

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
26 May 2006 (26.05.2006)

PCT

(10) International Publication Number
WO 2006/055387 A1

(51) International Patent Classification:
H05K 7/20 (2006.01)

(21) International Application Number:
PCT/US2005/040745

(22) International Filing Date:
10 November 2005 (10.11.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/522,857 14 November 2004 (14.11.2004) US

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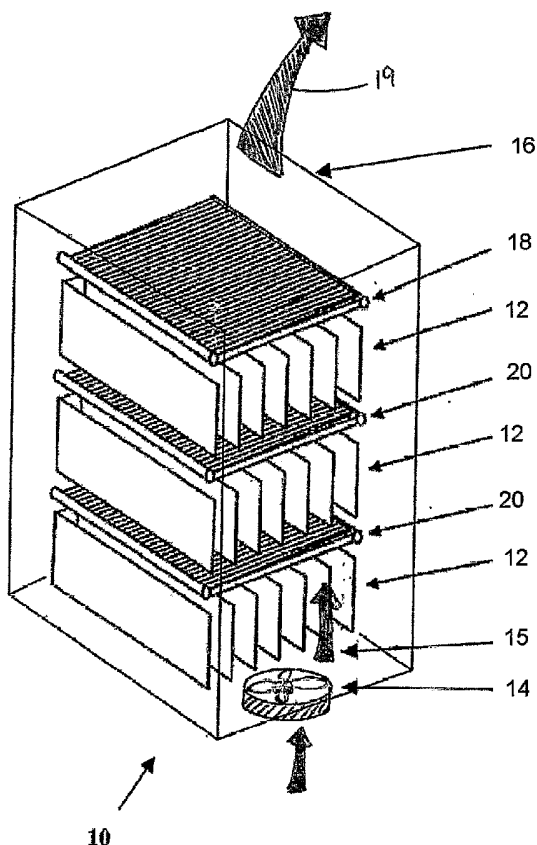
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(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN,
CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI,
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SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US,
UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,

[Continued on next page]

(54) Title: INTEGRATED HEAT EXCHANGER(S) IN A RACK FOR VERTICAL BOARD STYLE COMPUTER SYSTEMS



(57) Abstract: A system for cooling heat-generating objects (12), such as computer boards situated in a rack, includes an enclosure (16) in which the heat generating objects are situated. The enclosure has an air inlet and an air outlet, and a fan (14) induces airflow into the air inlet, through the enclosure and out the air outlet. A heat exchanger (20) is situated in the enclosure such that the heat exchanger is in a spaced apart relationship with the heat-generating object. Air moving through or past the heat-generating object is warmed, and the heat exchanger removes the heat before the air exits the enclosure.

WO 2006/055387 A1



ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

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**INTEGRATED HEAT EXCHANGER(S) IN A RACK
FOR
VERTICAL BOARD STYLE COMPUTER SYSTEMS**

BACKGROUND

5 The present disclosure relates to systems for cooling electronic and other heat-generating equipment, and more particularly to systems for cooling the air flowing in proximity to electronic equipment configured in vertical banks in a rack or cabinet.

 The growth of the computer industry over the past few decades has been phenomenal.

10 Many new computer designs combine multiple computer/processor boards to make "high end" computers and "servers". Due to the demand for floor space, computer boards are often configured to be "stacked" vertically in a rack or cabinet. Many existing cooling systems for electronic equipment contained in such a vertical rack do not provide adequate cooling. In many of these cooling systems, air is drawn into the bottom of the rack or cabinet containing

15 computer boards and moved vertically through the cabinet, progressively cooling the respective computer boards. In this design, the boards mounted "higher" in the rack receive warmer air than those mounted toward the bottom because the air has already passed over and absorbed heat from one or more boards. Consequently, the "higher" boards are not adequately cooled by the flow of warmer air.

20 At the same time, newer, more powerful microprocessors are constantly being introduced, but this higher performance is generally accompanied by significantly increased heat generation. Thus, these newer processor configurations are driving up heat loads to the point that "unaided" air cooling cannot provide enough capacity to keep these "stacked" computers from overheating. As a result, "stacked" servers may have to operate at reduced

25 processing speeds to limit the heat load, which in turn compromises performance.

In addition, existing cooling systems have a rather limited cooling capability. For instance, many existing cooling systems have heat densities of approximately 80 watts per square foot (W/ft^2), though some cooling systems still under development are said to possess heat densities of up to $150 \text{ W}/\text{ft}^2$. Even cooling systems having these heat densities, however,
5 may not effectively cool today's state-of-the-art electronic equipment.

