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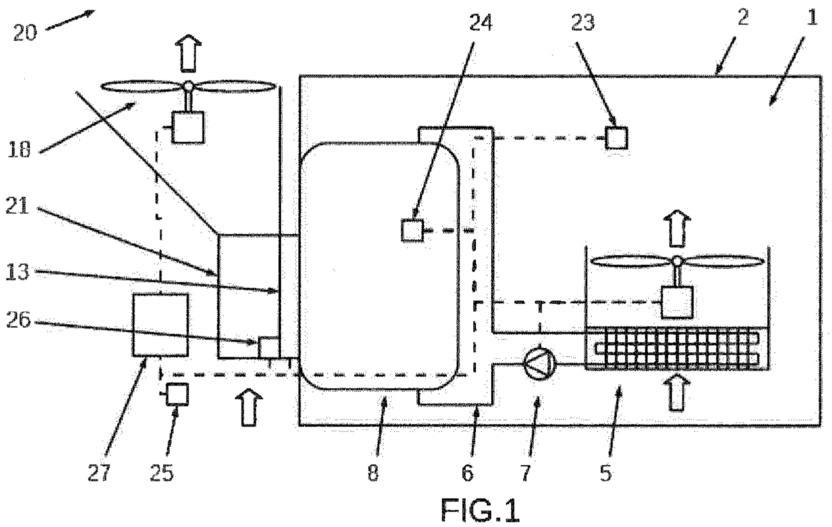

FIG.1

(57) Abstract: A heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature T\ inside (1) a room, the device comprising the device comprising at least one first means for heat distribution (5), a first liquid circuit (6) connected to said at least one first means for heat distribution (5), a first liquid transfer pump (7), at least one means for heat exchange (13) connected to a heat buffer (8). Said heat buffer (8) is liquidly connected to said at least one first means for heat distribution (5), and configured to comprise at least a part of said first liquid, wherein said heat buffer (8) is designed in accordance with Q_b = mbcpb (T_i - $7b^{opt}$), and derived in accordance with Formula (I) wherein P_{tot} is the total power required to operate said first liquid transfer pump (7), said at least one first means for heat distribution (5) and said at least one means for heat exchange (13). Thus, the heat pump device allows to condition the temperature inside a room in an energy efficient way.

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Heat pump device

Description

[Technical field]

The present invention relates to a heat pump device, and the use of the device, for conditioning the temperature inside a room.

[Background Art]

Rooms or containers comprising temperature sensitive contents, such as cargo containers comprising goods or server rooms comprising devices, are required to be thermal conditioned, i.e. the temperature inside these rooms has to be maintained within a given temperature range. Thermal conditioning is also advised for living/business rooms in order to, for example, maintain suitable humidity in all parts of a building and to free the air from excessive humidity during certain seasons. Fluctuations in time of the average interior temperature of rooms might be caused by several factors, for example (i) cavities in the housing of the room such as air gaps, doors, windows, etc., (ii) by the thermal properties of the material the housing of the room is made of, and/or (iii) the thermal leakage through insulation, all of which result in a natural heat exchange between ambient fluid, in particular air, and interior fluid, in particular air, resulting in a temperature rise or drop inside the room. On the other hand, temperature fluctuations may also be caused by processes inside a room which have a higher heat generating rate than the heat exchanging rate between the fluid contained in the room and the ambient fluid.

These temperature fluctuations might influence, besides others, the quality of the room content. In order to provide at least some limiting degree of protection, rooms are preferably conventionally equipped with state-of-the-art refrigeration units installed to control the interior fluid, in particular air, temperature. Most of these refrigeration units are vapor-compression refrigeration systems in which a refrigerant undergoes phase changes to cool the interior of the room. The cooled air is distributed using a blowing means, typically a fan. Typical power sources for the refrigeration system are diesel engines, diesel generators or external AC power, configured to continuously provide power to the refrigeration systems.

Exemplary of such apparatus include those disclosed in the published PCT application WO 2013/187997 A1, which is a refrigerated room including a room and a refrigeration unit. A plurality of refrigerant tubes are in fluid communication with the refrigeration unit and extend along a roof of the room. The plurality of refrigeration tubes are configured to convey refrigerant there through and cool an interior of the room via natural convection and thermal radiation. The method of cooling a cargo in a room disclosed in WO'997 includes flowing a refrigerant through a plurality of refrigerant tubes disposed at a roof of the room. Thermal energy is transferred from the air in the container to the refrigerant thereby cooling the container air. The container air is circulated via natural convection toward the cargo thereby cooling the cargo via thermal energy transfer to the container air. The container air is recirculated toward the plurality of refrigerant tubes. Another example of a system for conditioning is disclosed in the published PCT application WO2013/169874in particular Fig. 9a of the application. A drawback of these apparatus is that it does not provide an energy and cost efficient solution when thermal conditioning is required by boosting, i.e. a forced fast cooling or heating of the room in order to set the temperature within a predefined temperature range over a short time interval.

Boosting is appropriated after for example (un)loading operations during which the interior fluid, in particular air, and ambient fluid, in particular air, are (almost) in thermic equilibrium as a result of heat exchange via at least one means for (un)loading the container, for example a door. As a consequence of this fast heating or cooling, content will be transported or stored under similar conditions as those reached in warehouses. Hence, thermal boosting using this apparatus is costly and occupies a lot of room space since the configuration may include multiple heat pumps connected thermally in parallel to supply the heating/cooling request.

Therefore there is a need for new and improved devices.

[Summary of invention]

The present invention is made in light of the above problems, and has as its object to provide a device for an energy efficient conditioning of the temperature inside rooms, in particular when thermal boosting is required.

In a first aspect the present invention provides heat pump devices for conditioning the temperature T_i inside a room, the device comprising

at least one first means for heat distribution configured to be at least partly disposed inside said room, and configured to distribute heat between a first liquid and an interior fluid,

a first liquid circuit connected to said at least one first means for heat distribution,

a first liquid transfer pump configured to circulate said first liquid in said first circuit,

at least one means for heat exchange connected to a heat buffer and configured to exchange heat between said first liquid and an ambient fluid, wherein said ambient fluid is located outside said room.

According to a preferred embodiment, the present invention discloses a heat pump device for conditioning the temperature T_i inside a room, the device comprising at least one first means for heat distribution configured to be at least partly disposed inside said room, and configured to distribute heat between a first liquid and an interior fluid, a first liquid circuit connected to said at least one first means for heat distribution, a first liquid transfer pump configured to circulate said first liquid in said first circuit, at least one means for heat exchange connected to a heat buffer and configured to exchange heat between said first liquid and an ambient fluid, wherein said ambient fluid is located outside said room, said heat buffer is liquidly connected to said at least one first means for heat distribution, and configured to comprise at least a part of said first liquid, wherein said heat buffer is designed in accordance with $Q_b = m_b cp_b\left(T_i - T_b^{opt}\right)$, wherein Q_b is the heat to be comprised inside said heat buffer, $m_b$is the total mass of said at least a part of said first liquid comprised in said heat buffer, $cp_b$is the mass weighted heat capacity of said at least a part of said first liquid comprised in said heat buffer, where T_i is the temperature inside said room and $T_b^{opt}$is the optimal temperature of said first liquid comprised in said heat buffer and derived in accordance with $\frac{\delta P_{tot}}{\delta T_b}\left(T_b^{opt}\right) = 0$, $\frac{\delta^2 P_{tot}}{\delta T_b^2}\left(T_b^{opt}\right) > 0$, wherein P_{tot} is the total power required to operate said first liquid transfer pump, said at least one first means for heat distribution and said at least one means for heat exchange. This allows a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature inside a room in an energy efficient manner since heat is stored in said heat buffer and a heat exchange takes place between said first liquid, provided to have a high heat capacity, and said ambient fluid located outside said room, using means for heat exchange configured to operate at a high COP (coefficient of performance). Indeed, said heat buffer and said means for heat exchange allow for the efficient pumping of heat, wherein said means for heat exchange may operate efficiently. For example, during hot summer days, it may be more energy efficient to charge the heat buffer during the cooler nights and use the stored heat when necessary during the day, and vice versa in during winter. A device according to the invention allows that the stored heat in said heat buffer is immediately available to condition the temperature inside said room, hence, thermal boosting may be executed in an energy efficient and/or fast way, wherein fast may refer to short time intervals during which the provided (and required) heating power is a factor of at least 1,1, 1,2, 1,5 or 2 larger than heating power, or steady state low power, needed to condition a room or container against heat insulation losses to ensure a steady state condition. The invention may be provided to condition the temperature inside the room over a short time period, preferably, but not limited to, tens of minutes or minutes when a sudden rise in temperature is measured with the first series of measuring sensors configured to measure the temperature inside 1 said room or container, for example a first series of temperature sensors. Another advantage of a device according to the present invention is its capability to operate also where the energy supply fluctuates in time, e.g. as in the case of photovoltaic solar panels. Indeed, said heat buffer allows to work on an averaged continuous basis with increased efficiency and the autonomy of an off-grid system in comparison with prior art heat pump devices, for example thermoelectric heat pump devices, in which electric batteries are generally installed to act as an energy buffer for sudden required heat bursts, i.e. thermal boosts, or higher rate heat pumping performed at reduced efficiency (hence decrease of autonomy) since the efficiency of the batteries decreases due to the peak loads from the means for heat exchange. Hence, a device according to the present invention decreases the operating costs since the configuration of its components do not have to be able to transfer the peak load of the device. In some embodiments of the invention, it also allows a decrease of the noise level compared to conditioning devices known in the art since the heat exchange between said first liquid and said interior fluid is decoupled from the heat exchange with said ambient fluid. By the terms "interior fluid", we intend to mean the fluid contained in the room. The latter heat exchange rate may be regulated within the limits of the device and be planned to optimize efficiency, noise pollution at specific times and autonomy via, for example, energy consumption during grid connection for a semi off-grid system or high solar irradiances in the case of a connected photovoltaic system. In addition, this allows to select a heat buffer volume and heat capacity of the at least a part of the first liquid comprised in the heat buffer, so that the required energy to condition the temperature inside the room may be store in an energy efficient manner hence designing a device where the working points may be on or near the optimal characteristics.

According to a particular embodiment of the invention, the at least one means for heat exchange comprises at least one compressor, a series of thermoelectric elements, or a combination of said at least one compressor and said series of thermoelectric elements. This allows to develop heat pump device according to the present invention wherein one may choose (before developing) or switch (when a combination is used) between refrigeration technologies depending on the available and/or required size, noise, or energy efficiency.

According to a preferred embodiment of the invention, said at least one compressor is fluidly connected to at least one component selected from the group consisting of a condenser, a circuit, an expansion valve, or an evaporator.

