. Then the front panel 14 provided with the indoor suction and exhaust ports 16 and 18 is fixedly secured to the open end of the housing 12 by having its slit on its upper edge (as viewed in FIG. 14) engaging the corresponding protrusion 88 upper edge of the housing 12 and its lower edge fixed to the lower edge of the housing 12 by screws 90 having the knob. In other respects the arrangement is identical to that shown in FIG. 11.

In FIG. 15, the upper edge of the front panel 14 is fixed to the housing by screws 92 but not by the engagement of the protrusion 88 with the slit. In other respects the arrangement is identical to that shown in FIG. 2 except that the heat exchanger 20 is detachably disposed in the housing 12 in the

similar manner as above described in conjunction with FIG. 14.

If the heat exchanger 20 is desired to be removed from the device for replacement or for other reasons, it is only required for the arrangement of FIG. 14 to release the screws 98 to disengage the lower edge of the front panel 14 from the housing 12. Then the panel is raised to disengage the slit thereon from the protrusion 88 on the housing 12 whereupon it can be removed from the open end of the housing. This is accompanied by the disengagement of the angle bracket 84 from the heat exchanger 20. Then the heat exchanger 20 can readily be pulled out from the housing 12. Thereafter the heat exchanger 20 may be checked, cleaned or replaced by a new heat exchanger and then the process reversed from that just described is effected until the front panel 14 is secured to the housing 12.

In the arrangement of FIG. 15 corresponding to that shown in FIG. 2, the front panel 14 can disengage from the housing 16 through the release of the screws 92. Then the process as above described in conjunction with FIG. 14 is repeated.

Thus the arrangements shown in FIGS. 14 and 15 are facilitated in maintenance to permit the efficiency of total heat exchange to be always held high.

Alternatively, the arrangement shown in either of FIGS. 14 and 15 may readily be used only to ventilate the associated room without effecting the temperature and humidity exchanges. In this event the heat exchanger 20 is removed from the housing 12 in the manner as above described after which an isolating plate 94 is hermetically supported by the opposite angle brackets 84 and 86 to isolate the suction passageway 40 from the exhaust passage 42 as shown in FIG. 16. Namely, FIG. 16 illustrates the arrangement of FIG. 15 having the shield plate 94 substituting the heat exchanger 20.

In the arrangement of FIG. 16, the suction fan 48s is operated to suck the open air as a suction stream from the outdoor suction port 36 directly into the associated room. On the other hand, the exhaust fan 48e is operated to such the room air, as an exhaust stream from the indoor exhaust port 16 through the outdoor exhaust port 38 into the atmosphere while the room air is not affected by the suction stream. As a result, the temperature and humidity exchanges are not effected between the suction and exhaust streams and instead the room is effectively ventilated. Thus the arrangement can be advantageously operated during the spring and autumn seasons in which the interior of the room is not required to be thermally isolated from the exterior thereof and without wastefully using the heat exchanger.

From the foregoing it will be appreciated that the invention has provided ventilating devices comprising the heat exchanger including no movable part and disposed the intersection of the suction and exhaust streams caused by the respective fan, so as to permit both streams to pass therethrough in cross relationship. Therefore the devices can be manufactured into simple construction with low costs as well as being formed into smart appearance having any desired width.

Referring now to FIG. 17, there is illustrated a motor vehicle incorporating the ventilating device of the invention. The motor vehicle is generally designated by the reference numeral 100 and comprises a front portion 102 a rear portion 104 provided on both sides with windows 106 (only those windows on one side being illustrated), a floor plate 108, front wheels 110 and rear wheels 112. The internal space of the vehicle is schematically shown as being confined by dotted line 114 and has the ventilating device 116 of the invention sealed through that wall 118 adjacent the front portion 102. The device 116 includes the indoor suction and exhaust ports 16 and 18 respectively opening in the space 114. The ventilating device 116 is illustrated in detail in FIG. 18 wherein like reference numerals designate the components identical to those shown in FIG. 2. The arrangement illustrated in FIG. 18 is identical to that shown in FIG. 2 excepting that the outdoor suction and exhaust ports 36 and 38 respectively include axial

flanges 96 and 98 respectively. Then the flange 96 serves to connect the suction port 36 to a suction conduit 120 opening in the surface of the front portion 102 while the flange serves to connect the exhaust port 38 to an exhaust conduit 122 opening in the floor plate 108. The details of the ventilating device 116 need not be further described because it is substantially identical to the device of FIG. 2. If desired, the centrifugal fans illustrated may be replaced by the cross flow type fans such as shown in FIG. 11.

