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D E S C R I P T I O N

Title of Invention

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THERMAL RECYCLING PLANT SYSTEM, APPARATUS FOR
CONTROLLING A THERMAL RECYCLING PLANT AND
METHOD OF CONTROLLING A THERMAL RECYCLING PLANT

Technical Field

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Embodiments of this invention relates to a thermal
recycling plant system for use in controlling air-
conditioning in buildings, factories and apartments, an
apparatus for controlling a thermal recycling plant,
and a method of controlling a thermal recycling plant.

Background Art

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In recent years, people have become more conscious
of the conservation of the global environment, now
demanding that the energy consumption should be
reduced. The demand for energy saving is growing.
People now request that energy saving legislation
should be revised and that conformance to standards
such as ISO 50001 should be stipulated. Attention is
therefore being paid to techniques that can reduce
energy consumption in comparatively large facilities,
such as buildings and factories.

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A large part of the energy consumed in a facility
is used in the air-conditioning system. In some
buildings, the air-conditioning system is responsible
for half the total energy consumed. Hence, if the
energy consumed by the air-conditioning system is
decreased, energy will be effectively saved in the

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building. In view of this, various techniques have been proposed, which efficiently operate the system (hereinafter called the "thermal recycling plant") that recycles thermal generated in the building, thereby raising energy efficiency.

Prior Art Documents

Pat. Doc. 1: Japanese Patent No. 4166051

Pat. Doc. 2: Japanese Patent No. 3783859

Pat. Doc. 3: Japanese Patent No. 4630702

Summary of the Invention

Technical Problem

In the existing technique, the control value set to minimize the energy consumption is calculated from the evaluation function based on the specification or operating history of the air-conditioning system. More specifically, the thermal recycling plant is studied as a group of controlled objects, and an optimization based on a modeling technique is performed, thereby calculating the target control values for the respective control objects. In this method, however, the specification or operating states of all components constituting the thermal recycling plant cannot always be taken into consideration. The operating state of the thermal recycling plant depends also on the environmental conditions, such as temperature and humidity. Inevitably, the modeling of the system is limited. Consequently, there may be discrepancy

between the control based on calculation and the actual operation of the system.

Assume that, by a calculation for minimize the energy consumption, a temperature (hereinafter referred to as the "preset coolant temperature" is recommended, which is higher than the ordinary value for the coolant temperature optimal at, for example, the output of a cold/heat source apparatus. If the preset temperature is increased, the power to the compressor for cooling the coolant can be reduced, ultimately to decrease the energy consumed in the cold/heat source apparatus. In this respect, the decrease of the preset temperature is theoretically advantageous. However, the cooling capability will decrease, because the temperature difference between the coolant and the any object cooled. As a result, the outdoor air-conditioning unit will have but inadequate dehumidifying capability, and a feedback that lowers the humidity will increase, possibly increasing the energy consumption in some cases.

Used as an index for evaluating the operating state of the thermal recycling plant is the coolant bypass flow rate. The coolant bypass flow rate is an amount in which the coolant flows per unit time flows (or is bypassed) from the outlet port of the chiller recycling thermal from the coolant, to the outlet port of the chiller. This flow rate remains sufficiently

high as long as the chiller has sufficient cooling capability. The coolant bypass flow rate, however, lowers if the load (for example, outdoor air-conditioning unit or indoor air-conditioning unit) must operate to achieve cooling. In this case, the standby cold/heat source apparatus is activated before the coolant bypass flow rate falls below a preset value. Thus, the control may be inappropriately performed, in some cases, possibly increasing the energy consumption in the thermal recycling plant in its actual operation, in spite of the target control values calculated for the respective control objects.

An object of this invention is to provide a thermal recycling plant system capable of saving energy, while maintaining a thermal recycling plant in normal operating state, an apparatus for controlling a thermal recycling plant, and a method of controlling a thermal recycling plant.

Solution to Problem

A control apparatus according to an embodiment controls a thermal recycling plant that circulates the coolant cooled by a cooling apparatus consuming energy, thereby recycling thermal from a load apparatus. The control apparatus comprises a calculating unit and a monitoring unit. The calculating unit calculates, by means of optimization, an optimal temperature that is optimal for the coolant for minimizing energy

consumption under given conditions. The monitoring unit monitors an operating state of the load apparatus, thereby to determine whether an abnormality exists in the load apparatus. If the monitoring unit determines that an abnormality exists, it controls the cooling apparatus, causing the same to cool the coolant to a temperature lower than the optimal temperature calculated.

Brief Description of Drawings

FIG. 1 is a block diagram showing an exemplary thermal recycling plant;

FIG. 2 is a system diagram showing an exemplary thermal recycling plant control system according to an embodiment;

FIG. 3 is a functional block diagram of the exemplary plant control apparatus 10 shown in FIG. 2;

FIG. 4 is a diagram showing an exemplary screen an output device 30 displays;

FIG. 5 is a diagram showing another exemplary screen the output device 30 displays;

FIG. 6 is a flowchart showing an exemplary process sequence the plant control apparatus 10 may perform;

FIG. 7 is a flowchart showing an exemplary process sequence of calculating an optimal preset coolant temperature;

FIG. 8 is a diagram showing a further exemplary screen that the output device 30 displays;

FIG. 9 is a diagram showing an exemplary preset coolant temperature upper limit table 15a;

FIG. 10 is a flowchart showing an exemplary process sequence a system monitoring unit 13 may perform;

FIG. 11 is a flowchart showing, in detail, a process sequence a cooling capability monitoring unit 13a may perform;

FIG. 12 is a flowchart showing, in detail, a process sequence a bypass flow rate monitoring unit 13b may perform;

FIG. 13 is a flowchart showing an exemplary process sequence a communication process unit 14 may perform;

FIG. 14 is a diagram showing exemplary parameters 15b for calculating the optimal coolant temperature;

FIG. 15 is a table showing exemplary calculated optimal coolant temperatures, arranged in time series;

FIG. 16 is a graph showing how values change for a specific time including the period shown in FIG. 15; and

FIG. 17 is a system diagram showing an exemplary thermal recycling plant control system according to another embodiment.