According to a preferred embodiment of the invention, said heat buffer further comprises at least one substance selected from the group consisting of phase change materials, paraffin, gels, molten salts, or reversible exothermic hydration materials, wherein said at least one substance is separated from said first liquid, wherein m_b is the total mass of said at least a part of said first liquid and said at least one substance comprised in said heat buffer, wherein cp_b is the mass weighted heat capacity of said at least a part of said first liquid and said at least one substance comprised in said heat buffer, and T_b^{opt} is the optimal temperature of said first liquid and said at least one substance comprised in said heat buffer. This allows to obtain a higher heat capacity of the heat buffer compared to a heat buffer containing only a first liquid. This allows to select a heat buffer volume and heat capacity of the at least a part of the first liquid and the at least one substance comprised in the heat buffer, so that the required energy to condition the temperature inside the room may be store in an energy efficient manner hence designing a device where the working points may be on or near the optimal characteristics.

According to a preferred embodiment of the invention, the device comprises a series of measuring sensors configured to measure the temperature T_i inside said room, a temperature T_a outside said room, the temperature T_b of said at least a part of said first liquid and said at least one substance comprised in said heat buffer, and the temperature at said at least one means for heat exchange.

According to a particular embodiment of the invention, the device comprises a controller to employ a relationship $P_{tot} \leq 2P_{tot}^{opt}$, in particular $P_{tot} \leq 1.5\ P_{tot}^{opt}$, more in particular $P_{tot} \leq 1.25\ P_{tot}^{opt}$, to condition the temperature inside said room, wherein P_{tot} is the total power required to operate said first liquid transfer pump, said at least one first means for heat distribution and at least one means for heat exchange, wherein the total optimized power P_{tot}^{opt} equals $P_{tot}$when the temperature T_b of said first liquid and said at least one substance in said heat buffer equals T_b^{opt} derived in accordance with $\frac{\delta P_{tot}}{\delta T_b} = 0$ and $\frac{\delta^2 P_{tot}}{\delta T_b^2}\left(T_b^{opt}\right) > 0$. This allows the device to operate in an energy efficient mode. Ideally meteorological information for the next hours or days and properties of the installed device can be used in a control strategy potentially further increasing the device efficiency.

According to a preferred embodiment of the invention, the device comprises a heat buffer which is at least partly disposed inside said room. This allows that heat exchange between said first liquid and said interior fluid might take place through the housing of said heat buffer. Hence, this heat exchange provides a continuous conditioning of the temperature inside the room. When properly designed, these heat losses may beneficially contribute the acclimatization of the room, reducing the operation time of a first liquid transfer pump and at least one means for distribution, for example a first heat exchanging forced convection means, hence, reducing the energy consumption.

According to a preferred embodiment of the invention, said first liquid circuit is at least partly formed by a first plurality of refrigerant tubes and configured to be disposed inside said room, wherein said first plurality of refrigerant tubes are made of a heat conductive metal configured to convey heat there through. This allows that heat exchange, between the first liquid contained in the first circuit and the interior fluid, might take place through the housing of the first plurality of refrigerant tubes into the room. Hence, this heat exchange provides a continuous conditioning of the temperature inside the room. Hence no additional insulation for these tubes is required, reducing device cost and installation time.

A preferred embodiment of the heat pump device, for example thermoelectric heat pump device, according to the invention, comprises a at least one second means for heat distribution configured to be disposed outside said room, and configured to exchange heat between a second liquid and said ambient fluid, a second liquid circuit disposed to liquidly connecting said at least one second means for heat distribution with said at least one means for heat exchange, and a second liquid transfer pump to circulate said second liquid in said second liquid circuit. This allows to have a more efficient thermal charging of the heat buffer since the (forced) heat exchange might take place between the second liquid and the ambient fluid, and between the first and second liquid using the means for heat exchange.

According to a preferred embodiment the invention, the second liquid circuit is at least partly formed by a second plurality of refrigerant tubes configured to be disposed outside said room, wherein said second plurality of refrigerant tubes are made of a heat conductive metal configured to convey heat there through. This allows to have an additional heat sink or heat exchange between the second liquid and the ambient fluid, hence, less energy is required to operate the second means for heat distribution, for example the second heat exchanging forced convection means. In addition, no additional insulation for these tubes is required, which reducing device costs and installation time.

According to a preferred embodiment of the invention, the device comprises a third liquid circuit disposed to liquidly connecting said heat buffer with said at least one means for heat exchange, and a third liquid transfer pump configured to circulate said first liquid in said third liquid circuit. The third liquid transfer pump allows to reduce the effect of conductive heat losses through the means for heat exchange when the means for heat exchange are not powered by disabling the pump and thus creating a larger conductive temperature barrier in the not moving third liquid.

According to a preferred embodiment of the invention, said first liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene. This allows to have an energy efficient transport of heat since these liquids have a preferable heat capacity.

According to a preferred embodiment of the invention, said second liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene. This allows to have an energy efficient transport of heat since these liquids have a preferable heat capacity.

According to a preferred embodiment of the invention, said means for heat exchange is a series of thermoelectric elements comprising a cold side and a hot side, and at least a part of said series of temperature sensors is configured to measure a temperature difference ΔT_{pe} over said cold side and said hot side of said series of thermoelectric elements.

Another aim of the present invention is to provide a room comprising at least one conditioning device according to any one of the mentioned embodiments of the invention. This room has the advantageously effect of condition the temperature inside in an energy and time efficient way.

Another aim of the present invention is to provide a use of the invention for the conditioning of the temperature inside a room, in particular air cargo container transport dollies comprising a housing configured to store cargo. By condition of the temperature inside a room when an embodiment of a heat pump device according to the present invention is in use, reference may be made to “positive heating” and/or “negative heating”, wherein positive heating of a room may result in an increase of the temperature of the at least one fluid and the at least one object contained in the room. Wherein negative heating of a room may result in a decrease of the temperature of the at least one fluid and the at least one object contained in the room. Hence, when reference is made to “heat”, reference may be made to energy added to (for heating) or removed from (for cooling) of the interior of a room, wherein at least part of the energy is exchanged between the first liquid and the heat buffer.

Embodiments of the present invention discloses a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature inside a room wherein the device further comprises a heat buffer liquidly connected to said first heat exchanging forced convection means, and provided to comprise said first liquid, and said series of thermoelectric elements connected to said heat buffer and provided to exchange heat between said first liquid and an ambient fluid, wherein said ambient fluid is located outside said room. This allows a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature inside a room in an energy efficient manner since heat is stored in said heat buffer and a heat exchange takes place between said first liquid, provided to have a high heat capacity, and said ambient fluid located outside said room, using thermoelectric elements provided to operate at a high COP (coefficient of performance). Indeed, said heat buffer and said series of thermoelectric elements allow for the efficient pumping of heat, wherein said thermoelectric elements operate most efficiently when the temperature difference over them is small. For example, during hot summer days, it may be more energy efficient to charge the heat buffer during the cooler nights and use the stored heat when necessary during the day, and vice versa in during winter. A device according to the invention allows that the stored heat in said heat buffer is immediately available to condition the temperature inside said room, hence, thermal boosting may be executed in an energy efficient way. Another advantage of a device according to the present invention is its capability to operate also where the energy supply fluctuates in time, e.g. as in the case of photovoltaic solar panels. Indeed, said heat buffer allows to work on an averaged continuous basis with increased efficiency and the autonomy of an off-grid system in comparison with prior art thermoelectric heat pump devices in which electric batteries are generally installed to act as an energy buffer for sudden required heat bursts, i.e. thermal boosts, or higher rate heat pumping performed at reduced efficiency (hence decrease of autonomy) since the efficiency of the batteries decreases due to the peak loads from the thermoelectric elements. Hence, a device according to the present invention decreases the operating costs since the configuration of its components do not have to be able to transfer the peak load of the device. The invention also allows a decrease of the noise level compared to conditioning devices known in the art since the heat exchange between said first liquid and said interior fluid is decoupled from the heat exchange with said ambient fluid. By the terms “interior fluid”, we intend to mean the fluid contained in the room. The latter heat exchange rate may be regulated within the limits of the device and be planned to optimize efficiency, noise pollution at specific times and autonomy via, for example, energy consumption during grid connection for a semi off-grid system or high solar irradiances in the case of a connected photovoltaic system.

According to a specific embodiment of the invention, the heat buffer further comprises a substance selected from the group consisting of phase change materials, paraffins, gels, molten salts, and reversible exothermic hydration materials, wherein said substance is separated from said first liquid. This allows to obtain a higher heat capacity of the heat buffer compared to a heat buffer containing only a first liquid.

According to a preferred embodiment of the invention, a series of temperature sensors are provided to measure the temperature T_i inside said room, the temperature $T_a$outside said room, the temperature T_b of said first liquid and said substance comprised in said heat buffer, and the temperature difference ΔT_{pe} over said cold side and said hot side of said series of thermoelectric elements.

According to a preferred embodiment of the invention, the heat buffer is designed in accordance with $Q_b = m_b cp_b(T_i - T_b^{opt})$, wherein Q_b is the heat to be comprised inside said heat buffer, m_b is the sum of the masses of said first liquid and said substance comprised in said heat buffer, cp_b is the mass averaged heat capacity of said first liquid and said substance comprised in said heat buffer, and T_b^{opt} is the optimal temperature of said first liquid and said substance comprised in said heat buffer and derived in accordance with $\frac{\delta P_{tot}}{\delta T_b} = 0$, $\frac{\delta^2 P_{tot}}{\delta T_b^2}(T_b^{opt}) > 0$,wherein P_{tot} is the sum of the power required to operate said first liquid transfer pump, said first heat exchanging forced convection means and said series of thermoelectric elements. This allows to select a heat buffer volume and heat capacity of the first fluid and substance, comprised in the heat buffer, so that the required energy to condition the temperature inside the room may be store in an energy efficient manner hence designing a device where the working points may be on or near the optimal characteristics.

According to a particular embodiment of the invention, a controller employs a relationship $P_{tot} \leq 2P_{tot}^{opt}$, in particular $P_{tot} \leq 1.5\ P_{tot}^{opt}$, more in particular $P_{tot} \leq 1.25\ P_{tot}^{opt}$, to condition the temperature inside said room, wherein P_{tot} is the sum of the power required to operate said first liquid transfer pump, said first heat exchanging forced convection means and said series of thermoelectric elements, wherein P_{tot}^{opt} equals $P_{tot}$when the temperature of said first liquid and said substance in said heat buffer equals T_b^{opt}. This allows the device to operate in an energy efficient mode. Ideally meteorologic information for the next hours or days and properties of the installed device can be used in a control strategy potentially further increasing the device efficiency

According to a preferred embodiment of the invention, the device comprises a heat buffer which is at least partly disposed inside said room. This allows that heat exchange between said first liquid and said interior fluid might take place through the housing of said heat buffer. Hence, this heat exchange provides a continuous conditioning of the temperature inside the room. When properly designed, these heat losses may beneficially contribute the acclimatization of the room, reducing the operation time of a first liquid transfer pump and a first heat exchanging forced convection means, hence, reducing the energy consumption.