In operation the suction fan 48s is operated to suck the fresh open air through the suction conduit 120, the suction port 36 to supply it through a heat exchanger 20 to the space 114 while at the same time the exhaust fan 48e is operated to suck air in the space 114 through the suction port 16, the heat exchanger 20 and the exhaust conduit 122 and thence to below the floor plate 108. As a result, the space 114 is ventilated while the heat exchanger 20 serves to effect the temperature and humidity exchanges or the so-called total heat exchange in the manner as previously described. Thus the ventilation is effected while the space 114 is kept in an approximately adiabatic state with respect to the exterior of the vehicle. This results in the advantages that air within the vehicle is kept fresh and comfortable in respective of whether the motor vehicle is in operation or stopped and without deteriorating the heating or cooling effect upon the space within the vehicle.

FIG. 19 illustrates an air conditioning equipment constructed in accordance with the principles of the invention. The reference numeral 200 generally designates a room to be airconditioned. The room 200 is confined by a floor 202 and walls one of which is denoted by the reference numeral 204 and typically shown as being means for isolating the interior from the exterior thereof. Disposed in one corner of the room 200 is an air conditioning equipment according to the principles of the invention generally designated by the reference numeral 206. The equipment 206 comprises a housing 208 including a front wall provided on the lower portion with an exhaust port 212. The exhaust port 212 serves to discharge air conditioned air as will be described hereinafter to the room 200 and the suction port 210 serves to suck air from the room 200. A horizontal partition 214 extends across the interior of the housing 208 to isolate the side of the exhaust port 212 from the side of the suction port 210 and has centrally sealed therethrough a main body 216 of the airconditioning equipment 206 including its own heat exchanger and blower (not shown). The main body 216 is provided on the lower surface as viewed in FIG. 19 with an inflow opening 218 and on the upper surface with a discharge opening 220.

A ventilating device generally designated by the reference numeral 222 is sealed through a lower portion of a rear wall opposite to the front wall provided with the exhaust and suction ports 212 and 210 respectively of the airconditioning housing 208. The ventilating device 222 is illustrated in detail in FIG. 20 wherein like reference numerals designate the components identical to those shown in FIG. 11. By comparing FIG. 20 with FIG. 11 it is readily seen that both arrangements are substantially identical in construction to each other.

Another horizontal partition 224 extends from the front panel 14 of the device 222 at a point intermediate both the ports 16 and 18 to the inner surface of the front wall of the housing 208 at a point immediately above the suction port 210 for the purpose of preventing any short-circuiting air current from occurring directly between the airconditioning exhaust and suction ports 210 and 212 respectively. The partition 224 provided with a vent hole 216 to permit the secondary air sucked from the room 200 to partly flow toward the inflow opening 218 of the main air conditioning body 216. The rear end portion of the ventilating device 222 is fitted into an air intake 228 disposed on the wall 204 with the external surface of the wall 204 substantially flush with the rear end face of the device 222 having disposed thereon the outdoor suction and exhaust port 36 and 38 respectively. The details of the ventilating device 222 will readily be understood from the

description for FIG. 11. If desired, the cross flow type fans illustrated may be replaced by the centrifugal fans such as shown in FIG. 2.

In operation, the airconditioning equipment 206 is operated to suck air in the room 200 through the suction port 210 the vent hole 226 and the inflow port 218 into the main body 216 where the air is warmed or cooled as the case may be. Then the warmed or cooled air is supplied to the room 200 through the discharge opening 220 and the exhaust port 212 whereby the interior of the room 200 is warmed or cooled. The direction of the air current is designated at the arrows F, G, H, I and J in FIG. 19.

