

OPERATION CONTROL SYSTEM FOR COLD GENERATION APPARATUS

FIELD OF THE INVENTION

[0001]

5 The present invention relates to an operation control system for a cold generation apparatus, and in particular to an operation control system for operating a cold generation apparatus in an energy saving manner.

DESCRIPTION OF THE RELATED ART

10 [0002]

 In the countries or regions such as the middle east where the outside air temperature is high throughout the year, the temperature difference between the cold water supplied from a cold generation apparatus (which generates cold) to an external load apparatus (which uses the cold and is, for example, the air conditioner) and the cold water returned from the external load apparatus to the cold generation apparatus is great. Therefore, the tandem-refrigerator type cold generation apparatuses, in which multiple refrigerators, for example, a high-temperature side refrigerator and a low-temperature side refrigerator, are connected in series, are used. The high-temperature side refrigerator processes the (high-temperature side) cold water returned from the external load apparatus, and the low-temperature side refrigerator processes the (low-temperature side) cold water after the cooling load is reduced by the cooling by the high-temperature side refrigerator. See, for example, Patent Document 1 and Patent Document 2 for the operation control of the tandem-refrigerator type cold generation apparatuses as above.

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PRIOR ART DOCUMENTS

Patent Documents

[0003]

Patent Document 1: JPS61-225528

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Patent Document 2: JPS60-023760

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0004]

35 However, in the conventional tandem-refrigerator type cold generation apparatuses as disclosed in Patent Document 1 and Patent Document 2, regardlessly of

the cooling load to be processed, the low-temperature side refrigerator is operated under a rated condition, and the high-temperature side refrigerator is operated under a partial cooling-load condition. That is, the refrigerators are not operated in an energy saving manner corresponding to the cooling load. In addition, the cold water pump, the cooling-water pump, and the cooling-tower fans in the conventional tandem-refrigerator type cold generation apparatuses are not operated in an energy saving manner corresponding to the condition of the outside air (e.g., the wet-bulb temperature).

[0005]

In the above situation, establishment of an operation control system for operating the tandem-refrigerator type cold generation apparatus in an energy saving manner corresponding to the cooling load and the condition of the outside air is demanded.

[0006]

Embodiments of the present invention have been developed in view of the above circumstances. Embodiments of the present invention seek to provide an operation control system for operating the tandem-refrigerator type cold generation apparatus, which can reduce the total energy consumption in the cold generation apparatus according to the cooling load and the condition of the outside air.

MEANS FOR SOLVING THE PROBLEMS

[0007]

According to the first aspect of the present invention, there is provided an operation control system for a cold generation apparatus including: cold-water piping through which cold water is supplied to an external load apparatus; a plurality of heat-pump type refrigerators which are arranged in series along the cold-water piping, and each has an evaporator and a condenser for cooling the cold water; a cold-water pump which supplies the cold water returned from the external load apparatus, to the external load apparatus through the refrigerators so that the cold water is cooled in the evaporator in each of the refrigerators; cooling-water pumps which are respectively arranged in correspondence with the refrigerators for supplying cooling water to the condenser in the refrigerators through cooling-water piping; and cooling towers which are respectively arranged for the refrigerators, and respectively have cooling-tower fans for cooling the cooling water with outside air. The operation control system includes: acquisition means which acquires a wet-bulb temperature of

the outside air taken into the cooling towers by the cooling-tower fans, a refrigeration load ratio as a ratio of an actual refrigeration load to a sum of preset values of refrigeration performance of the refrigerators, and a cold-water flow ratio as a ratio of an actual flow rate of the cold-water to a rated flow rate of the cold water; a simulator
5 which performs a simulation for determining an optimum value of a cooling-water flow ratio as a flow ratio between the cooling-water pumps corresponding to the refrigerators, an optimum value of an air flow ratio as a ratio between flow rates in the cooling-tower fans in the cooling towers, and an optimum value of a load sharing ratio as a ratio in which the refrigeration load ratio is shared (i.e., the actual refrigeration
10 load is shared) by the refrigerators, by calculating a coefficient of performance of the entire cold generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable, under a condition determined by the wet-bulb temperature, the refrigeration load ratio, and the cold-water flow ratio which are acquired by the acquisition means, where the optimum value of the cooling-water flow ratio, the optimum value of the air
15 flow ratio, and the optimum value of the load sharing ratio maximize a coefficient of performance (COP) of the cold generation apparatus; and control means which controls the cold-water pump on the basis of the cold-water flow ratio, controls temperatures of the cold water at outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls the cooling-water pumps and the
20 cooling-tower fans in the cooling towers on the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow ratio.

[0008]

As described above, in the above cold generation apparatus to which the operation control system according to the first aspect of the present invention is
25 applied, a cooling-water pump and a cooling-tower fan are provided for each of the refrigerators.

[0009]

In the above operation control system, the control means controls the cold-water pump of each refrigerator on the basis of the cold-water flow ratio. In
30 addition, the simulator performs a simulation for determining an optimum value of the cooling-water flow ratio, an optimum value of the air flow ratio, and an optimum value of the load sharing ratio which maximize the COP of the entire cold generation apparatus, where the cooling-water flow ratio is a flow ratio between the cooling-water pumps corresponding to the refrigerators, the air flow ratio is a ratio between air flow
35 rates in the cooling-tower fans in the cooling towers, and the load sharing ratio is a ratio in which the actual refrigeration load is shared by the refrigerators. Herein, the cooling-water flow ratio, the air flow ratio, and the load sharing ratio are variables in

the above simulation. Then, the control means controls the temperatures of the cold water at the outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls the cooling-water pumps and the cooling-tower fans in the cooling towers on the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow ratio.

[0010]

Here, a term of the COP is an abbreviation for “the Coefficient of Performance”, and also called a performance coefficient. Further, the preset values of refrigeration performance of the refrigerators are values of rated refrigeration performance of the refrigerators or refrigeration performance of the refrigerators which are arbitrarily set by a user.

[0011]

In the operation control system for the cold generation apparatus according to the first aspect of the present invention, the acquisition means which acquires the wet-bulb temperature of the outside air taken into the cooling towers by the cooling-tower fans, the refrigeration load ratio as the ratio of the actual refrigeration load to the sum of the preset values of refrigeration performance of the refrigerators, and the cold-water flow ratio as the ratio of the actual flow rate of the cold-water to the rated flow rate of the cold water. That is, it is possible to recognize the actually needed cooling performance in comparison with the total rated cooling performance of the entire cold generation apparatus.

[0012]

After the above acquisition, the simulator performs a simulation for determining an optimum value of the cooling-water flow ratio, an optimum value of the air flow ratio, and an optimum value of the load sharing ratio which maximize the COP, where the cooling-water flow ratio, the air flow ratio, and the load sharing ratio are variables. Therefore, it is possible to determine the ratio in which the refrigerators should share the load of refrigeration, the ratio in which the cooling-water pumps corresponding to the refrigerators should share the load of flowing the cooling water, and the ratio in which the cooling-tower fans corresponding to the refrigerators should share the load of cooling the cooling water in such a manner that the COP of the entire cold generation apparatus is maximized under the condition determined by the wet-bulb temperature of the outside air, the refrigeration load ratio, and the cold-water flow ratio which are acquired by the acquisition means.

[0013]

In addition, the control means controls the temperatures of the cold water at

the outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls the cooling-water pumps and the cooling-tower fans in the cooling towers on the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow ratio.

5 [0014]

Thus, the operation control system according to the first aspect of the present invention can control the cold generation apparatus so that the power consumption in the entire cold generation apparatus (of the tandem-refrigerator type) is minimized according to the cooling load and the outside air.

10 [0015]

In the operation control system for the cold generation apparatus according to the first aspect of the present invention, it is preferable that the simulator store a control table which indicates, in correspondence with the refrigeration load ratio and the wet-bulb temperature, the optimum value of the load sharing ratio or one or more optimum values of one or more of the temperatures of the cold water at the outlets of the respective refrigerators, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio which maximize the COP of the cold generation apparatus. In addition, it is preferable that when the refrigeration load ratio and the wet-bulb temperature which are acquired by the acquisition means are inputted into the simulator, the simulator select the optimum value of the load sharing ratio, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio by reference to the control table.

