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Weil

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[54] **ADIABATIC SATURATION COOLING MACHINE**

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[73] Assignee: **Gas Development Corporation,** Chicago, Ill.

[22] Filed: **May 18, 1972**

[21] Appl. No.: **254,807**

Related U.S. Application Data

[60] Division of Ser. No. 118,196, Feb. 23, 1971, which is a continuation of Ser. No. 791,000, Jan. 14, 1969, abandoned.

[52] **U.S. Cl.** **55/388,** 55/390, 62/94

[51] **Int. Cl.** **B01d 53/06**

[58] **Field of Search** 55/34, 388, 390; 62/94; 165/2

[56] **References Cited**

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3,009,540	11/1961	Munters	55/34
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Primary Examiner—Charles N. Hart
Attorney, Agent, or Firm—Molinare, Allegretti, Newitt & Witcoff

[57] **ABSTRACT**

An improved adiabatic saturation cooling machine of the open-cycle type and method of operation in which the capacity of the machine is increased by routing by-pass streams of air through either the S-wheel or the L-wheel. The amount of these by-pass streams are from 0 to 100 percent that of the main exhaust stream of air passing from the room through the S-wheel. In the first embodiment the by-pass air is outside air and is directed to the regenerative "side" of the S-wheel. Such a by-pass stream ranging from 95° to 80°F will cool the air from the S-wheel an additional 2.6 to 5.9°F below that capable by the room air exhaust stream alone. The outside air by-pass stream may be passed directly through the S-wheel or pretreated by passing through an E-pad. In the second embodiment, where there is sufficient air supplied to the burner section to regenerate the L-wheel, a portion of the primary room exhaust air stream is recirculated as a by-pass stream to the input face of the L-wheel. A third embodiment is directed to incoming air bypassing the E-pads from the cooling side of the S-wheel. A fourth embodiment is directed to a return by-pass for directing the first stream of incoming L-wheel air back out the regenerative "side" of the L-wheel.

