(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 April 2024 (18.04.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/080937 A1

(51) International Patent Classification:
F28F 1/02 (2006.01) *F28D 1/053* (2006.01)
F28F 1/32 (2006.01) *F24F 7/04* (2006.01)

(21) International Application Number:
PCT/SG2023/050695

(22) International Filing Date:
14 October 2023 (14.10.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10202251384B 14 October 2022 (14.10.2022) SG

(71) Applicant: **NATIONAL UNIVERSITY OF SINGAPORE** [SG/SG]; 21 Lower Kent Ridge Road, Singapore 119077 (SG).

(72) Inventors: **GUO, Shuai**; c/o National University of Singapore, College of Design and Engineering, Department of Mechanical Engineering, 21 Lower Kent Ridge Road, Singapore 119077 (SG). **CHENG, Kai Xian**; c/o National University of Singapore, College of Design and Engineering, Department of Mechanical Engineering, 21 Lower Kent Ridge Road, Singapore 119077 (SG). **LEE, Poh Seng**; c/o National University of Singapore, College of Design and Engineering, Department of Mechanical Engineering, 21 Lower Kent Ridge Road, Singapore 119077 (SG).

(74) Agent: **PINTAS-IPHOUSE PTE LTD**; 151, Chin Swee Road, # 12-14, Manhattan House, Singapore 169876 (SG).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,

(54) Title: AN APPARATUS, SYSTEM, AND METHOD FOR HEAT EXCHANGE

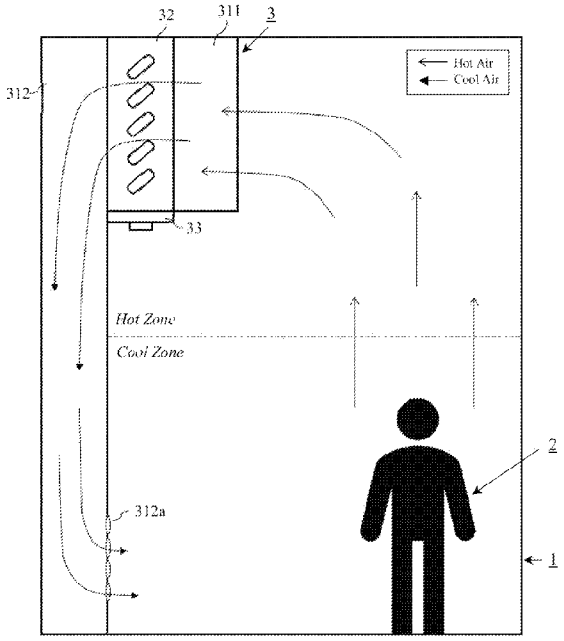


FIG. 1

(57) Abstract: This invention provides an apparatus for heat exchange comprising a plurality of fins, and a heat transfer coil in the form of a plurality of oblong sectional tubes being arranged in a single array. The fins are arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon. Furthermore, the oblong sectional tubes of the heat transfer coil each has a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and are operable to be installed with a tilt angle for them to be tilted with a major axis of the oblong sectional tube being in respect to a direction of the incoming convective fluid flowing through the heat transfer coil. A related system and method involving the apparatus are further described.

WO 2024/080937 A1

[Continued on next page]

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

AN APPARATUS, SYSTEM, AND METHOD FOR HEAT EXCHANGE

RELATED APPLICATION

[001] The present invention claims priority to Singapore patent application no. 10202251384B filed on 14 October 2022, the disclosure of which is incorporated in its entirety.

[002] The invention relates to heat exchange technologies for passive displacement cooling. More specifically, the invention relates to an apparatus for heat exchange suitable for passive displacement cooling, and its related system and method.

BACKGROUND OF THE INVENTION

[003] Passive displacement cooling involves leveraging natural convective air flows within an indoor or enclosed environment for cooling. Such cooling means may not require reliance on mechanically driven devices that constantly propel air currents within the indoor or enclosed environment. Hence, systems that perform passive displacement cooling are suited for on-demand and/or targeted cooling within the indoor or enclosed environment.

[004] However, widespread adoption of cooling means that perform passive displacement cooling remains to be seen as it has a slow response time and low cooling capacity due to reliance on natural convective air flows. Thus, a long duration of time is required to cool the indoor or enclosed environment.

[005] Moreover, current systems for heat exchange that perform passive displacement cooling include an apparatus for heat exchange for cooling air that is instead originally optimised for active cooling, and is to be operated in conjunction with mechanical fans to receive forced convective air flows. In other words, the usage of such an apparatus for heat exchange for cooling air is unsuitable for passive displacement cooling as passive displacement cooling demands different design parameters as cooling is done upon low-velocity air.

[006] Moreover, the fins utilised within current systems for heat exchange that perform passive displacement cooling have large areas that prove to be excessive for low-velocity

natural, passive convective flow, inducing unnecessary viscous forces to the flow without significant heat transfer downstream. The induced low mass flow rate coupled with the fully developed thermal boundary layer adversely affects the cooling capacity and response time. This further is compounded by the condensation under cooling conditions, where condensate retention increases flow resistance to the convective airflow.

[007] Among disclosed technologies over the prior art that may relate to an apparatus for heat exchange for passive displacement cooling include the disclosed work of Chen et al. (*Natural convection of plate finned tube heat exchangers with two horizontal tubes in a chimney: Experimental and numerical study*, 2019). Here, an apparatus for heat exchange implemented within a chimney was disclosed. This apparatus comprised a plate-finned heat transfer coil, with the coil being in the form of tubes having a circular cross-section.

[008] Yet another relevant disclosed technology over the prior art includes the disclosed work of Unger et al. (*Numerical optimization of a finned tube bundle heat exchanger arrangement for passive spent fuel pool cooling to ambient air*, 2020). Here, an apparatus for heat exchange for passive cooling of spent fuel assemblies was disclosed. This apparatus comprised a finned and bundled heat transfer coil, with the coil being in the form of tubes having various cross-sections arranged to be in an inline configuration or staggered configuration to cool fluid provided a vertical duct to a frontmost tube.

[009] However, the technologies of the afore-mentioned prior arts still face the above-mentioned issues as they perform passive displacement cooling. Accordingly, it is desirable to have an apparatus, system, and corresponding method for heat exchange that is suitable and optimized for natural convective air flows for passive displacement cooling, and further provides an improved response time and cooling capacity to cool the indoor or enclosed environment in a short duration of time.

SUMMARY OF INVENTION

[0010] The present invention is to provide an apparatus, system, and corresponding method for heat exchange that is suitable and optimized for natural convective air flows for passive displacement cooling. To achieve this objective, there is provided an apparatus for heat exchange being a finned heat transfer coil, with the coil being in the form of oblong sectional

tubes arranged to be in a single array, being either a single row or a single column. Each oblong sectional tube is to have a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and is tilted at an angle with respect to a convective airflow guided therethrough by the fins of the heat transfer coil.

[0011] Advantageously, the apparatus of the present invention provides reduced viscous forces. Hence, it has a higher mass flow rate and heat transfer rate than conventional configurations, while enabling an improved response time.

[0012] Advantageously as well, the apparatus of the present invention provides better condensation drainage due to the structure and configuration of the tubes. Hence, viscous effects due to water retention, especially on the fin surfaces, are reduced.

[0013] Advantageously as well, the apparatus of the present invention provides a more compact design for better adaptation to the space constraints and better aesthetics.

[0014] Advantageously as well, the apparatus of the present invention enables a reduction in the overall size of tubes of the heat transfer coil, thereby enabling lower material costs.

[0015] The present invention intends to provide an apparatus for heat exchange comprising a plurality of fins, and a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array. The fins are arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon.

[0016] Preferably, the oblong sectional tubes of the heat transfer coil each has a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

[0017] Preferably, the oblong sectional tubes of the heat transfer coil are operable to be installed with a tilt angle for them to be tilted with respect to a direction of the incoming convective fluid flowing through the heat transfer coil.

[0018] Preferably, the tilt angle ranges from substantially 0 degrees to 60 degrees.

[0019] Preferably, the oblong sectional tubes of the heat transfer coil are in aspect ratios ranging from substantially 2:1 to 5:1.

[0020] Preferably, the fins are each formed with a plurality of perforations to allow the oblong sectional tubes of the heating coil to pass therethrough.

[0021] The present invention further intends to provide a system for heat exchange comprising an apparatus for heat exchange that includes a plurality of fins and a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array, and a duct that accommodates the apparatus. The fins of the apparatus are arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon for outgoing convective fluid to flow into the duct.

[0022] Preferably, the oblong sectional tubes of the heat transfer coil of the apparatus each having a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

[0023] Preferably, the oblong sectional tubes of the heat transfer coil of the apparatus are operable to be installed with a tilt angle for them to be tilted with respect to a direction of the incoming convective fluid flowing over the heat transfer coil.

[0024] Preferably, the tilt angle of the tubes of the heat transfer coil ranges from substantially 0 degrees to 60 degrees.

[0025] Preferably, the oblong sectional tubes of the heat transfer coil of the apparatus are in aspect ratios ranging from substantially 2:1 to 5:1.

[0026] Preferably, the fins of the apparatus are each formed with a plurality of perforations to allow the oblong sectional tubes of the heating coil to pass therethrough.

[0027] Preferably, the system further comprises a pan disposed adjacently below the heat transfer coil to collect condensate formed on the apparatus.