[0016]

If the control table is not provided in the simulator, the simulator is required to repeat the operations of changing the load sharing ratio, the cooling-water flow ratio, and the air flow ratio as variables and calculating the COP until the maximum COP is determined. In addition, when the wet-bulb temperature of the outside air, the refrigeration load ratio, and the cold-water flow ratio vary, the simulator is required to perform the simulation again. Therefore, if the control table is not provided in the simulator, the calculation load imposed on the simulator becomes great, so that the power consumption in the entire operation control system increases.

[0017]

On the other hand, in the case where the control table is stored in the simulator, the simulator can select the optimum load sharing ratio, the optimum cooling-water flow ratio, and the optimum air flow ratio in correspondence with the wet-bulb temperature of the outside air and the refrigeration load ratio by reference to

the control table, so that the simulation load can be remarkably reduced.

[0018]

Further, in the operation control system for the cold generation apparatus according to the first aspect of the present invention, it is preferable that the operation control system further include a first inverter which enables change of a rotational frequency of the cold-water pump, second inverters which enable change of rotational frequencies of the cooling-water pumps, and third inverters which enable change of rotational frequencies of the cooling-tower fans, and the control means control through the first inverter, the second inverters, the third inverters the rotational frequencies of the cold-water pump, the cooling-water pumps, and the cooling-tower fans by converting the optimum value of the cold-water flow ratio, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio into inverter frequencies, and outputting the inverter frequencies to the first inverter, the second inverters, and the third inverters.

[0019]

In this case, it is possible to further reduce the power consumption in the cold generation apparatus by controlling the rotational frequencies of the cold-water pump, the cooling-water pumps and the cooling-tower fans through the invertors.

[0020]

Furthermore, in the operation control system for the cold generation apparatus according to the first aspect of the present invention, it is preferable that when one or more of the refrigerators shares 0% of the actual refrigeration load according to the optimum value of the load sharing ratio, the control means stop operation of the one or more of the refrigerators, and operation of one or more of the cooling-water pumps and one or more of the cooling-tower fans corresponding to the one or more of the refrigerators. In this case, the power consumption in the cold generation apparatus can be further reduced.

[0021]

According to the second aspect of the present invention, there is provided an operation control system for a cold generation apparatus including: cold-water piping through which cold water is supplied to an external load apparatus; a plurality of heat-pump type refrigerators which are arranged in series along the cold-water piping, and each have an evaporator and a condenser for cooling the cold water; a cold-water pump which supplies the cold water returned from the external load apparatus, to the external load apparatus through the refrigerators so that the cold

water is cooled in the evaporator in each of the refrigerators; at least one cooling tower which is arranged for the refrigerators, having a cooling-tower fan for cooling cooling water with outside air; and cooling-water pumps which are respectively arranged in correspondence with the refrigerators for distributing the cooling water cooled in the cooling tower, to the refrigerators through cooling-water piping, so that the cooling water cooled in the cooling tower is supplied to the condenser in each of the refrigerators. The operation control system includes: acquisition means which acquires a wet-bulb temperature of the outside air taken into the cooling tower by the cooling-tower fan, a refrigeration load ratio as a ratio of an actual refrigeration load to a sum of preset values of refrigeration performance of the refrigerators, and a cold-water flow ratio as a ratio of an actual flow rate of the cold-water to a rated flow rate of the cold water; a simulator which performs a simulation for determining an optimum value of a cooling-water flow ratio as a flow ratio between the cooling-water pumps corresponding to the refrigerators, an optimum value of an air flow rate in the cooling-tower fan in the cooling tower, and an optimum value of a load sharing ratio as a ratio in which the actual refrigeration load is shared by the refrigerators, by calculating a coefficient of performance of the entire cold generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable, under a condition determined by the wet-bulb temperature, the refrigeration load ratio, and the cold-water flow ratio which are acquired by the acquisition means, where the optimum value of the cooling-water flow ratio, the optimum value of the air flow rate, and the optimum value of the load sharing ratio maximize a coefficient of performance of the cold generation apparatus; and control means which controls the cold-water pump on the basis of the cold-water flow ratio, controls temperatures of the cold water at outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls the cooling-water pumps and the cooling-tower fan in the cooling tower on the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow rate.

[0022]

As described above, in the above cold generation apparatus to which the operation control system according to the second aspect of the present invention is applied, at least one cooling tower is provided for multiple refrigerators, and the cooling water cooled by the cooling-tower fan in the cooling tower is distributed to the multiple refrigerators by using the cooling-water pumps corresponding to the multiple refrigerators. In this case, the simulator in the operation control system according to the second aspect of the present invention can perform the simulation in a similar manner to the simulator in the operation control system according to the first aspect of the present invention, except that “the air flow ratio between the cooling-tower fans”

in the first aspect of the present invention should be replaced with “the air flow rate in the cooling-tower fan”.

[0023]

According to the third aspect of the present invention, there is provided an
5 operation control system for a cold generation apparatus including: cold-water piping
through which cold water is supplied to an external load apparatus; a plurality of
heat-pump type refrigerators which are arranged in series along the cold-water piping,
and each have an evaporator and a condenser for cooling the cold water; a cold-water
10 pump which supplies the cold water returned from the external load apparatus, to the
external load apparatus through the refrigerators so that the cold water is cooled in the
evaporator in each of the refrigerators; a cooling tower which is arranged for the
refrigerators, and has a cooling-tower fan for cooling cooling water with outside air;
and a cooling-water pump which is arranged for supplying the cooling water cooled in
15 the cooling tower, to the refrigerators from a high-temperature side to a
low-temperature side in succession through cooling-water piping, so that the cooling
water cooled in the cooling tower is supplied to the condenser in each of the
refrigerators. The operation control system includes: acquisition means which acquires
a wet-bulb temperature of the outside air taken into the cooling tower by the
20 cooling-tower fan, a refrigeration load ratio as a ratio of an actual refrigeration load to
a sum of preset values of refrigeration performance of the refrigerators, and a
cold-water flow ratio as a ratio of an actual flow rate of the cold-water to a rated flow
rate of the cold water; a simulator which performs a simulation for determining an
optimum value of a cooling-water flow rate in the cooling-water pump, an optimum
25 value of an air flow rate in the cooling-tower fan in the cooling tower, and an optimum
value of a load sharing ratio as a ratio in which the actual refrigeration load is shared
by the refrigerators, by calculating a coefficient of performance of the entire cold
generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable,
under a condition determined by the wet-bulb temperature, the refrigeration load ratio,
30 and the cold-water flow ratio which are acquired by the acquisition means, where the
optimum value of the cooling-water flow rate, the optimum value of the air flow rate,
and the optimum value of the load sharing ratio maximize a coefficient of performance
of the cold generation apparatus; and control means which controls the cold-water
pump on the basis of the cold-water flow ratio, controls temperatures of the cold water
at outlets of the refrigerators on the basis of the optimum value of the load sharing
35 ratio, and controls the cooling-water pump and the cooling-tower fan in the cooling
tower on the basis of the optimum value of the cooling-water flow rate and the
optimum value of the air flow rate.

[0024]

As described above, in the above cold generation apparatus to which the operation control system according to the third aspect of the present invention is applied, at least one cooling tower is provided for multiple refrigerators, and the cooling water cooled by the cooling-tower fan in the cooling tower is supplied to the multiple refrigerators in succession from the high-temperature side to the low-temperature side. In this case, the simulator in the operation control system according to the third aspect of the present invention can perform the simulation in a similar manner to the simulator in the operation control system according to the first aspect of the present invention, except that “the air flow ratio between the cooling-tower fans” in the first aspect of the present invention should be replaced with “the air flow rate in the cooling-tower fan”, and “the flow ratio between the cooling-water pumps” in the operation control system according to the first aspect of the present invention should be replaced with “the flow rate in the cooling-water pump”.

