

FIELD

5 The present invention relates to an air conditioner having a gravity cooling unit configuration.

BACKGROUND

10 Gravity cooling units are air conditioning devices that are typically ceiling mounted. Several known units are discussed briefly below.

 US patent no. 6435265 B1 discloses a gravity cooling unit which uses a pair of cooling columns that have the long axis of their fins angled toward each other to form a downwardly diverging air space between the cooling columns. Such angled fins result in larger cooling coils and their manufacture, along with its double drain pan design, is difficult and costly.

15 TTC Timmer Technology GmbH produces a gravity cooling unit which mounts a column of cooling coils against a wall. The wall has a cavity extending over its height that acts as duct to discharge cool air down to the bottom of a room. Such a full duct occupies precious office space. Its installation is impractical in certain settings due to the disruption that may be caused to existing infrastructure.

20 Existing air-conditioning unit control uses a thermostat to directly control the operation of a modulating valve for regulating the amount of coolant flowing into the air-conditioning unit. The thermostat senses temperature, checks against a pre-set temperature, and sends a signal to open or close the modulating valve depending on the difference between the sensed temperature and the pre-set temperature. Such a control mechanism does not allow a building operator to override the thermostat and remotely adjust the room temperature when required. In addition, as long as the
25 sensed temperature is above the pre-set temperature, coolant continues to flow through the air-conditioning units even when the room is unoccupied, resulting in energy wastage.

 When several gravity cooling units are connected to work simultaneously to cool a large space, a balance valve is installed on each of them to ensure that every cooling unit receives an
30 adequate amount of coolant to perform its individual task. Such installation is cumbersome and expensive. It is also time consuming to commission a system having a multitude of cooling coils with each having its own balancing valve.

 An object of the present invention is to provide a gravity cooling unit that addresses the shortcomings of the outlined existing systems.

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SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a gravity cooling unit comprising: at least one pair of cooling columns, wherein within each pair, both cooling columns are spaced apart and facing each other; a frame to house the at least one pair of cooling columns; and an air duct provided at a base of the frame, wherein an inlet of the air duct is located within or below the spacing within the at least one pair of cooling columns.

The disclosed gravity cooling unit can be mounted to the ceiling of a room to provide efficient and flexible gravity cooling solutions over known air-conditioning units. The manufacture of the gravity cooling unit is simple and inexpensive.

The ceiling mounted gravity cooling unit has two vertical columns of cooling coils to produce sufficient cooling capacity for space air-conditioning which increases its thermal mass through the introduction of a short down duct. In one implementation, there are three rows (or more) of cooling coils and cooling fins spaced 5mm apart. The short down duct is connected to the gravity cooling unit to create an extended unobstructed vertical channel needed for cooled air to build up velocity before discharge into the open. The short down duct prevents short-circuiting of air around the cooling coils, leading to improvement in the cooling capacity of the cooling coil. A condensate drip tray is provided to collect condensate from the cooling process. The tray is secured under the vertical columns in non-obstruction with the air passage. Mounting means are provided to secure the gravity cooling unit to the ceiling of a room to be cooled.

There is also disclosed a controller used to process information (e.g. temperature, humidity and presence of people in the room) received from sensors installed in the room. The controller sends a signal to modulating valves to open or close, controlling an amount of coolant flowing through the cooling coils, thereby ensuring room temperature is maintained at a preset point. The controller will command the modulating valve to shut off when the room is unoccupied, to prevent energy wastage for cooling an empty room. The controller-motion sensor configuration also allows a building operator to monitor and track the real time usage of a room, which improves building operational efficiency.

A control system is in place where each gravity cooling unit receives the correct amount of coolant at the right time, such as when room cooling is needed. A design is disclosed where a group of the gravity cooling units is connected to a pair of ring-looped coolant supply and return pipes to achieve good water balance. In a ring-loop installation, each of the gravity cooling units receives equal amount of chilled water, thereby eliminating the need of installing expansive balancing valve on each cooling unit on the same group.

According to a second aspect of the invention, there is provided a gravity cooling system comprising a plurality of the gravity cooling units, wherein each of the gravity cooling units is prefabricated to comprise: a cooling structure, a frame to house the cooling structure; and building services facilities grouped into one or more compartments, the one or more compartments being correspondingly located to at least another of the plurality of the gravity cooling units.

The disclosed prefabricated gravity cooling unit integrates supporting pipelines and the down-duct with the vertical cooling columns within an enclosure during fabrication. Such a prefabricated gravity cooling unit simplifies installation and reduces installation cost compared to known gravity cooling units. The prefabrication design concept accommodates integration with other building services, such as signal and power cables, to save ceiling space and improve construction productivity.

BRIEF DESCRIPTION OF THE DRAWINGS

Representative embodiments of the present invention are herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig 1 is a perspective view of a ceiling mounted gravity cooling unit having an air duct positioned in accordance with one embodiment of the present invention.

Fig 2 is a bottom view of the gravity cooling unit of Fig 1, taken along section F-F.

Fig 3 is a cross-section view of the gravity cooling unit of Fig 1, taken along section G-G.