7 Claims, 5 Drawing Figures

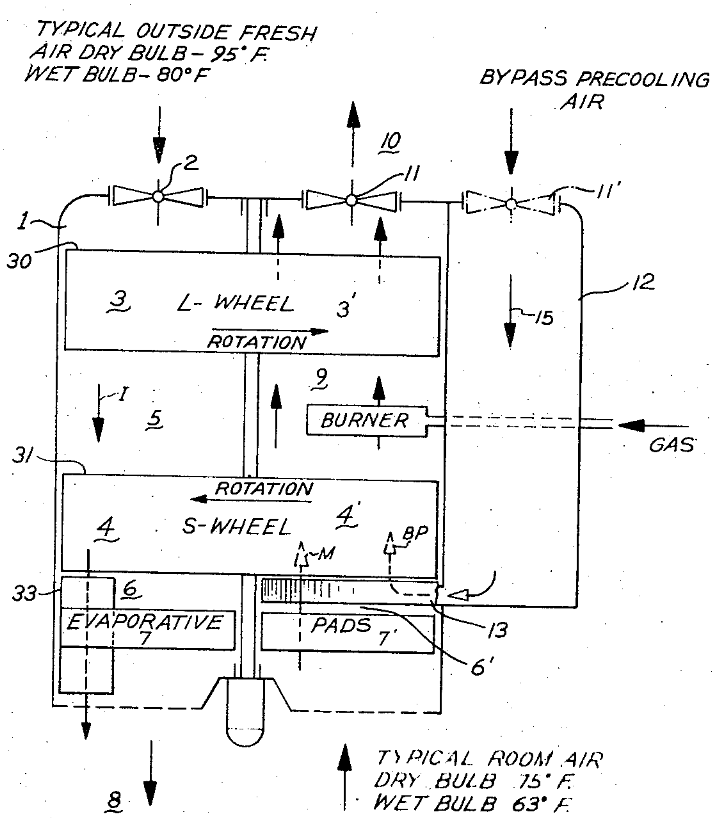
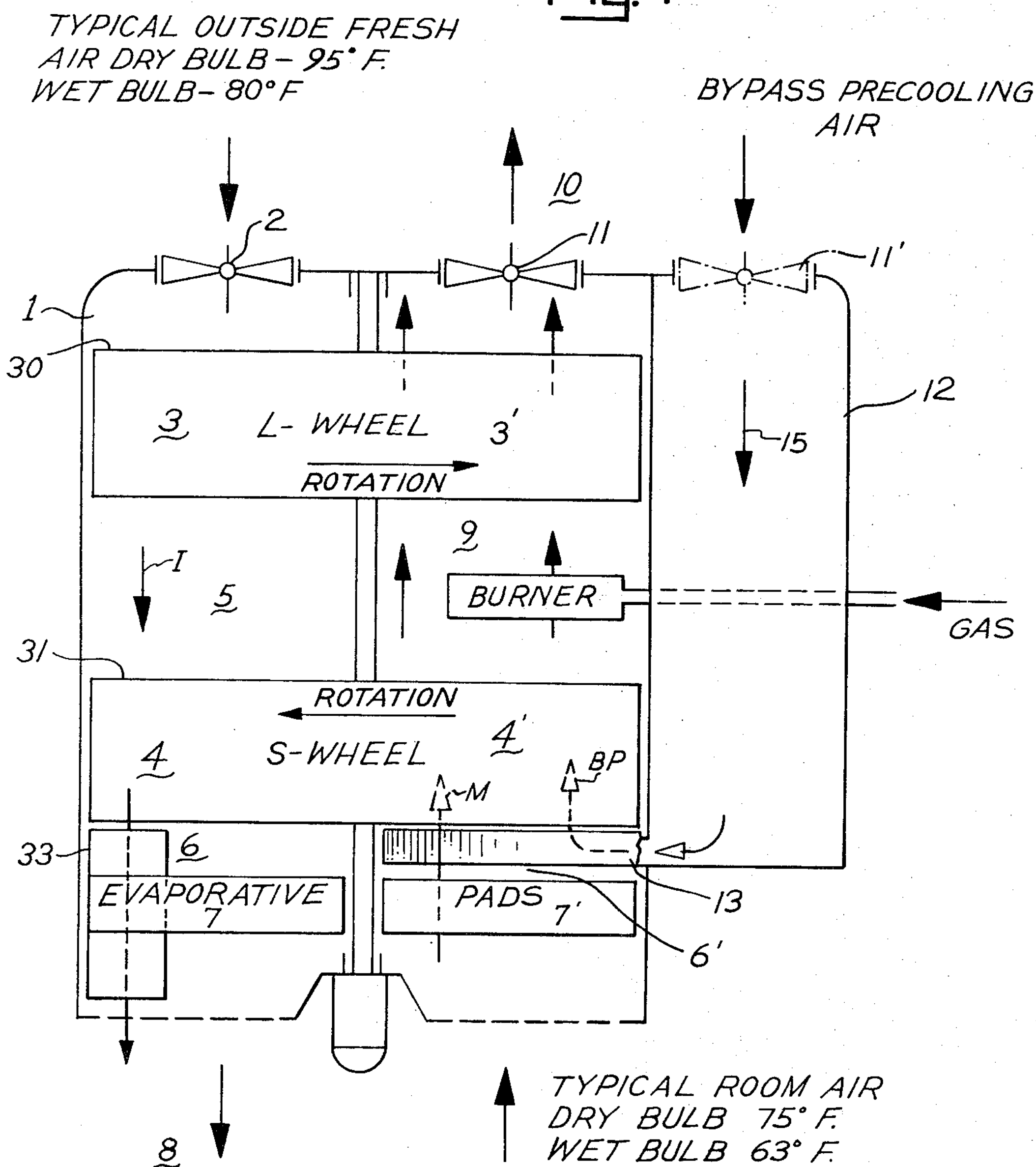


Fig. 1


TYPICAL OUTSIDE FRESH
AIR DRY BULB - 95° F.
WET BULB - 80° F
BYPASS PRECOOLING
AIR
10
2
11
11'
1
30
12
3
L- WHEEL
3'
ROTATION
15
9
I
5
BURNER
GAS
31
ROTATION
S-WHEEL
4
4'
BP
M
33
6
EVAPORATIVE
7
PADS
7'
13
6'
8
TYPICAL ROOM AIR
DRY BULB 75° F.
WET BULB 63° F.