According to a preferred embodiment of the invention, said first liquid circuit is at least partly formed by a first plurality of refrigerant tubes and provided to be disposed inside said room, wherein said first plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through. This allows that heat exchange, between the first liquid contained in the first circuit and the interior fluid, might take place through the housing of the first plurality of refrigerant tubes into the room. Hence, this heat exchange provides a continuous conditioning of the temperature inside the room. Hence no additional insulation for these tubes is required, reducing device cost and installation time.

A preferred embodiment of the heat pump device, for example a thermoelectric heat pump device, according to the invention, comprises a second heat exchanging forced convection means provided to be disposed outside said room and provided to exchange heat between a second liquid and said ambient fluid, wherein said second liquid is in contact with said series of thermoelectric elements, a second liquid circuit disposed to liquidly connecting said second heat exchanging forced convection means with said series of thermoelectric elements, and a second liquid transfer pump to circulate said second liquid in said second liquid circuit. This allows to have a more efficient thermal charging of the heat buffer since the (forced) heat exchange might take place between the second liquid and the ambient fluid, and between the first and second liquid using the thermoelectric elements.

According to a preferred embodiment the invention, the second liquid circuit is at least partly formed by a second plurality of refrigerant tubes provided to be disposed outside said room, wherein said second plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through. This allows to have an additional heat sink or heat exchange between the second liquid and the ambient fluid, hence, less energy is required to operate the second heat exchanging forced convection means. In addition, no additional insulation for these tubes is required, which reducing device costs and installation time.

According to a preferred embodiment of the invention, the device comprises a third liquid circuit disposed to liquidly connecting said heat buffer with said series of thermoelectric elements, and a third liquid transfer pump provided to circulate said first liquid in said third liquid circuit. The third liquid transfer pump allows to reduce the effect of conductive heat losses through the series thermoelectric elements when the thermoelectric elements are not powered by disabling the pump and thus creating a larger conductive temperature barrier in the not moving third liquid.

According to a preferred embodiment of the invention, the third liquid circuit is at least partly formed by a third plurality of refrigerant tubes, wherein said third plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through. This allows to have an additional heat sink or heat exchange between the third liquid and the interior fluid or ambient fluid, hence, less energy is required to perform a forced heat exchange. Hence no additional insulation for these tubes is required, reducing device costs and installation time.

According to a preferred embodiment of the invention, said first liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, and ethylene. This allows to have an energy efficient transport of heat since these liquids have a preferable heat capacity.

According to a preferred embodiment of the invention, said second liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, and ethylene. This allows to have an energy efficient transport of heat since these liquids have a preferable heat capacity.

A second aim of the present invention is to provide a room comprising at least one conditioning device according to any one of the mentioned embodiments of the invention. This room has the advantageously effect of condition the temperature inside in an energy and time efficient way.

A third aim of the present invention is to provide a use of the invention for the conditioning of the temperature inside a room, in particular air cargo container transport dollies comprising a housing provided to store cargo.

Further benefits and advantages of the present invention will become apparent after a careful reading of the detailed description with appropriate reference to the accompanying drawings.

[Brief description of the drawings]

FIG. 1 is a schematic of a cross section of a room constructed in accordance with a preferred embodiment of the present invention. For illustrative purposes, the components being part of this preferred embodiment are not represented on scale with respect to each other or the room.

FIG. 2 is a schematic of a cross section of a room constructed in accordance with a preferred embodiment of the present invention, comprising a second liquid circuit. For illustrative purposes, the components being part of this preferred embodiment are not represented on scale with respect to each other or the room.

FIG. 3 is a schematic of a cross section of a room constructed in accordance with a preferred embodiment of the present invention, comprising a third liquid circuit. For illustrative purposes, the components being part of this preferred embodiment are not represented on scale with respect to each other or the room.

FIG. 4 is a schematic of a cross section of a room constructed in accordance with a preferred embodiment of the present invention, comprising a second and a third liquid circuit. For illustrative purposes, the components being part of this preferred embodiment are not represented on scale with respect to each other or the room.

FIG. 5 is a graph depicting the operating power of a first liquid transfer pump, at least one means for heat distribution, for example a first heat exchanging forced convection means, and at least one means for heat exchange, for example a series of thermoelectric elements, normalized at the optimal power, as a function of the temperature difference between an ambient fluid and a first fluid in a heat buffer, in order to design a preferred embodiment according to the invention.

FIG. 6 is a schematic representation of at least one means for heat exchange, in particular a compressor system.

FIG. 7 is a schematic representation of the integration of a compressor system into the heat pump device according to a preferred embodiment of the invention.

FIG. 8 is a schematic representation of the integration of a compressor system into the heat pump device according to a preferred embodiment of the invention.

[Detailed description]

The detailed description set forth below in intended as a description of the presently preferred embodiment of the invention, and is not intended to represent the only form in which the invention may be construed or utilized. The description sets forth the functions and sequences of steps for constructing and operating the invention. It is to be understood, however, that the same or equivalent functions and sequences may be accomplished by different embodiments and that they are also intended to be encompassed within the scope of the invention.

Where in embodiments of the present invention reference is made to “compressor”, reference may be made to at least one means for heat exchange comprising at least one compressor, or reference may be made to at least one means for heat exchange comprising at least one compressor and at least one component selected from the group consisting of a condenser, an expansion valve and an evaporator, connected to each other to transfer at least one heat-carrying fluid.

Where in embodiments of the present invention reference is made to "conditioning the temperature inside a room", reference may be made to "boosting" wherein a forced fast cooling or heating of the room is performed in order to set the temperature within a predefined temperature range over a short time. According to at least one embodiment of the invention, thermal boosting may be executed in an energy efficient and/or fast way, wherein fast may refer to short time intervals during which the provided (and required) heating power is a factor of at least 1,1 to 2 times, preferably 1,2 to larger than heating power, or steady state low power, needed to condition a room or container against heat insulation losses to ensure a steady state condition. When reference is made to "steady state", reference may be made to a system for which the variables defining the behavior of the system are unchanging in time.

Where in embodiments of the present invention reference is made to "substance(s)" or to "at least one substance" comprised in the heat buffer, reference may be made to at least a part of the first liquid comprised in the heat buffer, or to at least a part of the first liquid and at least one substance selected from the group consisting of phase change materials, paraffin, gels, molten salts, and reversible exothermic hydration materials, comprised in said heat buffer.

By condition of the temperature inside a room when an embodiment of the present invention is in use, reference may be made to "positive heating" and/or "negative heating", wherein positive heating of a room may result in an increase of the temperature of the at least one fluid and the at least one object contained in the room. Wherein negative heating of a room may result in a decrease of the temperature of the at least one fluid and the at least one object contained in the room. Hence, when reference is made to "heat", reference may be made to energy added to (for heating) or removed from (for cooling) of the interior of a room, wherein at least part of the energy is exchanged between the first liquid and the heat buffer.

Where in embodiments reference is made to "a first means for heat distribution", reference may be made to, for example, first heat exchanging convection means and/or radiation means, for example ceiling heat exchangers, when in use may be able to exchange and/or distribute heat, wherein heat exchange may refer to heat exchange between at least two fluids, for example at least one liquid and air, which may be separated by a solid material, preferably a heat conductive material, and wherein heat distribution may refer to mixing of at least one fluid, for example air, in particular interior air. In further embodiments according to the present invention, a means for heat distribution may also be forced heat exchanging convection means.

Where in embodiment reference is made to "a second means for heat distribution", reference may be made to, for example, second heat exchanging convection means and/or radiation means, for example a means for blowing, typically a fan, when in use may be able to exchange and/or distribute heat, wherein heat exchange may refer to heat exchange between at least two fluids, for example at least one liquid and air, which may be separated by a solid material, preferably a heat conductive material, and wherein heat distribution may refer to mixing of at least one fluid, for example air, in particular interior air.

Referring now to the figures, and initially to FIG. 1, there is illustrated a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature in a room in accordance with a preferred embodiment of the invention. The room may be, but is not limited to, a container for storing or transporting cargo, a living/business room or a server room. The room comprises a housing 2 designed to store relevant content and to protect the content from being in thermal equilibrium with ambient fluid, in particular air wherein air is. The device according to the invention is also suited to be implemented in air cargo container transport dollies comprising a housing provided for storing cargo containers. Hence, the housing 2 may include a thermal insulated layer, such as foam boards or blankets. The housing 2 separates the inside or interior 1 of the room from the outside or exterior 20. Cavities in the housing may be filed with components, or part of components, of the device according to the invention, such as refrigerant tubes extending from the interior 1 to the exterior 20. Cavities in the housing 2 may also be filled with functionality means to access the room. The temperature inside the room might be obtained from a first series of measuring sensors 23, for example temperature sensors, provided to measure the temperature inside 1 the room. The first series of measuring sensors 23, for example temperature sensors, are preferably disposed close to the bottom and roof of the room provided to monitor the temperature inside the room in a reliable way.

At least one means for heat distribution 5, for example a first heat exchanging forced convection means, is provided to be at least partly disposed inside 1 the room and provided to exchange and/or distribute heat between a first liquid, contained in a first circuit 6 and interior 1 air. The at least one means for heat distribution 5, for example a first heat exchanging forced convection means, is provided to condition the temperature inside the room over a short time period, preferably, but not limited to, tens of minutes or minutes when a sudden rise in temperature is measured with the first series of measuring sensors configured to measure the temperature inside 1 said room or container, for example a first series of temperature sensors. This may occur due to an opening of the door(s) of the room and/or due to inserting cargo or the like being entered in the room at a different temperature than existing in the room. i.e. 'boosting'. Hence, this forced air supply for cooling or heating of the interior may be performed by a fan and a fan motor. This boosting is required when the value of the measured inside 1 temperature is not located in a required temperature value range to maintain the quality or functionality of the content. According to a preferred embodiment of the invention, at least one means for heat distribution 5, for example a first heat exchanging forced convection means, is provided to be at least partly contained inside the room. Hence, the at least one means for heat distribution 5, for example a first heat exchanging forced convection means, may also be integrated in the housing 2 of the room. The at least one means for heat distribution 5, for example a first heat exchanging forced convection means, is powered by an external energy source, such as, but not limited to, a series of batteries or solar panels or directly or indirectly connected to the power grid, and its operation is controlled by a controller 27 in such a manner that when the device is in its design conditions and the heat buffer is sufficiently charged, the desired internal temperature can be reached within the required conditioning time by applying sufficient flow rate to said at least one means for heat distribution 5, for example a first heat exchanging forced convection means, which is described later in this detailed description. The flow rate is preferably not too high with respect to the needed flow rate to limit the performance penalty of restrictive flow losses which increase with the flow rate.