Fig 4 illustrates air flow during operation of the gravity cooling unit of Fig 1.

Fig 5 shows a block diagram of a gravity cooling system having a plurality of the gravity cooling units of Fig 1.

Fig 6 shows a block diagram of a gravity cooling unit of Fig 1 after external connection with supporting pipelines.

Fig 7 shows side and front views of a gravity cooling unit, prefabricated in accordance with one embodiment of the present invention.

Fig 8 shows a block diagram of a gravity cooling system having a plurality of the prefabricated gravity cooling units of Fig 7.

Fig 9 shows side and front views of a gravity cooling unit, prefabricated in accordance with another embodiment of the present invention.

Fig 10 shows a block diagram of a gravity cooling system having a plurality of the prefabricated gravity cooling units of Fig 9.

Fig 11 shows a gravity cooling system having a plurality of the prefabricated gravity units of Fig 7 and a plurality of the prefabricated gravity units of Fig 9.

DETAILED DESCRIPTION

In the following description, various embodiments are described with reference to the drawings, where like reference characters generally refer to the same parts throughout the different views.

The present application, in a broad overview, relates to a gravity cooling unit. A gravity cooling unit is an air conditioner that cools air in an enclosure and is ceiling mounted. Air is cooled by allowing surrounding air to enter and pass over a cooling structure mounted inside the gravity cooling unit. The cooling structure is a heat exchanging component responsible for effecting cooling by removing heat from the entering air as it passes over the cooling structure. Heat removal may be effected by running a coolant through the cooling structure, such as cold water or refrigerant through pipes found in the cooling structure. The coolant is not limited to be a liquid, but may in any fluidic form, such as a gaseous medium.

The gravity cooling unit cools room air without using a fan or a blower. In various embodiments, its cooling structure has a pair of cooling columns, where the two cooling columns are arranged to have facing sides (also called the inner side since it is opposite to the side in which the surrounding air enters), with a space between the two cooling columns. An air duct is located such that its inlet is located within or below this space. This arrangement of the spaced apart cooling columns and the inlet of the air duct being located within or below the space leverages thermal dynamic law that warm and cold air has different density. Warmer air is less dense and lighter than colder air. Warm air will rise up to the outer sides (i.e. the side opposite to the inner side which faces the inner side of another cooling column) of the pair of cooling columns and pass through. The warm air is cooled as it passes through and emerges from the inner sides of the pair of cooling columns into the space between the two cooling columns. The cold air with higher density will sink and discharge into the surroundings via the air duct. Since the air duct has a smaller cross section than that of the space between the two cooling columns, the speed of the cold air increases after entering the inlet of the air duct.

In known set ups, supporting pipelines that are needed for operation of a gravity cooling unit are installed after a gravity cooling unit is ceiling mounted. These supporting pipelines carry fluids that are required for the cooling process (such as a coolant supply pipe to introduce coolant into the cooling column; and a coolant return pipe to allow the coolant to leave the cooling column, the coolant leaving the cooling column being warmer than the coolant that is introduced into the cooling column from having cooled down the warm air that passes into the cooling column) or are by products of the air cooling process (such as a condensate pipe for removal of condensate formed on the cooling

column after the warm air is cooled). The installation of such supporting pipelines after the ceiling mount of the gravity cooling unit is time consuming, tedious and costly.

The present application addresses these short comings by prefabricating the supporting pipelines into the gravity cooling unit. That is, when such a prefabricated gravity cooling unit is ceiling mounted, the supporting pipelines are already integrated with the gravity cooling unit at a predesignated location relative to the cooling structure of the gravity cooling unit, so that their separate installation is not required. During prefabrication, the supporting pipelines are grouped into one or more correspondingly located compartments, i.e. such prefabricated gravity cooling units have their supporting pipelines distributed in the same location(s) within their respective frame. For example, a first batch may have all supporting pipelines grouped into a compartment that is below the cooling structure, while a second batch may have some of the supporting pipelines grouped into a compartment that is above the cooling structure (such as the coolant supply pipe and the coolant return pipe) and the remaining supporting pipelines grouped into a compartment that is below the cooling structure (such as the condensate pipe). The supporting pipelines may be part of other building services facilities, i.e. one or more building services facilities is grouped into each of these compartments. The compartment may be implemented as an enclosure formed in the frame of the gravity cooling unit during prefabrication, with the building services facilities provided within the enclosure. Examples of building services facilities include components used for mechanical, electrical and plumbing (MEP) systems, such as power cables, lighting cables, computer network cables, telephone wiring, sprinkler pipes, water pipes, air supply pipes and gas pipes.

After a plurality of prefabricated gravity cooling units having correspondingly located supporting pipelines are ceiling mounted, a gravity cooling system can be readily realised by coupling each of the supporting pipelines of adjacent prefabricated gravity cooling units together with a respective connection pipe. With the prefabricated gravity cooling units being orderly mounted, the supporting pipelines of adjacent units will automatically be in alignment. The connection pipe can have a straight configuration and a short length, without requiring bending to achieve interconnection.