[0028] Preferably, the duct includes a horizontal portion and a vertical portion which has a substantially right-angle bend in relation to each other.

[0029] Preferably, the apparatus is located within the horizontal portion of the duct while being adjacent to the vertical portion of the duct.

[0030] Preferably, the vertical portion of the duct has a length that extends from the vertical portion to a level that is below the horizontal portion.

[0031] The present invention also intends to provide a method for heat exchange, comprising the steps of configuring an apparatus for heat exchange to include a plurality of fins and a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array, and configuring a duct to accommodate the apparatus. The fins of the apparatus are each arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon for outgoing convective fluid to flow into the duct.

[0032] Preferably, the method further comprises the step of configuring the oblong sectional tubes of the heat transfer coil of the apparatus each having a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

[0033] Preferably, the method further comprises the step of orientating the oblong sectional tubes of the heat transfer coil of the apparatus to be at a tilt angle for them to be tilted with respect to a direction of the incoming convective fluid flowing over the heat transfer coil.

[0034] Preferably, the method further comprises the step of collecting condensate formed on the apparatus, by a pan that is disposed adjacently below the apparatus.

[0035] One skilled in the art will readily appreciate that the invention is well adapted to carry out the objects and obtain the ends and advantages mentioned, as well as those inherent therein. The embodiments described herein are not intended as limitations on the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] To facilitate an understanding of the invention, there is illustrated in the accompanying drawings the preferred embodiments from an inspection of which when considered in connection with the following description, the invention, its construction and operation and many of its advantages would be readily understood and appreciated.

[0037] FIG. 1 is a diagram illustrating a structure that includes at least one heat source and a system for heat exchange provided by the present invention that performs passive displacement cooling within the structure.

[0038] FIG. 2 illustrates a perspective sectional view of the system illustrated in **FIG. 1**.

[0039] FIG. 3 illustrates a perspective view of the apparatus for heat exchange provided by the present invention, which is within the system illustrated in **FIG. 1**.

[0040] FIG. 4 illustrates a sectional side view of portions of the system for heat exchange, which includes the apparatus for heat exchange in a first example configuration where the oblong sectional tubes of its heat transfer coil are arranged in a single array, the oblong sectional tube having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 0 degrees.

[0041] FIG. 5 illustrates a sectional side view of portions of the system for heat exchange, which includes the apparatus for heat exchange in a second example configuration where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 30 degrees.

[0042] FIG. 6 illustrates a sectional side view of portions of the system for heat exchange, which includes the apparatus for heat exchange in a third example configuration where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 45 degrees.

[0043] FIG. 7 illustrates a sectional side view of portions of the system for heat exchange, which includes the apparatus for heat exchange in a fourth example configuration where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 60 degrees.

[0044] FIG. 8 illustrates a graph of increment in sensible heat transfer against increment in mass flow rate for one or more simulated system models that pertain to systems of heat transfer.

[0045] FIG. 9 illustrates a sectional side view of a portion of a fin of the apparatus for heat exchange, which further illustrates simulated air temperature contours throughout a channel of the fin.

[0046] FIG. 10 illustrates a sectional side view of portions of a simulated first system model for heat exchange, which further illustrates its air temperature contours. The first system model includes an apparatus for heat exchange where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 0 degrees.

[0047] FIG. 11 illustrates a sectional side view of portions of a simulated second system model for heat exchange, which further illustrates its air temperature contours. The second system model includes an apparatus for heat exchange where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and are tilted at an angle of substantially 30 degrees.

[0048] FIG. 12 illustrates a sectional side view of portions of a simulated third system model for heat exchange, which further illustrates its air temperature contours. The third system model includes an apparatus for heat exchange where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-section, and are tilted at an angle of substantially 45 degrees.

[0049] FIG. 13 illustrates a sectional side view of portions of a simulated fourth system model for heat exchange, which further illustrates its air temperature contours. The fourth system model includes an apparatus for heat exchange where the oblong sectional tubes of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having

substantially rectangular cross-sections with round edges, or oval or elliptical cross-section, and are tilted at an angle of substantially 60 degrees.

[0050] FIG. 14 illustrates a sectional side view of portions of a simulated fifth system model for heat exchange, which further illustrates its air temperature contours. The fifth system model includes an apparatus for heat exchange where the tubes of its heat transfer coil are arranged in a single array, and have circular cross-sections.

[0051]FIG. 15 illustrates a sectional side view of portions of a simulated sixth system model for heat exchange, which further illustrates its air temperature contours. The sixth system model includes an apparatus for heat exchange where the tubes of its heat transfer coil are arranged in a two-row staggered configuration, and have circular cross-sections.

[0052] FIG. 16 illustrates a sectional side view of portions of a simulated seventh system model for heat exchange, which further illustrates its air temperature contours. The seventh system model includes an apparatus for heat exchange where the tubes of its heat transfer coil are arranged in a two-row inline configuration, and have circular cross-sections.

[0053] FIG. 17 illustrates a sectional side view of the simulated first system model for heat exchange, which further illustrates its velocity vectors.

[0054] FIG. 18 illustrates a sectional side view of portions of the simulated first system model for heat exchange, which further illustrates its velocity vectors.

[0055] FIG. 19 illustrates a sectional side view of portions of the simulated second system model for heat exchange, which further illustrates its velocity vectors.

[0056] FIG. 20 illustrates a sectional side view of portions of the simulated third system model for heat exchange, which further illustrates its velocity vectors.

[0057]FIG. 21 illustrates a sectional side view of portions of the simulated fourth system model for heat exchange, which further illustrates its velocity vectors.

[0058] FIG. 22 illustrates a sectional side view of portions of the simulated fifth system model for heat exchange, which further illustrates its velocity vectors.

DETAILED DESCRIPTION OF THE INVENTION

[0059] The present invention relates to an apparatus for heat exchange suitable for passive displacement cooling, and its related system and method. The invention may also be presented in a number of different embodiments with common elements.

[0060] According to the concept of the present invention, the apparatus for heat exchange comprises a heat transfer coil having a plurality of oblong sectional tubes, and a plurality of fins that are arranged along a longitudinal portion of the oblong sectional tubes wherein the oblong sectional tubes pass therethrough. The oblong sectional tubes are arranged to be in a single array. Preferably, each oblong sectional tube has a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and is laterally tilted at a tilt angle with respect to a convective airflow guided thereto by the fins. The aforementioned apparatus for heat exchange may be further implemented within a related system and method for heat exchange.

[0061] This invention will now be described in greater detail, by way of example, with reference to the figures. For ease of reference, common reference numerals or series of numerals will be used throughout the figures when referring to the same or similar features common to the figures.

[0062] FIG. 1 illustrates a structure **1** that includes at least one heat source **2** and an example system **3** for heat exchange that performs passive displacement cooling within the structure **1**. **FIG. 2** illustrates a perspective sectional view of the system **3** for heat exchange provided by the present invention.

[0063] The structure **1** is preferably an enclosed structure that substantially forms an indoor or enclosed environment. The enclosed structure **1** may be defined as having one or more walls, and it may be, by way of example, a room of a building. The structure **1** is further appropriately spaced so that convective fluid currents may form and flow therewithin.

[0064] The heat source **2** is preferably a living or non-living entity or occupant that may be within the structure **1**. In particular, the heat source **2** is a living entity or occupant that emits or dissipates heat as they perform bioactivities within the structure **1**. Alternatively, the heat source **2** is a non-living entity or occupant that emits or dissipates heat as it performs its intended functions.

[0065] The system **3** for heat exchange at least includes a duct having a horizontal portion **311** and a vertical portion **312**, an apparatus **32** for heat exchange, and a pan **33**. The system **3** facilitates a circulation of convective fluid currents within the structure **1** where the heat source **2** is located therein. In particular, the system **3** receives hot air as incoming convective fluid, cools it, and delivers cool air as outgoing convective fluid to the heat source **2**.

[0066] FIGS. 1 – 2 further illustrate that the horizontal portion **311** of the duct, the apparatus **32**, and a pan **33** are to be located at an elevated level within structure **1**, while the heat source **2** is located at a ground level within the structure **1** or a level that is below the elevated level. The vertical portion **312** of the duct is to extend from the elevated level to the ground level. Hence, it may be said that duct of the system **3** has an inverted L-shaped configuration, in which a substantially right angle is formed between its horizontal portion **311** and its vertical portion **312**.

[0067] FIGS. 1 – 2 further illustrate that the apparatus **32** is to be substantially accommodated within the horizontal portion **311** of the duct, and is to be disposed therewithin to be substantially adjacent and/or proximal to the vertical portion **312** of the duct. More specifically, the apparatus **32** is substantially adjacent and/or proximal to the right angle formed between the horizontal portion **311** and the vertical portion **312** of the duct. Such a configuration may prevent condensate formed on the apparatus **32** from entering the vertical portion **312** of the duct.

[0068] FIG. 1 further illustrates that the pan **33** is to be disposed below the apparatus **32**. The pan **33** is to collect and drain condensate formed and dripped from the apparatus **32** for it to be drained away for disposal or reuse.

