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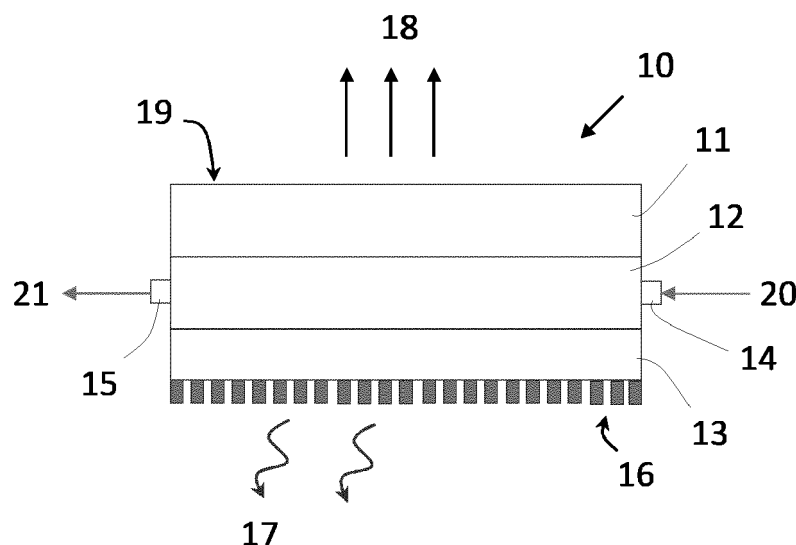
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(54) COOLING PANEL SUITABLE FOR USE IN A REFRIGERATION SYSTEM

(57) A cooling panel, particularly for cooling a condenser of a refrigeration system, the panel comprising a stack of a reflector top layer; a heat exchange layer; a hygroscopic evaporative bottom layer, wherein the reflector layer provides a radiative cooling of the heat

exchange layer, and the evaporative layer provides evaporative cooling of said heat exchange layer, said heat exchange layer being internally traversed by a heat exchange medium.

**Fig. 1**

Description

Field of application

[0001] The present invention relates to a cooling panel suitable for use in a refrigeration system, particularly for air conditioning.

Prior art

[0002] Refrigeration and air conditioning (AC) systems use most commonly a vapor-compression (VC) cycle wherein a suitable refrigerant in a closed loop is evaporated at a low pressure, to provide a net refrigeration effect, and subsequently condensed at a higher pressure. A key factor for the efficiency of such systems is the condensation temperature, therefore the cooling of the condenser.

[0003] There is a strong incentive to provide efficient AC systems. Space cooling is the fastest growing end-use of energy in the building sector. At the current pace, the global cooling energy demand is projected to triple by 2050, also representing a large and growing share of the peak electricity load. This puts enormous strains on electricity systems and poses a challenge in the context of climate change. The increasing cooling demand must be met the cooling sustainably with reduced carbon emissions.

[0004] Most condensers in current AC systems are air cooled or evaporative condensers. Air-cooled condensers are simple and require little maintenance, however they are large and offer a relatively high condensation temperature which result in low cycle efficiency and more power consumption. Evaporative condensers transfer the heat of condensation to another fluid which is typically water, they provide a lower condensation temperature compared to air-cooled units, however they require water which should be periodically replenished and maintained to avoid contamination.

[0005] An emerging technology is radiative cooling. Radiative coolers reflect sunlight while leveraging thermal radiation to transfer energy to the ambient. This technology is interesting in that it does not require cooling water, but the cooling power density of current radiative coolers is limited.

[0006] WO 2023/076435 discloses a hybrid evaporative and radiative cooling panel. This hybrid technology is promising but still has some challenges: solar absorption in the evaporative materials decreasing the cooling power and small water usage still needed for operation.

Summary of the invention

[0007] The invention aims to further improve the hybrid technology of evaporative and radiative cooling panels.

[0008] This aim is reached with a cooling panel according to claim 1. The cooling panel comprises a reflector top layer, a heat exchange layer, and a hygroscopic evapora-

tive bottom layer. Said layers form a stack, where the heat exchange layer is located in the stack between the reflector top layer and the evaporative bottom layer, and the heat exchange layer is thermally coupled with the reflector layer and the evaporative layer.