As is readily apparent, if equipment is not sufficiently cooled, the internal temperature of the electronic components in the equipment dramatically increases over relatively short periods of time, which may result in significantly reduced system performance and, in some cases, component or total system failure. Even where system performance is not
10 compromised, inefficient cooling may unnecessarily increase the cost of cooling the equipment. Thus, there remains a need for a cooling system that adequately and efficiently cools computer boards configured in vertical banks in a rack.

SUMMARY

A system for cooling heat generating objects, such as computer boards situated in a
15 rack, includes an enclosure in which the heat generating objects are situated. The enclosure has an air inlet and an air outlet, and a fan induces air flow into the air inlet, through the enclosure and out the air outlet. The fan may be situated adjacent the air inlet or outlet, or multiple fans may be used at the inlet and outlet. A heat exchanger is situated in the enclosure such that the heat exchanger is in a spaced apart relationship with the heat-generating object.
20 Air moving through or past the heat-generating object is warmed, and the heat exchanger removes the heat before the air exits the enclosure.

In certain exemplary embodiments, the heat exchanger is situated adjacent the air inlet. In further embodiments, the heat exchanger is situated adjacent the air outlet, or heat

exchangers are situated at both the inlet and outlet of the enclosure. Often, a plurality of heat-generating objects are situated vertically in the enclosure, and a plurality of heat exchangers are situated in the enclosure such that a heat exchanger is situated between adjacent heat generating objects in a spaced-apart relationship.

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BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

FIG. 1 is a perspective view schematically illustrating a system for cooling heat generating objects in a cabinet.

10

FIG. 2 is a perspective view schematically illustrating an alternative system for cooling heat generating objects in a cabinet.

FIGS. 3 and 4 are front and side views, respectively, schematically illustrating another system for cooling heat generating objects in a cabinet.

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While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

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DETAILED DESCRIPTION

Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will

of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort
5 might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

Turning now to FIG. 1, therein is illustrated an embodiment of a cooling system 10 for cooling heat generating objects 12 configured in banks within an enclosure such as a cabinet 16. Typically, the heat generating objects consist of electronic assemblies, such as circuit
10 board assemblies, received in racks in the cabinet 16. The cooling system includes a fan 14, which induces airflow in the direction of arrow 15, into the cabinet 16 through an inlet, upwardly and through the cabinet 16, exiting the cabinet 16 through an outlet. It will be apparent to one skilled in the art that fan 14 can be located at any position that will induce airflow through cabinet 16, and that a plurality of fans can be used. The airflow 15 cools the
15 electronic equipment 12 as it passes through each bank of equipment. The cooling of the electronic equipment 12 causes an increase in the temperature of the flowing air stream, such that air stream 19 exiting the outlet at the top of cabinet 16 is warmer than that entering the air inlet of the cabinet 16. The air stream itself is cooled as it passes the heat exchangers 20 located between each bank of electronic equipment 12. The heat exchangers 20 are spaced
20 apart from the equipment 12 such that an air space is defined between the equipment 12 and the heat exchangers 20. The air stream 19 is also cooled as it passes through the top heat exchanger 18 and exits outward, away from the components within cabinet 16, so that it does not add any unnecessary heat load to the room air conditioning.

Another system 10A is shown in FIG. 2, wherein a heat exchanger 22 is in front of, or alternately, before the first heat load or heat-generating device 12. As illustrated in FIG. 2, front heat exchanger 22 can be placed in-between fan 14 and the first heat-generating device 12. This allows for air to be “pre-cooled” prior to entering into or around the heat-generating devices. In a typical scenario, fan 14 induces airflow in the direction of arrow 15, upwardly and into cabinet 16 through an air inlet. The airflow first passes through front heat exchanger 22, where it is cooled prior to coming into contact with the heat generating devices 12. The now pre-cooled air then flows upwardly, through and/or around heat generating devices 12, and optionally through one or more additional, intermediate heat-exchangers 20, before passing through top heat exchanger 18 and exiting the cabinet 16 through an air outlet. As described previously, inclusion of a top heat exchanger 18 allows for the air stream 19 exiting the cabinet 16 to be cooled prior to exiting into the room, so as to minimize the effect on the heat load to the room air conditioning. As shown in FIG. 2, the heat generating devices 12 and the corresponding heat exchangers 18, 20, 22 are in a spaced-apart relationship, such that an air space is defined between the heat generating object 12 and the adjacent heat exchanger(s).