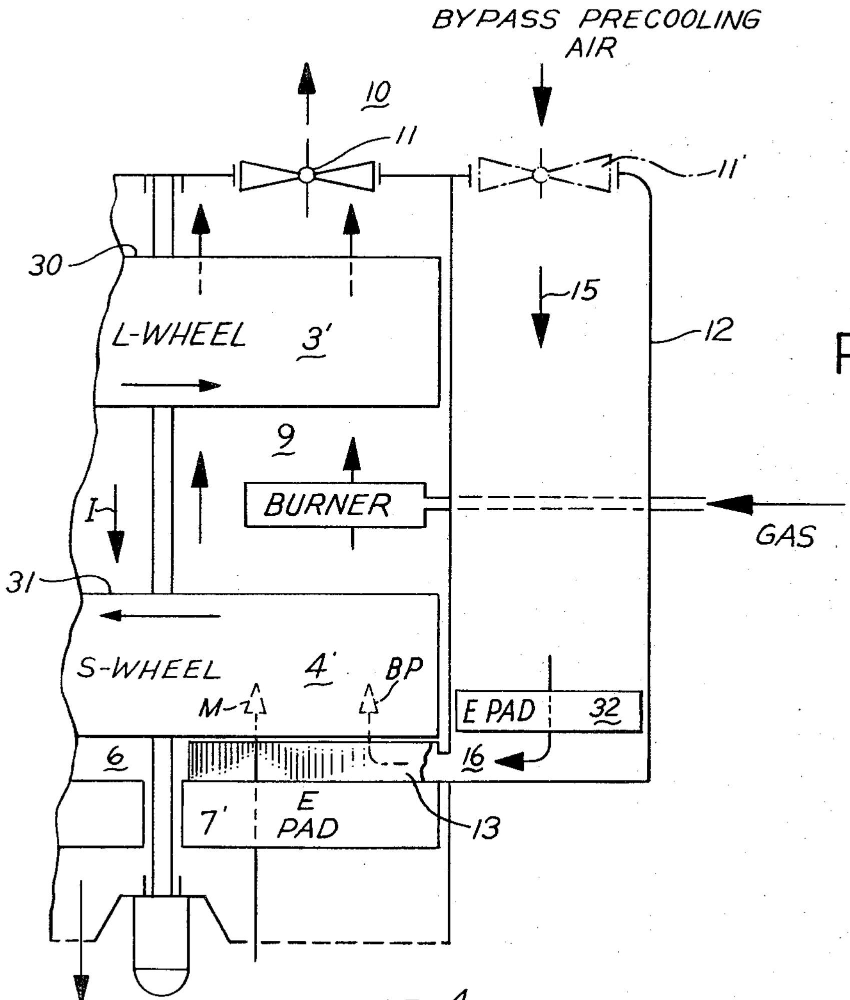

BYPASS PRECOOLING AIR
10
11
11'
30
15
12
L-WHEEL 3'
9
BURNER
GAS
I
31
S-WHEEL 4'
BP
M
E PAD 32
16
6
7'
E PAD
13

Fig. 2

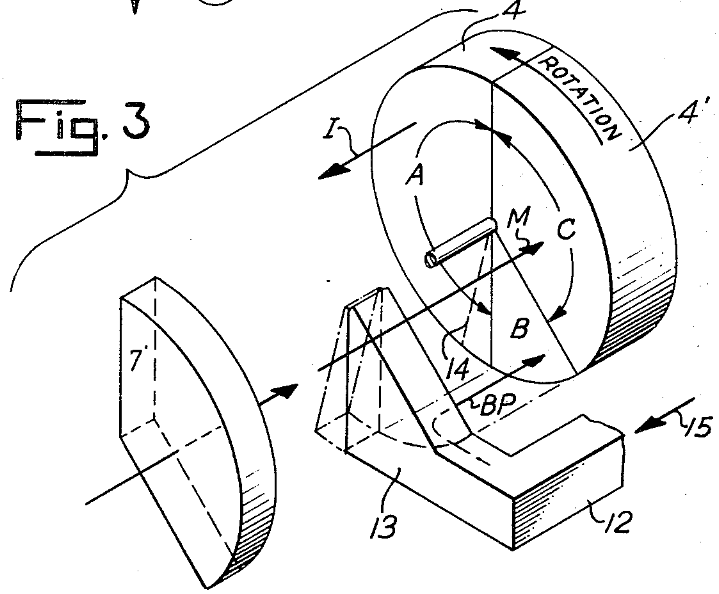

4
ROTATION
4'
I
A
M
C
B
7'
14
BP
15
13
12

Fig. 3

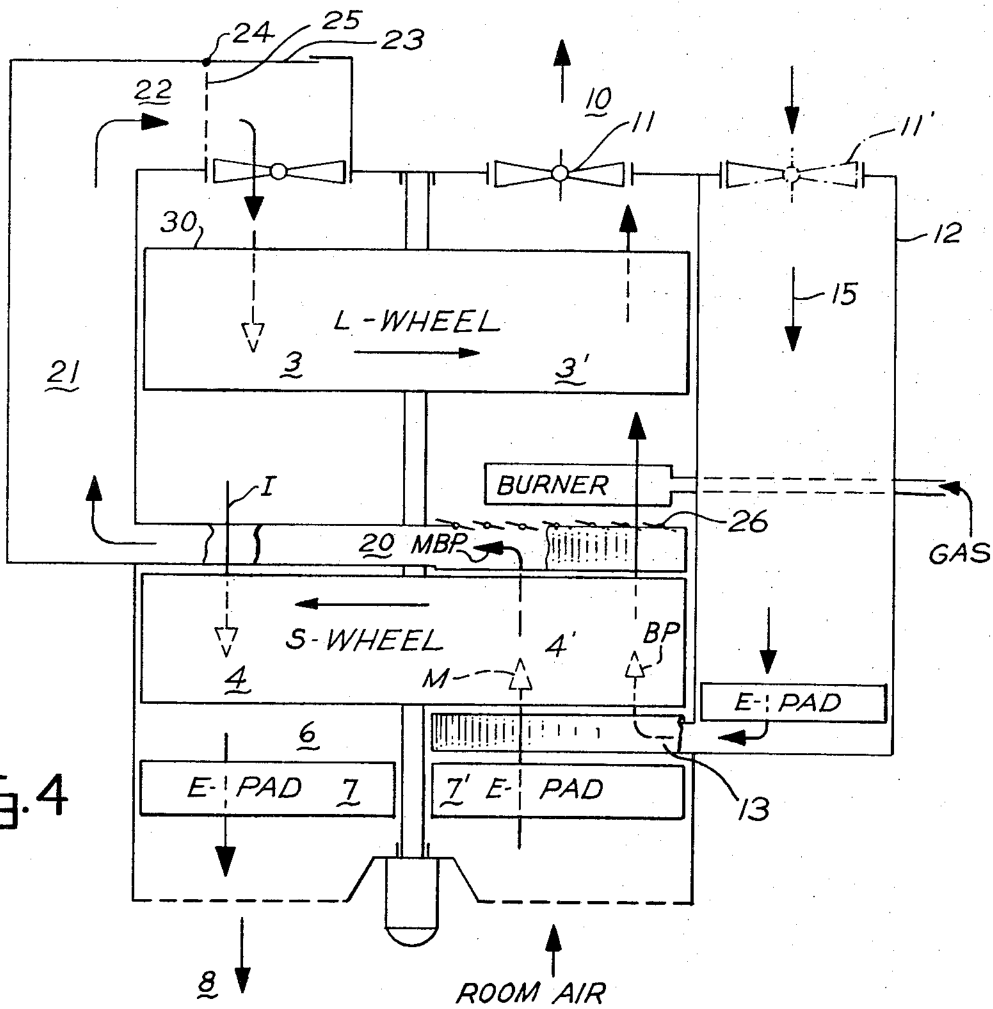

24
25
23
22
10
11
11'
30
12
15
L-WHEEL
3
3'
21
BURNER
I
26
GAS
20 MBP
S-WHEEL
BP
4'
4
M
E-PAD
6
E-PAD 7
7' E-PAD
13
8
ROOM AIR

Fig. 4

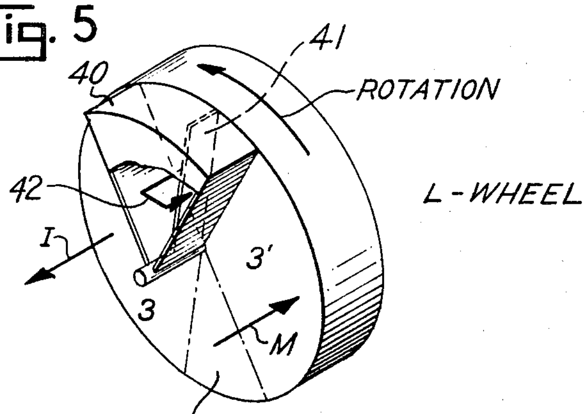

41
40
ROTATION
42
L-WHEEL
I
3'
3
M
43

Fig. 5

ADIABATIC SATURATION COOLING MACHINE

This is a division of application Ser. No. 118,196, filed Feb. 23, 1971 which is a continuation of application Ser. No. 791,000, filed Jan. 14, 1969 and now abandoned.

This invention relates to air conditioning, and in particular to improved efficiency of cooling involving improved process and apparatus for an open-cycle air conditioning unit.

Open-cycle air conditioners are well known in the art. One system, known as the Munters environmental control system (MEC) unit, is described in U.S. Pat. No. 2,926,502. Basically, open-cycle air conditioners operate by dehumidification and subsequent cooling of air wherein moist air is conditioned by a three-stage process to produce cool relatively dry air.

Open-cycle air conditioning systems comprise essentially four sections, considered in order from the interior room in which the air is to be conditioned toward the exterior: (1) an adiabatic evaporating section designated an E-pad, (2) a S-wheel section, for transfer of sensible heat to and from air, (3) a heating section, and (4) a L-wheel section for transfer of latent heat of condensation and evaporation. MEC units are fuel gas or electrically operated environmental control systems which provide cooling in the summer, heating in the winter, year-around control of humidity, and effective removal of dust and pollen. The principle involved in the cooling effect of the system is that dry, warm air can be simultaneously cooled and humidified by contacting it with water. In geographic areas where the air is both warm and humid, it must be dried before it can be cooled by evaporation. During the heating season of autumn, winter and spring, the unit can be used to warm and humidify cold, dry air by making minor changes in the unit's operating cycle.