[0069] FIG. 1 further illustrates the circulation of convective fluid currents within the structure **1**, with hot air and cool air being labelled accordingly. In particular, heat emitted

or dissipated by the heat source **2** shall heat its surrounding air, thereby creating hot air that is warmer and lighter. The hot air rises accordingly and enters the system **3** through an inlet of the horizontal portion **311** of the duct as incoming convective fluid. The hot air passes through the apparatus **32** for heat exchange to become cool air that is colder and denser. The cool air exits the apparatus **32** as outgoing convective fluid and goes towards the vertical portion **312** of the duct. The cool air may descend in a guided manner towards outlets **312a**, which are located at a similar level as the heat source **2**. With this, the duct may be said to supply cool air, and a cool air lake is formed near the ground level. As the cool air replaces the hot air, the circulation of convective fluid currents occurs. A cooling effect takes place due to the buoyancy force caused by the difference in air density. Thus, the heat source **2** at the ground level may experience cooling.

[0070] FIG. 3 illustrates a perspective view of an example apparatus **32** for heat exchange provided by the present invention, which may be a finned heat transfer coil. The apparatus comprises a plurality of fins **321** and at least one heat transfer coil having a plurality of oblong sectional tubes **322**, where the cross-section shape includes substantially rectangular cross-section with round edges, or oval or elliptical cross-section. The subsequent descriptions of **FIG. 3** are to be read with reference to the descriptions of **FIGS. 1 – 2**.

[0071] Preferably, the heat transfer coil is to perform cooling upon the received convective fluid. Hence, it may also be referred to as a "cooling coil".

[0072] The heat transfer coil may be configured to have its oblong sectional tubes **322** be either one of a single pass–multiple tube configuration, or a multiple pass–single tube configuration.

[0073] The fins **321** are preferably substantially planar or flat structures. Each fin **321** may include a longitudinal portion, which may correspond to its height axis. Each fin **321** may also include a lateral portion that is perpendicular to its longitudinal portion, which may correspond to its width axis.

[0074] The oblong sectional tubes **322** are preferably elongate structures that may have a substantially rectangular cross-section with round edges, or oval or elliptical cross-section. Each oblong sectional tube **322** may include a longitudinal portion, which oblong section has a width or major axis. Each oblong sectional tube **322** may also include a lateral portion

that is perpendicular to its longitudinal portion, which oblong section has a height or minor axis. Each oblong sectional tube **322** may be formed with its major:minor axes ratio having an aspect ratio of between substantially 2:1 to 5:1.

[0075] In particular, the fins **321** are arranged to be at right angles relative to the oblong sectional tubes **322**, and each of them has perforations to allow the longitudinal portions of the oblong sectional tubes **322** to pass therethrough.

[0076] In particular, the fins **321** may be horizontally distributed apart to be substantially equidistant with respect to each other along a longitudinal portion of the oblong sectional tubes **322**.

[0077] In particular, the fins **321** may be orientated along the longitudinal portions of the oblong sectional tubes **322** in such a way that their lateral portions are substantially perpendicular to the longitudinal portions of the oblong sectional tubes **322**.

[0078] In particular, the oblong sectional tubes **322** are arranged to be in a single array arrangement, and are vertically distributed along the height of the fins **321** to be substantially equidistant with respect to each other. For context, the term "single array" refers to a linear arrangement of items to form a single column or single row. Here, it is preferable that the oblong sectional tubes **322** are in a single array arrangement that allows all the oblong sectional tubes **322** to substantially receive conductive fluid in a simultaneous or near-simultaneous manner. Furthermore, with the oblong sectional tubes **322** being arranged to be in a single array arrangement along the height of the fins **321**, this arrangement may also be referred to as a "one-row" arrangement.

[0079] In particular, the oblong sectional tubes **322** are to have coolant flowing therewithin that flow across the longitudinal extent of the oblong sectional tubes **322**. One end of each oblong sectional tube **322** may receive chilled or room-temperature coolant, and another end of each tube may transfer away heated coolant. The coolant may be, by way of example, water, or any fluid with a substantial specific heat capacity.

[0080] In particular, the oblong sectional tubes **322** may be operable to be configured or installed with the major axis at an angle with respect to incoming convective fluid that is guided thereto by the fins **321**. This angle is henceforth referred to as "tilt angle". The tilt

angle may be between substantially 0 degrees and 60 degrees, but most preferably between 0 degrees and 30 degrees. Accordingly, the fins **321** have perforations that follow the tilt angle of the oblong sectional tubes **322**.

[0081] In another interpretation of the tilt angle, the tilt angle may be defined as an angle that is defined between the width axis of the fins **321** and the width/major axis of the oblong tubes **322**. Similarly, the tilt angle may be between substantially 0 degrees and 60 degrees, but most preferably 0 degrees and 30 degrees. Accordingly as well, the fins **321** have perforations that follow the tilt angle of the oblong sectional tubes **322**.

[0082] It is to be noted that the length axis, width axis, and height axis of the fins **321** and oblong sectional tubes **322** are intended to be referential and relative terms and are not intended to be interpreted to limit the fins **321** and oblong sectional tubes **322** in terms of their relation or orientation. Furthermore, the axes of the fins **321** and oblong sectional tubes **322** may also be expressed in any other geometrical systems, such as the Cartesian coordinate system, or the like.

[0083] In particular, a heat transfer coil with a plurality of oblong sectional tubes **322** having a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, may enable the fins **321** to be shorter in terms of their width, length, and/or height. Hence, the fins **321** may have a reduced surface area. Thus, its experienced viscous forces may be reduced.

[0084] In particular, a heat transfer coil with a plurality of oblong sectional tubes **322** that have a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and tilted at a tilt angle may be more aerodynamically streamlined and induce less air flow resistance, compared to a heat transfer coil with a plurality of tubes that have a circular cross-section.

[0085] In particular, a heat transfer coil with a plurality of oblong sectional tubes **322** that have a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and are tilted at a tilt angle helps in the removal of condensate formed thereon, which further reduces air flow resistance.

[0086] **FIG. 3** further illustrates interactions of apparatus **32** within system **3** for performing heat exchange.

[0087] A method for heat exchange may now be described. It is noted that the steps described for the method are to be interpreted as non-limiting, and minor modifications to the steps (e.g., combination, additions, omissions, or swaps) are permissible by a skilled person without substantial deviation from as described. Furthermore, all steps or some of the steps may occur in a simultaneous or non-simultaneous manner.

[0088] In a first step, the apparatus **32** is configured to have a plurality of fins **321** and a heat transfer coil in the form of a plurality of oblong sectional tubes **322** arranged in a single array. A duct is further configured to accommodate the apparatus **32** according to as previously described.

[0089] In a second step, the apparatus **32** is configured for each oblong sectional tube **322** of the heat transfer coil to have a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

[0090] In a third step, the oblong sectional tubes **322** of the heat transfer coil of the apparatus **32** are configured to be orientated at a tilt angle for them to be tilted with the major axis in respect to an intended direction of the incoming convective fluid flowing over the oblong sectional tubes **322** of the heat transfer coil. Preferably, the tilt angle is between substantially 0 degrees and 30 degrees.

[0091] In a fourth step, incoming convective fluid in the form of hot air is received from the inlet of the horizontal portion **311** of the duct and moves towards the apparatus **32**.

[0092] In a fifth step, the incoming convective fluid is then guided by the fins **321** of the apparatus **32** to flow through the apparatus **32**.

[0093] In a sixth step, the incoming convective fluid flowing through the apparatus **32** is met with resistance by the oblong sectional tubes **322**. The oblong sectional tubes **322**, which has coolant flowing therewithin, absorbs heat from the incoming convective fluid. Thus, heat is exchanged between the incoming convective fluid and the coolant flowing within the oblong sectional tubes **322**, with heat being transferred from the incoming convective fluid

and the coolant flowing within the oblong sectional tubes **322**. With this, the coolant becomes heated coolant. The heated coolant may exit the apparatus **32** to flow towards to a different heat exchange apparatus for heat dissipation.

[0094] In a seventh step, as heat is transferred from the convective fluid to the coolant, condensation occurs within the apparatus **32** with condensate in the form of water droplets being formed at either one or both the fins **321** and the oblong sectional tubes **322**.

[0095] With the fins **321** being configured to be perpendicular to the oblong sectional tubes **322**, the condensate formed thereon may naturally flow according to gravity, thereby dripping towards the pan **33**.

[0096] With the oblong sectional tubes **322** being preferably tilted at a tilt angle, the condensate formed thereon may naturally flow according to gravity according to the tilt angle of the oblong sectional tubes **322**, thereby dripping towards the pan **33**.

[0097] With this, heat has been transferred from the incoming convective fluid to the coolant, and the incoming convective fluid is cooled. Thus, the hot air has become cool air.

[0098] In an eighth step, the pan **33** collects condensate dripped from the apparatus **32** for it to be delivered away for disposal or reuse.

[0099] Finally, in a ninth step, the cool air exits the apparatus **32** as outgoing convective fluid that flows towards the vertical portion **312** of the duct, and subsequently descends to the ground level to reach the heat source **2**.

[00100] FIGS. 4 – 7 illustrate one or more example configurations of the apparatus **32** for heat exchange within the system **3** for heat exchange.

[00101] FIG. 4 illustrates a sectional side view of portions of the system **3** for heat exchange, which includes the apparatus **32** for heat exchange in a first example configuration where the oblong sectional tubes **322** of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and have a tilt angle of substantially 0 degrees.