[0009] The heat exchange layer includes an input connection for a heat exchange medium, an output connection for said medium, and an internal path for said medium from the input connection to the output connection. Said internal path is entirely within the heat exchange layer, namely the path of the cooling medium does not traverse the top layer or the bottom layer. Accordingly, the cooling medium is not in fluidic connection with either the top layer nor to the bottom layer.

[0010] The panel of the invention can be used for cooling the condenser of a refrigeration system or AC system, wherein the intermediate heat exchange layer removes heat from a heat exchange medium of the condenser, for example water in a closed loop.

[0011] Said heat exchange layer transfers heat to the top layer and bottom layer, to which it is thermally coupled. Hence the heat removed from the condenser, by means of said heat exchange medium passing through the heat exchange layer, is discharged to the ambient partly via radiative cooling provided by the top layer and partly via evaporative cooling provided by the bottom layer.

[0012] A noticeable advantage of the invention is that the evaporative heat transfer path and the radiative heat transfer path are separated and do not interfere with each other. Particularly, the solar heating of the evaporative layer is greatly reduced or virtually eliminated. The net cooling power is significantly increased. A panel according to the invention can achieve a high cooling power such as, for example, a peak power around 600 W/m² assuming ambient temperature of 25-30 °C, compared to known panels limited to a power of not more than 150 W/m² and/or consuming a considerable amount of water.

[0013] The invention decouples the radiative layer from the evaporative layer, as they are not in direct physical contact with each other. Accordingly, the problem of avoiding interference between the evaporative cooling and radiative cooling is solved. The processes of radiative and evaporative cooling are exploited efficiently to cool the medium in the heat exchanger layer.

[0014] An interesting feature of the invention is that the evaporative layer is shielded from solar heating while the evaporation/vapor absorption path is unobstructed.

[0015] In interesting embodiments, the evaporative layer has an area-enhanced structure with a high surface/volume ratio. Accordingly, the invention combines passive radiative cooling and area-enhanced evaporative cooling. A remarkable feature of the evaporative layer is the ability to replenish the water content by sorption of water from humid air. Accordingly, the use of the panel may include periods of active cooling alternate to period for regeneration of the evaporative layer. A very interesting application is air conditioning of buildings

where active cooling is performed during the day and regeneration of the evaporative layer is performed during the night.

Description of the invention

[0016] The reflector layer is suitable to reflect solar radiation and to emit infrared radiation providing a radiative cooling of the heat exchange layer. The reflector layer (top layer) may include reflector film for LCD backlights, such as enhanced specular reflector films available from 3M, or equivalent. Another interesting embodiment is the use of radiative cooling paints.

[0017] The evaporative layer is suitable to capture water from ambient air (humid air) by a sorption process and to provide evaporative cooling of said heat exchange layer by desorption of water stored in the layer.

[0018] The evaporative layer includes a hygroscopic material which is preferably a hygroscopic salt. In a preferred embodiment, said evaporative layer includes a hydrogel to support the hygroscopic material. In a very interesting embodiment, said hydrogel has a structure obtained by additive manufacturing. Preferably, said hydrogel is a photopolymerizable hygroscopic salt-containing hydrogel and said structure is obtained by vat photopolymerization additive manufacturing. In a particularly preferred embodiment, said hydrogel is selected from polyacrylamide, polyacrylic acid and poly (ethylene glycol). The above materials are given as nonlimiting examples and a skilled person understands that other suitable polymers may be used for the making of the hydrogel.

[0019] The additive manufacturing (AM) technique is used to provide a structure with a large surface/volume ratio, thus highly effective in the process of evaporative cooling. An example of a structure obtainable by additive manufacturing and suitable for the bottom layer of the inventive panel is a micro-trees structure including dendritic (tree-like) projections where the hydrogel is deposited. Other suitable structures are those used for battery cathodes, drug release tablets and heat exchangers.

[0020] Structures obtained by AM can be named area-enhanced architected hygroscopic hydrogels. Said hydrogels combine a high evaporative cooling power with the ability to capture a large amount of water (water capacity). This is a major improvement over the conventional hydrogels where the performance is dictated by thickness. In the prior art, thin hydrogel films have larger surface-area to volume ratios and thus allow for high evaporation rates, but their total cooling capacities are limited by the low water mass that can be retained by the layer. In contrast, thickening the hydrogel increases the water mass per area but results in slower evaporation rates due to the reduced surface-area to volume ratio. In preferred embodiments of the invention, AM-made 3D architecture is used to obtain materials with both large water capacities and high surface-area to volume ratios.