The first circuit 6 is connected to at least one means for heat distribution 5, for example a first heat exchanging forced convection means, and is configured to convey a first liquid. This first liquid may be, but is not limited to, the group consisting of water, mixture water and glycol, mineral oil, terphenyl, liquid metals, or ethylene, or a combination of. The first liquid preferably is a liquid with a high heat capacity, able to meet the cooling and heating requirements of the device that remains liquid in the operating temperature range. According to a preferred embodiment of the invention, the first circuit 6 is at least partly formed by a first plurality of refrigerant tubes which are disposed inside 1 the room. The first circuit may be disposed close to the roof of the room which in case of cooling, supports to cool the room in an energy efficient way since convection will distribute the heat uniformly over the interior of the room. The first plurality of refrigerant tubes may be made of a heat conductive metal provided to convey heat contained in the first liquid there through, such as, but not limited to, a copper or aluminum material.

A first liquid transfer pump 7 is comprised in the first liquid circuit 6 and provides the circulation of the first liquid in the first liquid circuit 6. The first liquid transfer pump provides a minimum mass flow rate of the first liquid equal to the required rate of heat exchanged with the interior 1 divided by the product of the specific heat capacity of first liquid and a factor of 20°C and a maximum mass flow rate of the first liquid equal to the required rate of heat exchanged with the interior 1 divided by the product of the specific heat capacity of first liquid and a factor of 0,02°C in cooling or heating mode required to perform a fast heat exchange between the first liquid and the interior of the room. The mass flow rate or volume flow rate or capacity or pressure of the first liquid transfer pump 7 is controlled by the controller 27. The first liquid transfer pump 7 is connected to the aforementioned energy source for operating.

A heat buffer 8 is liquidly connected to the at least one means for heat distribution 5, for example a first heat exchanging forced convection means, via first circuit 6 and provided to at least partly contain the first liquid. Hence, the heat buffer 8 is configured to operate as a thermal battery, storing thermal energy or heat as a consequence of heat exchange between the first liquid and ambient fluid, in particular air. A series of means for performing this heat exchange is described below. The heat buffer 8 is preferably, but not limited to, cylindrical shaped because this shape react to the stresses caused by internal pressures much more favorably. Because liquid pressure acts in all directions a round wall shape will see even distribution of pressure, whereas any shape with corners will see concentrations of load due to pressure acting on either side of the corner pushing the two sides apart. The heat buffer has a minimum capacity such that the temperature in the heat buffer changes maximal 20°C per discharge event.

According to a preferred embodiment of the invention, the heat buffer is at least partly disposed in the room. Heat exchange takes place between the first liquid contained in the heat buffer 8 and the interior 1. A second series of measuring sensors 24, for example temperature sensors, is disposed inside the heat buffer 8 provided to measure the temperature of the at least one substance comprised in the heat buffer 8, for example the temperature T_b of said at least a part of said first liquid and said at least one substance comprised in said heat buffer 8. These measurements are transferred by means of a connection between from the second series of measuring sensors 24, for example temperature sensor, to measure the temperature and the controller 27. Based on the temperature difference measured by the first series of measuring sensors 23, for example temperature sensors, to measure the temperature inside 1, and the second series of measuring sensors 24, for example temperature sensors, to measure the temperature T_b of said at least a part of said first liquid and said at least one substance comprised in said heat buffer 8, the controller may operate the first fluid pump and at least one means for heat exchange 13, for example a series of thermoelectric elements, to condition the temperature inside the room. The at least one means for heat exchange 13, for example a series of thermoelectric elements, disposed to be in contact with the heat buffer are preferably, but not limited to, Peltier elements. The at least one means for heat exchange 13, for example a series of thermoelectric elements, are configured to exchange heat between the first liquid and the ambient fluid, in particular air, hence, they comprise a first solid-air heat exchanger 21. The at least one means for heat exchange 13, for example a series of thermoelectric elements, may be disposed in the housing 2 of the room and in direct contact with the heat buffer 8. The position of the at least one means for heat exchange 13, for example a series of thermoelectric elements, is not limited to the aforementioned configuration, i.e. they may also be disposed at least partly inside or outside the room. Hence, in case heat may be transferred from the at least one substance and/or at least a part of said at least first liquid contained in the heat buffer 8 to the ambient fluid, i.e. in case the device is configured to cool the interior of the room, the cold side of the series of thermoelectric elements 13 is in direct contact with the substance(s) contained in the heat buffer 8 or in direct contact with the walls of heat buffer 8, which preferably at least locally is foreseen of a thermal conductive material which directly or indirectly is in contact with the substance(s) in the heat buffer 8, and the hot side is in direct contact with first solid-air heat exchanger 21 which is in direct contact with the ambient fluid, in particular air. A third series of measuring sensors 26, for example temperature sensors, may be placed close to the at least one means for heat exchange 13, for example a series of thermoelectric elements, to measure the local temperature difference between, for example, the hot and cold side of the series of thermoelectric elements 13. The third series of measuring sensors 26, for example temperature sensors, may be provided to measure the temperature difference over the hot and cold side of the series of thermoelectric elements. These measurements are sent to the controller 27 and may be used to control the thermoelectric elements in an energy efficient manner and / or monitor the state of the device and / or thermoelectric elements. Forced air blowing of the ambient fluid, in particular air, may be provided by a blower 18 disposed at the outside 20 of the room. If the blower 18 is not installed, the heat exchanger is preferably of sufficient size to be able to exchange heat with the outside 20 environment by means of natural convection. A fourth series of measuring sensors 25, for example temperature sensors, is disposed outside provided to measure the temperature of the ambient fluid, in particular air. Measurements are sent to the controller 27 to have the possibility be able to estimate the heat losses through the insulation upfront and act accordingly and / or determine the needed amount of energy stored in the buffer 8 as a temperature difference relative to the temperature inside 1, measured by a first series of measuring sensors 23, for example temperature sensors, to be able to reacclimatize the interior 1 in an adequate manner when the doors are opened, goods are inserted or the like.

Referring now to FIG. 2, there is illustrated a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature in a room in accordance with a preferred embodiment of the invention. The device includes the elements of the device in FIG. 1 and, additionally includes at least one second means for heat distribution 17, for example a second heat exchanging forced convection means, which have to be disposed outside the room. The at least one second means for heat distribution 17, for example a second heat exchanging forced convection means, provides heat exchange between a second liquid or fluid and the ambient fluid. A forced blower, preferably a fan operated by a fan motor, may be provided to enhance the heat exchange effect. The at least one second means for heat distribution 17, for example a second heat exchanging forced convection means, is in liquid contact with the at least one means for heat exchange 13, for example a series of thermoelectric elements, via a second liquid circuit 15. This second liquid circuit is configured to convey the flow of the second liquid or fluid between the at least one means for heat exchange 13, for example a series of thermoelectric elements, and the at least one second means for heat distribution 17, for example a second heat exchanging forced convection means. The second liquid circuit 15 is at least partly formed by a second plurality of refrigerant tubes which are disposed outside said room, wherein said second plurality of refrigerant tubes are preferably made of a heat conductive metal provided to convey heat there through. The plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat contained in the first liquid there through, such as, but not limited to, a copper or aluminum material. Preferably, the part of the tubes in direct contact with the fluid in the room is isolated to avoid heat sink. A second liquid transfer pump 16 is used to circulate the second liquid in the second liquid circuit 15. This second liquid transfer pump 16 has a minimum mass flow rate of the second liquid equal to the average rate of heat exchanged with the exterior 20 divided by the product of the specific heat capacity of second liquid and a factor of 20°C and a maximum mass flow rate of the second liquid equal to the average rate of heat exchanged with the exterior 20 divided by the product of the specific heat capacity of second liquid and a factor of 0,001°C. The type of pumps that are used are preferably well known in the state-of-the art and are preferably able to work energy efficient. The second liquid transfer pump 16 is controlled by the controller 27 and is in active mode when the heat buffer 8 has to be charged, preferably after the boosting mode. A fourth series of measuring sensors 25, for example temperature sensors, is disposed outside provided to measure the temperature of the ambient fluid, in particular air. Measurements are sent to the controller 27 to have the possibility be able to estimate the heat losses through the insulation upfront and act accordingly and / or determine the needed amount of energy stored in the buffer 8 as a temperature difference relative to the temperature inside 1, measured by the first series of measuring sensors 23 to measure the temperature, for example temperature sensors, to be able to reacclimatize the interior 1 in an adequate manner when the doors are opened, goods are inserted or the like.

Referring now to FIG. 3, there is illustrated a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature in a room in accordance with a preferred embodiment of the invention. The device includes the elements of the device in FIG. 1 and, additionally a third liquid circuit 10 which is at least partly disposed inside the room and liquidly connects the heat buffer 8 with the at least one means for heat exchange 13, for example a series of thermoelectric elements. The third liquid circuit 10 may comprise of a third plurality of refrigerant tubes. This third plurality of refrigerant tubes may be made of a heat conductive metal provided to convey heat contained in the first liquid there through, such as, but not limited to, a copper or aluminum material. The refrigerant tubes located outside 20 are preferably insulated. The tubes disposed to be in direct contact with the interior fluid, in particular air, of the room may be isolated depending on the desired heat exchange. Insulating at least a part of the tubes disposed to be in direct contact with the interior fluid may avoid a heat sink or heat exchange between the first fluid contained in the third liquid circuit and the interior fluid, in particular air, contained in the room. A third liquid transfer pump 11 is provided to circulate said first liquid in said third circuit 10. The third circuit 10 might provide a faster charging of the heat buffer 8 since heat exchange may take place between two liquids or fluids in the at least one means for heat exchange 13, for example a series of thermoelectric elements. A controller 27 controls the operations of the different components comprised in an embodiment of the invention. A fan 18 is provided to facilitate the heat exchange with the exterior 20.

According to a preferred embodiment of the invention, the third liquid circuit 10 is at least partly formed by a third plurality of refrigerant tubes, wherein said third plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through.

Referring to FIG. 4, there is provided a schematic of a heat pump device, for example a thermoelectric heat pump device, for conditioning the temperature in a room in accordance with a preferred embodiment of the invention. The device includes the elements of the device in FIG. 1, FIG. 2 and FIG. 3.

