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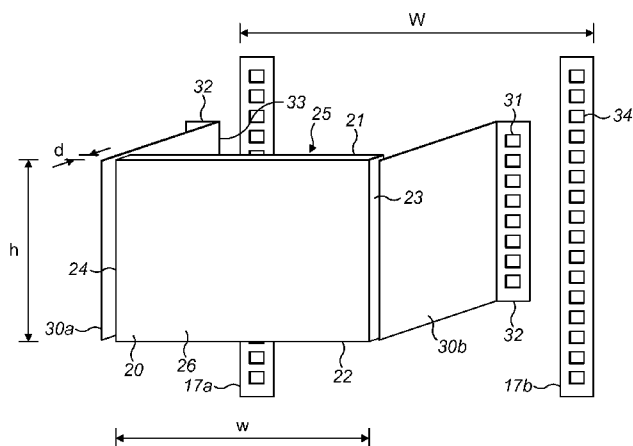


FIG. 2

(57) Abstract: The present invention provides a cooling unit for electronic equipment housed within a server cabinet. The electronic equipment is mounted to front and/or rear vertical U- rails of the server cabinet. The cooling unit (20) comprises a heat exchanger and it is configured to hold the heat exchanger within or substantially within the confines of the server cabinet to the rear of the electronic equipment. This enables it to absorb heat from air exhausted from the rear of the electronic equipment. The cooling unit is preferably mounted to the rear vertical U-rails (17a, 17b) of the cabinet and provides passive cooling. In one arrangement, the cooling unit is part of a cooling system that is arranged to operate as a thermosyphon. More than one of the cooling units (20) may be provided within the server cabinet, positioned according to the thermal loading.



Cooling Unit and Cooling System

The present invention relates to a new cooling unit and a cooling system employing the cooling unit for computer equipment in server racks and to in-row cooling of computer rooms.

In modern data centres and server rooms, and now increasingly for IT networks in offices, the main electronic computer equipment is being housed in metal IT cabinets which are constructed to standard sizes and are generally referred to as "server racks". The IT cabinets or racks house a rack comprising two pairs of vertical U-rails, one pair at the front and one pair at the rear, that the equipment is attached to. The vertical U-rails are metal rails with sets of holes punched at specified positions to define interval heights corresponding to 1U (1.75 inches or 44.45 mm) in accordance with the Electronics Industry Association EIA 310-D standard. The computer equipment is then bolted to these metal rails via cage nuts fitted to these holes. It is usual to enclose the rack-mounted computer equipment within a server cabinet using solid side panels and perforated front and rear doors that are secured to the frame of the cabinet. Where cabinets are located next to each other in a row, side panels may be removed for convenience. A door is usually provided on the front and rear of the cabinet, or panels may be left off the server cabinet to allow access to the equipment inside.

With the increases in computing power have come increases in rack temperatures and special measures have had to be adopted to cool the equipment. For example, a fully populated blade server chassis of 7U to 10U in height is now capable of giving off up to 10kW of heat with an exhaust air stream that reaches temperatures up to 20°C higher than the air temperature at the inlet to the servers. When the rack is completely filled with servers, the total amount of heat generated can be 20-30kW or more. The hot air also tends to be expelled in a relatively concentrated jet of hot air.

ASHRAE in conjunction with all computer manufacturers have issued Thermal Guidelines for Data Processing Environments with allowable temperature and humidity range at which IT equipment will function and recommended temperature and humidity range at which IT equipment operation is reliable. These conditions refer to the air at the intake of the IT servers. Data centre design engineers adhere to these recommendations. Various room and row based cooling systems have been developed to attain these recommendations, such as computer room air conditioner

units, aisle and row cooling units, etc.. However in most cases, the cooling systems must be installed during the construction of the computer room before the computer equipment is in place, or if it is fitted later then it requires the computer room or the equipment in the server rack to be shut down whilst the new cooling systems are installed.

A number of manufacturers make floor-mounted, tall cooling units that are located within the rows of equipment between a pair of racks to provide cooling for the adjacent racks of computer equipment. In addition to such known "close coupled" cooling systems, it is also known to provide additional cooling units that are sized to be mounted in the racks themselves. These can be retrofitted easily into the server racks and a product of this type is described in GB-B-2463956 and marketed by Datacentience, a division of Semper Holdings Ltd, under the name "delta-T". These may be supplied as half or full-rack height cooling units.

A further cooling solution is provided by IBM, Eaton-Williams and Vette. In this known system, the rear door of the IT server cabinet is taken off and is replaced with a new one which includes a large cooling coil extending substantially the full length and width of the cabinet's exterior dimensions. The new rear door and cooling coil extend into the aisle beyond the normal rear boundary of the original server cabinet, though not significantly. This system uses a supply of chilled water within the coil to try to remove heat as it exits from the rear of the computer equipment. However, there are differences between the cabinets made by one manufacturer and another, and consequently the replacement of the rear door with another rear door holding the chilled water heat exchanger may not always be straightforward and may require a door frame adapter or other such modification to fit the rack and support the weight of the large coil.

A similar rear door heat exchanger is provided by Hitachi. In that arrangement, the full height cooling coil contains a refrigerant in the form of R134a. The refrigerant cooling circuit is coupled with a chilled water/glycol circuit of a central chiller which rejects the heat to the outdoors. Cooling fans are provided on the rear door heat exchanger to draw air through the cooling coil.

There is a desire to make improvements to these known systems.

Viewed from a first aspect, the present invention can be seen to provide a cooling unit for electronic equipment housed within a server cabinet, the electronic equipment being mounted to front and/or rear vertical U-rails of the server cabinet in use, the cooling unit comprising a heat exchanger, the cooling unit being configured to hold the heat exchanger within or substantially within the confines of the server cabinet to the rear of the electronic equipment, to absorb heat from air exhausted from the rear of the electronic equipment.

The present inventor has identified that a useable void is present within the cabinet dimensions to the rear of the computer equipment, i.e., behind the rear pair of U-rails. An internal rear boundary, such as a rear door (if present), a removable rear panel or a rear frame member of the cabinet, may mark the furthest extent of this useable void that the cooling unit, and hence the heat exchanger, is preferably within. Thus preferably the cooling unit is located within the normal rectangular footprint of the base of the server cabinet, in contrast to the replacement rear door cooling units of the prior art which extend beyond this.

The heat exchanger is therefore located within a region of the server cabinet that extends from behind the rear vertical U-rails to an internal rear boundary of the server cabinet. By positioning the heat exchanger in this way, it is closer to the source of heat than the known rear door cooling units, and better localised cooling can be achieved. The heat is substantially removed at source before it has a chance to dissipate within the server cabinet or into the room. It can be provided as an individual rack solution for low or high density cooling needs. It also does not take up any IT server space in the rack and preserves the integrity of the rear door locking system to maintain security for the IT equipment within the rack.

Preferably the heat exchanger is a cooling matrix, in particular a microchannel heat exchanger, comprising a plurality of tubes linking a common inlet header to a common outlet header of the matrix. Such heat exchangers are thinner for a given cooling capacity. Accordingly, preferably the heat exchanger is of a sufficiently thin profile that any existing door does not need to be removed. Thus preferably any existing rear door, if fitted to the cabinet, remains in place once the heat exchanger has been mounted in position. No door frame adapters or other modification to the rear of the cabinet should be required to install the heat exchanger.

However embodiments are also envisaged where the space required for data cables inside the rear of the rack becomes congested due to the number of IT servers occupying the rack or the rear vertical U-rails may be set a long way back in the cabinet because the computer equipment is deep, and so although the intake face of the heat exchanger may be within the server cabinet, i.e., the heat exchanger is benefiting from being as close as possible to the computer equipment, the back of the heat exchanger may extend into the aisle slightly beyond the normal rear boundary of the server cabinet.

Preferably the cooling unit is provided with one or more mounting brackets that is/are configured for attachment to one or both of the rear vertical U-rails. Regardless of the make of the server cabinet, and hence regardless of the internal configuration of the panels or supporting frame members within the cabinet, the vertical U-rails will be configured according to the EIA 310-D standard. This allows the mounting bracket to fit to any server rack which has been made to the EIA 310-D standard, without modification.

Thus, viewed from a second aspect, the present invention can be seen to provide a cooling unit for rack-mounted electronic equipment, the cooling unit comprising a heat exchanger, preferably in the form of a cooling matrix, the cooling unit having a mounting bracket which is configured for mounting to one or more vertical U-rails of a server rack, the mounting bracket being arranged to hold the heat exchanger off the back of the server rack in a position facing the rear of the electronic equipment.

The cooling unit of this aspect is configured for mounting to U-rails conforming to the EIA 310-D standard and may be used in conjunction with server racks that are open on all sides or mounted within a server cabinet that comprises vertical U-rails in accordance with the first aspect. Any preferred features mentioned with respect to the second aspect apply equally to the first and other aspects, and vice versa, and should be read in conjunction therewith.