[00102] FIG. 5 illustrates a sectional side view of portions of the system **3** for heat exchange, which includes the apparatus **32** for heat exchange in a second example configuration where the oblong sectional tubes **322** of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and have a tilt angle of substantially 30 degrees.

[00103] FIG. 6 illustrates a sectional side view of portions of the system **3** for heat exchange, which includes the apparatus **32** for heat exchange in a third example configuration where the oblong sectional tubes **322** of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and have a tilt angle of substantially 45 degrees.

[00104] FIG. 7 illustrates a sectional side view of portions of the system **3** for heat exchange, which includes the apparatus **32** for heat exchange in a fourth example configuration where the oblong sectional tubes **322** of its heat transfer coil are arranged in a single array, with the oblong sectional tubes having substantially rectangular cross-sections with round edges, or oval or elliptical cross-sections, and have a tilt angle of substantially 60 degrees.

[00105] From hereon, evaluations that were carried out to validate the performance of the support structure will be described. It is to be noted that parameters defined or determined in these evaluations are not meant to be interpreted as limitations to the scope of the present invention.

[00106] One or more system models were created and numerically analysed using commercially available software, which may be, by way of example, Ansys Fluent™. In particular, each system model was created to be substantially similar to the sectional view of the system **3** for heat exchange as illustrated in **FIG. 2**.

[00107] In total, seven system models were made, and simulations were performed upon them.

[00108] The system models include a first system model based on the first example configuration shown in **FIG. 4** that is referred to as “one-row flat”, a second system model based on the second example configuration shown in **FIG. 5** that is referred to as “one-row

flat 30 degrees", a third system model that is based on the third example configuration shown in **FIG. 6** that is referred to as "one-row flat 45 degrees", and a fourth system model that is based on the fourth example configuration shown in **FIG. 7** that is referred to as "one-row flat 60 degrees".

[00109] Further included are a fifth model that is configured to have one-row tubes with a circular cross-section that is referred to as "one-row circular", a sixth model that is configured to have two-row staggered tubes with a circular cross-section that is referred to as "two-rows circular (staggered)", and a seventh model that is configured to have two-row inline tubes with a circular cross-section that is referred to as "two-rows circular (inline)".

[00110] For the evaluations, the influence of each system model's configuration on their mass flow rate and cooling capacity was investigated. Furthermore, their velocity vectors and their airflow temperature contours were evaluated.

[00111] In particular, for the evaluations, the tubes of the heat transfer coil of the first model, the second model, the third model and the fourth model, were made to have a tube sectional axis aspect ratio of substantially 3:1.

[00112] In particular, for the evaluations, the fin length and tube spacing of all system models were made to be in accordance with standard heat transfer coil dimensions known in the art.

[00113] In particular, for the evaluations, the tubes of the heat transfer coil of all system models were all made to have a heat transfer area of the same.

[00114] In particular, for the evaluations, the air temperature received by the simulated inlet of the duct of all system models was made to be constant.

[00115] In particular, for the evaluations, all system models were made for their ducts to have the vertical portion having a height of substantially 800 mm and gap of substantially 100 mm.

[00116] In particular, for the evaluations, all system models were made for their ducts to have the horizontal portion having an inlet that has a width of substantially 100 mm.

[00117] In particular, for the evaluations, all system models may be made to have their heat transfer coil have a height of substantially 305 mm.

[00118] In particular, for the evaluations, the tubes of the heat transfer coil of all system models were made to have a length of substantially 50 inches (or 127 cm) or a collective length of substantially 50 inches (or 127 cm).

[00119] In particular, for the evaluations, the fins for all system models were made to have a density of substantially 10 FPI (fins per inch) and a channel gap of substantially 1.27 mm.

[00120] A simulation for half-fin channel was performed upon all seven system models, and their results are shown in Table 1 below.

[00121] A graph of increment in sensible heat transfer against increment in mass flow rate, was made based on the results shown in Table 1, and is illustrated in **FIG. 8**.

[00122] It is to be noted that the sixth system model was taken as a baseline for its comparison with all other system models.

Model No.	**Type**	**Mass Flow Rate, $\dot{m}$ (kg/s)**	**Average temperature decrease, ΔT (K)**	**Sensible Heat Transfer, Q_a (W)**	**Mass flow increment**	**Sensible heat transfer increment**
1	One-row flat	0.083	15.7	1316.5	36.1%	26.1%
2	One-row flat 30 degrees	0.082	15.7	1302.9	34.4%	24.8%
3	One-row flat 45 degrees	0.080	15.7	1273.1	31.1%	21.9%
4	One-row flat 60 degrees	0.078	15.7	1231.4	27.9%	17.9%
5	One-row circular	0.079	15.7	1252.9	29.5%	20.0%
6	*Two-row circular (staggered)*	*0.061*	*16.9*	*1044.1*	-	-
7	Two-row circular (inline)	0.061	16.9	1045.2	0.02%	0.11%

Table 1

[00123] As shown in Table 1, the results indicate that for systems models having coils with flat tubes with rectangular cross-sections and round edges (i.e. the first system model to the fourth system model), the first system model has the highest mass flow rate $\dot{m}$ and sensible

heat transfer $\boldsymbol{Q_a}$, and the second system model has the second highest mass flow rate $\dot{\boldsymbol{m}}$ and sensible heat transfer $\boldsymbol{Q_a}$.

[00124] As shown in Table 1, the results indicate that systems models having coils with tubes that are of a single array "one-row" (i.e., the first system model to the fifth system model) have better mass flow rate $\dot{\boldsymbol{m}}$ and cooling capacity compared to systems models having coils with tubes that are of a multi array "two-row" (i.e., the sixth system model and the seventh system model).

[00125] As shown in Table 1, when comparing between the sixth system model and the first system model, the first model has a substantial increase of 36.1% in its mass flow rate $\dot{\boldsymbol{m}}$ compared to the sixth system model, from substantially 0.061 kg/s to substantially 0.083 kg/s. Furthermore, the first system model has a substantial increase of 26.1% in its sensible heat transfer $\boldsymbol{Q_a}$, from substantially 1044.1 W to substantially 1316.5 W.

[00126] As shown in Table 1, when comparing between the sixth system model and the second system model, the second model has substantial increase of 34.4% in its mass flow rate $\dot{\boldsymbol{m}}$ compared to the sixth system model, from substantially 0.061 kg/s to substantially 0.082 kg/s. Furthermore, the second system model has a substantial increase in its sensible heat transfer $\boldsymbol{Q_a}$, from substantially 1044.1 W to substantially 1302.9 W.

[00127] Hence, it is evident that improvement in the performance of the apparatus for heat exchange, by having it configured according to the first system model or the second system model, are attributed to factors that include (i) a reduction of viscous force derived from the shorter fin length/width/height and a reduced row length/width/height, and (ii) the flat tubes having a more streamlined design compared to circular tubes.

[00128] As shown in **FIG. 9**, the thermal boundary layers within the fin merge before leaving the narrow fin spacing. This phenomenon implies that the after-coil temperatures are similar for all design configurations, which can be observed from the Average Temperature Decrease, $\Delta \boldsymbol{T}$, in Table 1.

[00129] FIGS. 10 – 16 illustrate the temperature contour simulations of all seven system models. Unlike the forced convective flow that has a constant mass flow rate, natural convective flow has a mass flow rate that requires consideration of multiple parameters.

[00130] In particular, the mass flow rate induced by the tubes of the heat transfer coil is a balance between (i) the buoyancy forces derived from the temperature difference, and (ii) the viscous forces between the fluid-solid interface. The buoyancy forces derived from the temperature difference may relate to the variation of density with temperature, which may be obtained from the momentum equation that is coupled with energy equation in natural convection and Boussinesq approximation.

[00131] As shown in Table 1, when comparing systems models having coils with tubes that are of a single array "one-row" (i.e., the first system model to the fifth system model) and systems models having coils with tubes that are of a multi array "two-row" (i.e., the sixth system model and the seventh system model), those of the former has a lower Average Temperature Decrease, ΔT. This is because there is a bypass at the top and bottom of the tubes of the heat transfer coil as observed from **FIGS. 10 – 14**.

[00132] However, the Average Temperature Decrease, ΔT, within systems models having coils with tubes that are of a single array "one-row" (i.e., the first system model to the fifth system model) is not high enough to cause a significant difference in density to overcome the additional viscous force incurred by the longer flow path within systems models having coils with tubes that are of a multi array "two-row" (i.e., the sixth system model and the seventh system model).

[00133] Hence, systems models having coils with tubes that are of a single array "one-row" (i.e., the first system model to the fifth system model) yield higher mass flow rate. Their decrease in heat transfer area is compensated by the higher heat transfer coefficient with higher mass flow rate.

[00134] FIGS. 17 – 22 illustrate the velocity vector simulations of the first system model to the fifth system model, which are all systems models having coils with tubes that are of a single array "one-row".

[00135] As shown in **FIGS. 18 – 22** the first system model to the fourth system model incurs less blockage to the convective fluid flow as its coils with flat tubes with rectangular cross-sections and round edges enable a more streamlined airflow as compared to tubes with circular cross-sections.

[00136] However, as shown in **FIGS. 18 – 22**, as the tilt angle becomes larger, the frontal area of the tubes becomes larger, hence there is more blockage to the received incoming convective fluid. With reference to Table 1, the mass flow rate of the third system model is very close to that of the fifth system model, and the fourth system model incurs a lower mass flow rate than the fifth system model.