[0025]

Although multiple refrigerators are necessary in the cold generation apparatus to which the operation control system according to the first to third aspects of the present invention is applied, it is sufficient to provide at least one cooling tower for the multiple refrigerators as long as the at least one cooling tower has a cooling capacity which can accommodate the refrigeration capacities of the multiple refrigerators.

[0026]

It is preferable that each of the cold generation apparatuses in the first to third aspects of the present invention further include bypass piping which is arranged for each of the refrigerators and bypasses each of the refrigerators. Further, it is preferable that the operation control system have a control valve which is arranged for each of the refrigerators, can be opened for allowing passage through the bypass piping for each of the refrigerators, and can be closed for stopping passage through the bypass piping for each of the refrigerators. In this case, the control means opens the control valve arranged for each of one or more of the refrigerators when operation of the one or more of the refrigerators is stopped.

[0027]

If the cold water flows into a stopped refrigerator, the circulation resistance and the load imposed on the cold-water pump increase. However, in the case where the cold water bypasses the stopped refrigerator by using the bypass piping, the load imposed on the cold-water pump can be reduced, and therefore the power consumption

can be reduced.

EFFECT OF THE INVENTION

[0028]

5 According to embodiments of the present invention, the tandem-refrigerator type cold generation apparatus can be controlled in such a manner that the power consumption in the entire cold generation apparatus is reduced in correspondence with the cooling load and the condition of the outside air. Therefore, it is possible to provide an operation control system for a cold generation apparatus, the system
10 capable of more remarkably reducing the power consumption than conventional systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029]

15 FIG. 1 is a diagram illustrating configurations of a cold generation apparatus and an operation control system for the cold generation apparatus according to a first embodiment of the present invention;

 FIG. 2 is a diagram illustrating configurations of a cold generation apparatus and an operation control system A for the cold generation apparatus as a first variation
20 of the first embodiment of the present invention;

 FIG. 3 is a diagram illustrating configurations of a cold generation apparatus and an operation control system for the cold generation apparatus as a second variation of the first embodiment of the present invention;

 FIG. 4 is a diagram illustrating configurations of a cold generation apparatus and an operation control system for the cold generation apparatus as a third variation
25 of the first embodiment of the present invention;

 FIG. 5 is a diagram indicating a sequence of operations for a simulation performed by a simulator;

 FIG. 6 is a diagram illustrating an example of a part of a control table, in
30 which the optimum value of the relative cooling-water flow rate in a high-temperature side cooling-water pump is indicated in correspondence with the refrigeration load ratio and the wet-bulb temperature;

 FIG. 7 is a diagram illustrating an example of a part of the control table, in which the optimum value of the relative air flow rate in a high-temperature side cooling-tower fan is indicated in correspondence with the refrigeration load ratio and
35 the wet-bulb temperature;

 FIG. 8 is a diagram illustrating an example of a part of the control table, in

which the optimum temperature of cold water at the outlet of a high-temperature side refrigerator is indicated in correspondence with the refrigeration load ratio and the wet-bulb temperature;

FIG. 9 is a diagram illustrating configurations of a cold generation apparatus and an operation control system for the cold generation apparatus according to a second embodiment of the present invention; and

FIG. 10 is a diagram illustrating configurations of a cold generation apparatus and an operation control system for the cold generation apparatus according to a third embodiment of the present invention.

MODES FOR CARRYING OUT THE INVENTION

[0030]

Hereinafter, the operation control systems for cold generation apparatuses as preferable embodiments of the present invention will be explained with reference to the accompanying drawings. In addition, in the following explanations, identical or equivalent elements or constituents may be indicated by the same reference numbers through all the embodiments and variations.

[0031]

<<Cold Generation Apparatus and Operation Control System for the Same>>

FIG. 1 is a diagram illustrating configurations of a cold generation apparatus A and an operation control system for the cold generation apparatus according to the first embodiment.

[0032]

The cold generation apparatus A is an apparatus for supplying cold to an external load apparatus B which uses the cold and is, for example, an air conditioner. In the cold generation apparatus of FIG. 1, two refrigerators, a high-temperature side refrigerator and a low-temperature side refrigerator, are arranged in series. Specifically, the two refrigerators 1 and 2 are series arranged midway in cold-water piping 17a, through which cold water is supplied to the external load apparatus B and cold water heated by the external load apparatus B is returned to the cold generation apparatus.

[0033]

The high-temperature side refrigerator 1 is the refrigerator which the cold water returned from the external load apparatus B first passes through, and the low-temperature side refrigerator 2 is the refrigerator which cools the cold water incompletely cooled by the high-temperature side refrigerator 1. to a target temperature, and supplies the cooled cold water to the external load apparatus B. Although the two

refrigerators are arranged in the example of FIG. 1, more than two refrigerators may be arranged.

[0034]

The refrigerators 1 and 2 are heat-pump type refrigerators. Although the internal constructions of the heat-pump type refrigerators 1 and 2 are not indicated, an evaporator and a condenser are arranged as main components in each of the refrigerators 1 and 2 in such a manner that refrigerant circulates through the evaporator and the condenser. In each of the refrigerators 1 and 2, the cold water flowing through the cold-water piping 17a is cooled by evaporating by the evaporator the refrigerant in the liquefied form (i.e., liquefied refrigerant) into vaporized refrigerant, the vaporized refrigerant is condensed into the liquefied refrigerant by being cooled by the condenser, and the refrigerant liquefied by the condenser is returned to the evaporator. The heat-pump type refrigerators may be, for example, turbo refrigerators, or absorption refrigerators.

[0035]

In the cold-water piping 17a, a cold-water pump 3, a cold-water flow meter 11a, a first thermometer 12a, a second thermometer 12b, and a third thermometer 12c are arranged as well as the refrigerators 1 and 2. The first thermometer 12a measures the temperature of the cold water on the inlet side of the high-temperature side refrigerator 1, the second thermometer 12b measures the temperature of the cold water on the outlet side of the high-temperature side refrigerator 1, and the third thermometer 12c measures the temperature of the cold water on the outlet side of the low-temperature side refrigerator 2. (The temperature of the cold water on the inlet side of the low-temperature side refrigerator 2 is identical to the temperature of the cold water on the outlet side of the high-temperature side refrigerator 1.) Therefore, the cold water heated by the external load apparatus B is conveyed by the cold-water pump 3 through the cold-water piping 17a, and passes through the high-temperature side refrigerator 1, in which the cold water is cooled to a predetermined temperature. Subsequently, the cold water cooled to the predetermined temperature passes through the low-temperature side refrigerator 2, in which the cold water is further cooled to the target temperature. Thereafter, the cold water cooled to the target temperature is supplied to the external load apparatus B.

[0036]

The cold-water flow meter 11a and the first, second, and third thermometers 12a, 12b, and 12c are connected to a control means 23 (explained later) through cables, through which the measured values are inputted into the control means 23. For simple

illustration, the cables for the above connections to the control means 23 are not shown in FIG. 1 (and also in FIGS. 2 to 4 and 9, and 10).

[0037]

In addition, an inverter 8, which is connected to a control instruction unit 25 in the control means 23, is connected to a driving motor (not shown) for driving the cold-water pump 3. The control instruction means 25 controls through the inverter 8 the rotational frequency of the driving motor for the cold-water pump 3 according to the cold-water flow ratio L_{rate} (%), which is the ratio of the actual flow rate of the cold water to the rated flow rate of the cold water.

[0038]

Further, bypass piping 17b connecting the inlet side and the outlet side of the high-temperature side refrigerator 1 is arranged for the high-temperature side refrigerator 1, and a control valve 15 is arranged in the bypass piping 17b. The control valve 15 is connected to the control instruction unit 25 in the control means 23 through a cable. When the control instruction unit 25 closes the control valve 15, the cold water flowing through the cold-water piping 17a flows into both of the high-temperature side refrigerator 1 and the low-temperature side refrigerator 2. When the control instruction unit 25 opens the control valve 15, the cold water flowing through the cold-water piping 17a bypasses the high-temperature side refrigerator 1 and flows through only the low-temperature side refrigerator 2.