On the other hand, the exhaust fan 48a is disposed in the ventilating device 222 is operated to suck one portion of the air sucked through the air conditioning port 210, through the suction port 16 into the device 222 as shown at the arrows K in FIG. 20. Then the sucked air is passed through the device and exhausted externally of the room 200 through the exhaust port 38 along a path as shown at the arrows L, M and N in FIG. 20. Simultaneously the suction fan 48a e in the ventilating device 222 is operated to suck the open air through the suction port 36 into the device and then supply it through the exhaust port 18 to the inflow opening 218 of the main body 216.

As a result, that air supplied to the room 200 from the main body 216 has added thereto the fresh open air while one portion of air contaminated in the room is exhausted externally of the room. Therefore the interior of the room 200 is warmed or cooled while at the same time it is ventilated. At that time the heat exchanger 20 within the ventilating device 222 is operated to effect the temperature and humidity exchanges or the total heat exchange between the exhaust and suction streams flowing through the ventilating device 222 in the manner as previously described in conjunction with FIGS. 3 through 10. Therefore although the exhaust and suction streams flow from and into the room 200 the interior of the room 200 is maintained in approximately adiabatic state with respect to the exterior thereof with the result that the ventilation effected by the ventilating device 222 does not much change the temperature and humidity in the room 200.

The arrangement is advantageous in that the fresh open air is used to warm or cool the interior of the associated room with a high efficiency because the open air is introduced into the room with an approximately adiabatic state maintained between the interior and exterior of the room.

What we claim is:

1. A ventilating device for ventilating a room comprising, in combination: a box-shaped housing including a suction port and an exhaust port facing each of the interior and exterior portions of a room to be ventilated; a plurality of partitions within said housing defining a suction passage and an exhaust passage each communicating one suction port and one exhaust port and wherein said suction passage and exhaust passage open into a common heat-exchange space; a suction fan disposed in said suction passage operable to form a suction air stream along said suction passage; an exhaust fan disposed in said exhaust passage operable to form an exhaust air stream along said exhaust passage; and combined heat-moisture transfer means disposed within said common heat-exchange space for effecting continuous and simultaneous transfer of heat and moisture between the suction air stream and the exhaust air stream, said combined heat-moisture transfer means including a plurality of laminations composed of a material sufficiently thermally conductive and permeable to moisture to effect continuous and simultaneous transfer therethrough of both heat and moisture, said plurality of laminations being superposed on one another at predetermined substantially equal intervals defining therebetween a plurality of gaps, and means for communicating alternate ones of gaps formed between said laminations with said suction passage and the remaining gaps with said exhaust passage.

2. A ventilating device as claimed in claim 1 wherein each of said fans is of a centrifugal type.

3. A ventilating device as claimed in claim 1 wherein each of said fans is of a cross flow type.

4. A ventilating device as claimed in claim 1 wherein said laminations of said heat exchanger are composed of Japanese paper.

5. A ventilating device as claimed in claim 1 wherein said suction and exhaust fans are of a centrifugal type including a multi-vane impeller and disposed so as to render said multi-vane impellers coaxial with each other and wherein a common electric motor for driving said fans is provided including a driving shaft connected at the opposite ends to respective ones of said multi-vane impellers.

6. A ventilating device as claimed in claim 1 wherein said suction and exhaust fans are of a centrifugal type including a multi-vane impeller and disposed so as to render said multi-vane impellers coaxial with each other, a common electric motor including a driving shaft connected at the opposite ends to said multi-vane impellers respectively, and wherein said centrifugal suction fan is disposed between said suction port communicating with said suction passage and said heat-exchange space while said centrifugal exhaust fan is the same in output as said suction fan and disposed between said suction port communicating with said exhaust passage and said heat-exchange space.

7. A ventilating device as claimed in claim 1 wherein said housing includes an opening near to the interior of the room, and a front decorated panel detachably closing said opening, and including said suction port and said exhaust port facing the room, support means disposed within said housing, and a support member secured to the internal surface of said front panel cooperative with said support means to removably support said heat exchanger therebetween such that said front panel disengages from said housing to permit said heat exchanger to be removed from said housing through said opening thereof.

8. A ventilating device as claimed in claim 1 wherein the housing includes an opening near to the interior of the room, and a front decorated panel detachably closing said opening housing, and including said suction port and said exhaust port facing the room, support means disposed within said housing, a support member secured to the internal surface of said front panel cooperative with said support means to removably support said heat exchanger therebetween such that said front panel disengages from the housing to permit the heat exchanger to be removed from said housing through said opening thereof, and an isolating plate capable of being detachably sandwiched at the intersection of the suction and exhaust passages between said support means and said support member thereby to cause the exhaust stream to be sucked through said exhaust port on the side of the room and simultaneously to cause the suction stream to be discharged through said suction port on the side of the room.