[0021] Other processes suitable to realize a hydrogel

with enhanced surface/volume ratio include but are not limited to: polymerization-induced phase separation (PIPS), vapor-induced phase separation (VIPS), thermal induced phase separation (TIPS), phase separation, the use of porogens that are removed post-polymerization, solvent casting/particle leaching, gas foaming, emulsion templating, electrospinning, freeze casting (also known as ice templating).

[0022] The hydrogel may include structural features adapted to increase a contact surface with ambient air. Said structural features increase the contact area between air and hydrogel and may be in the form of extended and/or internally architected structures. The provision of such features facilitates the exchange (capture and release) of water vapor with air. Accordingly, the evaporative effect and regeneration of hydrogel are enhanced.

[0023] The term "architected structure" is used to denote a structure of the material with customized properties given by the geometry. An architected structure is obtainable, for example, with additive manufacturing or other processes mentioned above. In preferred embodiments of the invention, the hydrogel layer is architected to increase the contact area between air and hydrogel when air pass through the structure.

[0024] In an embodiment, the structure of hydrogel includes a base portion and an extension portion extending from the base portion. The base portion faces the heat exchange layer on one side and, on the other side, supports the extension portion. Preferably the hydrogel is continuous in the base portion and includes openings in the extension portion to facilitate the circulation of air within the hydrogel structure. Preferably, the thickness of said base portion is smaller than the thickness of said extension portion.

[0025] In an embodiment, the extension portion includes a plurality of elements, each element being separate from other elements, preferably a width of said elements decreasing when a distance from the base portions increases.

[0026] As mentioned above, the structure of the inventive panel provides shielding of the hydrogel layer from solar heating, so that the solar radiation does not affect the exchange of water vapor and related function of evaporative cooling.

[0027] The hydrogel material is preferably selected from polyacrylamide, polyacrylic acid and poly (ethylene glycol).

[0028] Preferably, the heat exchange layer is directly in physical contact with the top layer and with the bottom layer, for instance through one or more surfaces(s) thereof, so that heat can also be transferred by conduction between the layers.

[0029] A further aspect of the invention is a refrigeration system according to the claims.

[0030] The refrigeration system includes a working fluid which is evaporated and condensed in a loop, to provide a net refrigeration, wherein the condensation of

said working fluid is performed in a condenser and heat of condensation of said working fluid is transferred to a cooling medium. The system includes at least one panel as described above, wherein an output line of the cooling medium from the condenser is connected to the fluid inlet connection of the heat exchange layer of the panel, and the fluid outlet connection of said heat exchange layer is connected to a line feeding the cooling medium back to the condenser. Preferably the refrigeration system is part of an air conditioning system.

[0031] In a preferred application, the top layer of the panel is sky-facing to facilitate the radiative cooling.

[0032] A further aspect of the invention is a method of refrigeration performed with the inventive panel. The method may include steps of: a working fluid is evaporated and condensed in a cycle to provide a net refrigeration, heat of condensation of said working fluid is transferred to a cooling medium, the cooling medium is cooled by passage through the internal path of the heat exchange layer of at least one panel according to the invention as above described.

[0033] An interesting feature of the invention is the ability of the panel to regenerate the evaporative layer, by sorption of water from humid air. A panel according to the invention may operate according to an active cooling phase and a regeneration phase, wherein: during the active cooling phase the heat exchange layer is cooled by radiative cooling provided by the top layer and by evaporative cooling provided by the bottom layer; during the regeneration phase the bottom layer captures water from air (sorption). It can be said the panel of the invention performs a self-charging evaporative-radiative cooling.

[0034] Preferably, a method according to the invention includes that the active cooling phase is performed during the day and the regenerative phase is performed at night. During day-time operation, the water in the hydrogel will evaporate to provide cooling to the exchanger layer in the middle; at night, leveraging the lower ambient temperature and the typically higher relative humidity of air, the hydrogel will spontaneously capture water from the air due to the water affinity of the hygroscopic salts and replenish the water capacity.