[0039]

Cooling towers 6 and 7 are respectively arranged for the high-temperature side refrigerator 1 and the low-temperature side refrigerator 2. For each of the refrigerators 1 and 2, cooling-water piping 18a or 18b, which is a circulation path of cooling water, is arranged between the condenser and the cooling tower 6 or 7. That is, the cooling water circulates through the cooling-water piping 18a or 18b for each of the refrigerators 1 and 2. (In FIG. 1, the cooling-water piping 18a or 18b is illustrated by a dot-dash line.) Although the constructions of the cooling towers 6 and 7 are not illustrated in FIG. 1, for each of the refrigerators 1 and 2, a cooling-tower fan 21a or 21b, a spray pipe (not shown), and a cooling-water reservoir tank (not shown) are arranged. In each of the cooling towers 6 and 7, the cooling water is cooled by taking the outside air into the cooling tower 6 or 7 through the cooling-tower fan 21a or 21b, and counter currently bringing the outside air into contact with the cooling water sprayed from the spray pipe. For each of the refrigerators 1 and 2, the cooling water cooled by the outside air in the cooling tower 6 or 7 is conveyed by a cooling-water pump 4 or 5 through the cooling-water piping 18a or 18b to the condenser in the

refrigerator 1 or 2, so that the refrigerant circulating through the evaporator and the condenser is cooled. For each of the refrigerators 1 and 2, an inverter 10a or 10b, which is connected to the control instruction unit 25 in the control means 23 through a cable, is connected to a driving motor (not shown) for driving the cooling-tower fan 21a or 21b. Thus, the control instruction unit 25 controls through the inverters 10a and 10b the rotational frequencies of the driving motors for the cooling-tower fans 21a and 21b on the basis of an optimum air flow ratio calculated by a simulator 24 in the control means 23 (as explained later).

[0040]

Hereinafter, the denotations of the respective elements provided in correspondence with the high-temperature side refrigerator 1 may be preceded by the words "high-temperature side", and the denotations of the respective elements provided in correspondence with the low-temperature side refrigerator 2 may be preceded by the words "low-temperature side". For example, the cooling-water piping 18a corresponding to the high-temperature side refrigerator 1 may be referred to as "high-temperature side cooling-water piping 18a", and the cooling-water piping 18b corresponding to the low-temperature side refrigerator 2 may be referred to as "low-temperature side cooling-water piping 18b".

[0041]

In addition, the cold generation apparatus A illustrated in FIG. 1 is provided with an outside-air thermometer 19 and an outside-air hygrometer 20 for measuring the temperature and the humidity of the outside air taken into the cooling towers 6 and 7. The outside-air thermometer 19 and the outside-air hygrometer 20 are connected to the control means 23 through cables. A cooling-water flowmeter 11b or 11c, an inlet thermometer 13a or 14a, and an outlet thermometer 13b or 14b are arranged in each of the high-temperature side cooling-water piping 18a and the low-temperature side cooling-water piping 18b. Each of the inlet thermometers 13a and 14a measures the temperature of the cooling water at the inlet of the corresponding cooling tower, and each of the outlet thermometers 13b and 14b measures the temperature of the cooling water at the outlet of the corresponding cooling tower. The cooling-water flowmeters 11b and 11c, the inlet thermometers 13a and 14a, and the outlet thermometers 13b and 14b are connected to the control means 23 through cables. In addition, inverters 9a and 9b, which are connected to the control means 23, are respectively connected to the cooling-water pumps 4 and 5. Thus, the control instruction unit 25 controls through the inverter 9a and 9b the rotational frequencies of driving motors for the cooling-water pumps 4 and 5 on the basis of an optimum cooling-water flow ratio calculated by the

simulator 24 in the control means 23 (as explained later).

[0042]

Further, for each of the refrigerators 1 and 2, the outlet thermometer 13b or 14b (of the cooling tower 6 or 7) and the inverter 10a or 10b (through which the cooling-tower fan 21a or 21b is controlled) are connected to a first temperature-indicating controller 16a or 16b through cables (as indicated by dotted lined in FIG. 1). The first temperature-indicating controllers 16a and 16b control the rotational frequencies of driving motors for the cooling-tower fans 21a and 21b on the basis of the optimum air flow ratio so that the temperatures of the cooling water measured by the outlet thermometer 13b or 14b become predetermined temperatures, respectively, where the optimum air flow ratio is indicated in instructions from the control instruction unit 25 to the inverters 10a and 10b. In each of the high-temperature side refrigerator 1 and the low-temperature side refrigerator 2, the inlet thermometer 13a or 14a (of the cooling tower 6 or 7) and the inverter 9a or 9b (through which the cooling-water pump 4 or 5 is controlled) are connected to a second temperature-indicating controller 16c or 16d through cables (as indicated by dotted lined in FIG. 1). The second temperature-indicating controllers 16c and 16d control the rotational frequencies of driving motors for the cooling-water pumps 4 and 5 on the basis of the optimum cooling-water flow ratio so that the temperatures of the cooling water measured by the inlet thermometer 13a or 14a become predetermined temperatures, respectively, where the optimum cooling-water flow ratio is indicated in instructions from the control instruction unit 25 to the inverters 9a and 9b. The control of the rotational frequencies of the driving motors may be, for example, PID (proportional integral derivative) control. However, the control of the rotational frequencies need not be PID control.

[0043]

Although the cold generation apparatus illustrated in FIG. 1 has a construction which is most preferable, it is possible to consider variations and modifications within the scope of the present invention. For example, the bypass piping 17b and the control valve 15 may be dispensed with as illustrated in FIG. 2, the first temperature-indicating controllers 16a and 16b and the second temperature-indicating controllers 16c and 16d may be dispensed with as illustrated in FIG. 3, and the bypass piping 17b, the control valve 15, and the first temperature-indicating controllers 16a and 16b and the second temperature-indicating controllers 16c and 16d may be dispensed with as illustrated in FIG. 4.

[0044]

< Operation Control System >

Next, an operation control system for the cold generation apparatus A will be explained below.

5 [0045]

The cold-water flow meter 11a measures the flow rate L of the cold water flowing through the cold-water piping 17a, the first, second, and third thermometers 12a, 12b, and 12c respectively measure the temperatures T1_{in}, T1_{out}, and T2_{out} of the cold water at the inlet of the high-temperature side refrigerator 1, the outlet of the high-temperature side refrigerator 1, and outlet of the low-temperature side refrigerator 2. In addition, the cooling-water flowmeters 11b and 11c respectively measure the flow rates of the cooling water flowing through the high-temperature side cooling-water piping 18a and the low-temperature side cooling-water piping 18b, the inlet thermometers 13a and 14a respectively measure the temperatures of the cooling water at the inlets of the cooling towers 6 and 7, and the outlet thermometers 13b and 14b respectively measure the temperatures of the cooling water at the outlets of the cooling towers 6 and 7. Further, the outside-air thermometer 19 measures the temperature Ta of the outside air, and the outside-air hygrometer 20 measures the humidity RH of the outside air. The measured values obtained by the above meters are inputted into the control means 23, which calculates the refrigeration load ratio Q (%), the outside-air wet-bulb temperature TWB (°C), and the cold-water flow ratio L_{rate} (%).

[0046]

The refrigeration load ratio Q (%) is the ratio (%) of the actual cooling load to the total refrigerator performance of the refrigerators 1 and 2, and is calculated in accordance with the following formula (1).

[0047]

30
$$Q = \frac{L * \sigma * (T1_{in} - T2_{out}) * C_p}{60 * 1000 * (RT_{cap1} + RT_{cap2})} \quad (1)$$

[0048]

35 L ----- cold-water flow rate (L/min),
σ ----- density of water (kg/ m³),

$T1_{in}$ ----- temperature ($^{\circ}\text{C}$) of the cold water at the inlet of the high-temperature side refrigerator,

$T2_{out}$ ----- temperature ($^{\circ}\text{C}$) of the cold water at the outlet of the low-temperature side refrigerator,

5 C_p ----- specific heat of water ($\text{J/g}\cdot\text{K}$),

RT_{cap1} ----- value of the rated refrigeration performance (kW) of the high-temperature side refrigerator,

RT_{cap2} ----- value of the rated refrigeration performance (kW) of the low-temperature side refrigerator.