A gravity cooling unit that has an air duct located in the space between facing cooling columns can also be prefabricated to have correspondingly located supporting pipelines. In one implementation, several of the supporting pipelines may be disposed in a compartment where the air duct is located. In another implementation, the air duct is an optional feature in prefabricated gravity cooling units with correspondingly located supporting pipelines.

Fig 1 is a perspective view of a ceiling mounted gravity cooling unit A having an air duct positioned in accordance with one embodiment of the present invention.

The ceiling mounted gravity cooling unit A has two vertical cooling columns 1. While Figure 1 shows that their vertical mount results in the cooling columns 1 being parallel to each other, other

implementations (not shown) do not require a parallel orientation so that the cooling columns may have a tilted orientation.

Within each pair of the cooling columns 1, both are spaced apart, with an inner side of one the cooling column facing an inner side of the other cooling column. Each cooling column 1 has a plurality of pipes 3, wherein an array of spaced apart, elongate, cooling fins 2 is mounted parallel to each other along the length of one or more of the pipes 3. Each of the pipes 3 extends transverse to the cooling fins 2. The cooling fins 2 are rectangular in shape and spaced at 5mm apart. There is at least one coil 4 to join adjacent ends of the pipes 3 outside of the fins 2. The coil 4 may have a serpentine configuration, wherein an implementation of two cooling columns 1 having at least three rows of serpentine cooling coils 4 was found to increase the thermal mass of the gravity cooling unit A. The cooling coils 4 and the pipes 3 carry coolant, such as chilled water. The fins 2 and the coils 4 together form a slab-like structure.

With reference to Figs 3 and 4, the pair of cooling columns 1 is fixed to a frame 5 having mounting holes 6 which allow the gravity cooling unit A to be directly secured onto a ceiling B by bolts 7 and nuts 8. While not shown, the gravity cooling unit A can alternatively be suspended from the ceiling B by a pre-determined height using hanging rods and nuts that secure to the mounting holes 6 of the frame 5. The frame 5 may be made from any suitable metal, such as steel.

An air duct 12 is provided at a base of the frame 5. During air-conditioning, coolant flows through the coils 4 and pipes 3 to cool the fins 2 mounted on each of the pipes 3. The cooled fins 2 remove heat from the warm air that passes through the gaps in between the fins 2. The cooled air, being denser, sinks from the inner sides 13 of the cooling column 1 into the air duct 12. As the cooled air exits along the inner sides 13 to be released from the gravity cooling unit A through the air duct 12, more warm air is induced to enter the outer side of the cooling column 1 and over the fins 2 as shown by the arrows C in Fig 4 to replace the cooled air that exits the air duct 12. The air duct 12 thus establishes an air circulation path inside the gravity cooling unit A.

The air duct 12 increases the efficiency of the gravity cooling unit A because it creates an extended channel needed for the cooled air to build up velocity before being discharged into the open. This improves air circulation and the cooling capacity of the gravity cooling unit A. In one implementation, the air duct 12 has a length of at least 150mm. However, other implementations use an air duct 12 of different lengths.

Fig 4 shows that the inlet of the air duct 12 is located within the space 25 between facing cooling columns 1. Since the cold air is found within the space 25 between facing cooling columns 1 and also sinks below this space 25, the inlet of the air duct 12 may also be located below the space 25 between facing cooling columns 1. As such, the inlet of the air duct 12 is located in a region that spans from within the space 25 to below the space 25. It is also not essential that the centre of the

space 25 aligns with the centre of the air duct 12, as shown in Figs 3 and 4. Rather, the width of the space 25 allows for the centre of the air duct 12 to be offset from the centre of the space 25, as long as the inlet is within or below the space 25 between the facing cooling columns 1 and is positioned in alignment with the sinking cooled air that emerges from the inner sides 13 of the cooling columns 1.

5 Condensate forms on the surfaces of the fins 2 during cooling of warm air. The fins 2 are spaced 5mm apart to allow sufficient room for condensate droplets to flow down along the fins 2. A condensate drip tray 9 is provided at the base of the frame 5 and under the cooling columns 1 to collect these condensate droplets. The cooling columns 1 are secured to the frame 5 such that a gap exists between their bottom and the base of the frame 5. This gap prevents the cooling columns 1
10 from dipping into the condensate that accumulates at the condensate drip tray 9. The condensate tray 9 has a U-shaped cross-section and has a drain outlet 10 to which a condensate pipe 46 may be connected through a condensate line 14 to drain off condensate water collected in the tray 9.

 The air duct 12 is disposed at the condensate drip tray 9, with the outlet of the air duct 12 extending below the condensate drip tray 9. For example, an opening 11 is provided in the
15 condensate drip tray 9 to accommodate the air duct 12. Positioning the air duct 12 at the portion of the condensate drip tray 9 which is below the space 25 ensures that condensate from the fins 2 falls into the condensate drip tray 9 and not the air duct 12. In addition, the inlet of the air duct 12 is raised by having it extend above the condensate drip tray 9. This allows the inlet of the air duct 12 to be
20 above a water level at which the condensate is allowed to accumulate in the condensate drip tray 9 while being drained out from the drain outlet 10, safeguarding condensate from seeping into the air duct 12. The inlet of the air duct 12 may extend above the condensate drip tray 9 to a height where it is located within the space 25.