Description of Embodiments

FIG. 1 is a block diagram showing an exemplary thermal recycling plant. The embodiment describes an

example of a system that can control the thermal recycling plant of FIG. 1. In FIG. 1, the arrows indicate the directions in which coolant (for example, water) flows. The coolant recycles thermal from a plurality of coolant load apparatuses 500, flows through a pipe system and reaches cold/heat source apparatuses 100. The coolant load apparatuses 500 are components to be cooled, including household air-conditioners, pure water producers and outdoor air-conditioning units.

The outdoor air-conditioning unit is an apparatus configured to process outdoor air (fresh air) to be supplied to rooms. The outdoor air-conditioning unit consumes electric power to adjust the temperature and humidity of the air taken from outside. A parameter important to the outdoor air-conditioning unit is the air supply dew point. The air supply dew point must be appropriately controlled in order to prevent condensation in the air-conditioning ducts.

Each cold/heat source apparatus 100 is a cooling apparatus, also known as a "chiller". It cools the coolant on, for example, the principle of the heat pump. The thermal recycled from the coolant is transferred to a heat radiating system (not shown), and is ultimately radiated outside the building, by the dump heat exchanger or radiator mounted on the roof. Some of the cold/heat source apparatuses 100 are driven

to recycle thermal. How many should be driven depends on how much thermal must be recycled. The cold/heat source apparatuses 100 consume much energy. In order to save energy, it is therefore necessary to drive as
5 few cold/heat source apparatuses 100 as possible to achieve desirable air-conditioning.

The cooling function of the thermal recycling plant depends mainly on both the coolant temperature and the coolant flow rate. If the coolant temperature
10 is low, the coolant flow rate can be small to attain a desirable cooling function. Conversely, if the coolant temperature is high, the coolant flow rate must be large to attain the same cooling function. The term "flow rate" used here means either the amount of the
15 coolant flowing per unit time in the thermal recycling plant, or the amount of the coolant flowing per unit time in the bypass. This is because the flow rate in the bypass directly reflects the rate at which the coolant flows in the entire plant.

20 In the existing technique, a feedback is applied to set raise the coolant temperature in order to save energy. The coolant flow rate inevitably falls too much. As a result, additional cold/heat source apparatuses 100 are driven, ultimately increasing the
25 energy consumption and hence the running cost of the thermal recycling plant. In view of this, the embodiment is configured to apply a feedback in a

specific way, thereby driving cold/heat source apparatuses 100 in a minimum number, while maintaining a sufficient cooling capability and achieving energy saving, as will be explained below.

5 Needless to say, sufficient cooling capability may not be attained even if the coolant temperature is reduced as much as possible. In this case, additional cold/heat source apparatuses 100 must be activated. This embodiment does not exclude such an operation of
10 the thermal recycling plant. That is, the embodiment is designed to control the plant in accordance with not only the coolant temperature, but also the coolant flow rate, thereby to accomplish energy saving.

 In order to circulate the coolant between the
15 cold/heat source apparatuses 100, on the one hand, and the coolant load apparatuses 500, on the other, a primary pump 700 is provided at the inputs of the cold/heat source apparatuses 100, and a secondary pump 300 at the outputs of the cold/heat source apparatuses
20 100. Further, a primary header 200 and a secondary header 400 are provided at the input port and output port of a secondary pump 300, respectively. Thus, the pipes are efficiently arranged.

 Moreover, a return header 600 is provided on a
25 path extending from the coolant load apparatuses 500 to the primary pump 700. A coolant bypass route 800 extends from the primary header 200 to the return

header 600. In the bypass route 800, part of the coolant flows (circulates), returning to the cold/heat source apparatuses 100, without flowing through the coolant load apparatuses 500. The flow rate of the coolant flowing in the bypass route 800 is a barometer that indicates the margin of cooling capability of the cooling system. If the coolant flow rate decreases, the standby cold/heat source apparatuses will be activated, inevitably to increase the power consumption.

FIG. 2 is a system diagram showing an exemplary thermal recycling plant control system according to the embodiment. As shown in FIG. 2, device/sensor groups 61 to 6p as controlled objects include cold/heat source apparatuses 1, temperature sensors 2, flow rate sensors 3, outdoor air-conditioning unit 4 and pumps 5 and so on. The cold/heat source apparatuses 1 include the cold/heat source apparatuses 100 shown in FIG. 1.

The temperature sensors 2 are, for example, sensors configured to measure the temperature and humidity outside the outdoor air-conditioning units 4. The temperature sensors 2 measure also the air supply dew points at the cold/heat source apparatuses 1 and outdoor air-conditioning units 4. The flow rate sensors 3 measure the rates at which the coolant flows in the pipe system, particularly the rate at which the coolant flows in the bypass route 800.

Device/sensor groups 6l to 6p are controlled by control devices 5l to 5p, respectively. Control devices 5l to 5p are connected to, for example, a monitoring device 4l. Monitoring device is installed on each floor of, for example, a building. Hence, in most cases, several monitoring devices (4l to 4n) are used in the building. Each of control devices 5l to 5p functions at positions very close to the components it controls. Each control device gives control commands to the cold/heat source apparatuses 1, outdoor air-conditioning units 4, pumps 5, etc., and acquires sensor data from the temperature sensors 2 and flow rate sensors 3, etc.