Referring to FIG. 5, there is shown a relation to configure a preferred embodiment according to the invention. This relation allows to select a heat buffer volume and heat capacity of the first liquid so that the required heat buffer energy might be stored in an efficient manner and hence designing a device where the working points can be on or near the optimal characteristic. The energy Q_b stored in the heat buffer 8 with respect to the temperature T_i inside 1 the room and the average temperature T_b of the substance(s) inside the heat buffer 8 is:

$$Q_b = m_b cp_b (T_i - T_b) \qquad \text{(i)}$$

where m_b is the mass of the substance(s) in the heat buffer 8 and cp_b is the mass averaged heat capacity (at constant pressure) of the substance(s) in said heat buffer 8. The substance in the heat buffer might be the first fluid alone, or a combination of the first fluid with at least one substance selected from the group consisting of phase change materials, paraffin, gels, molten salts, and reversible exothermic hydration materials. The temperature T_b is not given and may be used to optimize the efficiency of the device, given further that the power provided to condition said inside room $\dot{Q}_1$ is depending on:

$$\dot{Q}_1 = \dot{m}_1 cp_1 (T_i - T_b) \qquad \text{(ii)}$$

where $\dot{m}_1$ is the mass flow rate of the first liquid transfer pump 7, cp_1 is the heat capacity of the first liquid. The power consumption of the first liquid transfer pump 7 and the at least one means for heat distribution 5, for example a first heat exchanging forced convection means, i.e. P_1, typically follows a relationship

$$P_1 = \alpha \dot{m}_1^{\beta} \qquad \text{(iii)}$$

where α and β are positive coefficients describing the relation. The at least one means for heat exchange 13, for example a series of thermoelectric elements, have a power consumption depending on the type of means that may be used. For example, when the at least one means for heat exchange 13 comprises a series of thermoelectric elements, the power consumption P_{te} may be by approximation equal to

$$P_{te} =\cdot n_{te}(c_0 + c_1 \cdot (T_a - T_b + \Delta T_{loss}) + c_2 \cdot I_{te}) I_{te} \qquad \text{(iv)}$$

for thermal conditioning the interior, where c_0, c_1, c_2 are coefficients characterizing the properties of the installed series of thermoelectric elements 13, T_a the temperature of the ambient fluid, in particular air, and I_{te} the average current flowing through an individual thermoelectric element, and n_{te} the number of installed thermoelectric elements. ΔT_{loss} is a term further representing additional temperature losses occurring in the device between the outside 20 and the heat buffer 8.

The degree of freedom for T_b can be chosen when combining equations (ii), (iii) and (iv) as follows:

$$P_{tot} = P_1 + P_{te} = \alpha \cdot \left(\frac{\dot{Q}_1}{cp_1 \cdot (T_i - T_b)}\right)^{\beta} + n_{te}(c_0 + c_1 \cdot (T_a - T_b + \Delta T_{loss}) + c_2 \cdot I_{te}) I_{te} \quad \text{(v)}$$

$$\frac{\delta P_{tot}}{\delta T_b} = 0 \rightarrow T_b^{opt} = T_i - \frac{\alpha \cdot \beta}{n_{te} I_{te} \cdot c_1} \cdot \left(\frac{\alpha \cdot \beta \cdot cp_1}{n_{te} I_{te} \cdot c_1 \cdot Q_1}\right)^{\frac{-\beta}{1+\beta}} \quad \text{(vi)}$$

The optimal temperature of the substance(s) inside said heat buffer T_b^{opt} for specific design conditions results in an optimal power consumption for those design conditions. This allows to condition the temperature inside said room in an energy efficient way, and according to equation (i) select a heat buffer volume and heat capacity of the first liquid so that the required buffer energy can be stored in an efficient manner and hence designing a device where the working points can be on or near the optimal characteristic.

In case the at least one means for heat exchange 13 comprises at least one compressor, the total power consumption P_{tot} may include the power consumption of the at least one compressor P_{comp}, wherein P_{comp} may be by approximation equal to

$$P_{comp} = f\left(Q_{comp}, (T_a - T_b + \Delta T_{loss}), c_{comp}\right) \quad \text{(vii)}$$

Wherein the function f is depending on the electric energy Q_{comp} to drive the compressor, T_a the temperature of the ambient fluid, the average temperature T_b of the substance(s) inside the heat buffer 8, T_{loss} representing additional temperature losses occurring in the device between the outside 20 and the heat buffer 8, and, besides others, the characteristics of the compressor and the type of cooling gas used, represented by c_{comp}. Information on this relation can be found in the specification sheet of the at least one compressor or can be obtained in a test setup by, for example, applying a specific heat flux and known voltage and observe the temperature difference and current consumption for different working points of the compressor system.

A potential first control strategy that allows for the conditioning of the interior could be to always have a given amount of energy in the heat buffer to be able to condition the interior. A distinction needs to be made if the system needs to be able to cool and heat the interior, this can be done based on the measured outside temperatures and the requested inside temperature. This is a simple control strategy that conditions the interior, but not necessary in an energy efficient manner as the needed energy to condition the interior is strongly depending on the outside conditions, the stored energy in the heat buffer would be the energy needed in the extreme working points of the system. Always reloading the buffer to this level is not efficient.

A potential second control strategy improving on this first strategy could be to try to estimate the needed energy to reacclimatize the interior and control the heat buffer temperature accordingly. This allows for a significant energy reduction. The needed energy Q_i to reacclimatize the interior can be the sum of following components and others:

1. If the doors of the room open, it is assumed that the conditioned air inside all escapes during the time the doors are opened and is replaced completely with outside air. Hence, the energy in the air of the room can be found as: $Q_{air} = \gamma f(T_o, T_i, RH_o)$ which is a function of the measured outside temperatureT_a, the measured inside temperature $T_i$and measured or remotely gathered outside relative humidityRH_o. The exact relation is well known in the psychometric literature. If there would not be a complete replacement of the inside air, a correction factor γ can be applied.

2. Because the interior air is assumed to be the outside air during a door opening, also the walls of the room will start to change in temperature. The exchanged energy from the walls can be approximated as: $Q_{wallexchanged} = Q_{wall}\left(1 - exp(-t/\tau)\right)$ (viii)where $Q_{wall}$is the total energy that the walls can hold with the difference in inside and outside temperature, which can be a value gathered from the design of the system, or it could be a value is fit based on the measurements during the previous operation cycles of the system. $t$is the time and $\tau$is a time constant that could also be fitted based on the previous measurements.

3. The heat of the inserted content. For most content being transported in the cold chain or any other temperature conditioned environment, the content most likely will be preconditioned hence they don't require energy to acclimatize. The system however could very well also be used, if designed properly, to quickly acclimatize unacclimatised content.

The sum of the terms above can be at least part of the energy needed to reacclimatize the interior, other terms may be added. From this energy two further system properties can be determined:

1. This energy has to be stored inside the said heat buffer which has a specific heat capacity and volume, hence a minimal temperature difference can be determined at

which the heat buffer holds at least the needed energy. From this difference the actual temperature $T_b$in the heat buffer can be calculated.

2. The needed energy together with a given time in which the interior needs to be reacclimatized results in the needed cooling/heating power. Which in combination with the measured heat buffer and internal temperature gives a relation to the needed flow rate of said first pump and the fan inside the room.

To be able to load the heat buffer with the needed energy further strategies are possible. A first buffer loading strategy can be, if the time between door openings can be known by approximation, is to determine the average thermal power needed to reload the heat buffer. Together with the measured temperature over the thermoelectric elements and the properties of the thermoelectric elements, the needed electric input power to drive the elements can be obtained.

An improved buffer loading strategy could be to also take the predicted local climatologic conditions into account and plan the heat buffer loading in such a manner that a further energy reduction can be obtained. Once the predictions are known the planner could find the optimum profile in an iterative manner, taking the properties the system into account. A typical exemplary thermoelectric element has following relations, (exact relations of the used thermoelectric elements are preferably used):

$$P_{te}(t) =\cdot n_{te}\left(c_0 + c_1 \cdot \left(T_a(t) - T_b(t) + \Delta T_{loss}(t)\right) + c_2 \cdot I_{te}(t)\right) I_{te}(t) \qquad \text{(ix)}$$

$$\dot{Q}_{te}(t) =\cdot n_{te}\left(d_0 + d_1\left(T_a(t) - T_b(t) + \Delta T_{loss}(t)\right) + d_2 \cdot I_{te}(t) + d_3 \cdot\cdot \left(T_a(t) - T_b(t) + \Delta T_{loss}(t)\right) I_{te}(t) + d_4 \cdot I_{te}(t)^2\right) \qquad \text{(x)}$$

where $\dot{Q}_{te}$is the thermal power on the side of the thermoelectric element connected the heat buffer. The constants d_1, d_2, d_3, d_4, or an alternative set of constants and corresponding factors and terms, describe the properties of the used thermoelectric elements. The equation is an exemplary form for the cooling condition, an equivalent form for heating the heat buffer can be derived from the characteristics of thermoelectric elements.

From these equations a relation between the thermal power, the temperature over the thermoelectric elements and the electric power can be obtained.

$$P_{te}(t) = f\left(T_a(t) - T_b(t) + \Delta T_{loss}(t), \dot{Q}_{te}(t)\right) \qquad \text{(xi)}$$

The shape of the latter $\dot{Q}_{te}(t)$can be changed in time with the constraint that the total energy exchanged with the heat buffer $Q_{te} = \int(\dot{Q}_{te}(t)dt)$needs to be constant and equal to the energy needed to refill the heat buffer to a certain level. The possibility to adapt the shape has an effect on total consumed electric power. An iterative search procedure can find a minimal power consumption, based on the predictions, which results in a profile of $\dot{Q}_{te}(t)$that could be requested from the thermoelectric elements and that would minimize the electric power consumption of the thermoelectric elements, hence further optimizing the system efficiency.

The requested power $\dot{Q}_{te}(t)$from the series of thermoelectric elements further translates with given relations into a control signal, which can be a voltage or current, applied by a controller and (power) electronics to the thermoelectric elements which hence will by approximation transfer the requested heat, if the system is working properly.

If the time to a next door opening event is not known or varies too much, a tradeoff can be made between energy efficiency and acclimatization quality. The latter can be improved by quickly reloading the heat buffer, but this would be at reduced system efficiency or the installed power of the thermoelectric module(s) could be increased to be able to transport more heat in a more efficient manner.

Referring to FIG. 6, there is provided a schematic representation of a means for heat exchange use in embodiments of the present invention, in particular a compressor system 60 comprised in a heat pump device according to a preferred embodiment of the invention. The compressor system 60 comprises of a compressor 61, for increasing the pressure and temperature of a heat transfer fluid, and at least one of the components selected from the group consisting of a condenser 63, also referred to as a hot heat exchanger, a fan 66, a circuit 62 configured to conduit at least one heat transporting fluid, an expansion valve 64, to expand the heat transfer fluid to form an expanded heat transfer fluid, or an evaporator 65, also referred to as a cool heat exchanger. In use, the condenser 63 enables heat transfer from the heat transporting fluid to an ambient fluid, whereas the evaporator 65 enables heat transfer from an ambient fluid to the transporting fluid.