 Using at least three rows of coils 4 and the air duct 12 provides high thermal mass, so that the gravity cooling unit A produces more BTU than gravity cooling units that do not have such an air duct.
25 The mounting holes 6 of the frame 5 also allows the gravity cooling unit A to be mounted at any location on the ceiling B of an enclosure. The layout of the two vertical cooling columns 1 being fixed on a steel structural frame 5 with a single continuous condensate tray 9 is a simple design. This simplifies manufacturing of the gravity cooling unit A, which results in lower manufacturing cost and allows for wide air-conditioning applications.

30 Fig 4 shows a block diagram of a single gravity cooling unit A installed for air-conditioning a room. The gravity cooling unit A is connected to a pair of coolant supply and return pipes 15 through a respective connected distribution pipe 44 having an isolation valve 16, which is used to shut off coolant supply to the gravity cooling unit A during maintenance. A modulating valve 17 is provided on one of the distribution pipes to regulate flow rate of coolant flow through the gravity cooling unit
35 A, thus controlling its cooling capacity. In the implementation shown in Fig 4, the modulating valve

17 is provided on the distribution pipe 44 that returns coolant to the coolant return pipe 15 and is located upstream from the isolation valve 16 along the same distribution pipe 44. When the modulating valve 17 opens to allow more coolant flow, the cooling capacity of the gravity cooling unit A increases. On the other hand, the cooling capacity of the gravity cooling unit A decreases as the modulating valve 17 closes to reduce coolant flow.

A controller 18 processes information received from a thermostat 19 and occupancy sensor 20 installed in the room and sends a signal to the modulating valve 17 to open or close, ensuring that room temperature is maintained at a preset point. The controller 18 will command the modulating valve 17 to shut off when the occupancy sensor 20 detects no human presence in the room. This prevents wasting energy for cooling an empty room.

The introduction of the controller 18 and the occupancy sensor 20 for gravity cooling unit A provides a means to effectively control valves that modulate coolant flow into the gravity cooling unit A. The controller 18 allows an operator to override thermostat settings and remotely adjust room temperature when required under certain circumstances. When the room is detected to be unoccupied, the occupancy sensor 20 will inform the controller 18 to shut off the modulating valve 17 to stop coolant flowing through the gravity cooling unit A, preventing energy wastage for cooling an empty room. The controller 18 and occupancy sensor 20 configuration thus allows a building operator to monitor and track the real time usage of a room, which improves building operation efficiency.

The pair of coolant supply and return pipes 15 is connected to a pair of coolant main supply and return lines, which is in turn in communication with a coolant source. That is, the coolant main supply line draws fresh coolant from the coolant source for channelling to the coolant supply pipe, while the coolant main return line receives spent coolant from the coolant return pipe for sending back to the coolant source. The pair of coolant main supply and return lines is shown in Fig 5.

Fig 5 shows a block diagram of a gravity cooling system having a plurality of gravity cooling units A. A plurality of gravity cooling units A is used because the area cooled is larger than that of Fig 4.

All gravity cooling units A in the same group are connected to a pair of coolant main supply and return lines 55 through a ring-loop circuit 21. With reference to Fig 4, the ring-loop circuit 21 performs the function of the pair of coolant supply and return pipes 15 for each of the gravity cooling units A, circumventing the need to individually connect each of the gravity cooling units to the pair of coolant main supply and return lines 55. The ring-loop connection provides good water balance whereby each gravity cooling unit A receives an equal amount of coolant, without the need for an expensive balancing valve for each gravity cooling unit A in the same group. The ring-loop circuit 21 has isolation valves 16 which perform the same function as those found in the distribution pipe of Fig 4. A modulating valve 17 is also installed at each end of the ring-loop circuit 21 to control the amount

of coolant flow, thus regulating the cooling capacity of the gravity cooling units A in the same group. In the implementation shown in Fig 5, the modulating valve 17 is provided on the segment of the ring-loop circuit 21 that returns coolant to the coolant main return line 55 and is located upstream from the isolation valve 16 along the same segment. When the modulating valve 17 opens to allow more coolant flow through the ring-loop circuit 21, the cooling capacity of the connected gravity cooling units A increases. On the other hand, the cooling capacity of the gravity cooling units A connected to the ring-loop circuit 21 decreases when the modulating valve 17 closes to reduce coolant flow. A controller 18 processes the information received from a thermostat 19 and an occupancy sensor 20 installed in the room and sends a signal to the modulating valve 17 to open or close, ensuring the room temperature is maintained at a preset point. When the room is detected to be unoccupied, the occupancy sensor 20 will inform the controller 18 to shut off the modulating valve 17 to stop coolant flowing through the gravity cooling units A, preventing energy wastage for cooling an empty room. The controller 18 and occupancy sensor 20 configuration thus allows a building operator to monitor and track the real time usage of a room, which improves building operation efficiency.