A single mounting bracket may extend to attach to both rear U-rails or more preferably two (or more) mounting brackets are provided, e.g., arranged on opposite side edges of the heat exchanger, each arranged for attachment to one of the U-rails. A mounting bracket may be configured to hinge or to be removed easily for allowing access to the rear of the IT equipment. It may include a quick release mechanism that interacts with the U-rails, preferably one or more of the holes of the U-rails. The

mounting bracket or brackets may comprise mechanical fixings such as quick release nut and bolt arrangements, a set of hooks for the holes in the U-rails, retractable devices such as pins incorporating retractable ball-bearings that lock behind the holes, etc.. The mounting brackets may also be adjustable, particularly in the depth direction of the server cabinet, to allow adjustment in the positioning of the heat exchanger within the confines of the server cabinet as space allows. The rear vertical U-rails may be set further forward in the cabinet for some server configurations, and so an adjustable mounting bracket can account for this, particularly where the mounting bracket is fixing to a rear frame member or to a rear of the cabinet rather than the U-rails.

The bracket(s) may also include a member or device for holding cabling at the rear of the equipment to one side or other of the hot air stream. The provision of the cooling unit in the void to the rear of the equipment also encourages the fitter to arrange the cabling in a neat bundle which is fixed off to one or both sides of the server cabinet. This in turn helps to avoid cables from obstructing the airflow at the rear of the equipment even in those areas where the cooling unit does not extend. There is less motivation to do this with the known replacement rear door heat exchangers.

According to a third aspect, the present invention can also be seen to provide a cooling unit comprising a heat exchanger, preferably in the form of a cooling matrix, the cooling unit being sized to fit within the confines of a server cabinet in a region extending between a rear pair of vertical U-rails of the server cabinet and an internal rear boundary of the server cabinet, the cooling unit being provided with one or more brackets that is/are configured to mount the heat exchanger to a vertical U-rail, a rear frame member of the server cabinet or a rear door of the server cabinet.

Any preferred features mentioned with respect to the third aspect apply equally to the first and other aspects, and vice versa, and should be read in conjunction therewith.

Preferably the width of the cooling unit (ignoring the mounting brackets) is less than the internal separation of the rear vertical U-rails. In other words, preferably it is less than 450 mm wide for a standard 19" rack, more preferably 400 mm wide or smaller ($250 \text{ mm} \leq w \leq 350 \text{ mm}$, where w is the width of the heat exchanger) in order to provide room at the side edges for cabling to pass.

In one embodiment the cooling unit is a full rack-height unit with the heat exchanger extending the entire height or substantially the entire height of the rack, e.g., 42U or in some instances higher.

In another embodiment the cooling unit is a half rack-height or smaller unit, e.g., less than 25U high. In certain embodiments the cooling unit may be less than 15U high, yet more preferably less 10U and for some applications it may even be 7U high or less.

In other words the cooling unit may be a relatively small and compact cooling device that can be positioned just where it is needed, ideally on the back of the U-rails (though could be fixed to the rear door or frame of the cabinet, or indirectly fitted to the rack via a bracket), directly behind a jet of hot air that is expelled from a modern blade server or other such device. The heat from the computer equipment discharges directly into the heat exchanger where it is neutralised before entering the room. The closer it is arranged to the computer equipment, the more effective it will be.

Preferably an intake face of the heat exchanger is positioned within 10 cm of the rear of the rack (i.e., within 10 cm of a line extending between rear edges of the rear vertical U-rails that defines the rear of the rack), more preferably within 7 cm, still more preferably within 5 cm and most preferably within 4 cm of the rear of the rack, so that it is as close as possible to the computer equipment.

Preferably the heat exchanger is retrofitted to an existing server cabinet but it could be provided as part of a new server cabinet with an internal cooling system solution. Thus according to a fourth aspect, the present invention can be seen to provide a server cabinet comprising an integral cooling unit, the cabinet comprising a plurality of frame members that support front and rear pairs of vertical U-rails in a spaced relationship with respect to the cabinet to provide a rack for rack-mountable equipment, wherein the server cabinet further includes a heat exchanger, preferably in the form of a cooling matrix, that is positioned behind the rear pair of vertical U-rails, the heat exchanger having an intake face that is positioned within 10 cm of the rear of the rack, more preferably within 7 cm and still more preferably within 5cm.

Any preferred features mentioned with respect to the fourth aspect apply equally to the first and other aspects, and vice versa, and should be read in conjunction therewith.

By mounting the heat exchanger close to the computer equipment, the heat exchanger can be used in a passive mode, relying on the fans of the computer equipment to direct the hot air through the matrix rather than requiring additional fans to draw the air through. The absence of additional fans results in considerable power savings (some of the known rear door heat exchangers include up to ten cooling fans to eject the air through the cooling coil). In addition the passive cooling unit will be silent in use. However, where desired, then low profile fans could be added too.

Embodiments employing a smaller heat exchanger, particularly one in the form of a cooling matrix, benefit from the heat exchanger being lighter in weight and will require less substantial brackets or modifications to fix the heat exchanger to the rear U-rails or the rear frame/rear door (e.g., the cooling matrix will be significantly lighter than the known full-size, chilled water, rear door alternatives). The heat exchanger can be of lower cooling power than the full size rear door heat exchangers as a result of where it is mounted, for example, it may be designed only to extract 5 or 10 kW because it can be positioned exactly over the heat source. Its size and position within the server cabinet also lends itself to being retrofitted once other cooling systems have been deployed in the computer room and have reached their cooling capacity. Much larger units, which are equal to or greater than 75% of the rack-height, for example having 20kW or 30kW capacities are also envisaged for use where high density rack loads are present and these could also be fitted retrospectively. Alternatively the computer room can be designed with each server cabinet of a row being provided with a full or half-rack height cooling unit fitted at the rear of the rack to avoid the need for computer room air conditioners (CRAC) units, cooling units mounted between the racks and other cooling units.

Preferably the heat exchanger is one which offers a high thermal efficiency. It is ideally not in the form of a conventional cooling coil, for example, comprising copper or aluminium tubing that has been wound into a serpentine and is mechanically expanded to aluminium fins. Instead it is a cooling matrix, preferably a microchannel heat exchanger. These take the form of a plurality of tubes that extend, typically in parallel, between common inlet and outlet manifolds. The cooling matrix splits the flow of the coolant across a set of pathways that pass in a grid-like manner through

the stream of hot air in the same direction. The tubes are extruded or otherwise formed with a plurality of smaller channels or passageways extending along the length of the tubes for the coolant to flow through in parallel within the tubes between the inlet and outlet manifolds. The tubes preferably each comprise three or more channels, more preferably five or more channels, most preferably seven or more channels. The tubes of the microchannel heat exchanger preferably have an elongate section that extends in the thickness direction of the matrix, i.e., in the direction of the hot air stream. This allows the channels to be arranged as an array of passageways arranged one behind the other in the direction of the airstream (the thickness direction of the cooling matrix), preferably as a linear array, that results in a much enhanced surface area to volume ratio and improved heat transfer than the traditional round copper tubes that are mechanically expanded to aluminium fins.

The matrix can be in the form of a single piece component or it can be made up of sections comprising one or more tubes that are coupled together to form the complete matrix. In one embodiment, each section includes a portion of an inlet manifold (header) on one end and a portion of an outlet manifold (header) on the other, the portions of the respective manifold combining together to form a complete manifold in the complete matrix assembly. Such a matrix of stackable modular sections offers a highly scalable cooling capacity to match closely the requirement of various levels of IT cabinet loads. There can also offer manufacturing cost savings, improved performance over certain single piece heat exchangers and improved reliability in terms of the joints between the tubes and manifold being better able to cope with the cyclic pressure and temperature changes. Faulty sections within the matrix can be replaced easily with little down time.

Another advantage of microchannel heat exchangers is that there is a lower air pressure drop associated with forcing the hot air stream through the matrix which ensures better air flow and requires lower fan power by the servers to blow the exhaust air through the matrix. There are also significant internal pressure drop advantages too, which allow use of a thermosyphon circuit at milder outdoor ambient without the need for pump assistance. The tubes of the cooling matrix are preferably made of aluminium, which has better heat conduction properties than copper and is a lightweight material. Another advantage with a cooling matrix is that the headers and outer tubes of the matrix protect and give rigidity to the aluminium zig-zag strips arranged between the tubes, which makes them much less prone to being damaged and thus losing cooling capacity and increasing air side pressure drop as compared

to the aluminium fins of the conventional Cu/Al serpentine cooling coils. It avoids the need to provide a protective grille in front of the matrix intake face, for example, as is required on the known chilled water replacement rear door heat exchangers.

Thus viewed from a fifth aspect, the present invention can be seen to provide a cooling unit for a server cabinet that is configured to be mounted within the confines of the server cabinet to the rear of a server rack, the cooling unit comprising a microchannel heat exchanger arranged to absorb heat being expelled from the rear of rack-mounted computer equipment, preferably as a passive microchannel heat exchanger.

Viewed from a sixth aspect, the present invention can be seen to provide a cooling system for computer equipment, the cooling system comprising:

- a cooling unit having a cooling matrix which provides an evaporator for a refrigerant-based cooling circuit, the cooling matrix being positioned to absorb heat that has been generated by computer equipment;

- an air cooled condensing device for rejecting the heat from the refrigerant contained in the cooling circuit; and

- supply and return pipes for completing the cooling circuit to convey refrigerant from the condensing device to the evaporator and back to the condensing device again,

wherein:

- the cooling matrix comprises a common inlet manifold, a common outlet manifold and a plurality of tube members, the tube members extending between the common inlet and outlet manifolds to convey refrigerant in parallel between the manifolds and each tube member comprising an array of internal passageways through which the refrigerant is directed.