9. In combination: a motor vehicle; a suction conduit and an exhaust conduit opening externally of the motor vehicle; a housing including an external suction port connected to said suction conduit, an external exhaust port connected to said exhaust conduit, and an internal suction port and an internal exhaust port facing the interior of the vehicle; a plurality of partitions within said housing defining a suction passage and an exhaust passage extending within said housing from the interior to the exterior of the vehicle and opening into a common heat-exchange space; a suction fan disposed in said suction passage operable to form a suction air stream along the suction passage; an exhaust fan disposed in said exhaust passage operable to form an exhaust air stream along said exhaust passage; and combined heat-moisture transfer means disposed within said common heat-exchange space for effecting continuous and simultaneous transfer of heat and moisture between the suction air stream and the exhaust air stream, said combined heat-moisture transfer means including a plurality of laminations composed of a material sufficiently thermally conductive and permeable to moisture to effect continuous and simultaneous transfer therethrough of both heat and moisture, said plurality of laminations being superposed on

one another at predetermined substantially equal intervals defining therebetween a plurality of gaps, and means for communicating alternate ones of gaps formed between said laminations with said suction passage and the remaining gaps with said exhaust passage.

10. A combination as claimed in claim 9 wherein said laminations of said heat exchanger are composed of Japanese paper.

11. An air conditioning equipment for conditioning a room comprising: a main body having an inflow side; and a ventilating device comprising a box-shaped housing including a suction port and an exhaust port facing each of the interior and exterior portions of the room to be conditioned; a plurality of partitions within said housing defining a suction passage and an exhaust passage each communication one suction port and one exhaust port and wherein said suction passage and exhaust passage open into a common heat-exchange space; a suction fan disposed in said suction passage operable to form a suction air stream along said suction passageway; an exhaust fan disposed in said exhaust passage operable to form an exhaust air stream along said exhaust passage; and combined heat-moisture transfer means disposed within said common heat-exchange space for effecting continuous and simultaneous transfer of heat and moisture between the suction air stream and the exhaust air stream, said combined heat-moisture transfer means including a plurality of laminations composed of a material sufficiently thermally conductive and permeable to moisture to effect continuous and simultaneous transfer therethrough of both heat and moisture, said plurality of laminations being superposed on one another at predetermined, substantially equal intervals defining therebetween a plurality of gaps, and means for communicating alternate ones of gaps formed between said laminations with said suction passage and the remaining gaps with said exhaust passage; and means for supplying the suction air stream to said inflow side of said main body.

12. An airconditioning equipment as claimed in claim 11 wherein said laminations of said heat exchanger are composed of Japanese paper.

13. A ventilating device for ventilating a room comprising: a housing having therein means defining an air induction system for inducing air from outside the room to be ventilated into the room and means defining an air discharge system for discharging air contained within the room to the outside thereof; and combined heat-moisture transfer means statically positioned within both said air induction and air discharge system for effecting continuous and simultaneous transfer of heat and moisture between the inducted and discharged air comprising a plurality of spaced-apart and superposed heat and moisture transfer surfaces defining therebetween a plurality of superposed static air flow paths, means communicating alternate ones of said flow paths with said air induction system and the remaining alternate flow paths with said air discharge system, and wherein said heat and moisture transfer surfaces are composed of a material sufficiently heat conductive and sufficiently permeable to moisture to allow moisture flow therethrough to continuously and simultaneously effect both heat and moisture exchange between the inducted and discharged air.

14. A ventilating device according to claim 13; including a spacer member disposed in the flow path between each two adjacent heat and moisture transfer surfaces, each said spacer member having an undulating configuration dividing the flow path into a plurality of individual and parallel flow paths.

15. A ventilating device according to claim 14; wherein the flow paths in communication with said air induction system extend transversely with respect to the flow paths in communication with said air exhaust system.

16. A ventilating device according to claim 13; wherein said heat and moisture transfer surfaces are composed of Japanese paper.

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