10 Note the divisor “ $60*1000$ ” is the factor for conversion from the unit L/min to the unit m^3/sec .

[0049]

In the above formula (1), * indicates multiplication, / indicates division, and this definition is the same as the following formulae.

15 [0050]

The above the values of the rated refrigeration performance are values indicated in a product specification by the manufacturer of the refrigerators, and stored in advance in the control means 23.

[0051]

20 Further, the control means 23 calculates the cold-water flow ratio L_{rate} (%) by using the refrigeration load ratio Q (%) calculated as above. The cold-water flow ratio L_{rate} (%) as defined before can be calculated by the following formula (2).

[0052]

25

$$L_{rate} = \frac{L}{L_{cap}} = \frac{Q * \frac{60 * 1000 * (RT_{cap1} + RT_{cap2})}{\sigma * \Delta T_{sp} * C_p}}{L_{cap}} \quad (2)$$

30 [0053]

Q ----- refrigeration load ratio (%)

σ ----- density of water (kg/m^3),

ΔT_{sp} ----- preset value of the difference $T1_{in} - T2_{out}$, and stored in the control means before starting operation of the cold generation apparatus A (K).

35 [0054]

C_p ----- specific heat of water ($\text{kg}/\text{kg}\cdot\text{K}$),

L_{cap} ----- rated flow rate of the cold water (L/min). The value of ΔT_{sp} is preset.

Furthermore, the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$) can be calculated from the outside-air temperature T_a and the outside-air humidity RH by using a known formula.

[0055]

The control means 23 controls the cold-water pump 3 in each refrigerator on the basis of the cold-water flow ratio, and performs a simulation by using the simulator 24 for obtaining the optimum value of the cooling-water flow ratio between the cooling-water pumps 4 and 5 in the refrigerators 1 and 2, the optimum value of the air flow ratio between the cooling-tower fans 21a and 21b, and the optimum load sharing ratio between the refrigerators 1 and 2 which maximize the COP (coefficient of performance) of the entire cold generation apparatus. In the simulation, the cooling-water flow ratio, the air flow ratio, and the load sharing ratio are used as variables. Then, the control means 23 controls the temperatures T_{1out} and T_{2out} of the cold water at the outlets of the refrigerators 1 and 2 on the basis of the load sharing ratio obtained as above, and controls the cooling-water pumps 4 and 5 and the cooling-tower fans 21a and 21b on the basis of the optimum cooling-water flow ratio and the optimum air flow ratio obtained as above.

[0056]

FIG. 5 indicates a sequence of operations for the simulation performed by the simulator 24. In the sequence of FIG. 5, it is possible to obtain the optimum value of the cooling-water flow ratio between the cooling-water pumps 4 and 5 in the refrigerators 1 and 2, the optimum value of the air flow ratio between the cooling-tower fans 21a and 21b, and the optimum load sharing ratio between the refrigerators 1 and 2 which maximize the COP of the entire cold generation apparatus, by varying all the variables including the cooling-water flow ratio, the air flow ratio, and the load sharing ratio. However, it is preferable to stepwise perform the simulation as explained below.

[0057]

First, the refrigeration load ratio Q (%) and the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$) calculated by the control means 23 are inputted into the simulator 24 (in step S101), and arbitrary constants (fixed values) are inputted into the simulator 24 as the cooling-water flow ratio between the cooling-water pumps 4 and 5 and the air flow ratio between the cooling-tower fans 21a and 21b (in steps S102 and S103). At this time, it is preferable that each of the inputted cooling-water flow ratio

and the inputted air flow ratio be a value which is assumed to be appropriate (i.e., assumed not to be an extreme value) in a range determined on the basis of the operational ranges of the cooling-water pumps 4 and 5 or the operational ranges of the cooling-tower fans 21a and 21b. For example, the inputted value of each of the cooling-water flow ratio and the air flow ratio is preferably 50:50. On the other hand, the cold-water flow ratio L_{rate} (%) is uniquely determined by the refrigeration load ratio Q (%) as indicated in the formula (2). Therefore, the refrigeration load ratio Q (%) is used as a representative factor in the operational control of the cold generation apparatus, and the cold-water flow ratio L_{rate} (%) is used in calculation of the power consumption in the cold-water pump 3.

[0058]

Then, an arbitrary value is inputted into the simulator 24 for the variable of the load sharing ratio (in step S104).

[0059]

Subsequently, the simulator 24 calculates the COP of the entire cold generation apparatus (in step S105).

[0060]

Specifically, the power consumption in each of the refrigerators 1 and 2 on the high-temperature and low-temperature sides, the cold-water pump 3, the cooling-water pumps 4 and 5, and the cooling-tower fans 21a and 21b is calculated. A value of the COP of each of the refrigerators 1 and 2 corresponding to data of the temperature of the cold water at the inlet of each of the refrigerators 1 and 2 and data of the cooling load on each refrigerator is generally published as a part of the product specification by the manufacturer of the refrigerator. Therefore, the COP of each refrigerator is estimated on the basis of the above value, and the power consumption W_1 in the high-temperature side refrigerator 1 and the power consumption W_2 in the low-temperature side refrigerator 2 are calculated by the following formula (3).

The temperatures of the cold water at the inlets of the refrigerators 1 and 2 are measured by the first and second thermometers 12a and 12b, the temperature of the cold water at the outlet of the refrigerator 2 is measured by the third thermometer 12c, and the cooling load on each refrigerator is calculated on the basis of the flow rate L of the cold water measured by the cold-water flow meter 11a, the differences between the temperatures measured by the first to third thermometers 11a to 11c, and the specific heat C_p of water.

[0061]

$$\text{Power Consumption in Refrigerator (kW)} = Q / \text{COP} \quad (3)$$

[0062]

In addition, the power consumption in the cold-water pump 3, the cooling-water pumps 4 and 5, and the cooling-tower fans 21a and 21b can be calculated by the following formula (4).

5 In the formula (4), f denotes the rotational frequency of the driving motor driving each of the cold-water pump 3, the cooling-water pumps 4 and 5, and the cooling-tower fans 21a and 21b, and W_0 is a rated power consumption of the driving motor (powered with, for example, commercial AC electric power with the frequency of 50 or 60 Hz). In addition, the motor efficiency is assumed to be 0.9 in the formula
10 (4).

[0063]

$$W = \frac{W_0}{(f/50)^3 * 0.9}$$

(in the case where frequency of the commercial AC electric power is 50 Hz),
or

$$W = \frac{W_0}{(f/60)^3 * 0.9}$$

15

(in the case where frequency of the commercial AC electric power is 60 Hz)

(4)

[0064]

20 Subsequently, the COP of each of the refrigerators 1 and 2 is calculated from the system power consumption W_{sys} by the following formula (5), where the system power consumption W_{sys} is the total power consumption in the cold generation apparatus A obtained from the values of power consumption in the respective components.

[0065]

25

$$COP = \frac{Q}{W_{sys}}$$

30

$$= \frac{Q}{(W_1 + W_2 + W_{cp} + W_{cwp1} + W_{cwp2} + W_{fan1} + W_{fan2})}$$

(5)

[0066]

W_1 ----- power consumption (kW) in the high-temperature side refrigerator 1,

5 W_2 ----- power consumption (kW) in the low-temperature side refrigerator 2,

W_{cp} ----- power consumption (kW) in the cold-water pump,

W_{cwp1} ----- power consumption (kW) in the high-temperature side cooling-water pump 4,

10 W_{cwp2} ----- power consumption (kW) in the low-temperature side cooling-water pump 4,

W_{fan1} ----- power consumption (kW) in the high-temperature side cooling-tower fan 21a,

W_{fan2} ----- power consumption (kW) in the low-temperature side cooling-tower fan 21b.