In a variant of this, viewed from a seventh aspect, the present invention can be seen to provide a cooling system for computer equipment, the cooling system comprising:

- a cooling unit having a heat exchanger for a water-based cooling circuit, the heat exchanger being positioned to absorb heat that has been generated by computer equipment;

- a plate heat exchanger connected to the water-based cooling circuit to transfer heat in the water-based cooling circuit to a refrigerant in a refrigerant-based cooling circuit;

an air cooled condensing device for rejecting the heat from the refrigerant contained in the refrigerant-based cooling circuit; and

supply and return pipes for completing the water-based and refrigerant-based cooling circuits to convey water from the cooling unit to the plate heat exchanger and back to the cooling unit again, and to convey refrigerant from the condensing device to the plate heat exchanger and back to the condensing device again,

wherein:

the heat exchanger of the cooling unit in the water-based cooling circuit comprises a common inlet manifold, a common outlet manifold and a plurality of tube members, the tube members extending between the common inlet and outlet manifolds to convey water in parallel between the manifolds and each tube member comprising an array of internal passageways through which the water is directed.

Any preferred features mentioned with respect to the fifth, sixth and seventh aspects apply equally to the earlier aspects, and vice versa, and should be read in conjunction therewith. For example, preferably the heat exchanger of the cooling unit is mounted in a server cabinet to the rear of the computer equipment, preferably by being mounted to at least one of the rear vertical U-rails and preferably arranged to operate passively (i.e., no fans). Preferably the condensing device is a condensing unit incorporating a compressor for the refrigerant-based circuit.

In some embodiments the heat exchanger uses water or a water/glycol mixture as the coolant. This offers benefits in terms of coolant costs and will be discussed further below. In others the heat exchanger may contain a refrigerant, in particular R-134a (tetrafluoroethane) or a future replacement of this such as HFO1234YF which will reduce the global warming potential (GWP) from the current 1300 figure of R134a to a GWP of less than 75. The use of a refrigerant has benefits in terms of efficiency, but it also poses significantly less risk to the computer equipment in the event that the cooling circuit develops a leak.

The combination of using a microchannel heat exchanger, with all the benefits it provides in terms of performance and efficiency, at the temperatures experienced at the rear of modern computer equipment, opens up the possibility of using free cooling when external ambient temperatures drop to as little as 10°C or below. The thermal head may even be sufficient to drive free cooling through the thermosyphon at external ambient temperatures of 12°C or higher, more preferably 14°C or higher, for example at 15°C.

Free cooling circuits have been around for some time and are often offered as factory fitted options to glycol cooled CRAC systems that have an evaporator (direct expansion (DX) coil) and use a compressor to enhance the efficiency of the cooling circuit. For many regions in the northern hemisphere, the low ambient temperatures experienced during the winter months and particularly overnight, offers the possibility to achieve good levels of cooling by using an auxiliary water/glycol cooling coil that is supplied directly from the dry air cooler while bypassing the water/glycol cooled condenser, leading to significant savings in energy costs by allowing the compressor to be switched off. Their use in computer rooms has generally been limited to new installations.

Similarly, auxiliary chilled water free cooling coils known as dual cool systems have been around for many years. These systems allow for a standard air cooled DX system to be supplied from an auxiliary free cooling chiller or drycooler when outdoor ambient temperatures are low enough. Such systems are not new. However, they do not incorporate a thermosyphon refrigerant circuit with an air-cooled condensing unit to reject the heat.

For example, in the known Hitachi system mentioned above, a thermosyphon is coupled with a chilled refrigerant to water/glycol heat exchanger which rejects the heat to the chilled water circuit of a chiller.

Thus, in preferred embodiments, the cooling circuit is set up with a thermosyphon which may be a refrigerant-based circuit extending from the outside to the server cabinet without intermediate heat exchangers or other intermediate circuits, or may be coupled to a water-based circuit that feeds water cooled by the thermosyphon to the heat exchanger in the computer room. The cooling circuit may include valves to maintain a desired flow direction. A pump may be provided to assist the flow within a thermosyphon section of the cooling circuit. An additional section of the cooling circuit may be provided with a compressor and shut-off/diverter valves. In this way the cooling circuit can be run as a conventional refrigerant-based compressor circuit of the air cooled condensing unit when external ambient temperatures are too warm for free-cooling (e.g., above 15°C), and then the compressor and the expansion device at the evaporator can be by-passed to provide the refrigerant-based thermosyphon circuit when external ambient temperatures make free-cooling

possible, allowing the compressor to be switched off, thus providing a more efficient means of cooling.

Rather than being matched exactly to the cooling load, preferably the capacity of the condensing unit corresponds to roughly twice the load of the one or more cooling units or an additional condensing unit is provided to give redundancy in the removal of the heat (e.g., an N+1 redundancy). Where N+1 condensing units are used for a redundant configuration, the additional condensing unit will provide the nominal full evaporator heat exchanger capacity delivered with N condensing units in full operation whenever outdoor temperatures are below 10°C. The additional surface area of the condensing heat exchangers provided by the redundancy in the condensing devices assists with generating the thermal head for driving the thermosyphon and enables the evaporator heat exchanger to reach a cooling capacity that can match the compressorised operation of a single air cooled condenser or condensing unit running at N capacity.

The temperature of the coolant passing through the heat exchanger of the cooling unit is preferably maintained above the surrounding air dew point temperature (e.g., maintained at 2°C higher) to prevent moisture condensing on the matrix, avoiding a potential source of drips of water that could be harmful to the computer equipment and dangerous to the operator if water were to come into contact with the electrical connections at the rear of the servers. Preferably more than one cooling unit is coupled to a condensing device or set of condensing devices to maintain similar cooling conditions at the rear of several items of equipment, either in the same server rack or, more preferably in different server racks. A coolant distribution unit (CDU) may be provided to help maintain similar coolant temperatures in the different coolant circuits and to adjust cooling flow in accordance with the cooling demand of the server cabinets. The condensing device may comprise one of a plurality of condensing units with shared cooling capacity, in order to provide redundancy in the cooling capacity.

Preferably the pipes which provide the feed and return to convey coolant from the heat exchanger (the evaporator) to the condensing device are non-metal pipes, more preferably they are plastic pipes. This reduces the chances of one of the heat exchanger pathways becoming blocked with swarf or other debris. The pipes and the heat exchangers of the cooling unit(s) and condensing device(s) are preferably connected together using push-fit or simple mechanical connectors rather than

soldered connections, and this is particularly for those connections which are within the computer room. The use of live flames to solder the connections would usually entail having to shut down the computer equipment for a period of time while the works are carried out, and therefore avoiding this provides significant advantages where the cooling unit is being retrospectively fitted to the server rack.

Certain preferred embodiments of the present invention will now be described in greater detail by way of example only and with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of a conventional server cabinet;

Figure 2 is a perspective view of a preferred heat exchanger provided with brackets for mounting to the vertical U-rails of a server rack for use in the cooling system of the present invention;

Figure 3 is a perspective view of a preferred heat exchanger in more detail;

Figure 4 is an enlargement of a section through a tube of a preferred heat exchanger;

Figure 5a shows a side view of a first server cabinet with a large cooling unit fitted to the rear of the rack, Figure 5b is a rear view of the server cabinet in Figure 5a, Figure 5c is a side view of a second server cabinet with three smaller cooling units and Figure 5d is a rear view of the server cabinet in Figure 5c;

Figure 6 is a representation of a cooling circuit for use with the heat exchanger;

Figure 7 is a representation of another cooling circuit for use with heat exchangers of a set of cooling units; and

Figure 8 is a representation of a further cooling circuit for use with heat exchangers of a set of cooling units.

Figure 1 shows a perspective view of a conventional server cabinet looking from the front and one side. The server cabinet 1 comprises frame members defining a front 2, a right side 3, a left side 4, a rear 5, a top 6 and a bottom 7. The references to "front" and "rear" correspond to the way that the computer equipment is to be arranged within the server cabinet 1.

In Figure 1, the front 2 of the cabinet 1 is provided with a door 8 hinged at one side and the rear 5 of the cabinet 1 is provided with a pair of doors 9 hinged to upright frame members in the form of posts 10. This is only by way of illustration and in

another manufacturer's cabinet the doors 8, 9 may be of a different configuration, the doors 8, 9 may be replaced by movable panels or other elements, or the doors 8, 9 may not be present altogether. The doors 8, 9 can also be a range of configurations and may be full or half width, may comprise a grille 11 or openings for ventilation, and they could also be flat or profiled.

The inside surface of the rear doors 9 (when closed) define a rear internal boundary 12 to the space that is available within the server cabinet 1 for the computer equipment. The rear doors 9 may close flush into a recess provided in the frame members, i.e., the rear internal boundary 12 may step in by the distance of the frame recess, or more usually the door(s) 9 will simply abut against a flat rear edge of the frame members forming the rear 5 of the server cabinet 1 (i.e., against posts 10), and so the rear internal boundary 12 corresponds to a rear extremity of the frame members. The internal face of the doors 9 may also be recessed within a frame, setting the rear internal boundary further back. Accordingly, the "rear internal boundary" should be seen as any relevant surface of the server cabinet that marks a rear extremity, inside which a cooling unit can still be fitted and considered as within the confines of the server cabinet (to be explained in more detail below).