FIGs. 3 and 4 schematically illustrate front and side views of another exemplary cooling system 10B. As shown therein, cooling system 10B comprises a first fan 14 spaced in front of, or before front heat exchanger 22. The system 10B also comprises a plurality of heat-generating devices 12 arranged vertically (one device 12 positioned above another) within cabinet 16, with one or more heat exchangers 20 interspaced between them as necessary in order to obtain the most efficient cooling, as well as a top heat exchanger 18 spaced downstream of the heat-generating devices 12, but still within cabinet 16. An air space is defined between each device 12 and the adjacent heat exchanger 20. At the top end of

system 10B near the cabinet's air outlet is a second fan, 24, which can be mounted externally to the cabinet 16, or can be optionally contained within cabinet 16. The use of a second fan 24 allows for the air that has been cooled by top heat exchanger 18 to be pulled upward and/or away from cabinet 16 and the components housed therein, so as to aid in minimizing addition of extra heat load to the room air conditioning system. In operation, the airflow stream is pulled into system 10B by first fan 14, and moves in the direction of arrow 15. Airflow is directed upward, through the cabinet, cooling the heat generating devices 12 as it passes through each bank. This airflow is itself further cooled as it passes front heat exchanger 20 and through or around the other heat exchangers 20 interspersed between devices 12. The airflow stream is then cooled a final time as it passes through or around top heat exchanger 18, and is drawn upward and out of cabinet 16 by second fan 24, pushing the air away from cabinet 16 and the components contained therein.

The second fan 24, as illustrated in FIGS. 3 and 4, can be attached directly to the top of cabinet 16. Alternatively, and equally acceptable, fan 24 can be contained at the upper portion of cabinet 16, such as intermediate between top heat exchanger 18 and the air outlet in the top panel of the cabinet. Equally acceptable, second fan 24 can be separated from the top of cabinet 16 by some distance, which can range from several millimeters to greater distances which will depend upon the strength of fan 24. For example, second fan 24 can be suspended from a roof structure, or be a part of or added into an existing cooling system.

Figures 1-4 show exemplary systems each having a plurality of heat generating objects and heat exchangers. Other embodiments include a single heat exchanger, such as front heat exchanger 22, downstream of a heat-generating device such as a bank of computer boards. Such a cooling system could be particularly useful for aiding in the cooling of heat-generating equipment that does not need more than one heat exchanger in order to be effectively and

efficiently cooled. A further advantage of the present invention is that it is scalable: that is, as many heat exchangers can be added incrementally as computer size and architecture dictate. As used herein, the term “downstream” refers to objects which follow another object, while the term “upstream” refers to objects which come before (although not necessarily immediately before) another object. In example, referring to FIG. 1, heat exchangers 20 are “downstream” of fan 14, and fan 14 is “upstream” of heat generating objects 12.

In certain exemplary embodiments, the heat exchangers are micro-channel refrigerant heat exchangers placed in the air stream after each vertically oriented bank of computer boards or other heat-generating device. With the use of micro-channel heat exchangers, the heat exchangers cool the hot air from each set of computer boards by transferring heat to a refrigerant (which is then pumped away) before that air contacts the next set of computer boards.

In some exemplary embodiments, the cooling refrigerant used is a non-conductive, two-phase refrigerant which acts as an alternative cooling medium instead of water so that a coolant leak does not pose a risk of an electrical short or similar hazard. This type of refrigerant allows for better heat transfer capacity in the same space because of the use of micro channel coils and because the refrigerant absorbs a significant amount of heat as it evaporates. The use of a two-phase refrigerant allows the heat exchangers to operate essentially isothermally, which provides a uniform air temperature to the computer boards. The use of such a system also allows for a smaller “footprint” than if water or other single-phase fluids are used.

The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the

art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention.

5 Accordingly, the protection sought herein is as set forth in the claims below.

- 9 -

CLAIMS**WHAT IS CLAIMED IS:**

1. A system for cooling heat generating objects, comprising:
an enclosure, the enclosure having an air inlet and an air outlet;
5 a heat generating object situated in the enclosure;
a fan for inducing air flow into the air inlet, through the enclosure and out the air
outlet; and
a heat exchanger situated in the enclosure such that the heat exchanger is in a
spaced apart relationship with the heat generating object.
- 10 2. The system for cooling heat generating objects of claim 1, wherein a
plurality of heat generating objects are situated vertically in the enclosure.
3. The system for cooling heat generating objects of claim 1, wherein the heat
exchanger is situated adjacent the air inlet.
4. The system for cooling heat generating objects of claim 1, wherein the heat
15 exchanger is situated adjacent the air outlet.
5. The system for cooling heat generating objects of claim 1, wherein the fan
is situated adjacent the air outlet.
6. The system for cooling heat generating objects of claim 1, wherein the fan
is situated adjacent the air inlet.