[00137] Whilst the first system model may yield the best results from simulation, a tilt angle is best introduced in consideration that the heat transfer coil will become wet due to the formation of condensate during heat transfer. Under these wet conditions, the retention and drainage behaviours of the condensate are dominated by the forces acting on their bodies including the surface tension, and flow drag caused by air velocity and gravity. Condensate retention affects the thermal–hydraulic performance of the heat exchange, and influences the quality of the outgoing convective fluid (cool air) and the comfort within the structure.

[00138] Hence, in consideration of real-world conditions, the second system model is most ideal as its tubes are with a tilt angle while having a performance that is close to the first system model. This enables the second system model to improve the drainage of the condensate since gravity compels it to drip away from the tube due to the introduced tilt. Furthermore, due to the tube having a substantially rectangular cross-section with round edges, the condensate may smoothly drip away. Furthermore as well, a better condensate drainage reduces the viscous forces on convective fluid flow, and improves its latent load removal, thereby compensating for the effects of reduced heat transfer area.

[00139] With this, the apparatus of the present invention, together with its related system and method, provides a substantial improvement in heat exchange for passive displacement cooling, while enabling an improved response time and cooling capacity to cool an indoor or enclosed environment in a short duration of time. The heat transfer coil having oblong sectional tubes that are of a substantially rectangular cross-section with round edges, or oval or elliptical cross-section, and are configured at a tilt angle, as provided by the present invention, enhances the mass flow rate, thereby providing improved response time and sensible cooling capacity.

[00140] The present invention is further validated for usage in green buildings that perform passive displacement cooling since the present invention has resolved major obstacles to its

widespread adoption. Moreover, the heat transfer coil of a reduced size enables a reduction of material costs in construction of the green buildings. Thus, passive cooling with zero air distribution energy may be provided to the green buildings for energy savings as the need for mechanical fans is eliminated.

[00141] The present disclosure includes as contained in the appended claims, as well as that of the foregoing description. Although this invention has been described in its preferred form with a degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangements of parts may be resorted to without departing from the scope of the present invention.

CLAIMS

1. An apparatus for heat exchange comprising

a plurality of fins; and

a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array;

wherein the fins are each arranged along a longitudinal portion of the oblong sectional tubes perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon.

2. The apparatus according to claim 1, wherein the oblong sectional tubes of the heat transfer coil each has a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

3. The apparatus according to claim 1 or 2, wherein the oblong sectional tubes of the heat transfer coil are operable to be installed with a tilt angle for a major axis of the oblong sectional tube to be tilted with respect to a direction of the incoming convective fluid flowing through the heat transfer coil.

4. The apparatus according to claim 3, wherein the tilt angle ranges from substantially 0 degrees to 60 degrees.

5. The apparatus according to any one of the preceding claims, wherein the oblong sectional tubes of the heat transfer coil are in aspect ratios ranging from substantially 2:1 to 5:1.

6. The apparatus according to any one of the preceding claims, wherein the fins are each formed with a plurality of perforations to allow the oblong sectional tubes of the heating coil to pass therethrough.

7. A system for heat exchange comprising:

an apparatus for heat exchange that comprises:

a plurality of fins; and

a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array;

and

a duct that accommodates the apparatus;

wherein the fins of the apparatus are each arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon for outgoing convective fluid to flow into the duct.

8. The system according to claim 7, wherein the oblong sectional tubes of the heat transfer coil of the apparatus each has a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

9. The system according to claim 7 or 8, wherein the oblong sectional tubes of the heat transfer coil of the apparatus are operable to be installed with a tilt angle for a major axis of the oblong sectional tubes to be tilted with respect to a direction of the incoming convective fluid flowing over the heat transfer coil.

10. The system according to claim 9, wherein the tilt angle ranges from substantially 0 degrees to 60 degrees.

11. The system according to any one of claims 7 to 10, wherein the oblong sectional tubes of the heat transfer coil of the apparatus are in aspect ratios ranging from substantially 2:1 to 5:1.

12. The system according to any one of claims 7 to 11, wherein the fins of the apparatus are each formed with a plurality of perforations to allow the oblong sectional tubes of the heating coil to pass therethrough.

13. The system according to any one of claims 7 to 12, further comprising a pan disposed adjacently below the heat transfer coil to collect condensate formed on the apparatus.

14. The system according to any one of claims 7 to 13, wherein the duct comprises a horizontal portion and a vertical portion which has a substantially right-angle bend in relation to each other.

15. The system according to claim 14, wherein the apparatus is located within the horizontal portion of the duct while being adjacent to the vertical portion of the duct.

16. The system according to claim 14 or 15, wherein the vertical portion of the duct has a length that extends from the vertical portion to a level that is below the horizontal portion.

17. A method for heat exchange, comprising the steps of:

configuring an apparatus for heat exchange to comprise:

a plurality of fins; and

a heat transfer coil in the form of a plurality of oblong sectional tubes arranged in a single array;

and

configuring a duct to accommodate the apparatus;

wherein the fins of the apparatus are each arranged along a longitudinal portion of the oblong sectional tubes substantially perpendicularly for guiding incoming convective fluid towards all the oblong sectional tubes for heat exchange to be performed thereupon for outgoing convective fluid to flow into the duct.

18. The method according to claim 17, further comprising the step of configuring the oblong sectional tubes of the heat transfer coil of the apparatus each having a substantially rectangular cross-section with round edges, or oval or elliptical cross-section.

19. The method according to claim 17 or 18, further comprising the step of orientating the oblong sectional tubes of the heat transfer coil of the apparatus to be at a tilt angle for a major axis of the oblong sectional tubes to be tilted with respect to a direction of the incoming convective fluid flowing over the heat transfer coil.

20. The method according to any one of claims 17 to 19, further comprising the step of collecting condensate formed on the apparatus, by a pan that is disposed adjacently below the apparatus.