The bottom 7 of the cabinet 1 may be open as shown, to allow cables to extend up from a sub-floor. The footprint of the cabinet 1 is defined by the rectangular form of the base frame members 13, which extend between upright posts 14 at the front 2 of the cabinet 1 to the rear posts 10 at the rear 5 of the cabinet 1. The format of the cabinet frame can vary considerably from one manufacturer to another. The bottom 7 of the cabinet 1 may be closed off by a base plate rather than open. The top 6 of the cabinet 1 may be closed off as shown, with openings 15 to allow cables and other utilities to pass into the cabinet 1, or it may include a grille or be open.

The server cabinet 1 also includes a front pair and a rear pair of vertical U-rails 16a, 16b, 17a and 17b respectively which define the "rack" that computer equipment is mounted to. The front and rear vertical U-rails 16a, 16b, 17a, 17b are provided with a pattern of holes setting out intervals of 1U for the computer equipment to be fastened to. The configuration of the rack's U-rails is precisely defined according to the EIA 310-D standard, and therefore this part of the server cabinet 1 will be the same for all manufacturers whereas the arrangement of the supporting frame members is likely to be quite different.

As shown in Figure 1, the position of the vertical U-rails 16a, 16b, 17a, 17b is set spaced in from the front 2 and rear 5 frame members of the cabinet 1 (posts 14 and 10), the rear vertical U-rails 17a, 17b being shown stepped in the most. This provides room at the front of the cabinet 1 to recess the fascias of the computer equipment behind the door 8, and at the rear it provides room for cables and connectors to protrude from the rear of the computer equipment. The depth of computer equipment can vary from one manufacturer to another and the rear U-rails may be positioned along horizontal rails at different locations accordingly. Usually there will be a large number of IT cables at the rear of the computer equipment and these may be bundled together to one side or other (or usually both) of the server cabinet 1. Vertical panels 18 may be provided behind the rear vertical U-rails 17a, 17b for tying these cables to the server cabinet 1.

Figure 2 shows a preferred embodiment of a cooling unit having a heat exchanger, which is in the form of a cooling matrix. The cooling matrix 20 comprises an air to coolant heat exchanger that mounts onto the rear vertical U-rails 17a, 17b of the server cabinet 1 (see Figure 4). The cooling matrix 20 is positioned in the space between the rear vertical U-rails 17a, 17b and a rear internal boundary 12, within the confines of the server cabinet 1 and to the rear of the computer equipment mounted in the rack of the server cabinet 1.

The cooling matrix 20 shown is of rectangular outline having a top edge 21, a bottom edge 22, a first side edge 23 which mounts to the left side 4 of the cabinet 1, a second side edge 24 which mounts to the right side 3 of the cabinet 1, an intake face 25 which is mounted towards the rear of the rack to receive the exhaust air from the computer equipment, and an outlet face 26 which faces away from the rear of the rack and towards the rear internal boundary of the cabinet 1. The structure of the cooling matrix 20 is shown in more detail in Figure 3 and will be described in more detail below.

The depth d of the cooling unit/cooling matrix 20 is chosen to be accommodated easily within the cabinet's internal dimensions between the rear vertical U-rails 17a, 17b and a rear internal boundary 12. In one embodiment the depth d is equal to or less than about 3 inches (75 mm), more preferably equal to or less than 2.5 inches (63 mm), more preferably still equal to or less than 2 inches (50 mm), and most preferably equal to or less than 1.5 inches (38 mm). In one particularly preferred embodiment the cooling unit 20 has a depth of around 1 inch (25 mm).

The rear internal boundary 12 of the server cabinet in Figure 1 is provided by the internal surface of the rear door 9. In another manufacturer's cabinet 1, the rear internal boundary 12 may be provided by a rear panel that fits to the rear frame members of the server cabinet 1. In another embodiment, there may be no rear door 9 or the rear door 9 may have been removed. In such embodiments, the rear internal boundary 12 can be seen to be a rear frame member (post 10 or base rear frame member 13) that defines a rear extremity of the server cabinet 1. Thus in the arrangements described the cooling unit 20 is intended to fit within the existing dimensions of the server cabinet 1 without requiring modification of the server cabinet 1 and without having to remove or replace any existing rear doors 9.

Examples of the cooling unit 20 being mounted in this way are shown in the side views of Figures 5a and 5c.

However, it is also envisaged that the cooling unit 20 could be of a depth greater than the depth D (see Figure 1) available in this region between the rear vertical U-rails 17a, 17b and a rear internal boundary 12, and the cooling unit 20 may protrude beyond the rear 5 of the server cabinet 1. Any existing rear door 9 could be removed to allow the cooling unit 20 to be fitted and could be replaced with a more bulbous version to improve the appearance. In such embodiments, preferably the cooling unit protrudes beyond the rear 5 of the server cabinet 1 by no more than 10 cm, more preferably less than or equal to 7.5 cm, still more preferably less than or equal to 5 cm. In these arrangements the cooling unit 20 is preferably arranged for mounting to the rear vertical U-rails 17a, 17b or to a rear frame member of the server cabinet 1. In all cases, because the heat exchanger is as close as possible to the rear of the computer equipment, greater than 50% of the depth d of cooling unit 20 is within the confines of the server cabinet 1, more preferably 75% or more.

The width w of the cooling unit 20 is sized to fit appropriately within the left and right sides 3, 4 of the server cabinet 1. In one example the width w is between 250 and 570 mm. Thus usually the width w of the cooling 20 will be less than the width W , the width to the outside edges of the vertical U-rails 17a, 17b. Preferably the cooling unit 20 is sized to fit within the interior dimension of the vertical U rails (e.g., less than 450 mm EIA 310D). The cooling matrix is preferably full-rack width (albeit probably stepped in from the vertical U-rails), though may be half-rack width or a different width as desired.

The height h of the cooling unit 20, depending on requirements, may be chosen to provide a full-rack height cooling matrix, e.g., 42U high, a half-rack height, e.g., 21U high, or a smaller rack height, e.g., 10U or less, as desired. More than one cooling unit 20 may be mounted to one set of vertical U-rails 17a, 17b, one above the other, or side by side.

Figure 5a shows a side view of a full-rack height cooling unit 20 fitted to the rear vertical U-rails of a server cabinet 1. Figure 5b is a rear view showing the cooling unit 20 in situ extending across the rear of the rack. Figure 5c is another embodiment showing four cooling units 20a, 20b, 20c, 20d of differing heights mounted to the rear vertical U-rails of the server cabinet 1 and Figure 5d is a corresponding rear view. Each cooling unit 20 of the lowest pair is half-rack width, and as described above could be extended in height to a full 42U or more.

As shown in Figure 2, the cooling unit 20 is provided with one or more mounting brackets 30a, 30b, for mounting the cooling unit 20 to one, or more preferably both, of the vertical U-rails 17a, 17b. The mounting brackets 30a, 30b comprise L-shaped members that attach or are fixed to the side edges 23, 24 of the cooling matrix 20. The mounting brackets 30a, 30b may include a series of holes 31, as shown, punched into a flange 32 of the bracket 30a, 30b that correspond to the U-rail holes 34. In this way, cage nuts may be used to secure the cooling unit 20 to the rear vertical U-rails 17a, 17b.

Clearly the mounting brackets 30a, 30b could be of any suitable number and form to suit the size and weight of the cooling matrix 20. For example each side edge 23, 24 may be provided with more than one mounting bracket 30a, 30b at an upper or lower end of the cooling matrix 20 and additional mounting brackets 30a', 30b' may be provided in a more central region of the cooling matrix 20 as shown in Figures 5a and 5b. One of the mounting brackets 30a may be provided with a hinge mechanism, for example, a piano hinge mechanism 33, so that when the mounting bracket(s) 30b on the other side edge of the cooling matrix is undone or released, the cooling unit 20 can be pivoted out of the way for allowing access to the rear of the computer equipment in the rack.

In another arrangement, the mounting brackets 30a, 30b may move telescopically to provide access between the intake face 25 of the cooling matrix 20 and the rear of

the computer equipment. Quick release mechanisms may be provided that either connect to the vertical U-rails 17a, 17b or to the cooling matrix 20 to allow it to be removed easily. Mounting brackets 30a, 30b may be provided with lugs or hooks that can locate into recesses or the holes 34 of the vertical U-rails 17a, 17b. More elaborate mechanisms could be provided where a moving element moves from an unlocked or open position to a locked one, for example, pins with retractable ball bearings or rotatable lugs could be provided that engage the holes 34 of the vertical U-rails 17a, 17b.

In another arrangement (not shown), the cooling unit 20 can be mounted on a pole provided to one side of the server cabinet 1. The mounting bracket may be in the form of a collar that is supported by the pole to transfer the weight of the heat exchanger 20 to the pole. The pole and collar arrangement form a rotatable connection, that allows the cooling unit to pivot away from the rack to provide access to the rear of the computer equipment. A catch may be provided to hold the heat exchanger 20 closed or alternatively it could rely on a rear door of the cabinet, when closed, to keep the heat exchanger held close to the computer equipment. In another embodiment the cooling unit could be suspended on a horizontal pole extending across the back of the rack. The cooling unit 20 can be pivoted out of the way when access is required to the rear of the computer equipment. The pole can contain the feed and return pipes for the coolant so that they extend along the pivot axis of the pole.