- 10 -

7. The system for cooling heat generating objects of claim 1, the fan is situated adjacent the air inlet and a second fan is situated adjacent the air outlet.

8. The system for cooling heat generating objects of claim 1, wherein a plurality of heat generating objects are situated vertically in the enclosure, and wherein a plurality of heat exchangers are situated in the enclosure such that a heat exchanger is situated between adjacent heat generating objects in a spaced-apart relationship.

9. The system for cooling heat generating objects of claim 1, wherein the heat exchanger contains micro-channels.

10. The system for cooling heat generating objects of claim 1, wherein the heat exchanger contains a refrigerant.

11. The system for cooling heat generating objects of claim 10, wherein the refrigerant is a two-phase refrigerant.

12. A system for cooling heat generating objects, comprising:
an enclosure, the enclosure having an air inlet and an air outlet;
a heat generating object situated in the enclosure;
means for inducing air flow into the air inlet, through the enclosure and out the air outlet; and
means for removing heat from the air flowing through the enclosure.

13. A method for cooling heat generating objects situated in an enclosure, the method comprising:

- 11 -

situating a heat exchanger in the enclosure such that the heat exchanger is spaced
apart from the heat generating object; and
inducing air flow into the air inlet, through the enclosure and out the air outlet
such that the heat exchanger removes heat from the air flowing through the
enclosure.

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14. The method of claim 13, wherein situating the heat exchanger includes
situating a heat exchanger adjacent the air inlet.

15. The method of claim 13, wherein situating the heat exchanger includes
situating a heat exchanger adjacent the air outlet.