The data, such as the values and operating states and preset values acquired at, for example, the data acquisition points in device/sensor group 6l, is collected in control device 5l and then transmitted to monitoring device 4l. Monitoring device 4l stores the data received from control device 5l, in an internal database (not shown). In the internal database, the data is held for a prescribed time (for example, 48 hours) or longer.

Monitoring device 4l transmits commands to control devices 5l to 5p, in accordance with the control logic set in it or with the control command or set value changing command coming from a higher control device. In response to a command coming from monitoring device

41, control device 51 supplies preset values or operating state data to device/sensor group 61. Monitoring device 41, control device 5m and device/sensor group 6m operate in a similar relationship. Also, monitoring device 4n, control device 5p and device/sensor group 6p operate in a similar relationship. Monitoring devices 41 to 4n are connected to the plant control apparatus 10 via a communication network, such as a local area network (LAN) provided in the building.

The plant control apparatus 10, monitoring devices 41 to 4n and control devices 51 to 5p perform hierarchical monitoring and controlling on device/sensor groups 61 to 6p, through the communication network. BACnet (registered trademark) is a representative protocol for the communication network.

The communication network is not limited to a LAN. It may be an Internet Protocol (IP) network or a virtual private network (VPN) of the system vendor. That is, the plant control apparatus 10 need not be installed in the same building as device/sensor groups 61 to 6p. Rather, the plant control apparatus 10 can be installed at a site geographically far from the building.

The plant control apparatus 10 comprises an input device 20 and an output device 30, both used as

human-machine interfaces. The input device 20 is, for example, a mouse, a keyboard or a touchpanel. The output device 30 is, for example, a liquid crystal display. The user may use these devices to visually confirm the data about the process the plant control apparatus 10 has performed, and input numerical values and characters to the plant control apparatus 10.

FIG. 3 is a functional block diagram showing an example of the plant control apparatus 10 shown in FIG. 2. As shown in FIG. 2, the plant control apparatus 10 may comprise a human-machine interface (HMI) processing unit 11, a preset coolant temperature calculating unit 12, a system monitoring unit 13, a communication unit 14, and a database unit 15. Of these components, the preset coolant temperature calculating unit 12, system monitoring unit 13 and communication unit 14 are process functions performed by an arithmetic operation based on the program stored in, for example, the program memory (not shown) incorporated in a central processing unit (CPU). The intervals at which to perform these process functions are performed can be set, independently of one another.

The HMI processing unit 11 is connected to the input device 20 and output device 30, and has the function of giving various data to the user and the function of receiving data from the user. Thus, the HMI processing unit 11 enables the system and the user

to exchange data. The data the HMI processing unit 11 has received is stored in the database unit 15.

5 The preset coolant temperature calculating unit 12 calculates a preset coolant temperature for the thermal recycling plant from the given conditions (for example, environmental conditions such as temperature and humidity, or the air-conditioning temperature and humidity the user has set), by means of optimization, mainly in order to minimize the energy consumption.

10 The data necessary for this calculation is obtained from the database unit 15 or monitoring devices 41 to 4n. The calculated values (hereinafter called the "optimal preset coolant temperature") are saved in the database unit 15.

15 The optimal preset coolant temperature is the best possible temperature at which to maintain the coolant for the purpose of saving energy. In the existing control system, this preset coolant temperature so calculated as described above is the sole control
20 value.

 The system monitoring unit 13 performs a function associated with the monitoring and controlling of the thermal recycling plant. The system monitoring unit 13 monitors the operating states of, particularly, the
25 coolant load apparatuses 500, and determines whether the coolant load apparatuses 500 have an abnormality or not. If any coolant load apparatus 500 is found to

have an abnormality, the system monitoring unit 13 controls the cold/heat source apparatus 100, whereby the coolant is cooled to a temperature lower than the optimal preset coolant temperature.

5 To be more specific, if the system monitoring unit 13 detects any abnormality in the thermal recycling plant, the temperature of the coolant is reduced below the optimal preset coolant temperature. In order to reduce the temperature of the coolant in this manner, a
10 predetermined correction value (a value by which to change the temperature at a time) is preset.

 The communication unit 14 communicates with monitoring devices 41 to 4n, exchanging data with monitoring devices 41 to 4n and transmitting the preset
15 values and control data to device/sensor groups 61 to 6p. The database unit 15 holds, in its storage area, an upper limit table 15a, a parameter table 15b, and an optimal coolant temperature 15c.

 The upper limit table 15a is a table of various
20 upper limits of the preset coolant temperatures, each associated with, for example, the absolute atmospheric humidity. In the upper limit table 15a, the lower limits of the preset coolant temperatures can be registered, too. The parameter table 15b is a table
25 registering the parameters for use in calculating the optimal coolant temperature (for example, the atmospheric temperature and humidity sensed by

sensors). The optimal coolant temperature 15c is the optimal preset coolant temperature actually calculated.

The system monitoring unit 13 comprises a cooling capability monitoring unit 13a and a bypass flow rate monitoring unit 13b, which are process functions
5 utilized in the embodiment.

The cooling capability monitoring unit 13a determines that the thermal recycling plant has an abnormality, if the difference between the temperature
10 measured by the temperature sensor 2 and the temperature set to the coolant load apparatus 500 remains greater than a preset value for a prescribed time or longer. This preset temperature value may depend on the optimal preset coolant temperature. Or,
15 this preset temperature value accords with the user's demand, and may not depend on the optimal preset coolant temperature. In the latter case, the preset temperature value is fixed at the dew point at the outdoor air-conditioning unit, and the plant control
20 apparatus 10 needs only to maintain the outdoor air-conditioning unit at the dew point, irrespective of the changes in the temperature of cold water.