15 Herein, until the COP reaches the maximum, the simulator 24 repeats the operations of changing the value of the load sharing ratio (in steps S106 and S107), and performing the above calculation of the COP (in step S105). Thus, a value of the optimum load sharing ratio which maximizes the COP of the entire cold generation apparatus under the condition that the cooling-water flow ratio between the
20 cooling-water pumps 4 and 5 and the air flow ratio between the cooling-tower fans 21a and 21b are respectively fixed to certain values is determined (when yes is determined in step S106).

[0067]

25 Subsequently, the simulator 24 calculates values of the COP (in steps S103 and S105) while using the values of the flow ratio and the air flow ratio and changing the value of the air flow ratio (in step 109 when no is determined in step S108), and obtains an optimum value of the load sharing ratio (in steps S104 to S108). Further, the simulator 24 calculates values of the COP (in steps S102 and S105) while using the values of the flow ratio and the air flow ratio and changing the value of the flow ratio
30 (in step 111 when no is determined in step S110), and obtains an optimum value of the load sharing ratio (in steps S103 to S110).

As explained above, the simulator 24 calculates the value of the COP for each combinations of the values of the flow ratio between the cooling-water pumps 4 and 5, the air flow ratio between the cooling-tower fans 21a and 21b, and the load sharing
35 ratio between the refrigerators 1 and 2, and determines a combination of a value of the (cooling-water) flow ratio between the cooling-water pumps 4 and 5, a value of the air

flow ratio between the cooling-tower fans 21a and 21b, and a value of the load sharing ratio between the refrigerators 1 and 2 which maximize the COP (in step S130), and determines the values of the (cooling-water) flow ratio, the air flow ratio, and the load sharing ratio in the determined combination as the optimum (cooling-water) flow ratio, the optimum air flow ratio, and the optimum load sharing ratio.

[0068]

Finally, the simulator 24 converts the optimum cooling-water flow ratio and the optimum air flow ratio obtained as above to inverter frequencies, and calculates the temperature T1out of the cold water at the outlet of the high-temperature side refrigerator 1 corresponding to the optimum load sharing ratio (maximizing the COP) as the optimum temperature of the cold water at the outlet of the high-temperature side refrigerator 1 (in step S113). Since the cold generation apparatus in the example illustrated in FIG. 1 has two refrigerators, it is sufficient to obtain the temperature of the cold water at the outlet of only the high-temperature side refrigerator 1. However, in the case where the cold generation apparatus has more than two refrigerators, the temperatures of the cold water at the outlets of the refrigerators except for the refrigerator arranged at the downstream end are respectively calculated.

[0069]

Thereafter, the simulator 24 transfers to the control instruction unit 25 the optimum temperature of the cold water at the outlet of the high-temperature side refrigerator 1 and the inverter frequencies obtained by the conversion from the optimum cooling-water flow ratio and the optimum air flow ratio as above.

[0070]

The control instruction unit 25 controls the cold-water pump 3 through the corresponding inverter on the basis of the cold-water flow ratio, controls the high-temperature side refrigerator 1 on the basis of the optimum temperature of the cold water at the outlet of the high-temperature side refrigerator 1, obtained by the simulator 24, and controls the cooling-water pumps 4 and 5 and the cooling-tower fans 21a and 21b on the high-temperature side and the low-temperature side through the respectively corresponding inverters on the basis of the inverter frequencies, obtained by the aforementioned conversion from the optimum cooling-water flow ratio and the optimum air flow ratio.

[0071]

As explained above, the operation of the entire cold generation apparatus having refrigerators arranged in series is controlled to minimize the total power consumption of the cold generation apparatus in correspondence with the cooling load

and the condition of the outside air. Therefore, it is possible to achieve superior energy saving performance to the conventional operational control of the cold generation apparatus.

[0072]

5 However, according to the sequence illustrated in FIG. 5, the optimum load sharing ratio, the optimum cooling-water flow ratio, and the optimum air flow ratio are obtained on the basis of the refrigeration load ratio Q (%), the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$), and the cold-water flow ratio L_{rate} (%) which are calculated as explained before. Therefore, when the refrigeration load ratio Q (%), the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$), and the cold-water flow ratio L_{rate} (%) vary, it is necessary to perform the simulation again for obtaining the optimum load sharing ratio, the optimum cooling-water flow ratio, and the optimum air flow ratio.

[0073]

15 In view of the above, it is possible to provide in the simulator 24 a control table containing information corresponding to the refrigeration load ratio Q (%) and the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$) for obtaining the optimum temperature of the cold water at the outlet. The provision of the control table can reduce the simulation load imposed on the simulator 24, and can further reduce the power consumption. Further, since the cold-water flow ratio L_{rate} (%) is used in calculation of the power consumption in the cold-water pump 3, the control table needs not contain information corresponding to the cold-water flow ratio L_{rate} (%).

[0074]

FIG. 6 illustrates an example of a part of the control table, in which optimum values of the relative cooling-water flow rate (%) in the cooling-water pump 4 are tabulated in correspondence with combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$). The relative cooling-water flow rate (%) in the cooling-water pump 4 is the ratio of the cooling-water flow rate in the cooling-water pump 4 to the sum of the cooling-water flow rates in the cooling-water pumps 4 and 5, and corresponds to the cooling-water flow ratio between the cooling-water pumps 4 and 5. Each of the optimum values of the relative cooling-water flow rate in the cooling-water pump 4 is obtained as a value maximizing the COP by performing in advance a simulation as explained before under the condition determined by one of the combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$). Although not shown, the control table also includes a part in which the optimum values of the relative cooling-water flow rate in the cooling-water pump 5 are tabulated in

correspondence with combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}C$).

[0075]

According to the part of the control table illustrated in FIG. 6, for example, when the refrigeration load ratio Q (%) is 60%, and the outside-air wet-bulb temperature TWB ($^{\circ}C$) is $10^{\circ}C$, the relative cooling-water flow rate in the cooling-water pump 4 maximizing the COP is 75%. When the refrigeration load ratio Q (%) is 10%, and the outside-air wet-bulb temperature TWB ($^{\circ}C$) is $10^{\circ}C$, the relative cooling-water flow rate in the cooling-water pump 4 maximizing the COP is 0%. In the latter case, the refrigeration load is small, and therefore the operation of the high-temperature side refrigerator 1 is stopped, so that the cooling-water pump 4 which supplies cooling water to the high-temperature side refrigerator 1 is stopped.

[0076]

FIG. 7 illustrates an example of a part of the control table, in which optimum values of the relative air flow rate (%) in the cooling-tower fan 21a are tabulated in correspondence with combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}C$). The relative air flow rate (%) in the cooling-tower fan 21a is the ratio of the air flow rate in the cooling-tower fan 21a to the sum of the air flow rates in the cooling-tower fans 21a and 21b, and corresponds to the air flow ratio between the cooling-tower fans 21a and 21b. Each of the optimum values of the relative air flow rate in the cooling-tower fan 21a is obtained as a value maximizing the COP by performing in advance a simulation as explained before under the condition determined by one of the combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}C$). Although not shown, the control table also contains a part in which the optimum values of the relative air flow rate (%) in the cooling-tower fan 21b are tabulated in correspondence with combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}C$).

[0077]

According to the part of the control table illustrated in FIG. 7, for example, when the refrigeration load ratio Q (%) is 60%, and the outside-air wet-bulb temperature TWB ($^{\circ}C$) is $10^{\circ}C$, the air flow ratio in the cooling-tower fan 21a maximizing the COP is 75%. When the refrigeration load ratio Q (%) is 10%, and the outside-air wet-bulb temperature TWB ($^{\circ}C$) is $10^{\circ}C$, the relative air flow rate (%) in the cooling-tower fan 21a maximizing the COP is 0%. In the latter case, the refrigeration load is small, and therefore the operation of the high-temperature side

refrigerator 1 is stopped, so that the cooling-tower fan 21a which cools the cooling water in the cooling tower 6 supplying the cooled cooling water to the high-temperature side refrigerator 1 is stopped.