[0035] A further application of the invention concerns the retrofitting of a refrigeration system, wherein the refrigeration system includes a condenser for condensation of a refrigerant fluid, the procedure includes the provision of at least one panel according to the invention, as herein described, for cooling said condenser.

Description of the figures

[0036] The invention is now elucidated with the help of the figures wherein:

Fig. 1 illustrates a panel according to an embodiment of the invention in the active cooling phase,

Fig. 2 illustrates the panel of Fig. 1 during regenera-

tion of the evaporative layer,

Fig. 3 illustrates a refrigeration system according to an embodiment of the invention,

Fig. 4 illustrates a rooftop application of panels of the invention.

[0037] Fig. 1 illustrates a cooling panel 10 including a reflector top layer 11, a heat exchange layer 12, a hygroscopic evaporative bottom layer 13. The heat exchange layer 12 has an inlet 14 and an outlet 15 for a heat exchange medium. The bottom layer 13 has an area-enhanced structure 16 supporting a hydrogel for sorption of water from ambient air.

[0038] The heat exchange layer 12 contains a path from the inlet 14 to the outlet 15, which may be a straight path or more elaborate, which is entirely within the layer 12.

[0039] It should be noted that the thickness of layers in Fig. 1 is not in scale, for example the top layer 11 may be a thin solar-reflecting layer or coating.

[0040] The arrows 17 in Fig. 1 denotes evaporative cooling whereas the arrow 18 denotes IR radiation of the top layer 11. Said top layer 11 is sky facing so that the upper surface 19 can emit IR radiation to the outer environment.

[0041] Fig. 1 illustrates active cooling operation (e.g. daytime operation) wherein a fluid 20 enters the heat exchange layer 12 at inlet 14 and leaves as cooled stream 21 from the outlet 15. Said fluid 20 can be a condenser cooling fluid, as illustrated in Fig. 3. The fluid 20 is cooled by a combination of evaporative cooling and radiative cooling.

[0042] Fig. 2 illustrates the panel 10 during regeneration of the evaporative layer 13 (e.g. during night time). The top layer 11 still emits IR radiation 18, whereas the bottom layer 13 in this phase captures water W from ambient air. The water content in the layer, particularly in the hydrogel supported by the structure 16, is replenished during this stage.

[0043] Fig. 3 illustrates the connection of the panel 10 to a vapor compression system. The main items of the VC system are shown: evaporator EV, compressor C, condenser COND, lamination valve LV. The operation of the VC system is known and not described in detail. The VC system uses a refrigerant which is evaporated and condensed in a closed loop. After evaporation, the compressed vapor 30 is sent to the condenser where it returns in a liquid state of stream 31, then the liquid is depressurized to the evaporation pressure by the lamination valve. The heat of condensation of the vapor 30 is transferred in the condenser to the fluid 20, which in turn is cooled in the panel 10 to provide the necessary heat dwell for the condenser.

[0044] Fig. 4 illustrates a rooftop application whereas a panel 10 or an array of panels is supported on a structure 40. Illustrated are also inlet line 20 and output line 21 of

the heat exchange fluid which is fed to, and collected from, the layer 12 of the panel 10. A plurality of panels 10 can be arranged in series or in parallel to cover a large surface. According to embodiments of the invention, a plurality of panels 10 can be connected in series or in parallel to form a module, and modules can be connected in series or in parallel to form a larger array.

Claims

1. A cooling panel comprising:

- a) a reflector top layer;
 - b) a heat exchange layer;
 - c) a hygroscopic evaporative bottom layer;
- wherein said layers form a stack, where the heat exchange layer is located in the stack between the reflector top layer and the evaporative bottom layer, and the heat exchange layer is thermally coupled with the reflector layer and the evaporative layer;
- the reflector layer (a) is suitable to reflect solar radiation and to emit infrared radiation providing a radiative cooling of the heat exchange layer, and the evaporative layer (c) is suitable to capture water from humid ambient air by sorption, and to provide evaporative cooling of said heat exchange layer,
- said heat exchange layer (b) includes an input connection for a heat exchange medium, an output connection for said medium, and an internal path for said medium from the input connection to the output connection, said internal path being entirely within the heat exchange layer.

2. A panel according to claim 1 wherein the evaporative layer (c) includes a hygroscopic material, preferably a hygroscopic salt.