The cooling capability monitoring unit 13a calculates a correction value for the optimal preset
25 coolant temperature, so that the load apparatuses, such as outdoor air-conditioning units 4, may not be insufficiently dehumidified. The correction value

calculated for correcting the optimal preset coolant temperature will hereinafter be called "correction value $\Delta T1$ ".

5 In the embodiment, correction value $\Delta T1$ is added to the optimal preset coolant temperature, providing a corrected optimal preset coolant temperature. Since correction value added lowers the temperature, the correction value is negative in most cases. The corrected optimal preset coolant temperature will be referred to as the "optimal preset coolant temperature (corrected)". Correction value $\Delta T1$ is stored in the database unit 15, together with the optimal preset coolant temperature (corrected).

15 The bypass flow rate monitoring unit 13b determines that the thermal recycling plant has an abnormality, if the flow rate in the bypass route 800 (FIG. 1), detected by any flow rate sensor 3 falls outside the predetermined reference range. Then, the bypass flow rate monitoring unit 13b calculates a correction value for the optimal preset coolant temperature, so that the cold/heat source apparatus 100 may not be unnecessarily activated, even if the bypass flow rate decreases. The correction value calculated at this point will hereinafter be called "correction value $\Delta T2$ ".

25 Correction value $\Delta T2$ calculated by the bypass flow rate monitoring unit 13b can be used, independently of

correction value ΔT_1 calculated by the cooling capability monitoring unit 13a. The corrected optimal preset coolant temperature, which has been corrected in accordance with the coolant flow rate, will also be referred to as the "optimal preset coolant temperature (corrected)".

FIG. 4 is a diagram showing an exemplary screen the output device 30 of the plant control apparatus 10 displays to enable the user to confirm the operating state of the thermal recycling plant control system. The screen shown in FIG. 4 shows that the preset coolant temperature calculating unit 12 is calculating the optimal preset coolant temperature. The screen shown in FIG. 4 displays icons, indicating that the thermal recycling plant control system has an abnormality.

FIG. 5 is a diagram showing another exemplary screen the output device 30 displays to enable the user to change the operating scheme of the plant control apparatus 10. The screen shown in FIG. 5 shows that the function of correcting the air supply dew point at the outdoor air-conditioning unit has been turned on, and that the function of correcting the bypass flow rate has been on. The former function is performed, by mainly the cooling capability monitoring unit 13a. The latter function is performed, by mainly the bypass flow rate monitoring unit 13b.

FIG. 6 is a flowchart showing an exemplary process sequence the plant control apparatus 10 may perform.

As FIG. 6 shows, the plant control apparatus 10 keeps waiting for the timing of calculating the optimal

5 preset coolant temperature (Step S1). This timing is based on the control cycles set by using, for example, the HMI processing unit 11. The plant control apparatus 10 repeats this process sequence shown in FIG. 6, each in one control cycle.

10 When the timing comes, the preset coolant temperature calculating unit 12 calculates the optimal preset coolant temperature (Step 2). Then, the system monitoring unit 13 starts monitoring the thermal recycling plant control system (Step S3). The
15 processes in Steps S2 and S3 may be performed at the same time or at different times, in accordance with the control cycle.

FIG. 7 is a flowchart showing an exemplary process sequence of calculating an optimal coolant temperature.

20 The preset coolant temperature calculating unit 12 acquires the outside temperature and humidity from the parameter table 15b. Then, the preset coolant temperature calculating unit 12 applies the outside temperature to, for example, the Wechsler-Highland
25 approximation, thereby calculating the pressure P_{sa} of saturated water vapor. The preset coolant temperature calculating unit 12 uses the following equations (1)

and (2), calculating the absolute atmospheric humidity (Step S21).

$$P_w = P_{sa} \times RH / 100 \quad \dots (1)$$

where P_w is the partial pressure [kPa] of water vapor,

5 P_{sa} is the pressure [kPa] of saturated water vapor, and R_h is the relative humidity [%].

$$X = 0.62198 \times P_w / (P - P_w) \quad \dots (2)$$

where X is the absolute humidity [kg/kgDA], and P

is the total pressure of air (at sea level, 0 m),

10 $[kPa] = 101.325 \text{ kPa}$.

If the wet bulb atmospheric temperature is 25°C

and the atmospheric humidity is 80%, the absolute

atmospheric humidity will be 0.016 kg/kgDA. If

monitoring device 41, for example, can directly

15 determine the absolute atmospheric humidity, Step 21

can be skipped.

The preset coolant temperature calculating unit 12

then refers to the upper limit table 15a, and

calculates the optimal preset coolant temperature from

20 the absolute atmospheric humidity calculated in Step

S21 (Step S22).

Next, the preset coolant temperature calculating

unit 12 performs a limit process, finding the upper and

lower limits of the optimal preset coolant temperature

25 (Step S23). If the optimal preset coolant temperature

greatly changes every time it is calculated, it should

not be applied directly to the thermal recycling plant.

Therefore, the optimal preset coolant temperature is corrected right after it has been calculated, preventing it from greatly changing from the previous optimal preset coolant temperature by more than a prescribed control margin.