However, the present Munters type of units suffer from an inadequate cooling step involved in the S-wheel section of the machine. The present S-wheels used in this type of machine are approximately 90 percent efficient. For example, air from the dehydrating L-wheel has an average temperature on the order of 190°F and is cooled to 75.7°F by the S-wheel during the cooling half of the cycle. In turn, the S-wheel is regenerated, i.e., recooled after taking up heat from the incoming air, by a 63°F stream of air exhausting from the room during the regenerative half of the cycle. This rather high temperature of the conditioned air from the S-wheel (75.7°F) is limited primarily by the wheel efficiency and, to some degree, to the outside ambient air temperature and humidity.

It is therefore an object of this invention to provide an improved open-cycle air conditioner assembly in which the cooling efficiency of the S-wheel is increased.

It is another object of this invention to provide an improved process of conditioning air whereby lower conditioned air temperatures are achieved, and recirculation of room air is possible when so desired.

Another object of this invention is to provide improved process and apparatus for rejecting a first segment of moist air input through the L-wheel back out through the regenerative side of said wheel.

Another object of this invention is to provide improved process and apparatus for bypassing air from the outside through the S-wheel, or first through an E-pad and then the S-wheel, or from the exit side of the S-wheel to the input side of the L-wheel, or from the cooling side of the S-wheel to the room without passing through an E-pad, and the various combinations of bypasses thereof.

Additional objects of this invention will be evident from the detailed description which follows.

The objects of this invention are achieved by directing streams of air through either the regenerative side of the S-wheel, and/or the input face of the L-wheel. In the first embodiment, the S-wheel is precooled by directing a stream of outside air through the wheel prior to passing the primary or main cooling stream of air exhausting from the room through the wheel. In the apparatus and method of this invention, as the S-wheel passes through the regenerative portion of the cycle, a first, precooling, stream of air is passed through the wheel. This precooling, or secondary air, may be ambient outside air and can be an amount less, as large, or larger than, the amount of the room exhaust air. The secondary air amount can be varied to achieve the desired final conditioned air temperature, and will be typically an amount of 20–100 percent of the main stream passing through from 1 to 50 percent, and preferably 5 to 30 percent, of the surface area of the S-wheel. The particular area value within this range may be determined to avoid excessive blower power requirements. Thereafter the room exhaust air stream, called the main or primary stream, is passed through an appropriately proportioned fraction of the S-wheel. Usually the amount of primary air exhausted is equivalent to the amount entering the room, but may be more or less as inside and outside environmental factors permit depending on the machine capacity.

In a second embodiment, which is preferably operated in conjunction with a bypass stream of outside air, a portion of the primary exhaust stream is directed as a bypass stream to the input face of the L-wheel.

Two other embodiments involve, respectively, passing incoming air directly to the room from the cooling "side" of the S-wheel without passing through an E-pad, in order to achieve humidity control and rejecting a first segment of moist air input through the L-wheel from the outside backout through the regenerative side of the L-wheel.

In the figures like numbers in different figures indicate similar or equivalent parts. The arrows show the air flow paths and are indicated in dashed lines where the air passes through an E-pad, a wheel, or a duct not shown in cross-section. All ducts are shown in diagrammatic cross-section except the portion between the regenerative side E-pad and S-wheel and a portion of the recycle duct, which are shown in plan view, and the duct of FIG. 5 which is shown in perspective.

FIG. 1 shows diagrammatically one embodiment of an open-cycle air conditioning system of this invention wherein the S-wheel is precooled by a stream of secondary, bypass air;

FIG. 2 shows diagrammatically a second embodiment of an open-cycle air conditioning system of this invention employing a pretreated stream of precooled bypass air;

FIG. 3 is an exploded perspective view of the interior face of an S-wheel showing qualitatively the portions of the wheel exposed to the precooling bypass stream and the primary cooling air streams respectively;

FIG. 4 shows diagrammatically a third embodiment employing ducting for recirculation of room air; and

FIG. 5 shows a perspective view partly in section of a return conduit for passing input air back out the L-wheel regenerative side.

Referring now to FIG. **1**, a conventional open-cycle system operating in the cooling mode may be described as follows: The incoming outdoor air is shown by the downwardly pointing arrow on the left side of the diagrammatic representation of an open-cycle unit **1.** To start the cooling half of the cycle, the warm, moist outside air is drawn into the unit by means of a fan **2** and passed through the input side **30** of a hot, dry L-wheel **3** which serves the function of taking up (sorbing) moisture from the air. In the figures the L-wheels rotate clockwise, from left to right as seen from the top. A major portion of the latent heat of condensation liberated by the water in being absorbed in the L-wheel is taken up by the air as it passes through the wheel.