As shown in Figure 3, the cooling matrix 20 preferably comprises a microchannel heat exchanger. These comprise a common inlet manifold 27a and a common outlet manifold 27b that are linked by a plurality of tubes 28, each extending between the inlet and outlet manifolds 27a, 27b. Each tube 28 contains a plurality of channels 29, as seen in more detail in Figure 4, that convey the coolant in parallel between the inlet and outlet manifolds 27a, 27b. The channels 29 are usually arranged as an array of internal passageways that extend lengthwise in the width direction w of the cooling matrix 20 and which are aligned with respect to one another as a row in the depth direction d of the cooling matrix 20. The tubes 28 are extruded from an aluminium alloy and are consequently a good conductor of heat as well as benefiting from being of lighter weight. The cooling matrix 20 may also be divided into a plurality of sections, each with its own inlet and outlet manifolds 27a, 27b. In one embodiment, the cooling matrix is formed from a plurality of sections, each providing one or more of the tubes 28 and having a portion of an inlet manifold 27a formed on

one end and a portion of an outlet manifold 27b formed on the other end. When the sections of the cooling matrix are assembled together, the portions of the manifolds combine together to form the complete inlet manifold 27a or outlet manifold 27b. In this way the cooling matrix can be supplied in any size easily.

Such microchannel heat exchangers offer much greater performance than the traditional serpentine coils. The air pressure drop through the heat exchanger may be up to 30% less, avoiding the need for additional fans; due to the proximity, the fans of the computer equipment are sufficient to provide air flow through the cooling unit. The internal pressure drop for the coolant can also be around 40% less on the gas side of the heat exchanger. This aspect reduces power required to run the compressor and enables more effective use of the thermosyphon principal for free cooling. The zig-zag strips provided between the tubes, are less prone to damage than the traditional aluminium fins of serpentine copper tube/aluminium fin coils. The microchannel coil is not really susceptible to capacity reduction and air flow impedance as is the case with the serpentine copper tube/aluminium fin coils.

The or each cooling unit 20 is preferably arranged to operate in a passive mode, using only the fans of the computer equipment to drive the air through the cooling matrix. In this way, no power is consumed in the rack and system power consumption is minimal. The noise of the fans is also avoided. If desired, however, fans can be added where necessary, though there is only limited room, or modifications to the door may be required.

The cooling matrix 20 contains a coolant to absorb heat from the computer equipment. In one embodiment this is a supply of chilled water which may contain one or more additives such as glycol. The temperature of the water is preferably kept between 16 to 21°C, more preferably 17 to 20°C. The water-based cooling circuit is preferably arranged to transfer absorbed heat to a refrigerant-based circuit via a plate heat exchanger which is part of a coolant distribution unit (CDU).

In another embodiment the coolant is a refrigerant such as R134a and the cooling matrix 20 is part of a refrigerant-based cooling circuit, for example as shown in Figure 6. In such arrangements, the cooling matrix 20 provides an evaporator 35 for the refrigerant-based cooling circuit, where the heat from the computer equipment turns the refrigerant from a liquid to a gas liquid vapour mixture. The heat is then carried by the refrigerant to an external air-cooled condensing unit 40, which preferably also

comprises a microchannel heat exchanger, where the heat is rejected to the outside. The refrigerant is then condensed and returned to the evaporator 35 as a liquid and the cycle is repeated.

The cooling circuit, or at least a section of the cooling circuit, is preferably arranged as a thermosyphon in order to take advantage of "free cooling". The temperature of the air exiting modern computer equipment can be in the region of 34-44°C. This together with the use of an efficient microchannel heat exchanger and a refrigerant such as R134a, can generate a sufficient thermal head to drive the thermosyphon when external ambient temperatures drop to 10°C or below. A pump 41 may be provided to assist the thermosyphon. When external temperatures are too high to drive the thermosyphon, then a compressor 42 can be used to drive the refrigerant around the cooling circuit as a normal refrigeration circuit. Valves 43 may be provided within the circuit to assist the flow of the refrigerant when it is operating as a thermosyphon and as a refrigeration circuit. An additional set of refrigerant pipes dedicated to the thermosyphon circuit may be installed in parallel to the ones used for the compressorised circuit operation.

The pipes 48 connecting the evaporator 35 to the condensing unit 40 are preferably made of plastics and are connected together using push-fit or simple mechanical connections (rather than being of metal and using soldered connections). This has benefits in terms of avoiding swarf that can become trapped in the passages of the microchannel heat exchanger. More importantly, it means that the cooling circuit can be connected up and repaired while the computer room is still operational because there are no live flames, e.g., for soldering the connections.

Figure 7 shows a preferred arrangement of a cooling circuit with the compressor and pump sections omitted for clarity. In this arrangement, three cooling units 20a, 20b and 20c provide the cooling load. Each of these may be a cooling matrix 20 provided in a different server cabinet 1 or they might be a set of cooling units that are provided in a single server cabinet, such as in the embodiment of Figures 5c and 5d. One or more cooling matrix 20 could also be located in a different part of the server cabinet, for example, it could be a matrix of a rack-mounted cooling unit that is fitted within the rack, or it could be a matrix of a cooling device that is external to the server cabinet, for example, fitted to a ceiling panel within the computer room. Each cooling matrix 20 is connected in parallel to a condensing plant 46 comprising at least a first condensing unit 40a and a second condensing unit 40b via a flow control device 44.

If not performed by the flow control device 44, a connection or flow controller 45 can be provided to share or control the distribution of the returned hot refrigerant to the two condensing units 40a, 40b.

Preferably the condensing units 40a, 40b are arranged to load share so that they usually run at half capacity in a N+1 redundant configuration. If a problem develops in one of them then the working condensing unit can take over at full capacity so that the cooling system is provided full N design capacity with at least an N+1 level of redundancy. The extra capacity provided by the redundancy also provides additional driving force when the cooling system is free cooling, allowing the cooling system to operate as a thermosyphon at higher outdoor ambient temperatures.

Preferably the compressor 42 is housed externally within a condensing plant 46 so that any maintenance does not disrupt the operation of the computer room. In addition, preferably a controller 47 is provided in the condensing plant 46 to control the operation of the compressor 42, the flow control device 44 and the pump 41.

Figure 8 illustrates a further cooling system employing a refrigerant-based circuit 49 and a water-based circuit 50 that feeds the multiple heat exchangers 20a, 20b, 20c. This arrangement has the advantage that it can reduce the amount of refrigerant required to cool the computer equipment by supplementing the refrigerant-based circuit 49 with a water-based circuit 50. Heat is transferred between the two circuits using a plate heat exchanger arranged in a coolant distribution unit 44. The coolant distribution unit 44 is able to control the flow through the circuits to the cooling units 20a, 20b, 20c to meet demand and control the temperature of the water as it leaves the CDU 44. Preferably the coolant supply temperature is controlled to be within a range of 17-20°C to avoid the occurrence of condensation at the cooling units. The heat exchangers 20a, 20b, 20c shown in the figure are preferably cooling units such as those that have been described above which are positioned to the rear of the computer equipment, preferably within the space between the rear vertical U-rails and a rear internal boundary, for example, a cabinet door. However it is also envisaged that these could be other forms of cooling unit, for example, rack-mounted cooling units, e.g., 10-25U high, ceiling mounted cooling units, or other units that are connected in parallel to the CDU 44. The CDU 44 may distribute coolant to six or more heat exchanger circuits, preferably six or more heat exchangers arranged within server cabinets.

Claims:

1. A cooling unit for electronic equipment housed within a server cabinet, the electronic equipment being mounted to front and/or rear vertical U-rails of the server cabinet in use, the cooling unit comprising a heat exchanger, the cooling unit being configured to hold the heat exchanger within or substantially within the confines of the server cabinet to the rear of the electronic equipment, to absorb heat from air exhausted from the rear of the electronic equipment.
2. A cooling unit as claimed in claim 1, wherein the cooling unit is configured for a server cabinet made to the EIA 310-D standard.
3. A cooling unit as claimed in claim 2, wherein the cooling unit is configured to hold the heat exchanger in a region of the server cabinet that extends from behind the rear vertical U-rails to an internal rear boundary of the server cabinet, where the internal rear boundary is provided by a rear door or a rear panel fitted to a frame of the server cabinet.
4. A cooling unit as claimed in claim 1, 2 or 3, wherein the cooling unit is sized and configured to fit within the internal dimensions of the server cabinet.
5. A cooling unit as claimed in any preceding claims, wherein the front and rear vertical U-rails of the server cabinet define a server rack and the cooling unit is configured to position an intake face of the heat exchanger within 10 cm of the rear of the rack, more preferably within 7 cm.
6. A cooling unit as claimed in any preceding claim, wherein the cooling unit is configured to mount to at least one of the rear vertical U-rails.
7. A cooling unit as claimed in any of claims 1 to 5, wherein the cooling unit is configured to mount to a rear door of the server cabinet.
8. A cooling unit as claimed in any of claims 1 to 6, wherein the cooling unit is configured to mount to a rear frame member of the server cabinet.
9. A cooling unit as claimed in any of claims 1 to 6, wherein the cooling unit is configured with means to mount indirectly to the server cabinet.