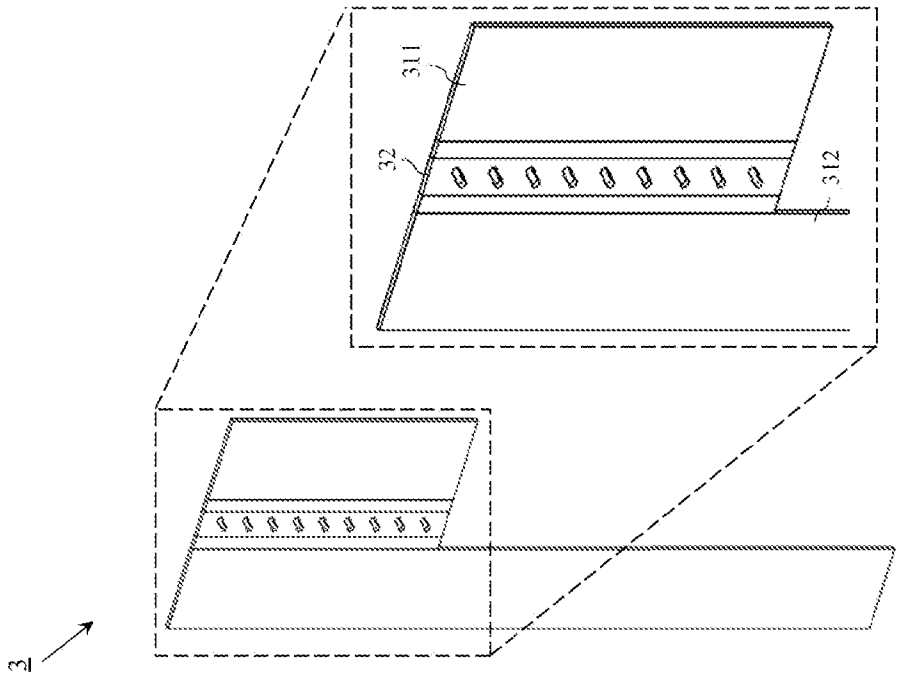

311
32
312
3

FIG. 2

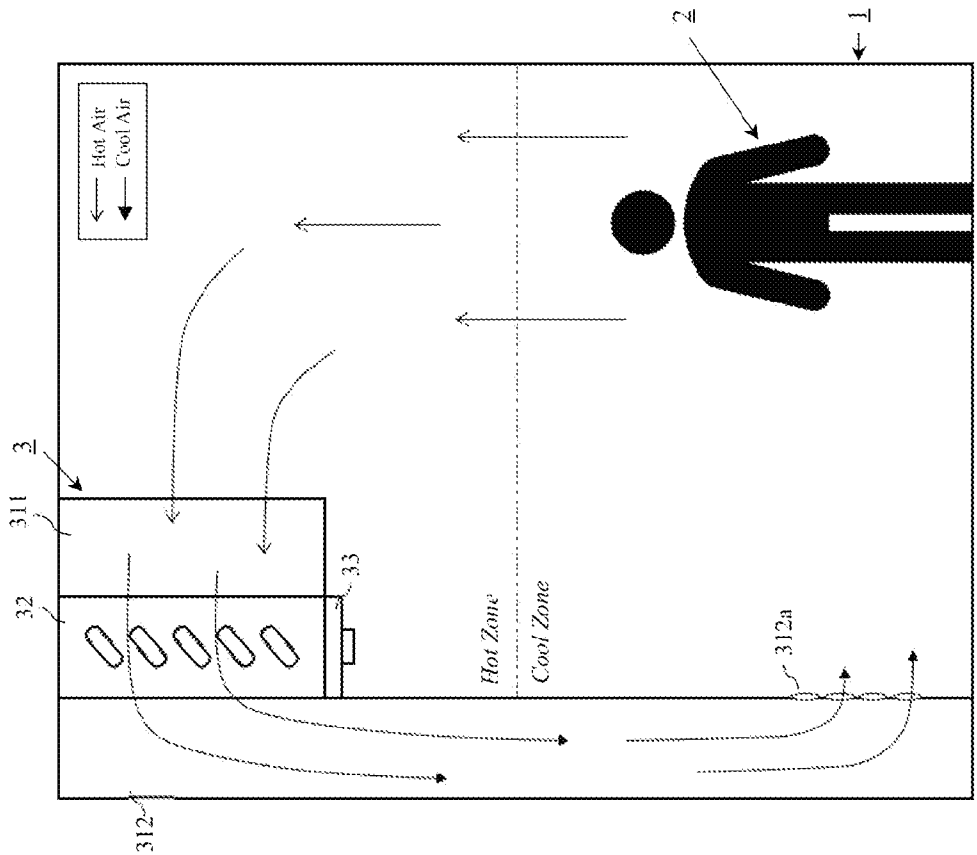

2
1
Hot Air
Cool Air
3
311
32
33
Hot Zone
Cool Zone
312a
312

FIG. 1

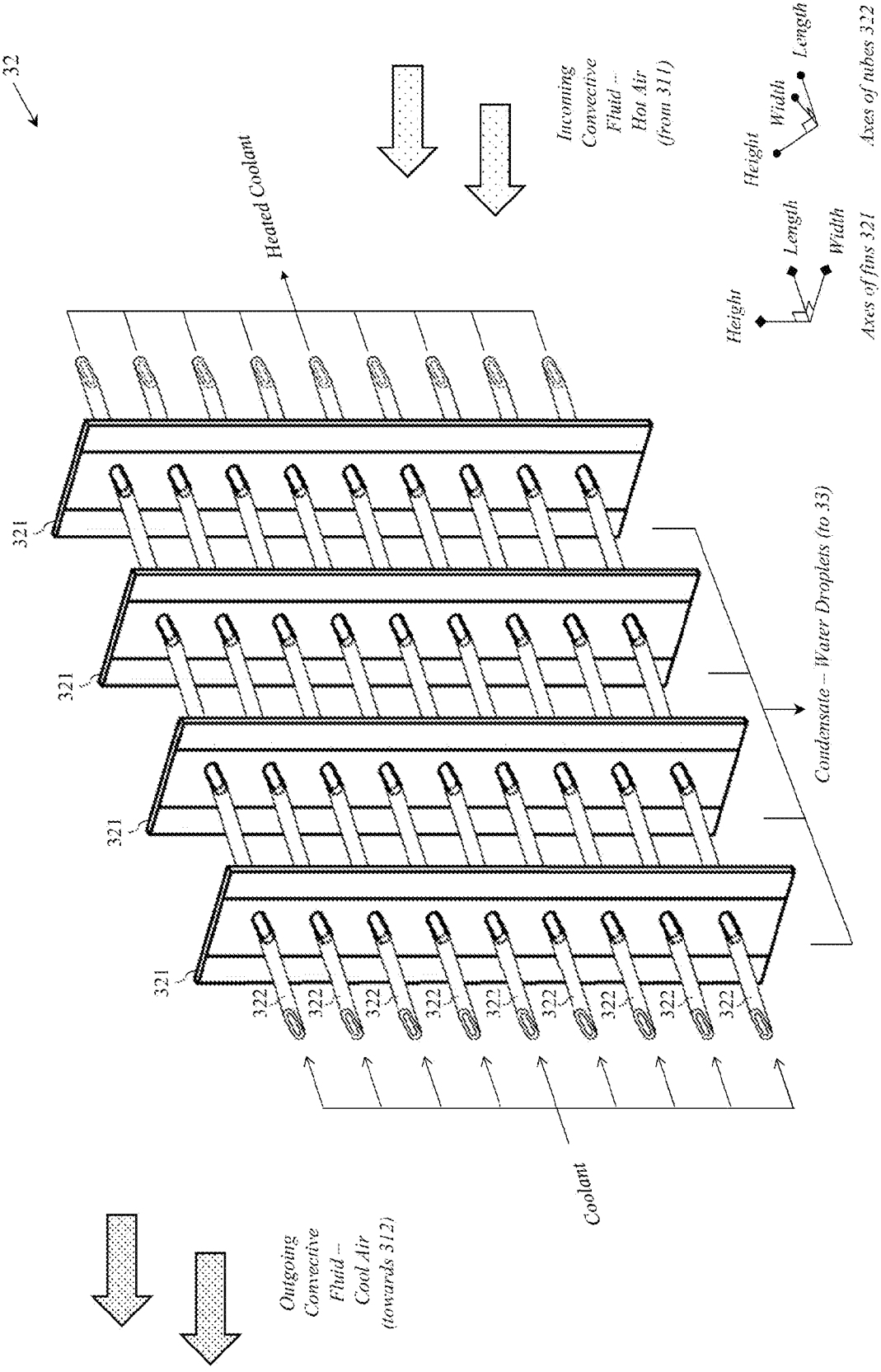

32
Heated Coolant
Incoming Convective Fluid – Hot Air (from 311)
Height
Width
Length
Axes of tubes 322
Height
Length
Width
Axes of fins 321
321
321
321
321
322
322
322
322
322
322
322
322
322
Condensate – Water Droplets (to 33)
Coolant
Outgoing Convective Fluid – Cool Air (towards 312)