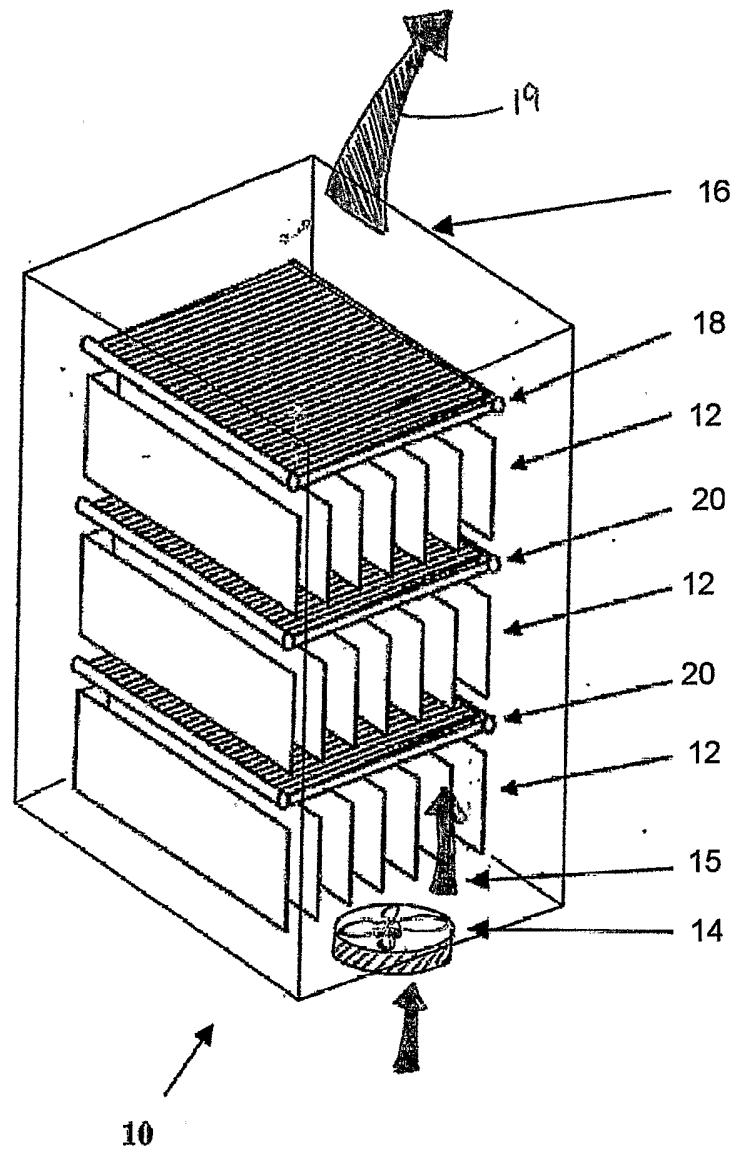
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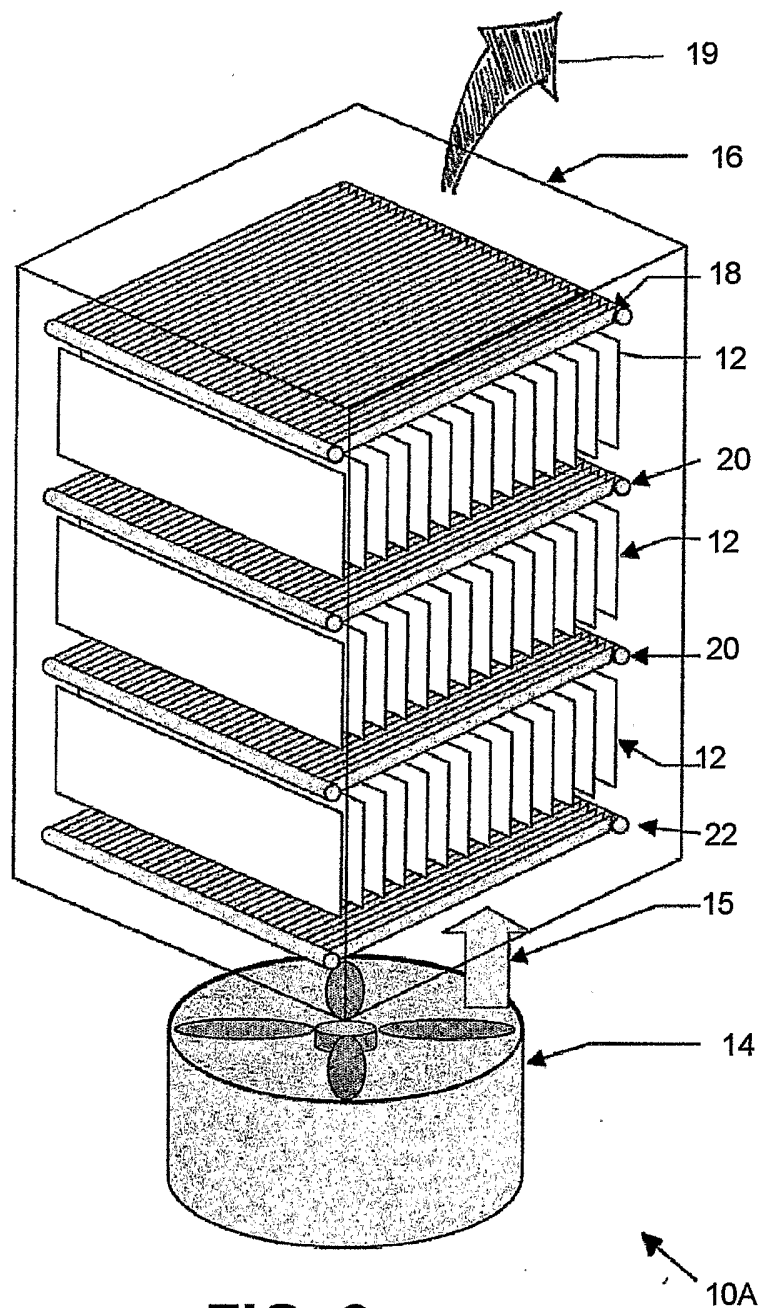
16. The method of claim 13, wherein a plurality of heat generating objects are
situated vertically in the enclosure, wherein situating the heat exchanger includes situating
a heat exchanger between adjacent heat generating objects such that the heat exchangers
and heat generating objects are spaced apart from one another.

17. The method of claim 13, wherein inducing airflow includes situating a fan
adjacent the air inlet.

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18. The method of claim 13, wherein inducing airflow includes situating a fan
adjacent the air outlet.