10. A cooling unit as claimed in any preceding claim, wherein the cooling unit is provided with a mounting bracket that has a quick release operation.
11. A cooling unit as claimed in any preceding claim, wherein the cooling unit is provided with a mounting bracket that hinges to allow the heat exchanger to be pivoted away from its position adjacent the rear of the computer equipment.
12. A cooling unit as claimed in any preceding claim, wherein the cooling unit is configured for passive cooling.
13. A cooling unit as claimed in any preceding claim, wherein the heat exchanger is a microchannel heat exchanger.
14. A cooling unit as claimed in claim 13, wherein the heat exchanger comprises a plurality of heat exchanger sections.
15. A cooling unit as claimed in any preceding claim, wherein the cooling unit is a height of 25U or smaller and is preferably of a width less than 450 mm.
16. A cooling unit for rack-mounted electronic equipment, the cooling unit comprising a heat exchanger in the form of a cooling matrix, the cooling unit having a mounting bracket which is configured for mounting to one or more vertical U-rails of a server rack, the mounting bracket being arranged to hold the heat exchanger off the back of the server rack in a position facing the rear of the electronic equipment.
17. A cooling unit comprising a heat exchanger in the form of a cooling matrix, the cooling unit being sized to fit within the confines of a server cabinet in a region extending between a rear pair of vertical U-rails of the server cabinet and an internal rear boundary of the server cabinet, the cooling unit being provided with one or more brackets that is/are configured to mount the heat exchanger to a vertical U-rail, a rear frame member of the server cabinet or a rear door of the server cabinet.
18. A cooling unit for a server cabinet that is configured to be mounted within the confines of the server cabinet to the rear of a server rack, the cooling unit comprising a microchannel heat exchanger that in use is arranged to absorb heat being expelled

from the rear of rack-mounted computer equipment as a passive microchannel heat exchanger.

19. A server cabinet including a cooling unit as claimed in any preceding claim.

20. A cooling system incorporating a cooling unit as claimed in any of claims 1 to 18, arranged to absorb heat from rack-mounted computer equipment, the cooling system including an outdoor air-cooled condenser or condensing unit for rejecting the absorbed heat to the outside.

21. A cooling system as claimed in claim 20, wherein the cooling unit is part of an indoor water-based cooling circuit which conveys absorbed heat via a plate heat exchanger to a refrigerant-based cooling circuit that includes the air-cooled condenser or condensing unit.

22. A cooling system as claimed in claim 21, wherein the water-based cooling circuit is fed by a coolant distribution unit that also feeds coolant to more than one cooling unit.

23. A cooling system as claimed in claim 20, wherein the cooling unit is part of a refrigerant-based cooling circuit which conveys refrigerant directly to the air-cooled condenser or condensing unit.

24. A cooling system as claimed in claim 23, wherein more than one cooling unit is in communication with the air-cooled condensing unit of the cooling system.

25. A cooling system as claimed in any of claims 21 to 24, wherein the refrigerant-based cooling circuit comprises more than one air-cooled condenser or condensing unit, the condensing units being arranged to share cooling load and provide a level of redundancy.

26. A cooling system as claimed in claim 25, wherein the level of redundancy is at least $N+1$ where N is a number of condensing units required for a notional cooling load provided by the one or more cooling units.

27. A cooling system as claimed in any of claims 21 to 26, wherein the refrigerant-based cooling circuit is arranged to operate as a thermosyphon when external temperatures allow.
28. A cooling system as claimed in any of claims 20 to 27, wherein the cooling unit is connected to pipes with push-fit connections.
29. A server cabinet comprising an integral cooling unit, the cabinet comprising a plurality of frame members that support front and rear pairs of vertical U-rails in a spaced relationship with respect to the cabinet to provide a rack for rack-mountable equipment, wherein the server cabinet further includes a heat exchanger in the form of a cooling matrix that is positioned behind the rear pair of vertical U-rails, the heat exchanger having an intake face that is positioned within 10 cm of the rear of the rack.
30. A server cabinet as claimed in claim 29, wherein the intake face is positioned within 7 cm of the rear of the server rack, more preferably within 5 cm of the rear of the server rack.
31. A server cabinet as claimed in claim 29 or 30, wherein the heat exchanger is a passive microchannel heat exchanger.