The air leaving the L-wheel is not uniform in temperature or humidity. I have found that air which first passes through the L-wheel after it has left the regenerative half of the cycle should not continue on to the S-wheel but be diverted into the regenerative stream. I have discovered that this portion of air serves primarily to cool the wheel with very little dehydration of the air. I have determined that at usual air velocities (about 200 feet per minute through the L-wheel rotating at a representative speed of 3–4 minutes per revolution), about a fifth of a minute for each 6 inches of wheel depth is required for this cooling section. This may also be expressed as the equivalent angle of rotation, θ, of between about 17°–24° per 6 inches wheel depth. The efficiency of the machine is enhanced if this portion of the air stream leaving the L-wheel is sent into the regenerative stream immediately upstream of the burner, as shown in FIG. **5.** FIG. **5** shows that the first portion of incoming air passing through a segment of the L-wheel identified by the angle θ is diverted in a bypass duct **40** back through the regenerative side of the L-wheel by means of baffle **41** as shown by the arrow **42.** As shown it can be diverted through the preceeding segment of the L-wheel **3'** in the regenerative half of the cycle, or alternatively through other segments of the L-wheel, for example, the first segment of the wheel rotating into the regenerative half of the cycle, as shown in phantom lines **43.** Alternatively, the portion of the duct protruding into the regenerative side may be eliminated with the rejected air segment mingling with the exiting regenerative air stream. The remaining portion of the air stream leaving the L-wheel while still hot, is sufficiently dry for the purposes of the machine up to a period of 2 minutes for each 6 inches of wheel depth in mild climate region such as Chicago. This dry segment is only 1.5 minutes in more severe humidity areas such as Texas.

The hot, dry incoming air, I, then passes through the cool portion **4** of a rotating S-wheel wherein it gives up most of its sensible heat to the wheel. For best S-wheel operation, the S-wheel should rotate in a direction opposite to the L-wheel. The two wheels may rotate in the same or opposite directions, and clockwise rotation of the L-wheel is not an absolute requirement. Since the S-wheel is water impervious and relatively cool, the air is cooled with no change in moisture content. In the ordinary cycle, at usual design conditions, the average temperature of the air incoming to the S-wheel at **5** after having passed through the L-wheel is on the order of about 190°F. Typically, a well-designed S-wheel is capable of on the order of 90 percent efficiency. With the S-wheel 90 percent efficiency, in the conventional systems, the incoming hot dry air from the L-wheel at **5** during the cooling half of the cycle is thus cooled to about 75.7°F at **6** prior to passage through the evaporative pad **7** and then into the room **8.**

Exiting from the S-wheel at **6,** relatively cool, relatively dry air passes over or through evaporative pads **7,** where water is evaporated and the air is humidified. Simultaneously, the latent heat of vaporization is extracted from the air (in order to evaporate the water into the air), thereby cooling the air. The resulting air issuing into a room or space to be conditioned **8** is typically at a lower dry bulb temperature than the outside air with about 95 percent relative humidity. This cooled, moist air is thus conditioned for room comfort. If desired, a preselected humidity level can be achieved by passing a controlled portion of stream **6** around the E-pad **7**, e.g., via bypass duct **33** (FIG. **1**).

The regenerative half of the cycle commences with typical room air passing through evaporative pads **7'** where the air is cooled while evaporating water from the pad. The resultant cool, relatively moist air is then passed over the hot portion **4'** of the S-wheel which is cooled thereby. It should be recalled that the S-wheel has been heated by taking up sensible heat from the hot dry air produced from the L-wheel, the dehydrating wheel. The air incoming to the S-wheel after passing through the evaporative pads is ordinarily on the order of 63°F.

Continuing with the regenerative half of the cycle, the moist air passing through the right side of the S-wheel **4'**, while cooling the rotating S-wheel so that it may repeat its portion of the cooling half of the cycle at **4,** is warmed. This warm, moist air then passes through a heating section **9.** This heating section typically employs a gas burner or other heat source where the temperature is greatly increased, producing very hot, of low relative humidity air, typically on the order of 325°F. This very hot air, because of the heat, has a low relative humidity which, when passed through the moist portion of the L-wheel **3'** dries the wheel. The very hot air is then exhausted to the outside **10** completing the regenerative half of the cycle. Meanwhile, the heated, dried L-wheel rotates into position to function in the cooling half of the cycle where it again sorbs moisture from incoming outdoor air.