FIG. 3

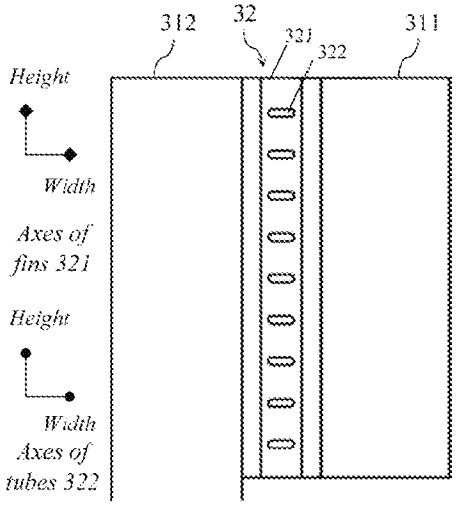


FIG. 4

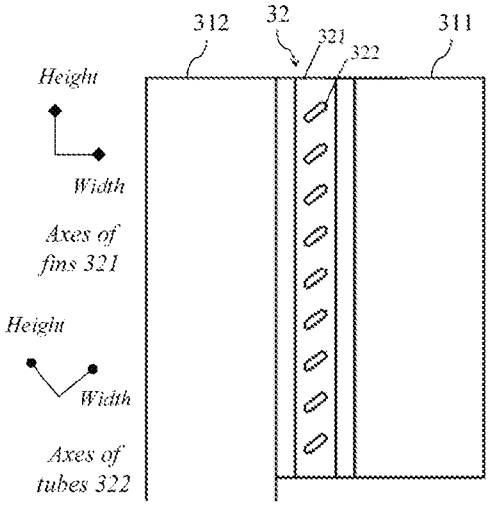


FIG. 5

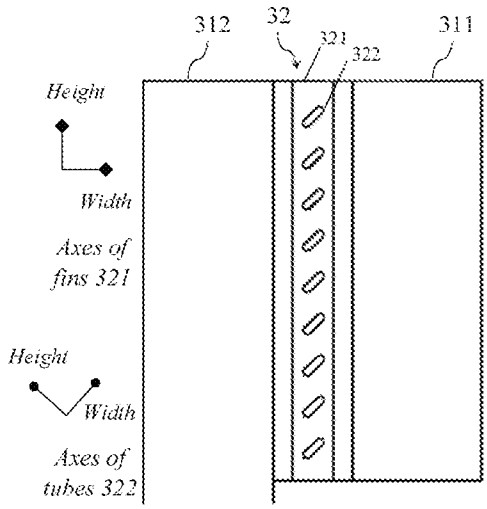


FIG. 6

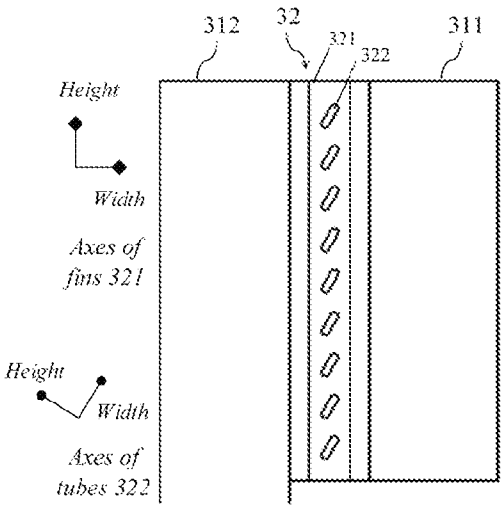


FIG. 7

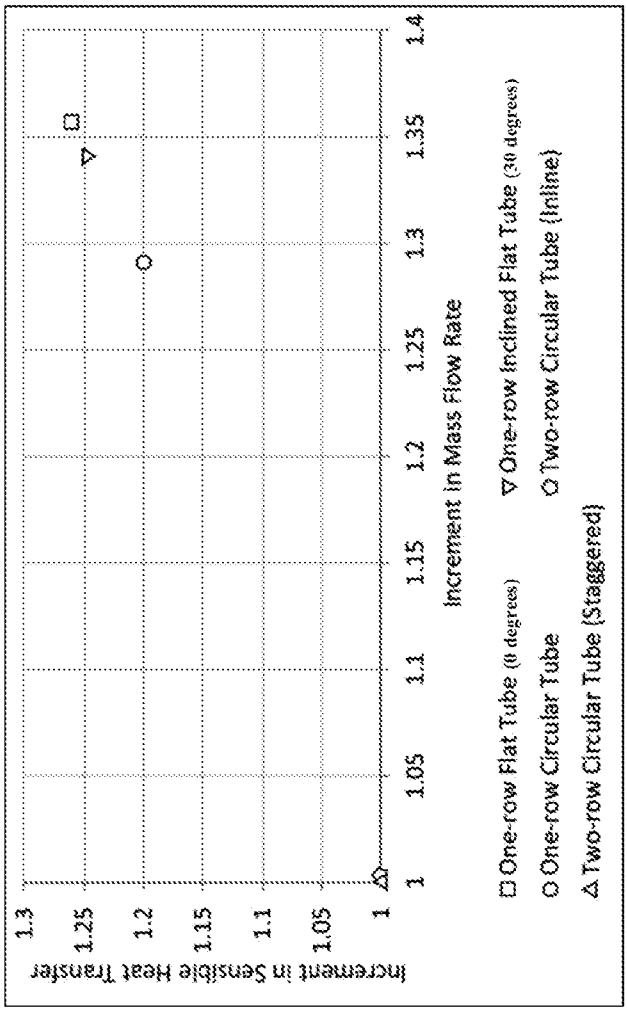

Increment in Sensible Heat Transfer
1.3
1.25
1.2
1.15
1.1
1.05
1
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
Increment in Mass Flow Rate
□ One-row Flat Tube (0 degrees)
▽ One-row Inclined Flat Tube (30 degrees)
○ One-row Circular Tube
○ Two-row Circular Tube (Inline)
△ Two-row Circular Tube (Staggered)

FIG. 8

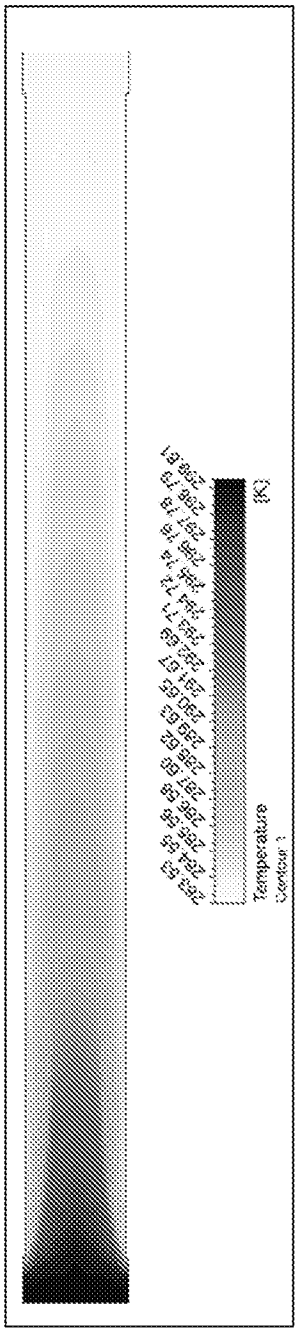

Temperature
Contour 1
[K]