Assume that the control margin is 3.0°C per hour (i.e., $3.0^{\circ}/\text{h}$) and that the preset coolant temperature calculating unit 12 has an operating cycle of 30 minutes. Then, the control margin for each calculation is half the value, i.e., 1.5°C . If the previous optimal preset coolant temperature is 7.2°C , the optimal preset coolant temperature will be calculated as 9.0°C . This increase exceeds the control margin. The preset coolant temperature calculating unit 12 therefore performs the limit process, correcting the optimal preset coolant temperature will to 8.7°C . The optimal preset coolant temperature, so corrected, is registered in the database unit 15 (thus, the optimal preset coolant temperature is now 15°C). The control margin involving the limit process may be set to the thermal recycling plant control system beforehand. Alternatively, it may be input at such an input screen as shown in FIG. 8.

FIG. 8 is a diagram showing an exemplary screen the output device 30 displays, guiding the user to input the control margin that involves the limit process of Step 23. The screen has a window, in which

the items (*1, 2, 3, . . .) are displayed in the row of actual cycles and the upper and lower limits of the water (coolant) temperature are set in association with the absolute atmospheric temperature.

5 FIG. 9 is a diagram showing an example of a preset coolant temperature upper limit table 15a. The preset coolant temperature upper limit table 15a is a table in which the upper limit and lower limit of the temperature preset for each absolute atmospheric
10 temperature are shown, associated with each other. The absolute atmospheric temperature can be set in a range of, for example, 0.0000 to 0.0400 kg/kgDA. The coolant temperatures set for the absolute atmospheric humidities of 0.0000 and 0.0400, respectively, are
15 automatically set to the values for the most similar atmospheric humidities.

 The items that can be set in the preset coolant temperature upper limit table 15a are limited in number. It would therefore be advisable to read two
20 preset absolute atmospheric humidities (for example, 0.0000 and 0.0400 kg/kgDA, which are most similar to the absolute atmospheric humidities acquired from the preset coolant temperature upper limit table 15a, to derive a linear or non-linear approximation from the
25 two preset absolute atmospheric humidities, and to calculate an optimal preset coolant temperature.

 Assume that the preset coolant temperature upper

limit table 15a has the content shown in FIG. 9. Also assume that the linear approximation for the absolute atmospheric humidity of 0.0160 kg/kgDA is applied. Then, an approximation of $-500 \times (\text{absolute humidity}) + 17.0 = (\text{optimal preset coolant temperature})$ will be obtained from items No. 2 and No. 3. If the absolute humidity of 0.0160 kg/kgDA is applied to this approximation, an optimal preset coolant temperature of 9.0°C will be obtained.

FIG. 10 is a flowchart showing an exemplary process sequence the system monitoring unit 13 may perform. As shown in FIG. 10, the cooling capability monitoring unit 13a incorporated in the system monitoring unit 13 corrects the air supply dew point of the air at the outdoor air-conditioning unit (Step S31). Then, the bypass flow rate monitoring unit 13b corrects the bypass flow rate (Step S32). Note that Step 31 and Step 32 can be switched in the order they are performed. Further, only one of them may be performed.

FIG. 11 is a flowchart showing, in detail, a process sequence the cooling capability monitoring unit 13a may perform. The cooling capability monitoring unit 13a reads the data about the outdoor air-conditioning unit from the database unit 15 and determines whether the thermal recycling plant has an abnormality (Step S311). The cooling capability

monitoring unit 13a then finds the difference between the air supply dew point of air at the outdoor air-conditioning unit 4 and the temperature detected by the temperature sensor 2. If this difference remains over
5 a prescribed value for a preset reference time, the cooling capability monitoring unit 13a determines that the thermal recycling plant has an abnormality (Step S312). Both the prescribed value and the reference time may be already registered in the system or may be
10 registered by using the HMI processing unit 11. Whether an abnormality has occurred or not is determined for all outdoor air-conditioning units. Even if an abnormality is found in one outdoor air-conditioning unit only, the thermal recycling plant
15 control system will be found not to be functioning well.

If the air supply dew point at the outdoor air-conditioning unit is found to be abnormal (YES in Step S312), the cooling capability monitoring unit 13a
20 determines whether the previous optimal preset coolant temperature is higher than the preset lower limit (Step S313). The lower limit of the coolant temperature has been registered in the system or can be registered by using the HMI processing unit 11. Alternatively, lower
25 limits of the coolant temperature may be set for the absolute atmospheric humidities, respectively, as shown in FIG. 9. In the case of FIG. 9, the lower limits are

obtained from the values calculated in Step S21 shown in FIG. 7.

If the previous optimal preset coolant temperature is higher than the preset lower limit (YES in Step S313), correction value $\Delta T1$ is decreased by a preset reference value XA (for example, 0.17) (Step S314), obtaining a correction value $\Delta T1 = \Delta T1 - XA$, thus obtained, is added to the optimal preset coolant temperature. An optimal preset coolant temperature (corrected) is thereby obtained.

On the other hand, if the dew point at the outdoor air-conditioning unit is not found to be abnormal (NO in Step S312), the cooling capability monitoring unit 13a determines whether correction value $\Delta T1$ is negative (Step S315). If correction value $\Delta T1$ is negative (YES in Step S315), it is increased by a reference value XB (for example, 0.17) preset beforehand (Step S316). Next, the cooling capability monitoring unit 13a determines whether correction value $\Delta T1$ is positive (Step S317). If correction value $\Delta T1$ is positive (YES in Step 317), the cooling capability monitoring unit 13a zeros the correction value $\Delta T1$ (Step S318). In this case, the optimal preset coolant temperature is not corrected.

FIG. 12 is a flowchart showing, in detail, a process sequence the bypass flow rate monitoring unit 13b may perform. The bypass flow rate monitoring unit

13b reads the coolant bypass flow rate from the database unit 15 (Step S321). The bypass flow rate monitoring unit 13b then determines whether the coolant bypass flow rate is lower than the lower limit value L1 (for example, 250 kg/s) (Step S322).