Referring to FIG.7 there is depicted a schematic representation of the integration of the compressor system 60 into the heat pump device according to a preferred embodiment of the invention when configured to be used for cooling, i.e. to decrease the temperature T_i inside 1 a room, hence the average temperature T_b of the substance(s) within the heat buffer 8 should be smaller thanT_i. In this configuration, the evaporator 65 may be placed to exchange heat between at least a part of the first liquid contained in the third liquid circuit 10 and the heat transporting fluid comprised in the circuit 62. The condenser 63 may be placed to dump the heat contained in the heat transporting fluid in the circuit 62 into at least a part of the second liquid comprised in the second liquid circuit 15. The controller 27 may be connected with the compressor 61 and/or with the expansion valve 64. According to a preferred embodiment of the heat pump device according to the invention, means for reversing the fluid flow, for example a reversing valve (not shown),may be placed in the compressor system 60 for switching from cooling to heating mode.

Referring to FIG.8, there is depicted a schematic representation of the integration of the compressor system 60 into the heat pump device according to the present invention, wherein the compressor system 60 comprises the expansion valve 64 and the compressor 61. In this configuration, the second liquid circuit 15 and the condenser 63 are equivalent means for heat exchange with an ambient fluid when the heat pump device according to the invention is used for cooling the interior 1 of a room or container. In this configuration, at least part of the evaporator 65 is disposed inside in the heat buffer 8 for heat exchange between the substance(s) inside the heat buffer 8 and the heat transporting fluid comprised in the circuit 62.

According to a preferred embodiment of the invention, at least one combination of the at least one component or system depicted in FIG. 7 and/or FIG. 8 may be combined, for example, the compressor 61, expansion valve 64 and evaporator 65 may be configured to be connected with the other components or elements depicted in FIG. 8. In particular and according to a preferred embodiment of the invention, the compressor 61 and expansion valve 64 may be connected to the at least one second means for heat distribution 17 preferably without being connected to a condenser 63 and/or a second liquid transfer pump 16. According to a preferred embodiment of the invention, a heat pump device may be configured comprising the compressor 61, condenser 63 and expansion valve 64 connected to the heat buffer 8, without the need to comprise an evaporator 65 and a third liquid transfer pump 11.The integration of a compressor system 60 within the heat pump device according the invention, is not limited to the preferred embodiments described above. Although the embodiments described in FIG.7 and FIG.8 are configuration of the invention used for cooling the interior 1 of the room, the invention may also be used for heating.

Claims

1. A heat pump device for conditioning the temperature T_i inside (1) a room, the device comprising
    a. at least one first means for heat distribution (5) configured to be at least partly disposed inside (1) said room, and configured to distribute heat between a first liquid and an interior fluid,
    b. a first liquid circuit (6) connected to said at least one first means for heat distribution (5),
    c. a first liquid transfer pump (7) configured to circulate said first liquid in said first circuit (6),
    d. at least one means for heat exchange (13) connected to a heat buffer (8) and configured to exchange heat between said first liquid and an ambient fluid, wherein said ambient fluid is located outside (20) said room,
    e. said heat buffer (8) is liquidly connected to said at least one first means for heat distribution (5), and configured to comprise at least a part of said first liquid, wherein said heat buffer (8) is designed in accordance with $Q_b = m_b cp_b (T_i - T_b^{opt})$, wherein Q_b is the heat to be comprised inside said heat buffer (8), m_b is the total mass of said at least a part of said first liquid comprised in said heat buffer (8), cp_b is the mass weighted heat capacity of said at least a part of said first liquid comprised in said heat buffer (8), where T_i is the temperature inside (1) said room and T_b^{opt} is the optimal temperature of said at least a part of said first liquid comprised in said heat buffer (8) and derived in accordance with $\frac{\delta P_{tot}}{\delta T_b}(T_b^{opt}) = 0$, $\frac{\delta^2 P_{tot}}{\delta T_b^2}(T_b^{opt}) > 0$, wherein P_{tot} is the total power required to operate said first liquid transfer pump (7), said at least one first means for heat distribution (5) and said at least one means for heat exchange (13).

2. The device according to claim 1, wherein the at least one means for heat exchange (13) comprises at least one compressor (61), a series of thermoelectric elements, or a

combination of said at least one compressor (61) and said series of thermoelectric elements.

3. The device according to claim 2, wherein said at least one compressor (61) is fluidly connected to at least one component selected from the group consisting of a condenser (63), a circuit (62), an expansion valve (64), or an evaporator (65).

4. The device according to any one of the claims 1 to 3, wherein said heat buffer (8) further comprises at least one substance selected from the group consisting of phase change materials, paraffin, gels, molten salts, or reversible exothermic hydration materials, wherein said at least one substance is separated from said first liquid, wherein m_b is the total mass of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), wherein cp_b is the mass weighted heat capacity of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), and T_b^{opt} is the optimal temperature of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8).

5. The device according to any one of claims 1 to 4, further comprising a series of measuring sensors (23, 24, 25, 26) configured to measure the temperature T_i inside (1) said room, a temperature T_a outside (20) said room, the temperature T_b of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), and the temperature at said at least one means for heat exchange (13).

6. The device according to any one of claims 1 to 5, further comprising a controller (27) to employ a relationship $P_{tot} \leq 2P_{tot}^{opt}$, in particular $P_{tot} \leq 1.5\ P_{tot}^{opt}$, more in particular $P_{tot} \leq 1.25\ P_{tot}^{opt}$, to condition the temperature inside (1) said room, wherein P_{tot} is the total power required to operate said first liquid transfer pump (7), said at least one first means for heat distribution (5) and at least one means for heat exchange (13), wherein the total optimized power P_{tot}^{opt} equals P_{tot} when the temperature T_b of said first liquid and said at

least one substance in said heat buffer (8) equals T_b^{opt} derived in accordance with $\frac{\delta P_{tot}}{\delta T_b} = 0$ and $\frac{\delta^2 P_{tot}}{\delta T_b^2}(T_b^{opt}) > 0$.

7. The device according to any one of claims 1 to 6, wherein said heat buffer (8) is at least partly disposed inside (1) said room.

8. The device according to claim any one of claims 1 to 7, wherein said first liquid circuit (6) is at least partly formed by a first plurality of refrigerant tubes and configured to be disposed inside (1) said room, wherein said first plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through.

9. The device according to any one of claims 1 to 8, further comprising
   g. at least one second means for heat distribution (17) configured to be disposed outside (20) said room, and configured to exchange heat between a second liquid and said ambient fluid,
   h. a second liquid circuit (15) disposed to liquidly connecting said at least one second means for heat distribution (17) with said at least one means for heat exchange (13), and
   i. a second liquid transfer pump (16) to circulate said second liquid in said second liquid circuit (15).

10. The device according to the previous claim, wherein said second liquid circuit (15) is at least partly formed by a second plurality of refrigerant tubes and provided to be disposed outside (20) said room, wherein said second plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through.

11. The device according to any one of claims 1 to 10, further comprising
   j. a third liquid circuit (10) disposed to liquidly connecting said heat buffer (8) with said at least one means for heat exchange (13), and
   k. a third liquid transfer pump (11) configured to circulate said first liquid in said third liquid circuit (10).

12. The device according to any one of claims 1 to 11, wherein said first liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene.

13. The device according to claim 9 or 10, wherein said second liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene.

14. Use of a heat pump device according to any one claims 1 to 13 for conditioning the temperature inside (1) a room, in particular an air cargo container transport dolly comprising a housing provided to store cargo container.

AMENDED CLAIMS
received by the International Bureau on 21 November 2017 (27.11.2017)

1. A heat pump device for conditioning the temperature T_i inside (1) a room, the device comprising
   a. at least one first means for heat distribution (5) configured to be at least partly disposed inside (1) said room, and configured to distribute heat between a first liquid and an interior fluid,
   b. a first liquid circuit (6) connected to said at least one first means for heat distribution (5),
   c. a first liquid transfer pump (7) configured to circulate said first liquid in said first circuit (6),
   d. at least one means for heat exchange (13) connected to a heat buffer (8) and configured to exchange heat between said first liquid and an ambient fluid, wherein said ambient fluid is located outside (20) said room,
   e. said heat buffer (8) is liquidly connected to said at least one first means for heat distribution (5), and configured to comprise at least a part of said first liquid, wherein said heat buffer (8) is designed in accordance with $Q_b = m_b cp_b\left(T_i - T_b^{opt}\right)$, wherein Q_b is the heat to be comprised inside said heat buffer (8), m_b is the total mass of said at least a part of said first liquid comprised in said heat buffer (8), cp_b is the mass weighted heat capacity of said at least a part of said first liquid comprised in said heat buffer (8), where T_i is the temperature inside (1) said room and T_b^{opt} is the optimal temperature of said at least a part of said first liquid comprised in said heat buffer (8) and derived in accordance with $\frac{\delta P_{tot}}{\delta T_b}\left(T_b^{opt}\right) = 0$, $\frac{\delta^2 P_{tot}}{\delta T_b^2}\left(T_b^{opt}\right) > 0$, wherein P_{tot} is the total power required to operate said first liquid transfer pump (7), said at least one first means for heat distribution (5) and said at least one means for heat exchange (13),
   f. a controller (27) to employ a relationship $P_{tot} \leq 2P_{tot}^{opt}$, in particular $P_{tot} \leq 1.5\ P_{tot}^{opt}$, more in particular $P_{tot} \leq 1.25\ P_{tot}^{opt}$, to condition the temperature inside (1) said room,

wherein the total optimized power P_{tot}^{opt} equals P_{tot} when the temperature T_b of said first liquid and said at least one substance in said heat buffer (8) equals T_b^{opt} derived in accordance with $\frac{\delta P_{tot}}{\delta T_b} = 0$ and $\frac{\delta^2 P_{tot}}{\delta T_b^2}(T_b^{opt}) > 0$.

2. The device according to claim 1, wherein the at least one means for heat exchange (13) comprises at least one compressor (61), a series of thermoelectric elements, or a combination of said at least one compressor (61) and said series of thermoelectric elements.

3. The device according to claim 2, wherein said at least one compressor (61) is fluidly connected to at least one component selected from the group consisting of a condenser (63), a circuit (62), an expansion valve (64), or an evaporator (65).

4. The device according to any one of the claims 1 to 3, wherein said heat buffer (8) further comprises at least one substance selected from the group consisting of phase change materials, paraffin, gels, molten salts, or reversible exothermic hydration materials, wherein said at least one substance is separated from said first liquid, wherein m_b is the total mass of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), wherein cp_b is the mass weighted heat capacity of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), and T_b^{opt} is the optimal temperature of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8).

5. The device according to any one of claims 1 to 4, further comprising a series of measuring sensors (23, 24, 25, 26) configured to measure the temperature T_i inside (1) said room, a temperature T_a outside (20) said room, the temperature T_b of said at least a part of said first liquid and said at least one substance comprised in said heat buffer (8), and the temperature at said at least one means for heat exchange (13).