The introduction of a ring-loop circuit to deliver coolant for large space air-conditioning overcomes the complexity and cost of installation methods that use a balance valve in each of its multiple cooling units, since only two valves need to be used to control cooling capacity of gravity cooling units A. The modulating valve 17 also provides override capability over thermostat 19 control.

With reference to Figs 4 and 5, the connection of the distribution pipes between the pair of coolant supply and return pipes 15 and the pair of cooling columns 1, the connection of the ring-loop circuit 21 between the pair of coolant main supply and return lines 55 and the pair of cooling columns 1; and the connection of the condensate line 14 between the condensate pipe 46 and the pair of cooling columns 1 are done after the gravity cooling unit A is ceiling mounted.

Fig 6 shows a block diagram of a gravity cooling unit A after such external connections are made. The pair of coolant supply and return pipes 15 is connected to the cooling columns 1 through its respective distribution pipe 44, while the condensate pipe 46 is connected to the cooling columns 1 through a condensate line 14. The pair of coolant supply and return pipes 15 and the condensate pipe 46 are exposed and placed on a supporting tray 623.

As such external connections are time consuming, tedious and costly, an alternative approach is to have one or more of such distribution pipes, the ring-loop circuit 21, the coolant supply and return pipes 15 and the condensate pipe 46 prefabricated with the gravity cooling unit A. Such a prefabricated gravity cooling unit A has such supporting pipelines integrated into its frame, so that the external connections shown in Fig 6 are no longer necessary. In addition, the supporting pipelines are grouped into one or more correspondingly located compartments, i.e. such prefabricated gravity

cooling units A have their supporting pipelines distributed in the same location(s) within their frame. Grouping the supporting pipelines, along with other building services facilities, into one or more correspondingly located compartments has the advantage of simplifying connections between the gravity cooling units A; short and straight connectors can be used to couple building services facilities of one gravity cooling unit A to another.

It is not necessary for all gravity cooling units A in a gravity cooling system to have their building services facilities grouped into one or more compartments that are correspondingly located. In one implementation, only two of its gravity cooling units A have their one or more compartments correspondingly located. Interconnection is then achieved, for example, by having a connection pipe couple each of the supporting pipelines from the one or more compartments that are correspondingly located (i.e. if the building services facilities has three supporting pipelines; a pair of coolant supply and return pipes 15 and a condensate pipe 46, there will be three connection pipes). In another implementation, adjacent gravity cooling units A have their supporting pipelines grouped into one or more correspondingly located compartments. Interconnection is then achieved by having a connection pipe couple each of the supporting pipelines from the adjacent gravity cooling units A.

Fig 7 is a side view 702 and a front view 704 along section A-A of the side view 702 of a prefabricated gravity cooling unit A that belongs to a gravity cooling system. The prefabricated gravity cooling unit A has building services facilities grouped into one or more correspondingly located compartments, in accordance with one embodiment of the present invention. Similar to the gravity cooling unit A of Fig 1, the gravity cooling unit A of Fig 7 has a structural frame 72 with mounting holes located at the top of the frame 702. The holes allow the gravity cooling unit A to be directly secured onto a ceiling by bolts and nuts 711, or suspended from the ceiling at a pre-determined height by hanging rods and nuts (not shown). The frame 72, which may be manufactured from steel, houses a cooling structure 71 and building services facilities grouped into one or more compartments, the one or more compartments being correspondingly located to at least another gravity cooling unit A of the gravity cooling system. For the sake of simplicity, only the supporting pipelines (a pair of coolant supply and return pipes 15 and a condensate pipe 46) of the building services facilities are shown in Fig 7 and discussed below.

The cooling structure 71 has a similar configuration to the pair of cooling columns 1 of Fig 1. As such, the cooling structure 71 has two spaced apart cooling columns, with one cooling column facing the other. Each cooling column has a plurality of pipes to carry coolant flow and at least one coil to join adjacent ends of the plurality of pipes. An array of spaced apart fins is mounted on each of the plurality of pipes, with each pipe extending transversely to the fins. An air duct 12 is provided at a base of the frame 72 within or below the space between the cooling columns. Although not shown, another implementation sees the cooling structure having only one such cooling column and

not two. In this other implementation, the prefabricated gravity cooling unit A does not have the air duct.

The prefabricated gravity cooling unit A has five modules. Module 712 houses the cooling structure 71 having two vertical cooling columns, parallel to each other. The two vertical cooling columns are fixed to the frame 72. A condensate drip tray 73 is provided under the two vertical cooling columns. The condensate drip tray 73 has a U-shaped cross-section with two drain outlets 75.

A chilled water pipe module 714 is provided above the cooling structure 71 or at the top of the frame 72, to house a pair of coolant supply and return pipes 15, which are connected to the vertical cooling columns of the cooling structure 71 via distribution pipes 74. A connector 716 is provided at each of the ends of the pair of coolant supply and return pipes 15.