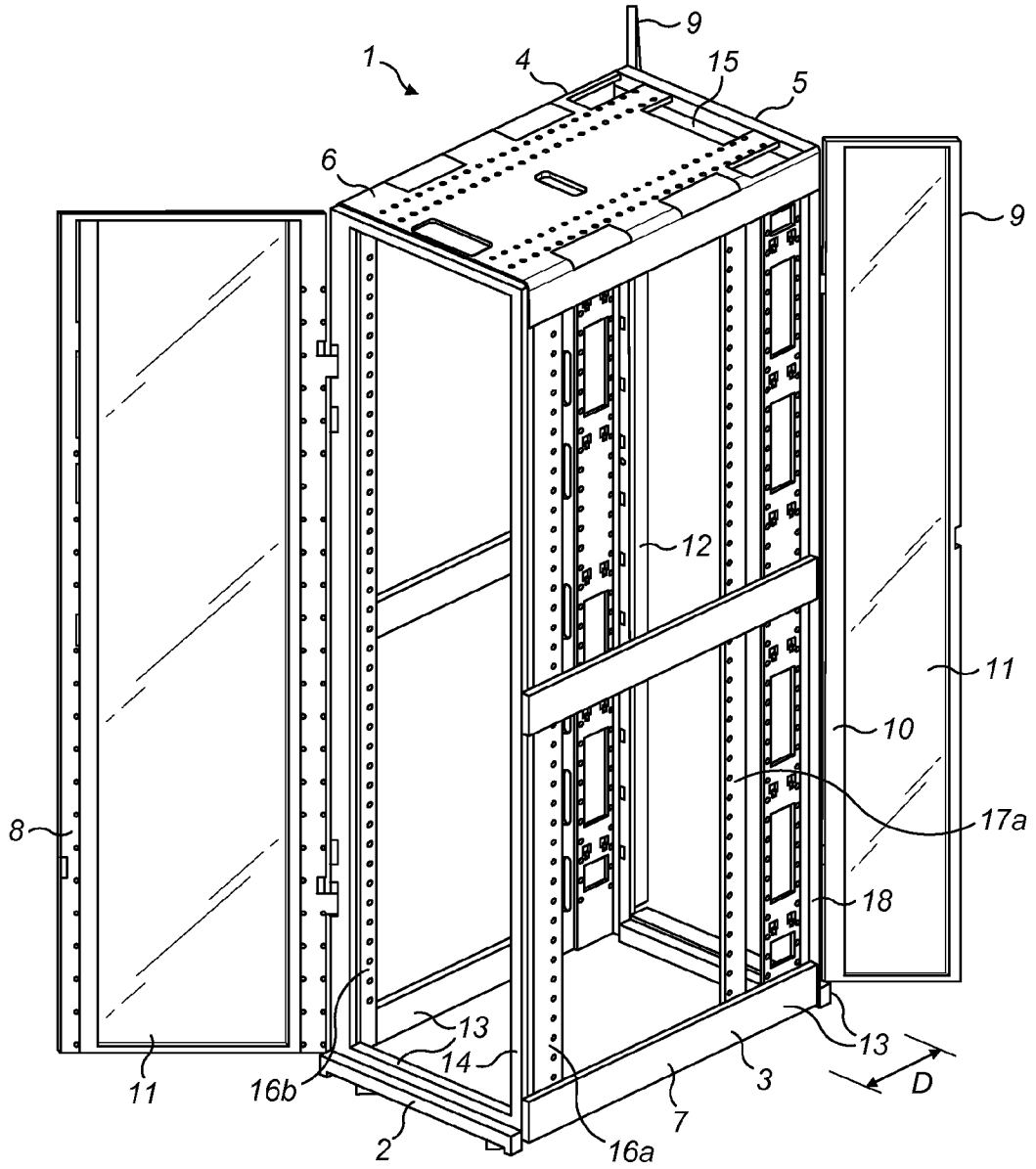


FIG. 1

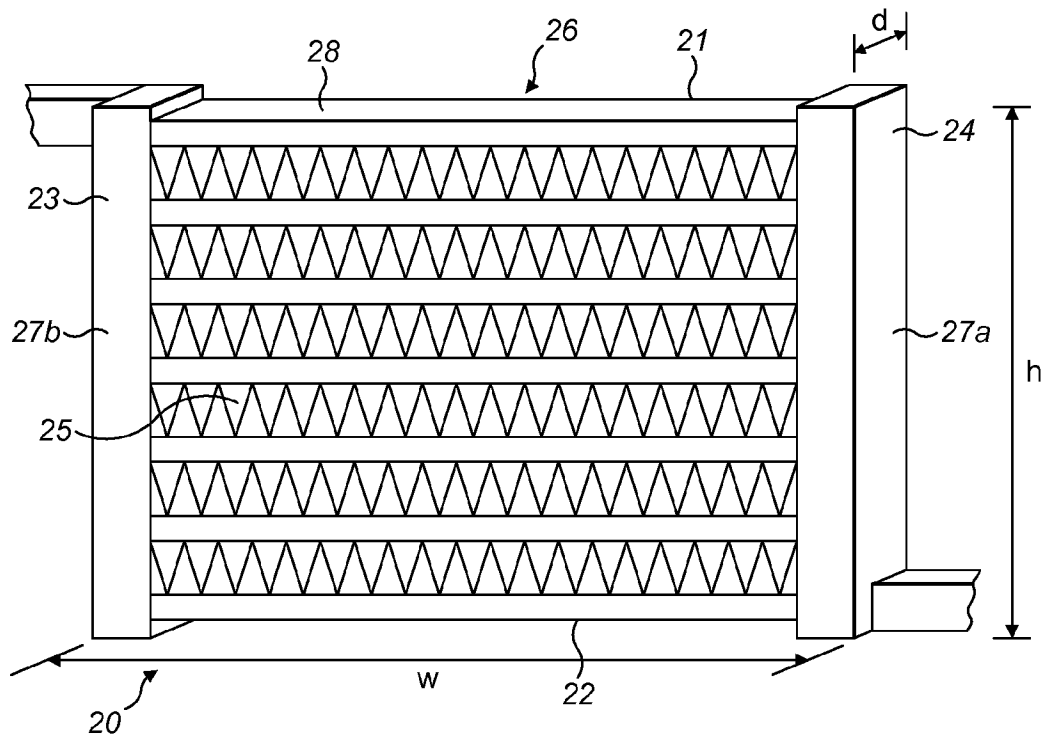


FIG. 3

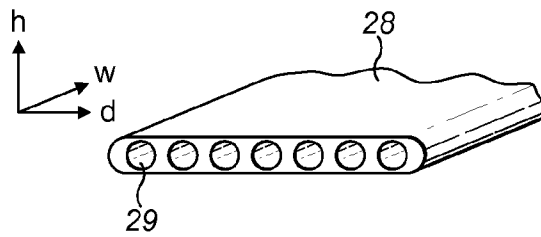


FIG. 4

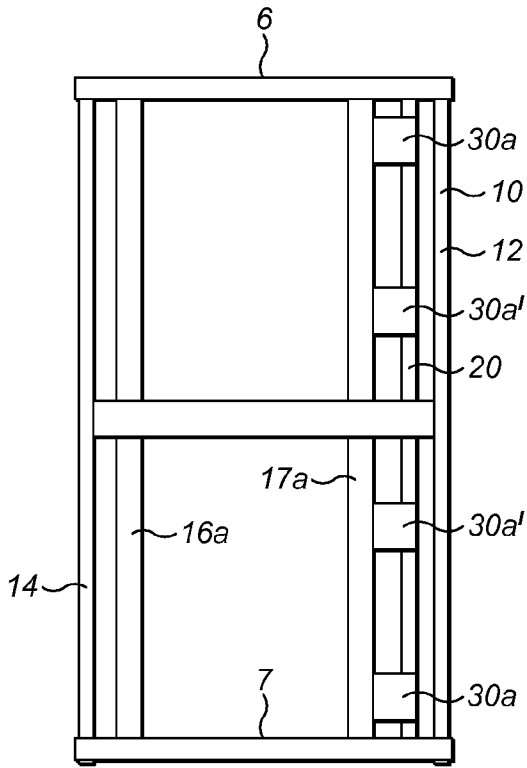


FIG. 5a

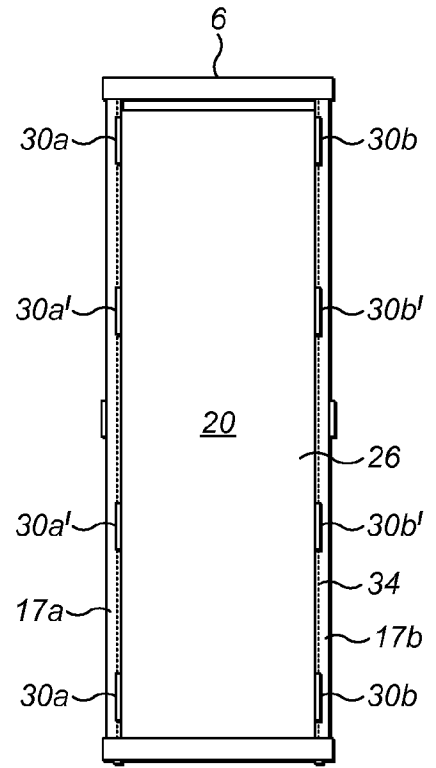


FIG. 5b