6. The device according to any one of claims 1 to 5, wherein said heat buffer (8) is at least partly disposed inside (1) said room.

7. The device according to claim any one of claims 1 to 6, wherein said first liquid circuit (6) is at least partly formed by a first plurality of refrigerant tubes and configured to be disposed inside (1) said room, wherein said first plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through.

8. The device according to any one of claims 1 to 7, further comprising
   g. at least one second means for heat distribution (17) configured to be disposed outside (20) said room, and configured to exchange heat between a second liquid and said ambient fluid,
   h. a second liquid circuit (15) disposed to liquidly connecting said at least one second means for heat distribution (17) with said at least one means for heat exchange (13), and
   i. a second liquid transfer pump (16) to circulate said second liquid in said second liquid circuit (15).

9. The device according to the previous claim, wherein said second liquid circuit (15) is at least partly formed by a second plurality of refrigerant tubes and provided to be disposed outside (20) said room, wherein said second plurality of refrigerant tubes are made of a heat conductive metal provided to convey heat there through.

10. The device according to any one of claims 1 to 9, further comprising
   j. a third liquid circuit (10) disposed to liquidly connecting said heat buffer (8) with said at least one means for heat exchange (13), and
   k. a third liquid transfer pump (11) configured to circulate said first liquid in said third liquid circuit (10).

11. The device according to any one of claims 1 to 10, wherein said first liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene.

12. The device according to claim 9 or 11, wherein said second liquid is selected from the group consisting of water, water-glycol mixture, mineral oil, terphenyl, liquid metals, or ethylene.

13. Use of a heat pump device according to any one claims 1 to 12 for conditioning the temperature inside (1) a room, in particular an air cargo container transport dolly comprising a housing provided to store cargo container.

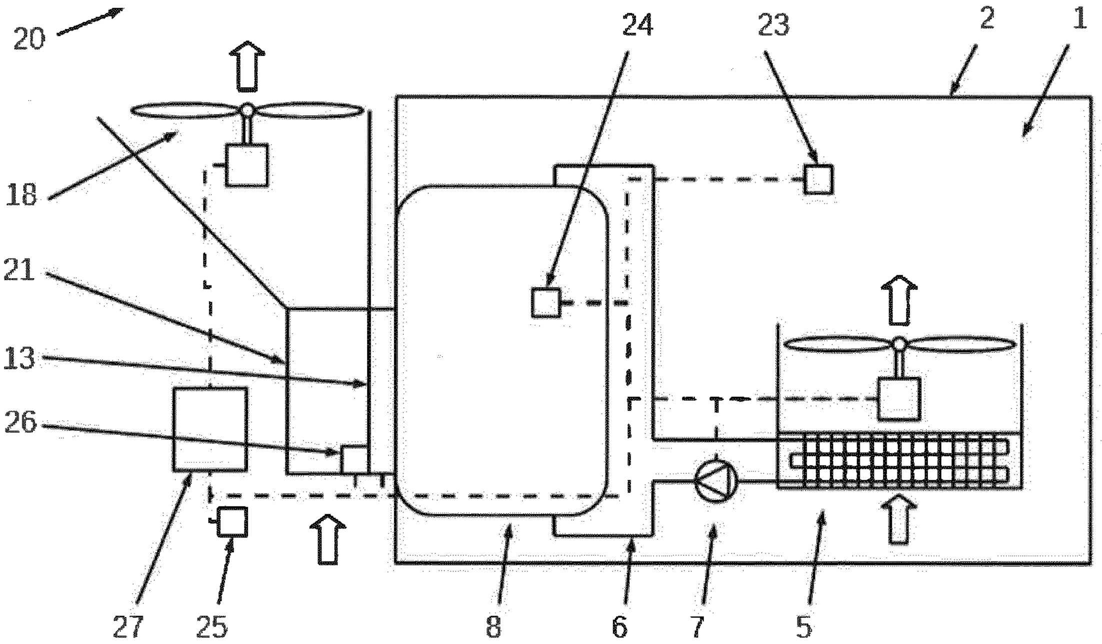
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FIG.1

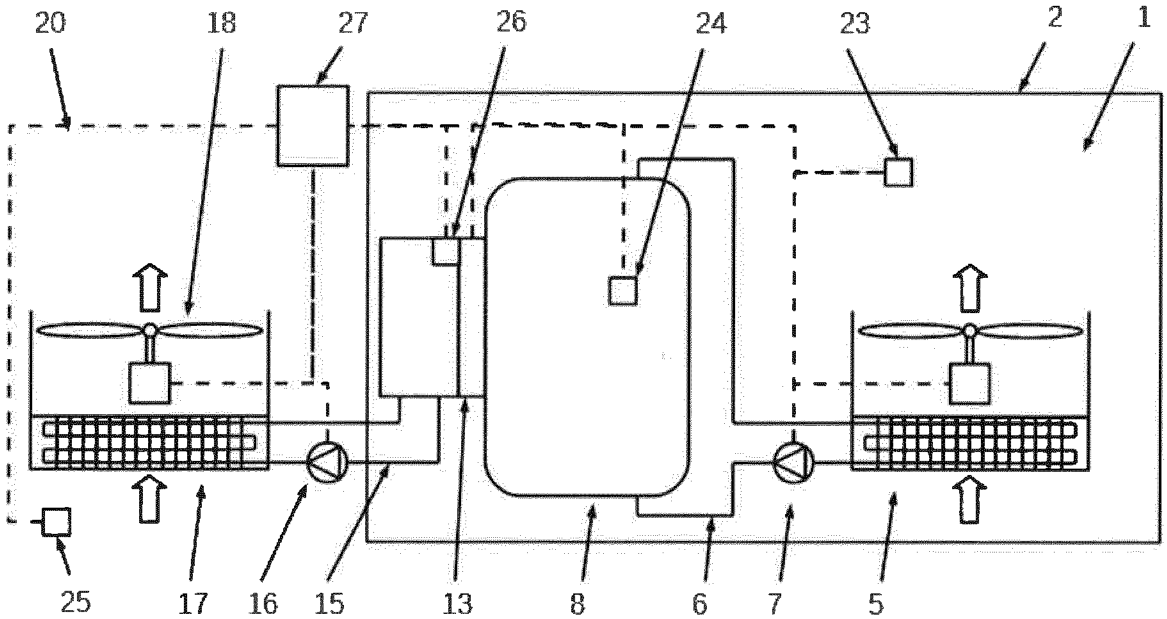
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FIG.2

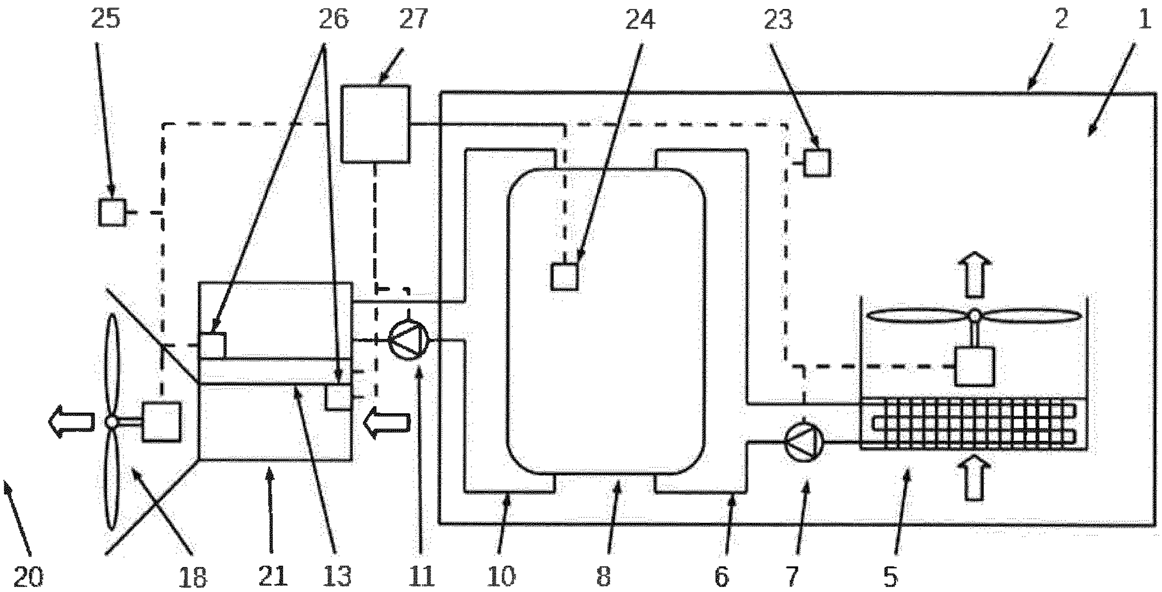
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FIG.3

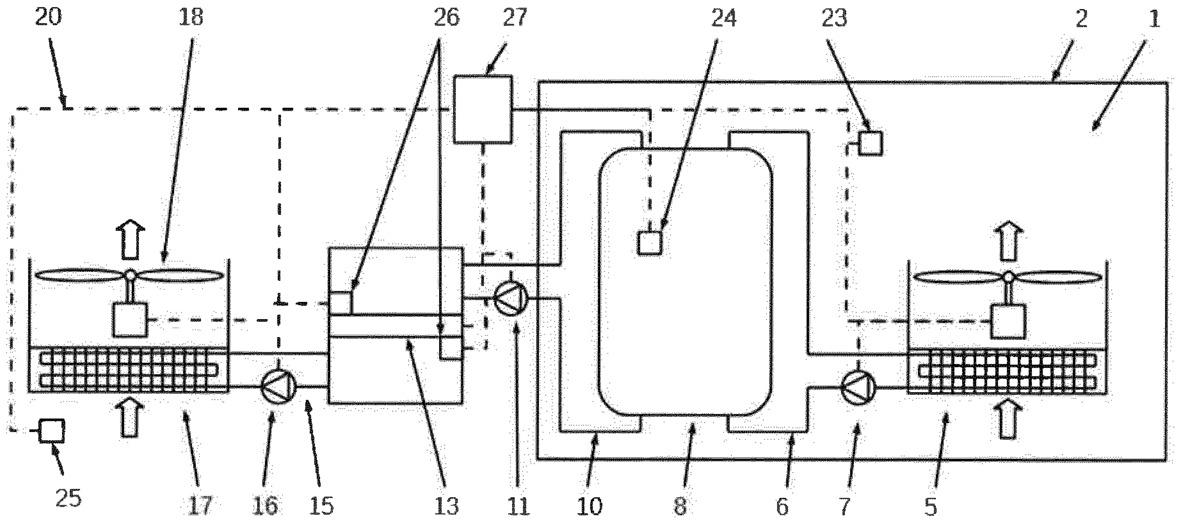
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FIG.4