A down duct module is provided below the condensate drip tray 73 to house the air duct 12. A condensate pipe module 715 is provided on one side of the down duct module to house the condensate pipe 46 that is connected to the condensate drip tray 73 by the two drain outlets 75 to ensure fast discharge of the condensate water from the condensate drip tray 73. A cable module 713 is provided on the other side of the down duct module for housing cables used for building services, such as signal and power cables, depending on needs.

The configuration shown in Fig 7 thus has the coolant supply pipe and the coolant return pipe (i.e. the pair of coolant supply and return pipes 15) disposed in a compartment of the frame 72 that is above the cooling structure 71. The condensate pipe 46 is disposed in a compartment of the frame 72 where the air duct is located. The configuration (not shown) where the air duct 12 is absent can also use a similar layout, whereby the prefabricated gravity cooling unit A has the coolant supply pipe and the coolant return pipe disposed in a compartment above the cooling structure 71; and wherein the condensate pipe 46 is disposed in a compartment below the cooling structure 71.

Fig 8 shows a block diagram of a gravity cooling system having a plurality of the prefabricated gravity cooling units A of Fig 7, labelled A1, A2 and A3. Correspondingly located supporting pipelines of the prefabricated gravity cooling units A1, A2 and A3 are joined together by respective connection pipes 817 and 818. Two short chilled water connection pipes 817 connect the pair of coolant supply and return pipes 15 via the connectors 716 (refer Fig 7), while a condensate water connection pipe 8T18 connects the condensate pipe 46 of adjacent prefabricated gravity cooling units A.

Fig 9 is a side view 902 and a front view 904 along section B-B of the side view 902 of a prefabricated gravity cooling unit B that belongs to a gravity cooling system. The prefabricated gravity cooling unit B has building services facilities grouped into one or more correspondingly located compartments, in accordance with one embodiment of the present invention. Similar to the gravity cooling unit A of Fig 1, the gravity cooling unit B of Fig 9 has a structural frame 92 with

mounting holes located at the top of the frame 902. The holes allow the gravity cooling unit B to be directly secured onto a ceiling by bolts and nuts 911, or suspended from the ceiling at a predetermined height by hanging rods and nuts (not shown). The frame 92, which may be manufactured from steel, houses a cooling structure 91 and building services facilities grouped into one or more compartments, the one or more compartments being correspondingly located to at least another gravity cooling unit B of the gravity cooling system. For the sake of simplicity, only the supporting pipelines (a pair of coolant supply and return pipes 15 and a condensate pipe 46) of the building services facilities are shown in Fig 9 and discussed below.

The cooling structure 91 has a similar configuration to the pair of cooling columns 1 of Fig 1. As such, the cooling structure 91 has two spaced apart cooling columns, with one cooling column facing the other. Each cooling column has a plurality of pipes to carry coolant flow and at least one coil to join adjacent ends of the plurality of pipes. An array of spaced apart fins is mounted on each of the plurality of pipes, with each pipe extending transversely to the fins. An air duct 12 is provided at a base of the frame 92 within or below the space between the cooling columns. Although not shown, another implementation sees the cooling structure having only one such cooling column and not two. In this other implementation, the prefabricated gravity cooling unit B does not have the air duct.

The prefabricated gravity cooling unit B has four modules. Module 912 houses the cooling structure 91 having two vertical cooling columns, parallel to each other. The two vertical cooling columns are fixed to the frame 92. A condensate drip tray 93 is provided under the two vertical cooling columns. The condensate drip tray 93 has a U-shaped cross-section with two drain outlets 95.

A down duct module is provided below the condensate drip tray 93 to house the air duct 12. A condensate pipe module 915 is provided on one side of the down duct module to house the condensate pipe 46 that is connected to the condensate drip tray 93 by the two drain outlets 95 to ensure fast discharge of the condensate water from the condensate drip tray 93.

The condensate pipe module 915 also houses a pair of coolant supply and return pipes 15, which are connected to the vertical cooling columns by distribution pipes 94. A connector 916 is provided at each of the ends of the pair of coolant supply and return pipes 15. A cable module 913 is provided on the other side of the down duct module for housing cables used for building services, such as signal and power cables, depending on needs.

The configuration shown in Fig 9 thus has the coolant supply pipe and the coolant return pipe (i.e. the pair of coolant supply and return pipes 15) and the condensate pipe 46 disposed in a compartment shared by the air duct 12. The configuration (not shown) where the air duct 12 is absent can also use a similar layout, whereby the prefabricated gravity cooling unit B has the coolant supply

pipe and the coolant return pipe disposed in a compartment above the cooling structure 91; and wherein the condensate pipe 46 is disposed in a compartment below the cooling structure 91.

Fig 10 shows a block diagram of a gravity cooling system having a plurality of the prefabricated gravity cooling units B of Fig 9, labelled B1, B2 and B3. Correspondingly located supporting pipelines of the prefabricated gravity cooling units B1, B2 and B3 are joined together by respective connection pipes 1017 and 1018. Two short chilled water connection pipes 1017 connect the pair of coolant supply and return pipes 15 via the connectors 916 (refer Fig 9), while a condensate water connection pipe 1018 connects the condensate pipe 46 of adjacent prefabricated gravity cooling units B.