**FIG. 1**

**FIG. 2**

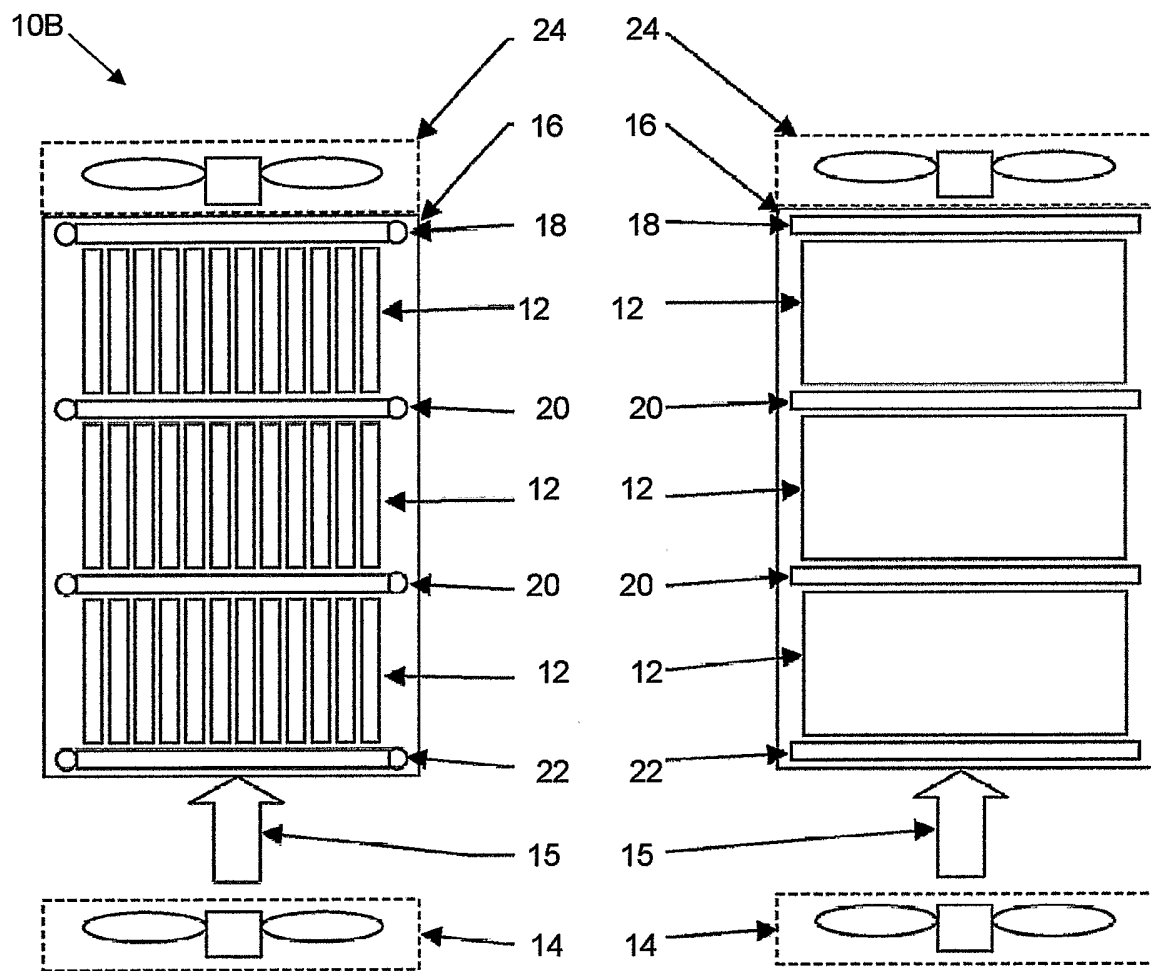


FIG. 3

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2005/040745

A. CLASSIFICATION OF SUBJECT MATTER
H05K7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H05K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2001/042616 A1 (BAER DANIEL B) 22 November 2001 (2001-11-22) paragraph [0002] paragraph [0021] - paragraph [0044] claim 16 figures 1-8	1,12,13
A	US 2002/039280 A1 (O'CONNOR STEPHEN D ET AL) 4 April 2002 (2002-04-04) column 1, line 16 - line 22 column 3, line 29 - column 5, line 34 figures 1-4	2-6, 14-18
A	US 6 557 624 B1 (STAHL LENNART ET AL) 6 May 2003 (2003-05-06) paragraph [0002] paragraph [0045] - paragraph [0065]; figures 1-5	9



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

22 March 2006

Date of mailing of the international search report

30/03/2006

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2005/040745

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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