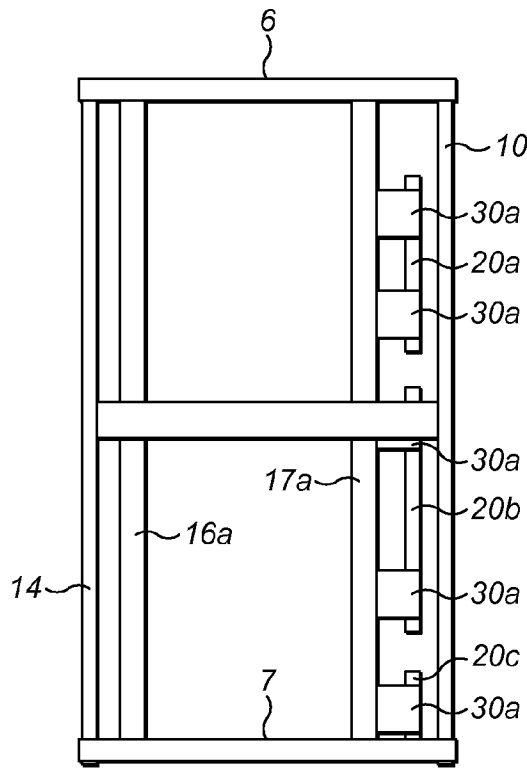


FIG. 5c

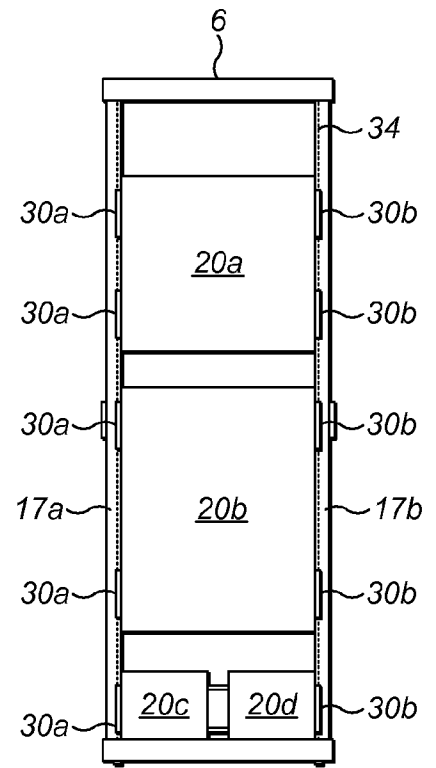


FIG. 5d

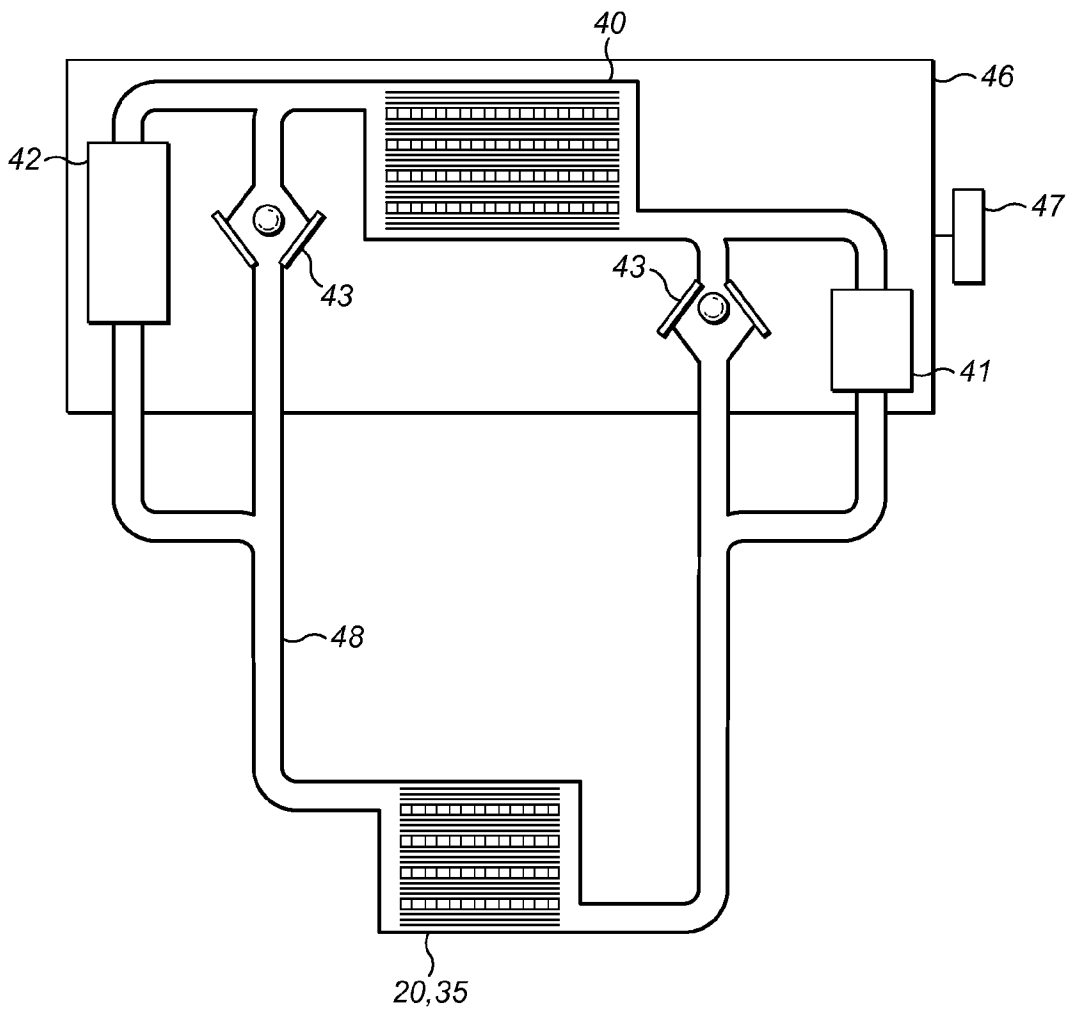


FIG. 6

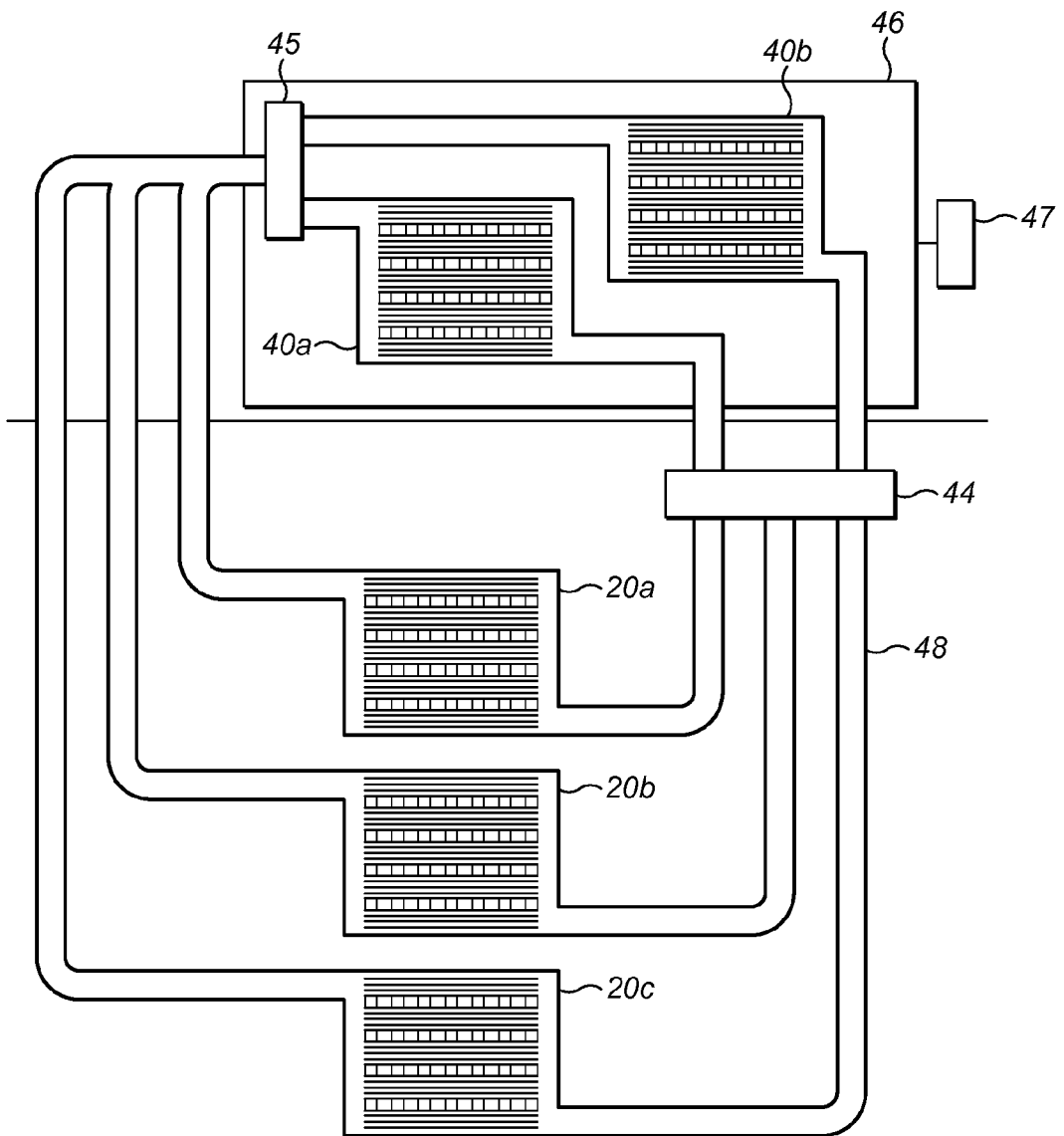


FIG. 7

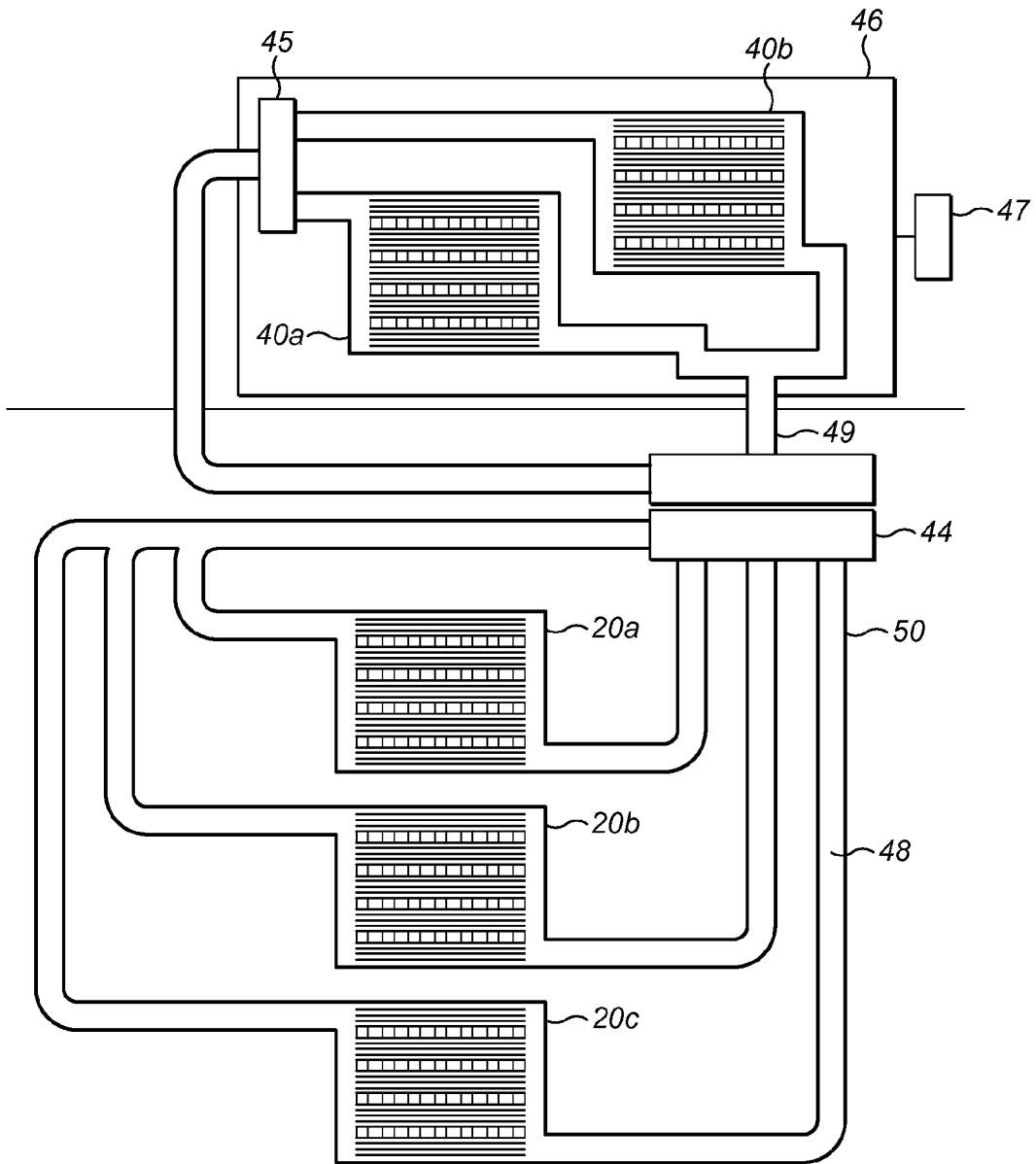


FIG. 8