Referring to Figs 7 and 9, both prefabricated gravity cooling units A and B share a common design in which supporting pipelines, an air duct 12 and a pair of cooling columns are integrated into their frames. Such a design streamlines on-site installation of the prefabricated gravity cooling units A and B and their connection to a coolant source, described below with respect to Fig 11.

Fig 11 shows a gravity cooling system having a plurality of the prefabricated gravity units A of Fig 7 and a plurality of the prefabricated gravity units B of Fig 9 for air-conditioning a room with a large floor area. The prefabricated gravity cooling units A and B are connected in series with connection pipes 1117 in a ring-loop and joined to a pair of coolant main supply and return lines 55.

The ring-loop connection provides good water balance whereby each of the prefabricated gravity cooling units A and B receives an equal amount of coolant, without the need for an expensive balancing valve for each prefabricated gravity cooling unit A and B in the same group. The ring-loop has isolation valves 1116 which perform the same function as those found in the distribution pipe of Fig 4. A modulating valve 1117 is also installed at each end of the ring-loop to control the amount of coolant flow, thus regulating the cooling capacity of the prefabricated gravity cooling units A and B in the same group. In the implementation shown in Fig 11, the modulating valve 1117 is provided on the segment of the ring-loop that returns coolant to the coolant return pipe 15 and is located upstream from the isolation valve 1116 along the same segment. When the modulating valve 1117 opens to allow more coolant flow through the ring-loop, the cooling capacity of the connected prefabricated gravity cooling units A and B increases. On the other hand, the cooling capacity of the prefabricated gravity cooling units A and B connected to the ring-loop decreases when the modulating valve 1117 closes to reduce coolant flow. A controller 18 processes the information received from a thermostat 19 and an occupancy sensor 20 installed in the room and sends a signal to the modulating valve 1117 to open or close, ensuring the room temperature is maintained at a preset point. When the room is detected to be unoccupied, the occupancy sensor 20 will inform the controller 18 to shut off the modulating valve 1117 to stop coolant flowing through the prefabricated gravity cooling units A and B, preventing energy wastage for cooling an empty room. The controller 18 and occupancy sensor 20

configuration thus allows a building operator to monitor and track the real time usage of a room, which improves building operation efficiency. Signal and power cables 1122 allowing the controller 18 to connect to the modulating valves 1117 can be laid and housed in the cable module 713 (confer Fig 7) and 913 (confer Fig 9) provided in the prefabricated gravity cooling units A and B.

5 Connecting the prefabricated gravity cooling units A and B into a ring-loop configuration for large space air-conditioning eliminates the need for a balance valve, which is required in known gravity cooling unit systems. Comparing the ring-loop configuration of Fig 11 against the ring-loop circuit 21 of Fig 5, it will be appreciated that the prefabricated gravity cooling units A and B do not require an external loop of pipes to establish fluid communication with the pair of coolant main
10 supply and return lines 55. The prefabricated gravity cooling units A and B, which uses a modular design approach, thus simplifies multiple connections of gravity cooling units and reduces installation costs. By prefabricating a gravity cooling unit with supporting pipelines grouped into designated compartments, the required co-ordination with other building services (e.g. cables, lights and sprinkler pipe) to install several of such prefabricated gravity cooling units is reduced.

15 It will be appreciated that the components described in respect of Figs 7 and 9 for grouping the supporting pipelines can also be used to group other building services facilities. Examples of building services facilities include components used for mechanical, electrical and plumbing (MEP) systems, such as power cables, lighting cables, computer network cables, telephone wiring, sprinkler pipes, water pipes, air supply ducts and gas pipes. An example of an air supply duct is one that
20 provides fresh air to a furthest gravity cooling unit within a system of gravity cooling units.

Deciding which of the designs disclosed above (the gravity cooling unit A shown in Fig 2; the prefabricated gravity cooling unit A shown in Fig 7; or the prefabricated gravity cooling unit B shown in Fig 9) for implementation may depend on infrastructure present at an installation location. For instance, if the installation location already has a network of pairs of coolant supply and return pipes,
25 the gravity cooling unit A of Fig 2 may be used. On the other hand, without such infrastructure, a mixture of the prefabricated gravity cooling unit A of Fig 7 and the prefabricated gravity cooling unit B of Fig 9 may be more appropriate.

In large enclosures, connecting a plurality of the gravity cooling units A of Fig 2 as set out in Fig 5; or a plurality of the prefabricated gravity cooling units A of Fig 7 and the prefabricated gravity
30 cooling units B of Fig 9, as set out in Fig 11, results in the formation of a double ring-loop coolant supply and return circuit. This ensures good water balance where each of the gravity cooling units receives an equal amount of coolant. Two modulating valves are installed on the coolant return segment at the end of the double ring-loop coolant supply and return circuit to control the amount of coolant flowing through, which controls the cooling capacity of the cooling units in the same ring-
35 loop. A controller is used to process the information received from a thermostat and an occupancy

sensor installed in the enclosure and send a signal to the modulating valves to determine the amount of coolant that can flow through, ensuring the room temperature is maintained at a preset point. The controller will command the modulating valves to shut off when the occupancy sensor detects that the enclosure is unoccupied, preventing wastage of energy for cooling an empty room.