If the coolant bypass flow rate is found lower than the lower limit value L1 (YES in Step S322), the bypass flow rate monitoring unit 13b determines whether the previous optimal preset coolant temperature is higher than the lower limit (Step S323). If the previous optimal preset coolant temperature is higher than the lower limit (YES in Step S323), the bypass flow rate monitoring unit 13b decreases correction value $\Delta T2$ by a reference value XC (for example, 0.17) (Step S324). Correction value $\Delta T2$ so decreased, i.e., $\Delta T2 - XC$, is added to the optimal preset coolant temperature, thereby obtaining an optimal preset coolant temperature (corrected).

In Step S322, the coolant bypass flow rate may be found equal to or higher than the lower limit value L1 (for example, 750 kg/s) (NO in Step S322). In this case, the bypass flow rate monitoring unit 13b determines whether the coolant bypass flow rate is higher than the upper limit value L2 (Step S325). If the coolant bypass flow rate is equal to or higher than the upper limit value L2 (YES in Step S325), the bypass flow rate monitoring unit 13b determines whether

correction value $\Delta T2$ is negative (Step S326).

Correction value $\Delta T2$ may be negative (YES in Step S326). In this case, the bypass flow rate monitoring unit 13b increases correction value $\Delta T2$ by a preset reference value XD (for example, 0.17) (Step S327).
5 The bypass flow rate monitoring unit 13b then determines whether correction value $\Delta T2$ so corrected is positive (Step S328). Correction value $\Delta T2$ corrected may be positive (YES in Step S328). Then, the bypass
10 flow rate monitoring unit 13b zeros correction value $\Delta T2$. Each parameter used in the process of FIG. 12 may be registered beforehand in the system or may be input at the HMI processing unit 11.

FIG. 13 is a flowchart showing a process sequence the communication unit 14 performs. The communication
15 unit 14 can perform a process in specific process cycles, for example, one-minute cycles. The communication unit 14 acquires optimal preset coolant temperature from the database unit 15, and outputs the
20 same to a data area that can hold the optimal preset coolant temperatures for the cold/heat source apparatuses monitored and controlled (Step S41). The communication unit 14 can use a protocol such as BACnet (registered trademark). Any optimal preset coolant
25 temperature may be first corrected and then output to the data area so that it may not fall outside a reference range. For example, the optimal preset

coolant temperature of 15.1°C may be corrected to 15.0°C and then output to the data area, if the upper limit of the temperature is 15.0°C.

5 The number of decimal places in the optimal preset
coolant temperature calculated may differ from the
number of decimal places in any optimal preset coolant
temperature the cold/heat source apparatus 100 can
receive. If this is the case, the cold/heat source
apparatus 100 may round off, cut off or round up the
10 optimal preset coolant temperature, thereby correcting
the temperature, and may output the optimal preset
coolant temperature so corrected. If the temperature
so corrected, i.e., the latest optimal preset coolant
temperature, has the same value as the previous optimal
15 preset coolant temperature, the cold/heat source
apparatus 100 may skip outputting the latest optimal
preset coolant temperature.

Next, the communication unit 14 acquires various
data about the thermal recycling plant and the data
20 about the atmosphere, which the plant control apparatus
10 uses, from monitoring devices 41 to 4n, control
devices 51 to 5p or device/sensor groups 61 to 6p, by
using a protocol such as BACnet (registered trademark).
The various data, thus acquired, is stored in the
25 database unit 15.

FIG. 14 is a diagram showing exemplary parameters
15b for calculating the optimal coolant temperature.

In the embodiment, the optimal preset coolant temperature is calculated at intervals of 10 minutes, the temperature change is limited to 3 degrees (Celsius) per hour, the optimal preset coolant temperature is corrected at intervals of 1 minute, and correction values $\Delta 1$ and $\Delta 2$ are changed by 0.017°C each time.

FIG. 15 is a table showing exemplary calculated optimal coolant temperatures, arranged in time series.

In the case of FIG. 15, the initial temperature is set to 12.0°C . The table shows the presence and absence of an abnormality, and also the values corrected. In FIG. 15, 0 and 1 indicate the absence of an abnormality and the presence of an abnormality, respectively, based on the detailed correction achieved by the cooling capability monitoring unit 13a. And 0, 1 and 2 indicate the absence of an abnormality, an erroneous lower limit value and an erroneous upper limit value, respectively, based on the detailed correction achieved by the bypass flow rate monitoring unit 13b. In FIG. 15, "Preset Temperature Corrected" is the optimal preset temperature (corrected), more precisely the sum of the optimal preset temperature and correction values $\Delta 1$ and $\Delta 2$. In accordance with the preset temperature thus corrected, the plant control apparatus 10 controls the thermal recycling plant including the plant control apparatuses 100.

FIG. 16 is a graph showing how various values change for a specific time (2 hours), including the period shown in FIG. 15. As shown in FIG. 16, $\Delta T1$ and $\Delta T2$ are negative after the temperature correction process is started, because the thermal recycling plant has strange cooling capability and the upper and lower limits of the coolant bypass flow rate have unusual values. In FIG. 16, line (a) indicates the optimal preset coolant temperature not corrected in consideration of correction value $\Delta T1$ or $\Delta T2$ calculated by the system monitoring unit 13. Thick line (b) indicates the preset coolant temperature, or optimal preset coolant temperature corrected in accordance with correction values $\Delta T1$ and $\Delta T2$. As seen from FIG. 16, the system monitoring unit 13, which has an additional function, can calculate an optimal preset coolant temperature, in consideration of not only the energy saving characteristic, but also the operating state of the thermal recycling plant.