3. A panel according to claim 2 wherein the evaporative layer (c) includes a hydrogel to support the hygroscopic material.

4. A panel according to claim 3 wherein the hydrogel has a structure obtained by any of: additive manufacturing (AM), polymerization-induced phase separation (PIPS), vapor-induced phase separation (VIPS), phase separation, the use of porogens that are removed after polymerization, solvent casting/-particle leaching, gas foaming, emulsion templating, electrospinning, freeze casting.

5. A panel according to claim 4 wherein the structure of hydrogel includes a structure to increase a surface of contact between the hydrogel and ambient air.

6. A panel according to claim 5 wherein the evaporative

layer includes a base portion and an extension portion extending from the base portion, the base portion faces the heat exchange layer on one side and, on the other side, supports the extension portion, wherein the hydrogel is continuous in the base portion and includes openings in the extension portion.

7. A panel according to claim 6 wherein a thickness of the base portion is less than a thickness of the extension portion.

8. A panel according to any of claims 3 to 7 wherein the hydrogel is a photopolymerizable hygroscopic salt-containing hydrogel and said structure is obtained by vat photopolymerization additive manufacturing.

9. A panel according to any of the previous claims, wherein the heat exchange layer is directly in contact with the top layer and with the bottom layer.

10. A refrigeration system including a working fluid which is cyclically evaporated and condensed to provide a net refrigeration, wherein the working fluid is condensed in a condenser and heat of condensation of said working fluid is transferred to a cooling medium, wherein:

the system includes at least one panel according to any of the previous claims;

an output line of the cooling medium from the condenser is connected to said input connection of the heat exchange layer of the panel, and the output connection of said heat exchange layer is connected to a line feeding the cooling medium back to the condenser.

11. A refrigeration system according to claim 10 wherein the at least one panel is sky-facing and the evaporative layer is exposed to ambient air.

12. A refrigeration system according to claim 10 or 11 wherein the refrigeration system is part of an air conditioning system.

13. A method of refrigeration including: a working fluid is evaporated and condensed in a cycle to provide a net refrigeration, wherein heat of condensation of said working fluid is transferred to a cooling medium, wherein the cooling medium is cooled by passage through the internal path of the heat exchange layer of at least one panel according to any of claims 1 to 9.

14. A method according to claim 13 wherein the operation of the at least one panel includes active cooling phase and a regeneration phase, wherein: during the active cooling phase the heat exchange layer is cooled by radiative cooling provided by the top layer and by evaporative cooling provided by the bottom

layer; during the regeneration phase the bottom layer captures water from air.

15. A procedure for revamping a refrigeration system, wherein the refrigeration system includes a condenser for condensation of a refrigerant fluid, the procedure includes the provision of at least one panel according to any of claims 1 to 9 for cooling said condenser.

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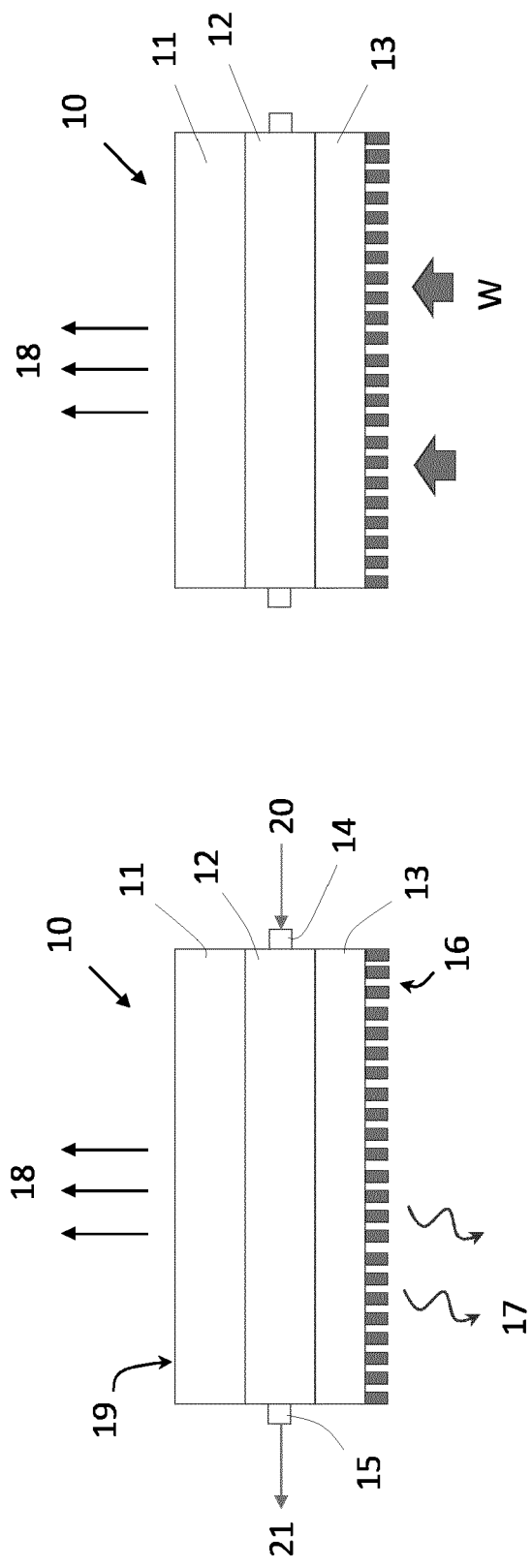