[0078]

FIG. 8 illustrates an example of a part of the control table, in which values of the optimum temperature at the outlet of the high-temperature side refrigerator 1 are tabulated in correspondence with combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$). The values of the optimum temperature at the outlet of the high-temperature side refrigerator 1 are respectively obtained from values of the optimum load sharing ratio, and each of the values of the load sharing ratio is obtained as a value maximizing the COP by performing in advance a simulation as explained before under the condition determined by one of the combinations of values of the refrigeration load ratio Q (%) and values of the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$). According to the part of the control table illustrated in FIG. 8, for example, when the refrigeration load ratio Q (%) is 10%, and the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$) is 10°C , the optimum temperature at the outlet of the high-temperature side refrigerator 1 maximizing the COP is 13.4°C . At this time, the temperature of the cold water returned from the external load apparatus B is also 13.4°C . When the refrigeration load ratio Q (%) is 60%, and the outside-air wet-bulb temperature TWB ($^{\circ}\text{C}$) is 10°C , the optimum temperature at the outlet of the high-temperature side refrigerator 1 maximizing the COP is 8.9°C .

[0079]

Although the values of the outside-air wet-bulb temperature TWB are indicated from 10°C to 30°C in steps of 1°C in the parts of the control table illustrated in FIGS. 6 to 8, the range of the outside-air wet-bulb temperature TWB is not limited to the indicated range.

[0080]

As indicated in FIGS. 6 to 8, in the case where the refrigeration load ratio Q (%) is in the range of 10% to 50%, the COP is maximized when the high-temperature side refrigerator 1 is stopped. Therefore, in the above case, the control instruction unit stops the operations of the cooling-water pump 4 and the cooling-tower fan 21a corresponding to the high-temperature side refrigerator 1, and opens the control valve 15 in the bypass piping 17b so that the cold water returned from the external load apparatus B directly flows into the low-temperature side refrigerator 2.

[0081]

As explained above, in the case where the control table is provided in the simulator 24, the necessary operations are only the acquisition of the refrigeration load ratio Q (%) and the outside-air wet-bulb temperature TWB ($^{\circ}C$) and the selection of the load sharing ratio or the optimum temperature of the cold water at the outlet of each refrigerator, the optimum flow ratio, and the optimum air flow ratio from the control table. Therefore, it is unnecessary to repeat the calculation for obtaining the values maximizing the COP. That is, it is possible to remarkably reduce the simulation load, and further reduce the power consumption.

[0082]

Since the opening of the control valve 15 in the bypass piping 17b makes the cold water bypass the high-temperature side refrigerator 1 when the high-temperature side refrigerator 1 is stopped, it is possible to reduce the circulation resistance of the cold water. Therefore, the load imposed on the cooling-water pump can be reduced, so that the power consumption can be further reduced.

[0083]

In the first embodiment, the control means 23 calculates the refrigeration load ratio Q (%), the outside-air wet-bulb temperature TWB ($^{\circ}C$), and the cold-water flow ratio L_{rate} (%) on the basis of the measured values obtained by the respective measuring instruments, and inputs the calculated values into the simulator 24.

However, the above calculation may also be performed by the simulator 24.

[0084]

<Other Construction of Cold Generation Apparatus>

FIG. 9 illustrates an operation control system for a cold generation apparatus as the second embodiment of the present invention. In the second embodiment, only a single cooling tower 6 common to a plurality of refrigerators is arranged, and cooling water cooled by a single cooling-tower fan 21 in a single cooling tower 6 is distributed to the refrigerators 1 and 2 by cooling-water pumps 4 and 5. The cooling water cooled by the cooling-tower fan 21 in the cooling tower 6 flows through cooling-water outlet piping 18, which branches into high-temperature side piping 18A and low-temperature side piping 18B respectively connected to the refrigerators 1 and 2. Therefore, the cooling water flowing through the cooling-water outlet piping 18 is split at the branch, and branched flows of the cooling water are respectively supplied to the refrigerators 1 and 2 through the high-temperature side piping 18A and the low-temperature side piping 18B. In the refrigerators 1 and 2, the branched flows of the cooling water are used for heat exchange. The branched flow of the cooling water used in the heat exchange in the high-temperature side refrigerator 1 flows through the

high-temperature side piping 18A, and the branched flow of the cooling water used in the heat exchange in the low-temperature side refrigerator 2 flows through the low-temperature side piping 18B. Then, both of flows of the cooling water being outputted from the refrigerators 1 and 2 and passing through the high-temperature side piping 18A and the low-temperature side piping 18B join into cooling-water inlet piping 18', and are returned to the cooling tower 6. The cooling-water pump 4 is arranged in the high-temperature side piping 18A, and the cooling-water pump 5 is arranged in the low-temperature side cooling-water piping 18b. Therefore, the flow ratio between the flow of the cooling water into the high-temperature side refrigerator 1 and the flow of the cooling water into the low-temperature side refrigerator 2 can be changed by controlling the rotational frequencies of the cooling-water pumps 4 and 5. Although the temperature-indicating controllers as illustrated in FIG. 1 are not arranged in the construction of FIG. 9, it is possible to arrange such temperature-indicating controllers in the construction of FIG. 9. In other respects, the construction of the second embodiment is identical to the first embodiment.

[0085]

The operations of the construction of FIG. 9 can be controlled in a similar manner to the construction of FIG. 1, except that "the air flow ratio between the cooling-tower fans 21a and 21b" in the explanations on the first embodiment should be replaced with "the air flow rate in the cooling-tower fan 21".

[0086]

FIG. 10 illustrates an operation control system for a cold generation apparatus as the third embodiment of the present invention. In the third embodiment, only a single cooling tower 6 common to a plurality of refrigerators is arranged, and cooling water cooled by a single cooling-tower fan 21 in a single cooling tower 6 is supplied to the refrigerators 1 and 2 in succession from the high-temperature side to the low-temperature side by using a single cooling-water pump 4.

[0087]

The operations of the construction of FIG. 10 can be controlled in a similar manner to the construction of FIG. 5, except that "relative air flow rate in each cooling-tower fan" in the explanations should be replaced with "air flow rate in cooling-tower fan 21", and "relative flow rate in each cooling-water pump" in the explanations should be replaced with "flow rate in cooling-water pump 4". That is, in FIG. 5, the above mentioned case represents that $L = 1$ where $L = 1 - x$, and $M = 1$ where $M = 1 - y$.

DESCRIPTION OF REFERENCE NUMERALS

[0088]

	A:	Cold Generation Apparatus
5	B:	External Load Apparatus
	1, 2:	Refrigerator
	3:	Cold-Water Pump
	4, 5:	Cooling-Water Pump
	6, 7:	Cooling Tower
10	8, 9a, 9b, 10a, 10b:	Inverter
	11a:	Cold-Water Flowmeter
	11b, 11c:	Cooling-Water Flowmeter
	12a:	First Thermometer
	12b:	Second Thermometer
15	12c:	Third Thermometer
	13a, 14a:	Inlet Thermometer
	13b, 14b:	Outlet Thermometer
	15:	Control Valve
	16a, 16b, 16c, 16d:	Temperature-Indicating Controller
20	17a:	Cold-Water Piping
	17b:	Bypass Piping
	18, 18a, 18b, 18A, 18B:	Cooling-Water Piping
	19:	Outside-Air Thermometer
	20:	Outside-Air Hygrometer
25	21a, 21b:	Cooling-Tower Fan
	23:	Control Means
	24:	Simulator
	25:	Control Instruction Unit

CLAIMS

[Claim 1] An operation control system for a cold generation apparatus including,
cold-water piping through which cold water is supplied to an external load
5 apparatus,

a plurality of heat-pump type refrigerators which are arranged in series along
the cold-water piping, and each have an evaporator and a condenser for cooling the
cold water,

a cold-water pump which supplies the cold water returned from the external
10 load apparatus, to the external load apparatus through the refrigerators so that the cold
water is cooled in the evaporator in each of the refrigerators,

cooling-water pumps which are respectively arranged in correspondence with
the refrigerators for supplying cooling water to the condenser in the refrigerators
through cooling-water piping, and