As described above, not only a preset coolant temperature optimal for saving energy in the thermal recycling plant is calculated in the embodiment, but also the difference between any two values, respectively preset to and actually measured in the thermal recycling plant, is monitored. (For example, the difference between the air supply dew point preset to the outdoor air-conditioning unit and the air supply

dew point measured at the outdoor air-conditioning unit is monitored). Then, the optimal preset coolant temperature is corrected in accordance with the difference monitored. The cooling capability of the outdoor air-conditioning unit can therefore be prevented from becoming insufficient to cause an abnormality. Further, in the embodiment, the coolant bypass flow rate is monitored, and the optimal preset coolant temperature is corrected, also in accordance with the coolant bypass flow monitored. As a result, any cold/heat source apparatus in standby state would not be unnecessarily activated. In view of these features, the embodiment is believed to promote energy saving.

Any existing techniques are no more than the calculation of an optimal preset coolant temperature by means of optimization. The coolant load apparatus, such as outdoor air-conditioning unit, may receive an excessive load and may fail to acquire a sufficient dehumidifying capability, inevitably raising the air supply dew point. In such a case, some other coolant load apparatus, which are in standby state, are unnecessarily activated, possibly impairing the energy saving.

By contrast, this embodiment has the function of correcting the optimal preset coolant temperature. This embodiment can therefore provide a thermal

recycling plant system, an apparatus for controlling a thermal recycling plant, and a method of controlling a thermal recycling plant, which can keep the thermal recycling plant in a normal operating state, thereby to save energy.

[Another Embodiment]

FIG. 17 is a system diagram showing an exemplary thermal recycling plant control system according to another embodiment. In the thermal recycling plant control system shown in FIG. 2, device/sensor groups 61 to 6p, control devices 51 to 5p, monitoring devices 41 to 4n and plant control apparatus 10 are provided on the same network. Nonetheless, this invention is not limited to the configuration shown in FIG. 2. That is, as shown in FIG. 17, the plant control apparatus 10 may be connected via the IP network 900 to device/sensor groups 61 to 6p, control devices 51 to 5p and monitoring devices 41 to 4n. In other words, the plant control apparatus 10 is connected via a data communication network to a plurality of thermal recycling plants, each including cold/heat source apparatuses 1 and plant control apparatuses 100. The plant control apparatus 10 therefore controls each thermal recycling plant via the data communication network.

In this embodiment so configured, one server can accomplish all cold/heat source apparatuses installed

in a building or factory. To be more specific, the plant control apparatus 10 first acquires data from the monitoring devices provided in building or factory (sites), then calculates preset coolant temperatures optimal for the respective sites, and finally outputs the data representing the optimal coolant temperatures to the monitoring devices, respectively. To any person with ordinary skill in the art, it would be obvious that a gateway should be used at each site in order to connect the monitoring device to the network 900.

The database unit 15 may store preset coolant temperature upper limit tables 15a, parameters 15b for calculating the optimal coolant temperature and optimal coolant temperature 15c, in the same number as the sites. In addition, the database unit 15 may store a database that holds the data for managing the sites.

The communication unit 14 obtains various data from the registered sites and stores the data in the database unit 15. If any optimal preset coolant temperature is changed, the communication unit 14 outputs the optimal preset coolant temperature to the monitoring device provided at the associated site. The preset coolant temperature calculating unit 12 and the system monitoring unit 13 repeat the process as many times as the sites registered, thereby calculating the preset coolant temperatures for the respective sites. Except for the points described here, the process

performed in the second embodiment is identical to the process performed in the first embodiment.

The present invention is not limited to the embodiments described above. Optimal preset coolant temperatures, for example, can, of course, be
5 calculated not only by the method shown in the flowchart of FIG. 7, but also by the known optimization utilizing the evaluation function with respect to the optimal preset coolant temperatures. Further, the
10 functions of monitoring devices 41 to 4n and control devices 51 to 5p may be implemented in the plant control apparatus 10.

In the embodiments described above, whether an abnormality has developed or not is determined from the
15 air supply dew point at the outdoor air-conditioning unit. However, the data from which to determine the existence of an abnormality is limited to the air supply dew point at the outdoor air-conditioning unit. Any data that shows the operating state of the thermal
20 recycling plant and serves to calculate the difference between the actual temperature and the preset temperature can be used, instead, to determine the existence of an abnormality. For example, the temperature of ultra pure water in a pure water
25 producer and the outlet port temperature of a low temperature water circulation system can be utilized for this purpose. Moreover, various data items may be

used in combination, to determine the existence of an abnormality.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

Explanation of the Symbols

100 ...cold/heat source apparatuses, 500 ...coolant load apparatuses, 700 ...primary pump, 300 ...secondary pump, 200 ...primary header, 400 ...secondary header, 600 ...return header, 800 ...bypass route, 1 ...cold/heat source apparatuses, 2 ...temperature sensors, 3 ...flow rate sensors, 4 ...outdoor air-conditioning units, 5 ...pumps, 10 ...plant control apparatus, 41, 4n ...monitoring devices, 51 to 5p ...control devices, 61 to 6p ...device/sensor groups, 900 ...IP network.

C L A I M S

1. A thermal recycling plant system comprising:

a cooling apparatus which is configured to cool
coolant recycling thermal from coolant circulating in a
load apparatus and which consumes energy while
operating; and

a controller configured to control the cooling
apparatus,

wherein the controller comprises:

a calculator configured to calculate an optimal
temperature that is optimal for the coolant by
optimization calculation for minimizing energy
consumption under given conditions;

a monitor configured to monitor an operating state
of the load apparatus, thereby to determine whether an
abnormality exists in the load apparatus,

the monitor controls the cooling apparatus,
causing the same to cool the coolant to a temperature
lower than the optimal temperature calculated, on
determining that an abnormality exists in the load
apparatus.