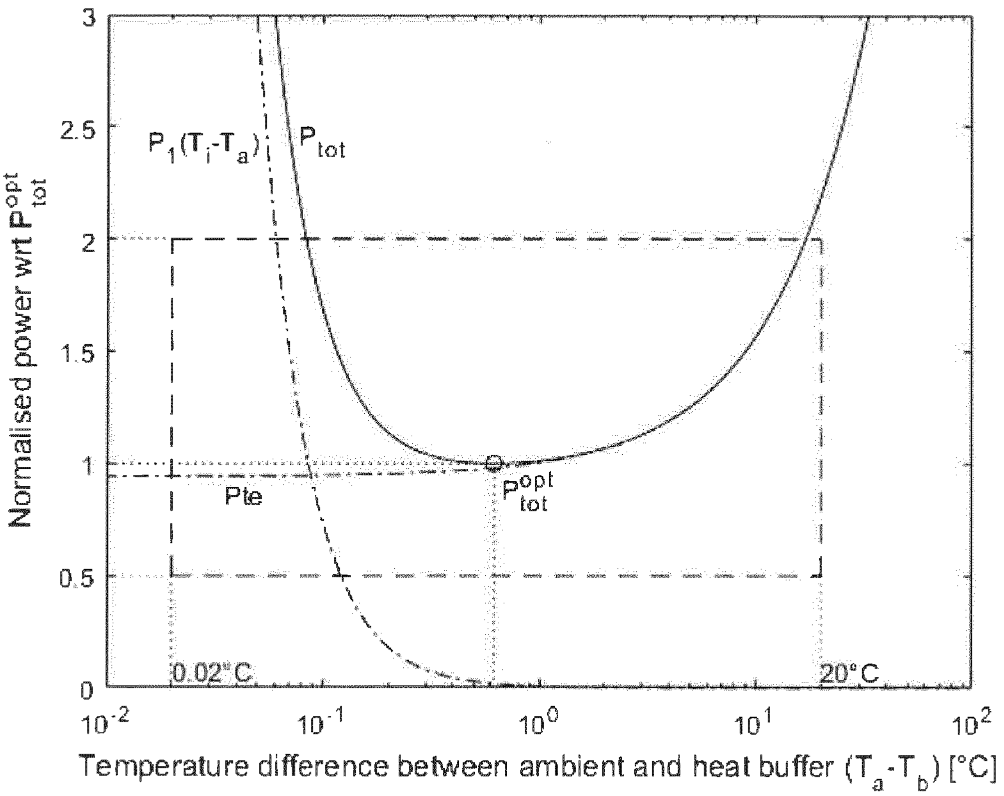
3
2.5
2
1.5
1
0.5
0
Normalised power wrt P_{tot}^{opt}
$P_1(T_i-T_a)$
P_{tot}
Pte
P_{tot}^{opt}
0.02°C
20°C
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Temperature difference between ambient and heat buffer (T_a-T_b) [°C]

FIG. 5

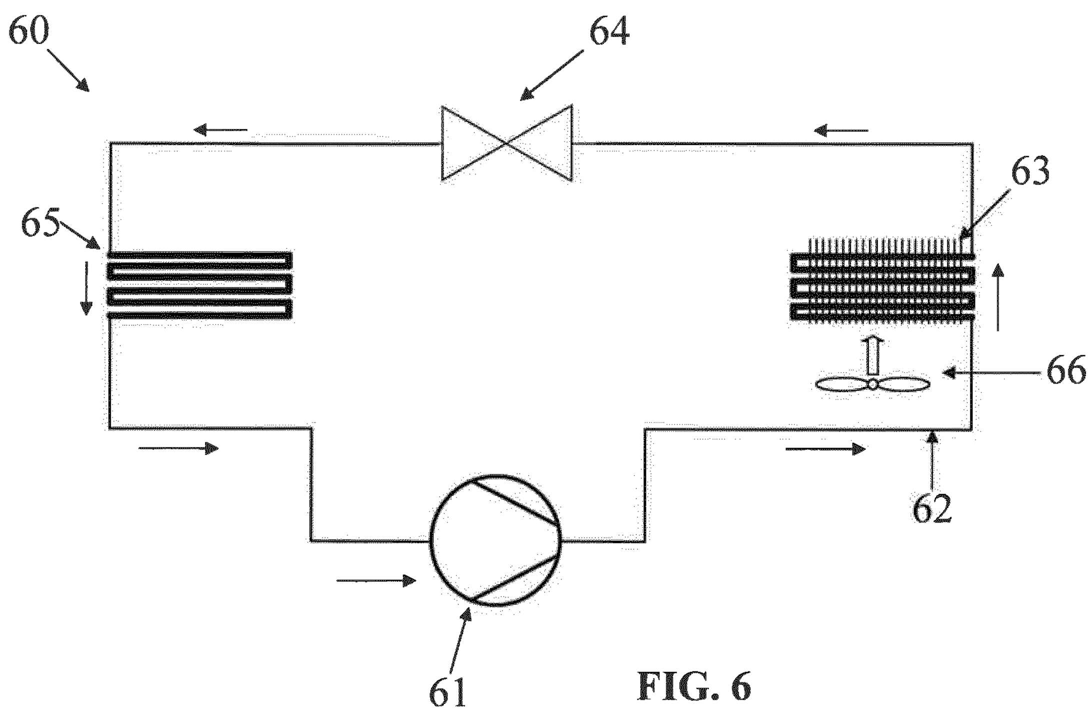
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FIG. 6

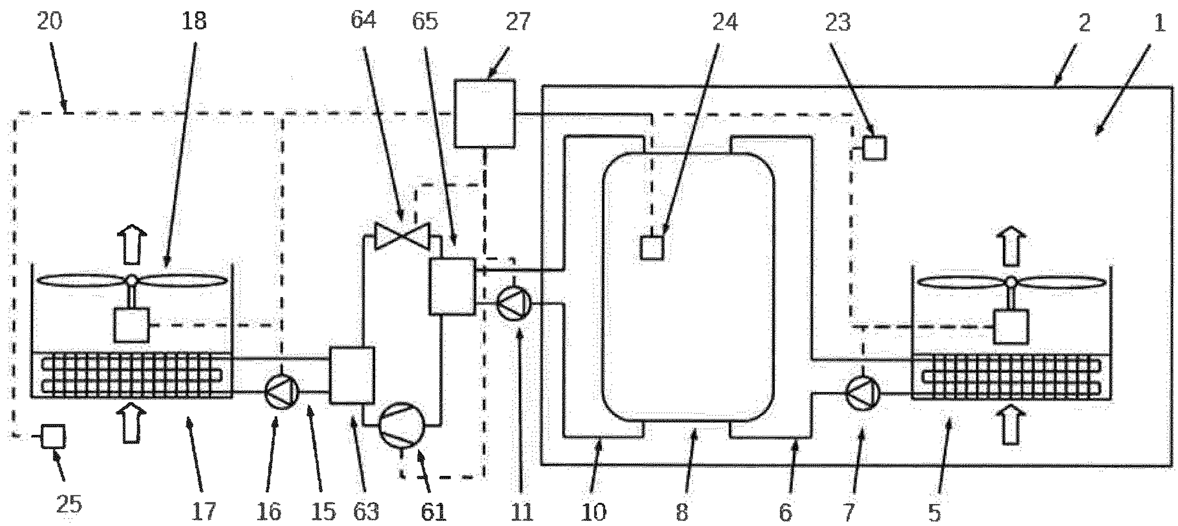
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FIG.7

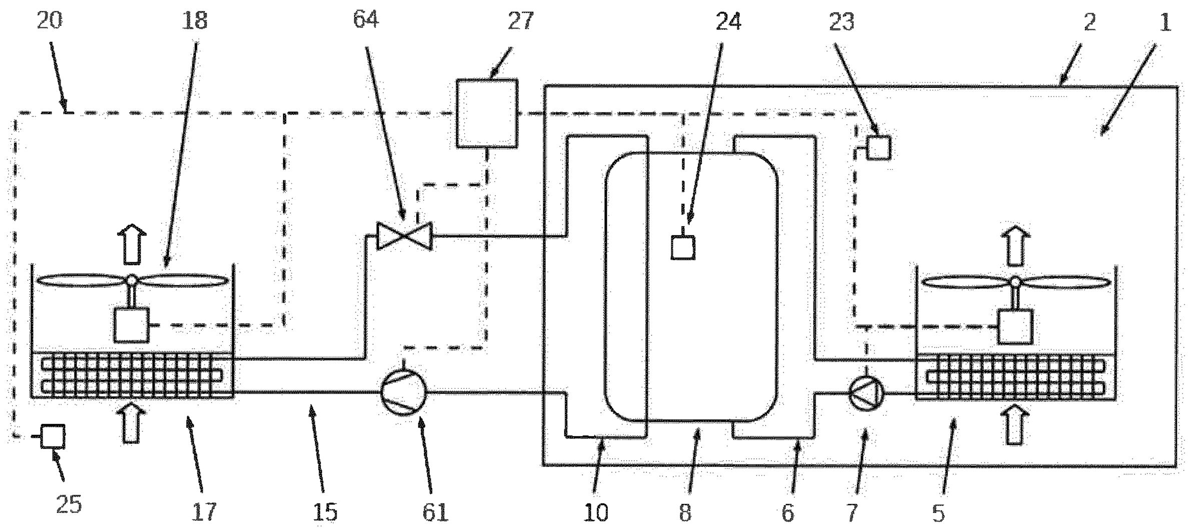
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FIG.8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/066031

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25B21/02 F25B30/00
ADD. F25B25/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 2 306 111 A1 (DAIKIN IND LTD [JP]) 6 April 2011 (2011-04-06) paragraphs [0006] - [0007], [0050] - [0057] paragraphs [0062] - [0080]; figure 1 -----	1-3,5,7, 8,11-14 4,6,9,10
X A	WO 2008/113121 A1 (L P E GROUP PTY LTD [AU]; MILOJKOVIC PETER [AU]) 25 September 2008 (2008-09-25) page 7, line 14 - page 10, line 29; figures 1,2 -----	1-4,7,8, 11-14 5,6,9,10
X A	US 2016/003502 A1 (ZELISSEN MARCUS JOZEF GERTRUDIS [NL]) 7 January 2016 (2016-01-07) paragraphs [0037] - [0042]; figures 1,3,4,5 -----	1,2,4, 7-10,14 5,6,12, 13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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
11 September 2017	22/09/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Weisser, Meinrad

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/066031

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2306111 A1	06-04-2011	EP 2306111 A1	06-04-2011
		WO 2009148011 A1	10-12-2009
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US 2016003502 A1	07-01-2016	EP 2959237 A1	30-12-2015
		US 2016003502 A1	07-01-2016
		WO 2014129886 A1	28-08-2014