In one embodiment of this invention (still referring to FIG. **1**), a stream of bypass air **15** (secondary air) is drawn in by means of fan **11** (or optionally by fan **11'** shown in phantom lines) into the duct **12** shown at one side of the apparatus. The air shown by the dashed arrow BP is directed by suitable ducting **13** through a portion of the S-wheel. The portion of the S-wheel which receives the bypass air from the outside is on the order of from 1–50 percent of the surface area of the regeneration side of the S-wheel, preferably 5–30 percent, that segment is identified as segment B in FIG. **3.** As shown in the figures, that portion is preferably a portion of the right side of the S-wheel, but may be partially or entirely on the left side.

The term "side" has the meaning here of portion, and the regenerative "side" need not be identical to half the S-wheel, as shown in FIG. **3** by the phantom line **14.** For example, ducting to and from the wheel faces may be arranged to divide the wheel faces area into any desired number of parts and proportions, including radial (angular) or concentric annular portions, or the like. Where the wheel faces area is divided into three segments for (1) the input air being conditioned, (2) the secondary precooling air, and (3) the primary exhaust air, respectively, only the input air portion would be termed the input "side," with the remaining portions constituting the regenerative "side" even though they may constitute, say, two-thirds of the wheel area.

Continuing with the regenerative portion of the method and apparatus of this invention, 100 percent of the room exhaust air (the main or primary air stream indicated by dashed arrow M in the figures) is directed through the remaining portions of the regenerative "side" or portion of the S-wheel as shown in segment C of FIG. 3. For example, in this embodiment, where the room exhaust or primary air stream and the input air stream passing from **5** to **6** are volumetrically equal, and the secondary bypass air stream **15** passing through segment B of the S-wheel (see FIG. 3) is on the order of 95°F, the 190°F stream passing inwardly from **5** via face **31** through segment A of the S-wheel (see FIG. 3) will be cooled to about 73.1°F at **6**. In contrast, where no bypass air stream is used, only 75.7°F would be achieved at **6**. Thus, this embodiment of the invention resulted in about a 2.6°F drop at **6**, and a corresponding efficiency increase.

Referring now to FIG. **2**, a second embodiment of the invention employs a bypass air stream **15** routed first through an evaporative pad **32**, via ducting **13** before passing through an appropriate portion of the S-wheel **4'**. In passing first through the evaporative pad, a 95°F bypass air stream is evaporatively cooled to about 80°F at **16**. The water vapor added may be preselected in amount up to adiabatic saturation. This results in an improvement in the cooling of the conditioned stream **6** of 5.9°F over that achieved without the bypass, where the same main and input air stream as above are used. This 5.9°F improvement corresponds to an increase of 24 percent in machine capacity if no other changes are made.

As can be seen from FIG. **3**, the bypass air stream BP from the outside passing through the appropriate segment B of the S-wheel operates to precool the S-wheel since the wheel rotates first into the bypass segment B from the cooling half cycle portion or side **4**. Thus, the S-wheel of this invention employs the use of three streams of air, the added one being outside air, either untreated or evaporatively precooled. The apparatus of this invention thus has an equivalent cooling efficiency of over 95 percent, in cooling the hot air I incoming from the L-wheel at **5**, as compared to efficiency figures of on the order of 90 percent for MEC units not employing the bypass of this invention.

Although the use of a third stream increases the blower requirements, the increase is offset by the increased capacity of the machine. Where an improved machine of this invention is to have the original capacity, the blower requirements can actually be lower than the original machine.

By way of example, the various potential gains through use of a bypass stream of this invention can be illustrated in the following table which relates the total water consumption, the blower power requirements, the delivered temperature, and the amount of bypass air used as compared to conventional machines of same

Table I

Ratio Bypass Air/Room Exhaust Air	Relative Temperature of Conditioned Air Delivered to E-pad, °F (at 6 in FIG. 2)	Relative Total Water Consumption, Ratio	Relative Total Blower Power, Ratio
0	0	1.0	1.0
1/9	−2.8	.92	.76
2/8	−4.7	.90	.69
3/7	−5.6	.95	.72
4/6	−5.9	1.05	.77
1	−5.9	1.16	.97

capacity. In this example the bypass stream is precooled as in FIG. **2**, and the amount of the precooled bypass stream is expressed in terms of a ratio of its mass relative to that of the primary or room exhaust stream mass.

When the bypass air:primary exhaust air ratio is greater than 2 : 3, the room exhaust air may be recirculated as shown in the embodiment of FIG. **4**. In this embodiment the burner air is supplied completely by the bypass air. Even where there is less than 2 : 3 ratio, a portion of the room exhaust air can be recirculated. Under mild conditions, where full burner operation is not used, full recirculation is possible even though the ratio is less than 2 : 3.