2. The thermal recycling plant system according
to claim 1, wherein the monitor corrects the
temperature of the coolant from the optimal temperature
by a prescribed correction value, on determining that
an abnormality exists in the load apparatus.

3. The thermal recycling plant system according

to claim 1, wherein the monitor determines that an abnormality exists if a difference between the temperature of the load apparatus, measured by a temperature sensor, and a preset temperature of the load apparatus remains equal to or larger than a
5 prescribed value, for a prescribed time.

4. The thermal recycling plant system according to claim 3, wherein the load apparatus is an outdoor air-conditioning unit, and the temperature sensor
10 measures an air supply dew point at the outdoor air-conditioning unit.

5. The thermal recycling plant system according to claim 1, wherein the monitor determines that an abnormality exists if a flow rate of the coolant,
15 measured by a flow rate sensor, falls outside a prescribed reference range.

6. The thermal recycling plant system according to claim 5, wherein the flow rate sensor measures the flow rate at which the coolant flows back from an
20 outlet port of the cooling apparatus to an inlet port thereof.

7. The thermal recycling plant system according to any one of claims 1 to 6, which comprises a plurality of cooling apparatuses, the monitor controls
25 the cooling apparatuses operating, thereby cooling the coolant to a temperature lower than the optimal temperature in order to minimize the number of cooling

apparatuses operating.

8. The thermal recycling plant system according to claim 1, wherein the controller is connected to the cooling apparatus via a data communication network, and
5 the monitor controls the cooling apparatus via the data communication network.

9. A control apparatus for controlling a thermal recycling plant which circulates coolant cooled by driving a cooling apparatus consuming energy, thereby
10 to recover heat from a load apparatus, the control apparatus comprising:

a calculator configured to calculate an optimal temperature that is optimal for the coolant by optimization calculation for minimizing energy
15 consumption under given conditions;

a monitor configured to monitor an operating state of the load apparatus, thereby to determine whether an abnormality exists in the load apparatus,

wherein the monitor controls the cooling
20 apparatus, causing the same to cool the coolant to a temperature lower than the optimal temperature calculated, on determining that an abnormality exists in the load apparatus.

10. The control apparatus according to claim 9,
25 wherein the monitor corrects the temperature of the coolant from the optimal temperature by a prescribed correction value, on determining that an abnormality

exists in the load apparatus.

11. The control apparatus according to claim 9,
wherein the monitor determines that an abnormality
exists if a difference between the temperature of the
5 load apparatus, measured by a temperature sensor, and a
preset temperature of the load apparatus remains equal
to or larger than a prescribed value, for a prescribed
time.

12. The control apparatus according to claim 11,
10 wherein the load apparatus is an outdoor air-
conditioning unit, and the temperature sensor measures
an air supply dew point at the outdoor air-conditioning
unit.

13. The control apparatus according to claim 9,
15 wherein the monitor determines that an abnormality
exists if a flow rate of the coolant, measured by a
flow rate sensor, falls outside a prescribed reference
range.

14. The control apparatus according to claim 13,
20 wherein the flow rate sensor measures the flow rate at
which the coolant flows back from an outlet port of the
cooling apparatus to an inlet port thereof.

15. The control apparatus according to any one of
claims 9 to 14, wherein the thermal recycling plant
25 comprises a plurality of cooling apparatuses, the
monitor controls the cooling apparatuses operating,
thereby cooling the coolant to a temperature lower than

the optimal temperature in order to minimize the number of cooling apparatuses operating.

16. The control apparatus according to claim 9, which is connected to the thermal recycling plant via a data communication network, and in which the monitor controls the cooling apparatus via the data communication network.

17. A method of controlling a thermal recycling plant which circulates coolant cooled by driving a cooling apparatus consuming energy, thereby to recover heat from a load apparatus, the method comprising:

calculating an optimal temperature that is optimal for the coolant by optimization calculation for minimizing energy consumption under given conditions;

15 monitoring an operating state of the load apparatus, thereby to determine whether an abnormality exists in the load apparatus, and

controlling the cooling apparatus, causing the same to cool the coolant to a temperature lower than the optimal temperature calculated, if an abnormality is determined to exist in the load apparatus.

18. The method controlling a thermal recycling plant, according to claim 17, wherein the temperature of the coolant is corrected from the optimal temperature by a prescribed correction value, if an abnormality is determined to exist in the load apparatus.

19. The method controlling a thermal recycling plant, according to claim 17, wherein an abnormality is found to exist if a difference between the temperature of the load apparatus, measured by a temperature
5 sensor, and a preset temperature of the load apparatus remains equal to or larger than a prescribed value, for a prescribed time.

20. The method controlling a thermal recycling plant, according to claim 19, wherein the load
10 apparatus is an outdoor air-conditioning unit, and the temperature sensor measures an air supply dew point at the outdoor air-conditioning unit.

21. The method controlling a thermal recycling plant, according to claim 17, wherein an abnormality is
15 determined to exist if a flow rate of the coolant, measured by a flow rate sensor, falls outside a prescribed reference range.

22. The method controlling a thermal recycling plant, according to claim 21, wherein the flow rate
20 sensor measures the flow rate at which the coolant flows back from an outlet port of the cooling apparatus to an inlet port thereof.

23. The method controlling a thermal recycling plant, according to any one of claims 17 to 22, wherein
25 the thermal recycling plant comprises a plurality of cooling apparatuses, and if an abnormality is determined to exist, the cooling apparatuses are

controlled, while operating, thereby cooling the coolant to a temperature lower than the optimal temperature in order to minimize the number of cooling apparatuses operating.