FIG. 9

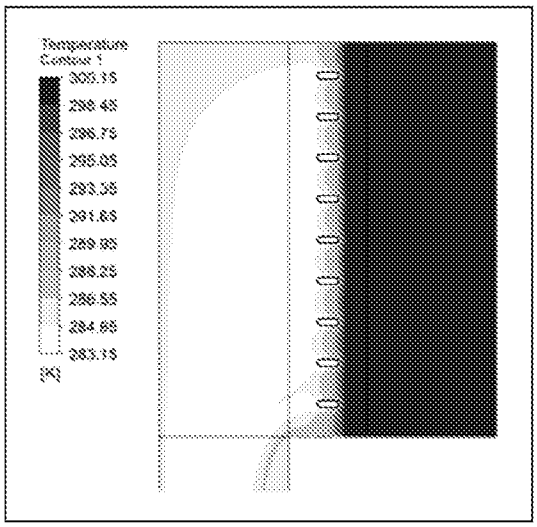


FIG. 10

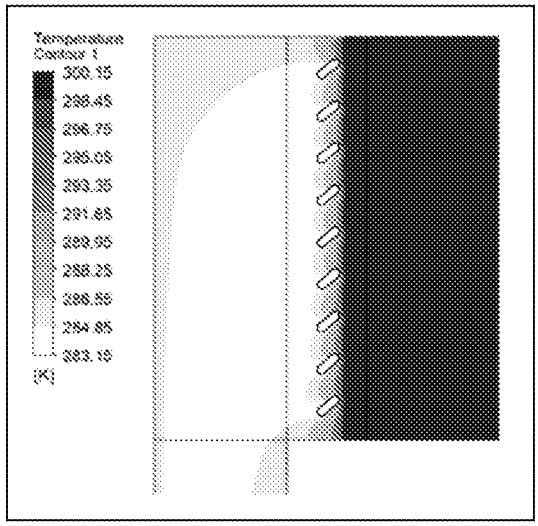


FIG. 11

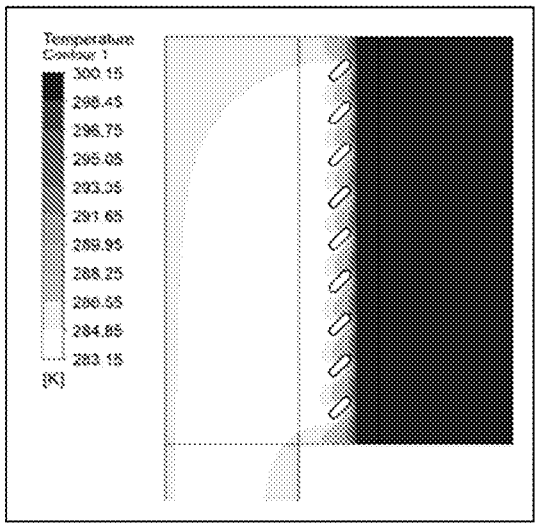


FIG. 12

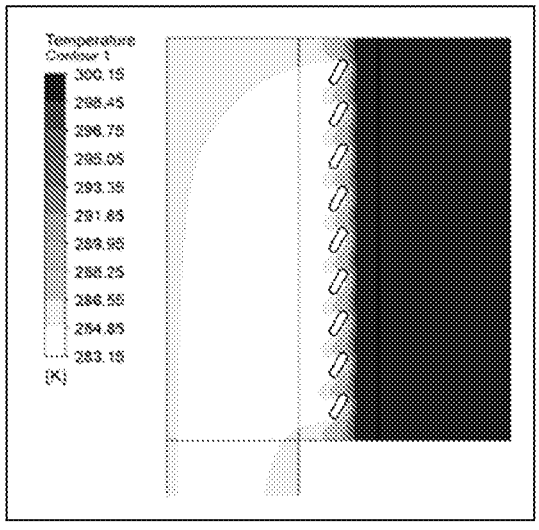


FIG. 13

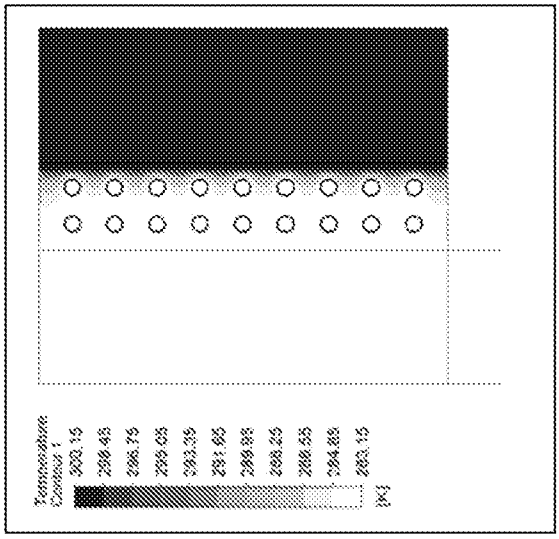


FIG. 16

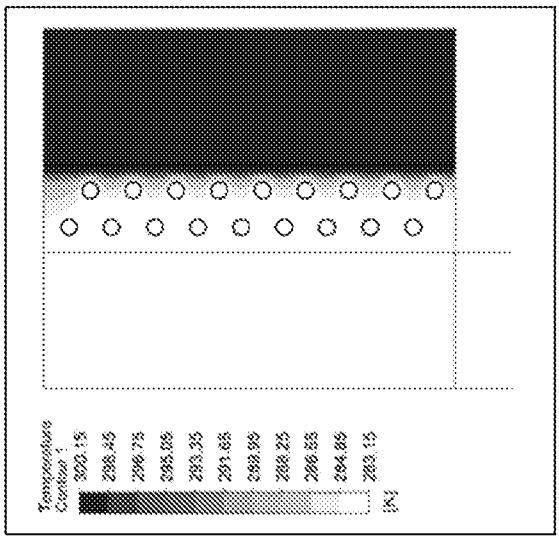


FIG. 15

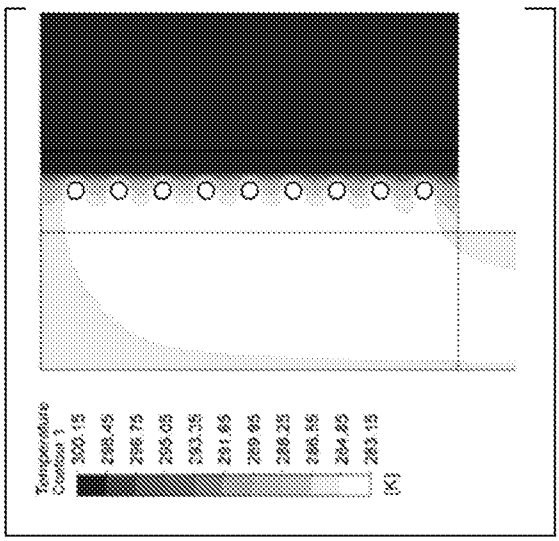


FIG. 14

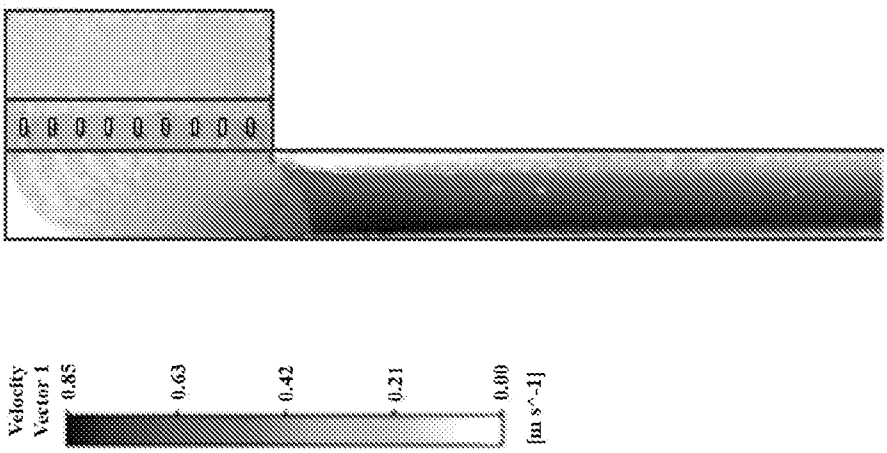


FIG. 17

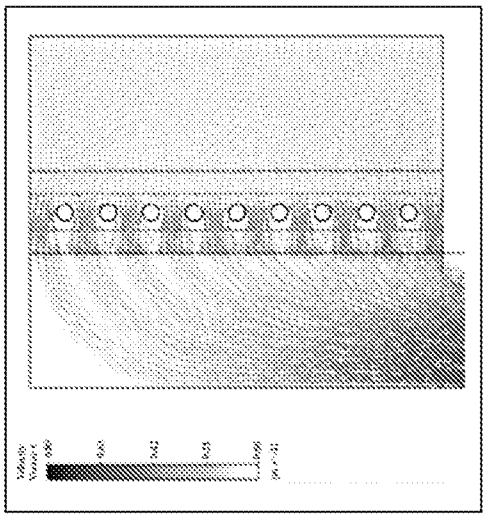


FIG. 22

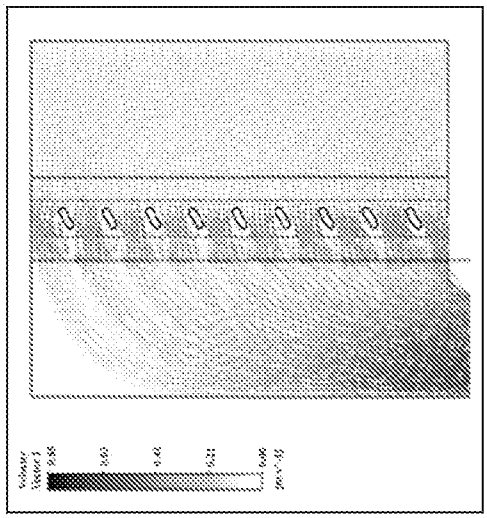


FIG. 19

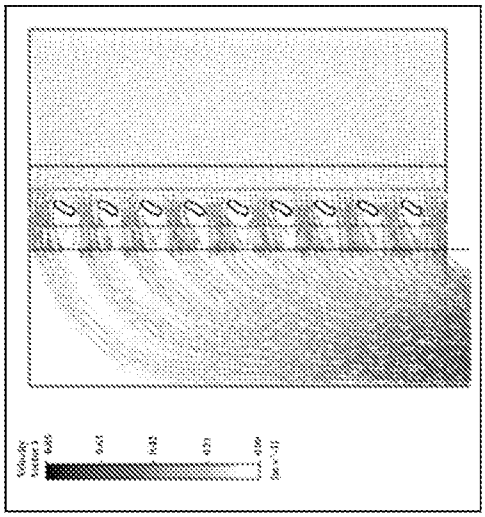


FIG. 21

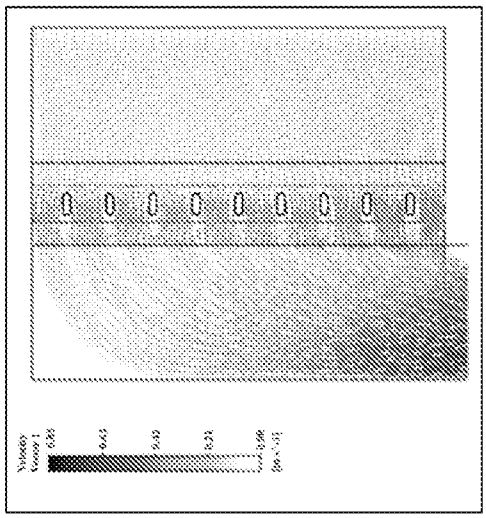


FIG. 18

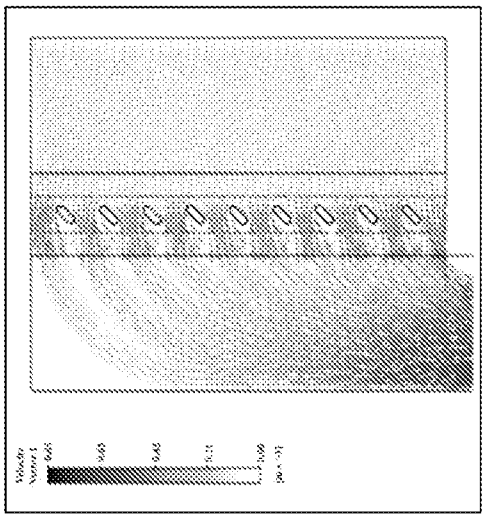


FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2023/050695

A. CLASSIFICATION OF SUBJECT MATTER

F28F 1/02 (2006.01) ***F28F 1/32 (2006.01)*** ***F28D 1/053 (2006.01)*** *F24F 7/04 (2006.01)*

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F28F, F28D, F24F

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

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

FamPat: heat exchanger, tube, fin, tilt, inclined, angled, displacement cooling, ventilation and related terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP H05-079654 A (SHARP KK AND TOYO RADIATOR CO LTD) 30 March 1993 Figures 1-4; paragraphs [0021]-[0024], [0027] and [0031]-[0035] of the machine translation.	1-13, 17-20 14-16
X	EP 3561430 A2 (PANASONIC INTELLECTUAL PROPERTY MANAGEMENT CO., LTD.) 30 October 2019 Figures 1 and 2; paragraphs [0027], [0028] and [0031].	1-6
X	US 2021/0239409 A1 (YATSUYANAGI, A. ET AL.) 5 August 2021 Figures 1, 3 and 12; paragraphs [0029] and [0050]-[0051].	1-6

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02/01/2024 *(day/month/year)*	09/01/2024 *(day/month/year)*

Name and mailing address of the ISA/SG	Authorized officer
Intellectual Property Office of Singapore 1 Paya Lebar Link, #11-03 PLQ 1, Paya Lebar Quarter Singapore 408533 Email: pct@ipos.gov.sg	Pan Shanshan (Ms) IPOS Customer Service Tel. No.: (+65) 6339 8616

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2023/050695

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2008-002746 A (UMETSU, K.) 10 January 2008 Figures 1-3; paragraphs [0069]-[0071] of the machine translation.	1-6
Y	CN 109990414 A (CAI, W. ET AL.) 9 July 2019 Figures 1 and 7; abstract; paragraphs [0004]-[0007], [0053] and [0065]-[0066] of the machine translation.	14-16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2023/050695

Note: This Annex lists known patent family members relating to the patent documents cited in this International Search Report. This Authority is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP H05-079654 A	30/03/1993	NONE	
EP 3561430 A2	30/10/2019	CN 110398163 A JP 2019190727 A	01/11/2019 31/10/2019
US 2021/0239409 A1	05/08/2021	EP 3809086 A1 WO 2019/239520 A1 CN 112204331 A AU 2018427607 A1 SG 11202010610Y A	21/04/2021 19/12/2019 08/01/2021 17/12/2020 27/11/2020
JP 2008-002746 A	10/01/2008	NONE	
CN 109990414 A	09/07/2019	NONE	