Referring now to FIG. **4**, this embodiment of this invention employs a bypass stream routed by duct **13** as in the embodiment of FIG. **2** described above. The room exhaust stream instead of going to the L-wheel on the regenerative side, is directed, via suitable ducts **20, 21, 22** to the input side of the L-wheel. When not in use, louvre **23**, pivotable at **24**, is disposed in its closed position **25** and the flow-through louvres **26** in duct **20** opened to provide operation as in the device of FIG. **2.** The machine of this embodiment is adjustable between zero and full recirculation, e.g., by adjustment of the louvres **23** and/or **26.** Thus advantage may be taken of greater efficiency on mild days without the use of this recirculation method, while on severely hot and humid days recirculation permits greatest efficiency.

During the heating season, the MEC unit of this invention has the capability of delivering heated, filtered and controlled humidification of air to the space to be conditioned. Conversion of the unit from cooling to heating is accomplished very simply by stopping rotation of the S-wheel and increasing the speed of rotation of the L-wheel. During the heating cycle, exhaust air from the conditioned space is heated by the gas burner and this heat is then transferred to the rotating L-wheel as exhaust air passes through the L-wheel to the outside. The heat thus stored in the L-wheel is utilized when relatively cold outside air is drawn through the L-wheel, which in this mode of operation functions as a very efficient heat exchanger. Moisture generated by combustion of gas is recycled to the incoming air to provide humidity levels adequate in most cases. Air heated by the L-wheel then passes through the stationary S-wheel. If necessary, the air may be passed through a water curtain or evaporative pad where dust or pollen is removed and the air is further humidified to a desired level before it is delivered to the conditioned space. Optionally, all the air may pass directly to the space via bypass conduit **33.** In this mode of operation the bypass air system **11, 12, 13** shown in FIGS. **1, 2** and **4** is not utilized.

Such open cycle environmental control systems in both the heating and cooling modes can utilize 100 percent outside air, unlike most air conditioning systems, which, except on mild days, must recycle inside air. Because of the water curtain or evaporative pads employed, all such air is subject to removal of dust and pollen before it enters the conditioned space.

While I have described my invention in connection with specific embodiment thereof, it is to be understood that this is by way of illustration and not by way of limitation, and the scope of my invention is defined solely by the appended claims which should be construed as broadly as the prior art will permit.

I claim:

1. In an open-cycle environmental control system unit of the type having means for passing outside air as a first air stream in a first direction through said unit, means for passing room air as a second air stream in a second direction through said unit, means for isolating said first and second air streams from each other, an L-wheel and an S-wheel continuously rotating through said first and second air streams, said S-wheel and said isolating means cooperating to define at a given moment in time a first side and a second side of said S-wheel, an interface between said first side and said second side, said S-wheel rotating from said first side through said interface, and a segment of said second side, said segment being adjacent to said interface, means for directing said first air stream through said first side of said S-wheel whereby said first side absorbs heat from said first air stream to cool said first air stream, and means for directing said second air stream through said second side of said S-wheel whereby said second side transfers said absorbed heat to said second air stream to cool and regenerate said S-wheel, the improvement comprising means for passing outdoor air as a third air stream in said second direction through said unit and means for directing said third air stream through said segment, said third air stream means and said third air stream directing means cooperating to define means for pre-cooling said second side of said S-wheel prior to said cooling by said second air stream.

2. The improvement of claim **1** wherein said segment is 5 to 30 percent of the surface area of said S-wheel.

3. The improvement of claim **1** wherein said third air stream means includes a duct in communication with the outdoor and said S-wheel and means for producing air flow within said duct positioned in association therewith.

4. The improvement of claim **1** wherein said third air stream means includes means for supplying water vapor to said third air stream in an amount up to adiabatic saturation.

5. The improvement of claim **1** which includes means for directing said first air stream exiting said first side of said S-wheel through an evaporative pad.

6. The improvement of claim **1** including means for directing a portion of said first air stream passing through the segment of said L-wheel first entering said first air stream directly into said second air stream.

7. In an open-cycle environmental control system unit of the type having means for passing outside air as a first air stream in a first direction through said unit, means for passing room air as a second air stream in a second direction through said unit, means for isolating said first and second air streams from each other, an L-wheel and an S-wheel continuously rotating through said first and second air streams, said L-wheel and said isolating means cooperating to define at a given moment in time a first side and a second side of said L-wheel, an interface between said first side and said second side, said L-wheel rotating from said second side through said interface, and a segment of said first side, said segment being adjacent to said interface, means for directing said first air stream through said first side of said L-wheel whereby said first side absorbs moisture from said first air stream to dehumidify said first air stream, and means for directing said second air stream through said second side of said L-wheel whereby said second side transfers said absorbed moisture to said second air stream to regenerate said L-wheel, the improvement comprising means for directing the portion of said first air stream passing through said segment of said L-wheel directly into said second air stream.

* * * * *