Fig. 2

Fig. 1

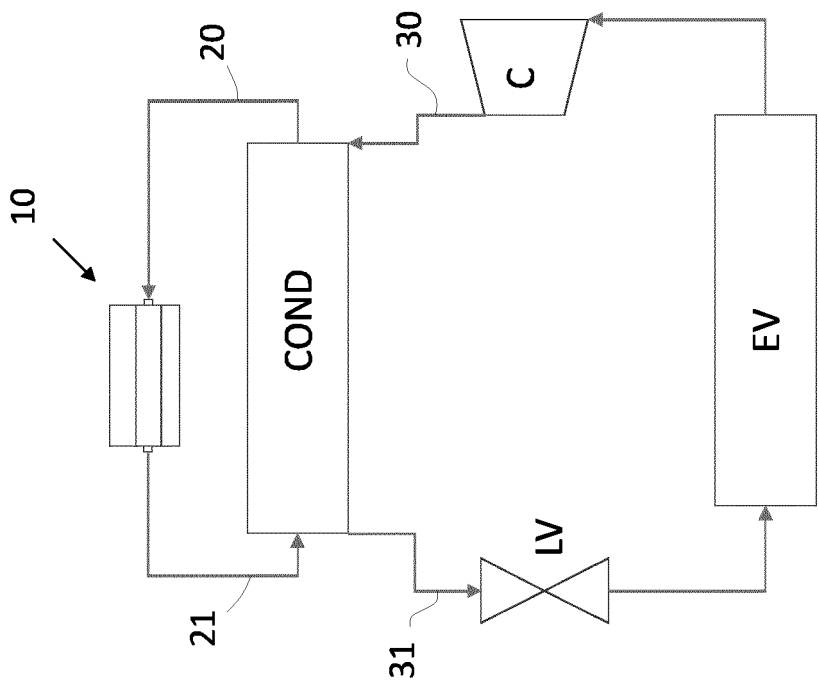


Fig. 3

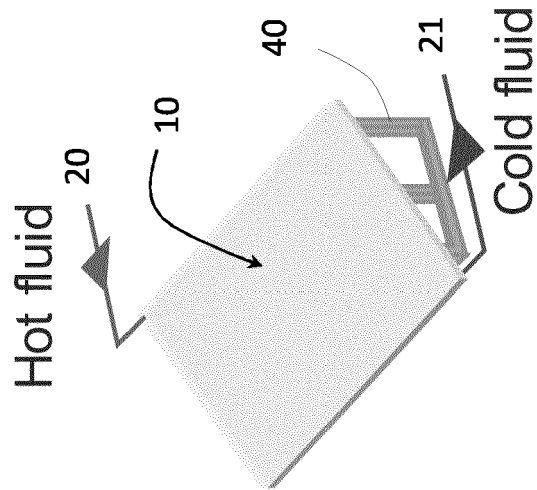


Fig. 4



EUROPEAN SEARCH REPORT

Application Number

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 24 April 2024	Examiner Degen, Marcello
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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REFERENCES CITED IN THE DESCRIPTION

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