5 In the application, unless specified otherwise, the terms "comprising", "comprise", and grammatical variants thereof, intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, non-explicitly recited elements.

10 While this invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes can be made and equivalents may be substituted for elements thereof, without departing from the spirit and scope of the invention. In addition, modification may be made to adapt the teachings of the invention to particular situations and materials, without departing from the essential scope of the invention. Thus, the invention is not limited to the particular examples that are disclosed in this specification, but encompasses all embodiments falling within the scope of the appended claims.

CLAIMS

1. A gravity cooling unit comprising:
 - at least one pair of cooling columns, wherein within each pair, both cooling columns are
 - 5 spaced apart and facing each other;
 - a frame to house the at least one pair of cooling columns; and
 - an air duct provided at a base of the frame, wherein an inlet of the air duct is located within or below the spacing within the at least one pair of cooling columns.
- 10 2. The gravity cooling unit of claim 1, further comprising a condensate drip tray provided at the base of the frame, wherein the air duct is disposed at the condensate drip tray and has an outlet that extends below the condensate drip tray.
3. The gravity cooling unit of claim 2, wherein the inlet of the air duct extends above the
- 15 condensate drip tray.
4. The gravity cooling unit of claim 2 or 3, wherein the condensate drip tray has a drain outlet.
5. The gravity cooling unit of any one of the preceding claims, wherein each of the cooling
- 20 columns comprises
 - a plurality of pipes;
 - at least one coil to join adjacent ends of the plurality of pipes; and
 - an array of spaced apart fins mounted on each of the plurality of pipes, with each pipe extending transversely to the fins.
- 25 6. The gravity cooling unit of claim 5, wherein the fins are rectangular and spaced 5mm apart.
7. The gravity cooling unit of any one of the preceding claims, wherein the at least one pair of cooling columns is secured to the frame such that a gap exists between their bottom and the base of
- 30 the frame.
8. The gravity cooling unit of any one of the preceding claims, wherein both cooling columns in the at least one pair of cooling columns are mounted parallel to each other.

9. A gravity cooling system comprising a plurality of the gravity cooling units of any one of the preceding claims, wherein each of the gravity cooling units comprises
- building services facilities grouped into one or more compartments, wherein at least two of the plurality of the gravity cooling units have their one or more compartments correspondingly
- 5 located, and
- a respective connector to couple each of the building services facilities from the one or more compartments that are correspondingly located.
10. The gravity cooling system of claim 9, wherein the building services facilities comprise any
- 10 one or more of a coolant supply pipe; a coolant return pipe; a condensate pipe; and components for mechanical, electrical and plumbing (MEP) systems.
11. The gravity cooling system of claim 10, wherein within each of the plurality of the gravity cooling units, the coolant supply pipe and the coolant return pipe are disposed in a compartment
- 15 above the at least one pair of cooling columns; and wherein the condensate pipe is disposed in a compartment where the air duct is located.
12. The gravity cooling system of claim 10, wherein within each of the plurality of the gravity cooling units, the coolant supply pipe, the coolant return pipe and the condensate pipe are disposed in
- 20 a compartment shared by the air duct.
13. A gravity cooling system comprising a plurality of the gravity cooling units, wherein each of the gravity cooling units is prefabricated to comprise:
- a cooling structure,
- 25 a frame to house the cooling structure; and
- building services facilities grouped into one or more compartments, the one or more compartments being correspondingly located to at least another of the plurality of the gravity cooling units.
- 30 14. The gravity cooling system of claim 13, further comprising
- a respective connector to couple each of the building services facilities from the one or more compartments that are correspondingly located.

15. The gravity cooling system of claim 13 or 14, wherein the building services facilities comprise any one or more of a coolant supply pipe; a coolant return pipe; a condensate pipe; and components for mechanical, electrical and plumbing (MEP) systems.
- 5 16. The gravity cooling system of claim 15, wherein within each of the plurality of the gravity cooling units, the coolant supply pipe and the coolant return pipe are disposed in a compartment above the cooling structure; and wherein the condensate pipe is disposed in a compartment below the cooling structure.
- 10 17. The gravity cooling system of claim 15, wherein within each of the plurality of the gravity cooling units, the coolant supply pipe, the coolant return pipe and the condensate pipe are disposed in a compartment below the cooling structure.
- 15 18. The gravity cooling system of any one of the claims 13 to 17, wherein the cooling structure comprises at least one pair of cooling columns, wherein within each pair, both cooling columns are spaced apart and facing each other.
19. The gravity cooling system of any one of the claims 13 to 17, wherein the cooling structure comprises a cooling column.
- 20 20. The gravity cooling unit of claim 18 or 19, wherein the cooling column comprises
a plurality of pipes;
at least one coil to join adjacent ends of the plurality of pipes; and
an array of spaced apart fins mounted on each of the plurality of pipes, with each pipe
25 extending transversely to the fins.