15 cooling towers which are respectively arranged for the refrigerators, and
respectively have cooling-tower fans for cooling the cooling water with outside air;

the operation control system comprising:

an acquisition means which acquires a wet-bulb temperature of the outside air
taken into the cooling towers by the cooling-tower fans, a refrigeration load ratio as a
20 ratio of an actual refrigeration load to a sum of preset values of refrigeration
performance of the refrigerators, and a cold-water flow ratio as a ratio of an actual
flow rate of the cold-water to a rated flow rate of the cold water;

a simulator which performs a simulation for determining an optimum value of
a cooling-water flow ratio as a flow ratio between the cooling-water pumps
25 corresponding to the refrigerators, an optimum value of an air flow ratio as a ratio
between flow rates in the cooling-tower fans in the cooling towers, and an optimum
value of a load sharing ratio as a ratio in which the actual refrigeration load is shared
by the refrigerators, by calculating a coefficient of performance of the entire cold
generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable,
30 under a condition determined by the wet-bulb temperature, the refrigeration load ratio,
and the cold-water flow ratio which are acquired by the acquisition means, where the
optimum value of the cooling-water flow ratio, the optimum value of the air flow ratio,
and the optimum value of the load sharing ratio maximize a coefficient of performance
of the cold generation apparatus; and

35 a control means which controls the cold-water pump of the refrigerators on
the basis of the cold-water flow ratio, controls temperatures of the cold water at outlets
of the refrigerators on the basis of the optimum value of the load sharing ratio, and
controls the cooling-water pumps and the cooling-tower fans in the cooling towers on

the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow ratio.

[Claim 2] The operation control system according to claim 1, wherein the simulator stores a control table which indicates the optimum value of the load sharing ratio or one or more optimum values of one or more of the temperatures of the cold water at outlets of the refrigerators, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio which maximize the coefficient of performance, in correspondence with the refrigeration load ratio and the wet-bulb temperature, and when the refrigeration load ratio and the wet-bulb temperature which are acquired by the acquisition means are inputted into the simulator, the simulator selects the optimum value of the load sharing ratio, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio by reference to the control table.

[Claim 3] The operation control system according to claim 1, further comprising a first inverter which enables change of a rotational frequency of the cold-water pump, second inverters which enable change of rotational frequencies of the cooling-water pumps, and third inverters which enable change of rotational frequencies of the cooling-tower fans; wherein the control means controls through the first inverter, the second inverters, the third inverters the rotational frequencies of the cold-water pump, the cooling-water pumps, and the cooling-water pumps by converting the cold-water flow ratio, the optimum value of the cooling-water flow ratio, and the optimum value of the air flow ratio into inverter frequencies, and outputting the inverter frequencies to the first inverter, the second inverters, the third inverters.

[Claim 4] The operation control system according to claim 1, wherein when one or more of the refrigerators shares 0% of the actual refrigeration load according to the optimum value of the load sharing ratio, the control means stops operation of the one or more of the refrigerators, and operation of one or more of the cooling-water pumps and one or more of the cooling-tower fans corresponding to the one or more of the refrigerators.

[Claim 5] An operation control system for a cold generation apparatus including, cold-water piping through which cold water is supplied to an external load apparatus, a plurality of heat-pump type refrigerators which are arranged in series along

the cold-water piping, and each have an evaporator and a condenser for cooling the cold water,

a cold-water pump which supplies the cold water returned from the external load apparatus, to the external load apparatus through the refrigerators so that the cold water is cooled in the evaporator in each of the refrigerators,

at least a cooling tower which is arranged for the plurality of refrigerators, and has a cooling-tower fan for cooling cooling water with outside air, and

cooling-water pumps which are respectively arranged in correspondence with the refrigerators for distributing the cooling water cooled in the cooling tower, to the plurality of refrigerators through cooling-water piping, so that the cooling water cooled in the cooling tower is supplied to the condenser in each of the refrigerators,

the operation control system comprising:

an acquisition means which acquires a wet-bulb temperature of the outside air taken into the cooling tower by the cooling-tower fan, a refrigeration load ratio as a ratio of an actual refrigeration load to a sum of preset values of refrigeration performance of the refrigerators, and a cold-water flow ratio as a ratio of an actual flow rate of the cold-water to a rated flow rate of the cold water;

a simulator which performs a simulation for determining an optimum value of a cooling-water flow ratio as a flow ratio between the cooling-water pumps corresponding to the refrigerators, an optimum value of an air flow rate in the cooling-tower fan in the cooling tower, and an optimum value of a load sharing ratio as a ratio in which the actual refrigeration load is shared by the refrigerators, by calculating a coefficient of performance of the entire cold generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable, under a condition determined by the wet-bulb temperature, the refrigeration load ratio, and the cold-water flow ratio which are acquired by the acquisition means, where the optimum value of the cooling-water flow ratio, the optimum value of the air flow rate, and the optimum value of the load sharing ratio maximize a coefficient of performance of the cold generation apparatus; and

a control means which controls the cold-water pump on the basis of the cold-water flow ratio, controls temperatures of the cold water at outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls the cooling-water pumps and the cooling-tower fan in the cooling tower on the basis of the optimum value of the cooling-water flow ratio and the optimum value of the air flow rate.

[Claim 6] An operation control system for a cold generation apparatus including, cold-water piping through which cold water is supplied to an external load

apparatus,

a plurality of heat-pump type refrigerators which are arranged in series along the cold-water piping, and each have an evaporator and a condenser for cooling the cold water,

5 a cold-water pump which supplies the cold water returned from the external load apparatus, to the external load apparatus through the refrigerators so that the cold water is cooled in the evaporator in each of the refrigerators,

at least a cooling tower which is arranged for the plurality of refrigerators, and has a cooling-tower fan for cooling cooling water with outside air, and

10 a cooling-water pump which is arranged for supplying the cooling water cooled in the cooling tower, to the plurality of refrigerators in succession from a high-temperature side to a low-temperature side through cooling-water piping, so that the cooling water cooled in the cooling tower is supplied to the condenser in each of the refrigerators,

15 the operation control system comprising:

an acquisition means which acquires a wet-bulb temperature of the outside air taken into the cooling tower by the cooling-tower fan, a refrigeration load ratio as a ratio of an actual refrigeration load to a sum of preset values of refrigeration performance of the refrigerators, and a cold-water flow ratio as a ratio of an actual
20 flow rate of the cold-water to a rated flow rate of the cold water;

a simulator which performs a simulation for determining an optimum value of a cooling-water flow rate in the cooling-water pump, an optimum value of an air flow rate in the cooling-tower fan in the cooling tower, and an optimum value of a load sharing ratio as a ratio in which the actual refrigeration load is shared by the
25 refrigerators, by calculating a coefficient of performance of the entire cold generation apparatus on the basis of arbitrary load sharing ratios inputted as a variable, under a condition determined by the wet-bulb temperature, the refrigeration load ratio, and the cold-water flow ratio which are acquired by the acquisition means, where the optimum value of the cooling-water flow rate, the optimum value of the air flow rate, and the
30 optimum value of the load sharing ratio maximize a coefficient of performance of the cold generation apparatus; and

a control means which controls the cold-water pump on the basis of the cold-water flow ratio, controls temperatures of the cold water at outlets of the refrigerators on the basis of the optimum value of the load sharing ratio, and controls
35 the cooling-water pump and the cooling-tower fan in the cooling tower on the basis of the optimum value of the cooling-water flow rate and the optimum value of the air flow rate.

[Claim 7] The operation control system according to any of claims 1, 5, and 6, wherein the cold generation apparatus further includes bypass piping which is arranged for each of the refrigerators and bypasses each of the refrigerators, and a control valve which is arranged for each of the refrigerators, can be opened for allowing passage
5 through the bypass piping for each of the refrigerators, and can be closed for stopping passage through the bypass piping for each of the refrigerators; and the control means opens the control valve arranged for each of one or more of the refrigerators when operation of the one or more of the refrigerators is stopped.