THERMAL MANAGEMENT CONTROL METHOD FOR DATA CENTER, AND ELECTRONIC DEVICE AND READABLE STORAGE MEDIUM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Chinese Patent Application No. 202410274045.1, filed on March 11, 2024, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present application relates to the technical field of communication, and in particular, to a thermal management control method for a data center, an electronic device, and a readable storage medium.

BACKGROUND

[0003] With the rise of information industries such as 5G, big data, cloud computing, artificial intelligence, and industrial Internet, the demand for data centers in China is continuously increasing. In order to respond to the national “dual carbon” goals, reduce system Power Usage Effectiveness (PUE) of data centers, and construct new green data centers, it is crucial to adopt advanced models and algorithms to perform real-time optimization control of the thermal management system of data centers.

[0004] For real-time energy-saving control of the thermal management control system of data centers, domestic and foreign scholars mainly adopt a single modeling approach using either a mechanism model or a data model. Currently, mechanism models are used to model the components of the thermal management system of data centers, and the corrected model has relatively high accuracy. This method optimizes the system operating parameters based on the mechanism model, greatly reducing the system operating energy consumption. However, this type of modeling method has complex principles, requires technicians to possess professional thermodynamic knowledge, has high computational costs and low computational efficiency, and makes it difficult to achieve real-time computational optimization of the system.

[0005] In recent years, an increasing number of scholars have taken alternative approaches and continuously attempted to adopt data model methods for energy-saving optimization and control of the thermal management system of data centers. By adopting data-driven models for temperature prediction of data centers, the computational efficiency is high, which provides ideas for subsequent energy-saving optimization control. However, this type of modeling method completely relies on the quality of collected data, has high data costs, lacks thermodynamic knowledge support, may exhibit “reverse logic” situations, and may even lead to system failures. With a small amount of early-stage data collection, the model accuracy is low and the energy-saving effect is poor.

[0006] That is, although both mechanism models and data models can describe the thermodynamic state of the thermal management system for a data center and provide mathematical expressions for system optimization control, the two types of models each have advantages and disadvantages. The mechanism model has high model accuracy but low computational efficiency, making real-time optimization difficult. The data model, while having high computational efficiency, lacks thermodynamic knowledge support, depends on the quality and quantity of data, has low model accuracy, and is prone to “reverse logic” situations.

SUMMARY

[0007] The main objective of the present application is to provide a thermal management control method for a data center, an electronic device, and a readable storage medium.

[0008] To achieve the above objective, the present application provides a thermal management control method for a data center, including: acquiring first data, the first data characterizing a plurality of actual operating conditions of the data center under operating conditions, and a control parameter and an operating mode under each actual operating condition; performing data supplementation on the first data based on a pre-trained mechanism model to obtain second data; and performing, based on the second data, in combination with a preset optimization algorithm, optimization to obtain a target control parameter and a target operating mode for the data center, and performing thermal management control on the data center according to the target control parameter and the target operating mode.

[0009] In addition, to achieve the above objective, the present application further provides a thermal management control system, the thermal management control system is applied to the thermal management control method for the data center as described above, and the thermal management control system includes: a liquid cooling system, an air cooling system and a server,

the liquid cooling system includes a cooling device, a heat exchanger, a first three-way valve, a first water pump, and a second water pump, where the heat exchanger includes a first pipeline and a second pipeline, the first pipeline is provided with a first water inlet and a first water outlet, the second pipeline is provided with a second water inlet and a second water outlet, the first three-way valve includes a liquid inlet, a first liquid outlet, and a second liquid outlet, and the cooling device is a cooling tower or an air cooler; the air cooling system includes a refrigeration device, a fan, a second three-way valve, and a third water pump, where the second three-way valve includes a water inlet end, a first water outlet end, and a second water outlet end, and the refrigeration device is a chiller or a refrigeration unit; where an outlet end of the cooling device, the first water inlet, the first water outlet, the liquid inlet, the first liquid outlet, and an inlet end of the cooling device form a liquid cooling circuit, and the first water pump is disposed in the liquid cooling circuit; a coolant outlet of the server, the second water inlet, the second water outlet, and a coolant inlet of the server form a heat exchange circuit, the second water pump is disposed in the heat exchange circuit, and a fluid in the heat exchange circuit is configured to exchange heat with a fluid in the liquid cooling circuit in the heat exchanger; a liquid outlet end of the refrigeration device, the water inlet end, the first water outlet end, a liquid cooling inlet of the fan, a liquid cooling outlet of the fan, and a liquid inlet end of the refrigeration device form an air cooling circuit, the third water pump is disposed in the air cooling circuit, and the fan is configured to blow cold air to the server; and the air cooling circuit is in communication with the liquid cooling circuit through the second water outlet end, and the liquid cooling circuit is in communication with the air cooling circuit through the second liquid outlet.

[0010] In addition, to achieve the above objective, the present application further provides an electronic device, including: a memory, a processor, and a thermal management control program for a data center stored on the memory and executable on the processor, and the thermal management control program for the data center, when executed by the processor, implements the thermal management control method for the data center as described above.

[0011] In addition, to achieve the above objective, the present application further provides a storage medium, the storage medium is a computer-readable storage medium, a thermal management control program for a data center is stored on the computer-readable storage medium, and the thermal management control program for the data center, when executed by a processor, implements the thermal management control method for the data center as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] In order to more clearly describe the technical solutions of the embodiments of the present application or the related art, a brief introduction will be given below to the drawings required for use in the description of the embodiments or the related art. Obviously, the drawings described below are merely some embodiments of the present application. For those of ordinary skill in the art, other drawings may be obtained based on the structures shown in these drawings without exerting creative effort.

[0013] FIG. 1 is a schematic flow chart of a thermal management control method for a data center according to an embodiment of the present application.

[0014] FIG. 2 is a flow chart of real-time energy-saving optimization and control of a thermal management system for a data center according to an embodiment of the present application.

[0015] FIG. 3 is a schematic diagram of a dual-drive flow of a thermal management system for a data center according to an embodiment of the present application.

[0016] FIG. 4 is a schematic scenario diagram of thermal management control of a data center according to an embodiment of the present application.

[0017] FIG. 5 is a schematic diagram of an operating mechanism of a system-level dual-drive mechanism model according to an embodiment of the present application.

[0018] FIG. 6 is a schematic diagram of an operating mechanism of an equipment-level dual-drive mechanism model according to an embodiment of the present application.

[0019] FIG. 7 is a schematic diagram of mutual calibration and optimization between a data model and a mechanism model according to an embodiment of the present application.

[0020] FIG. 8 is a flow chart of model calibration and optimization using a model coefficient correction method according to an embodiment of the present application.

[0021] FIG. 9 is a flow chart of model calibration and optimization using an error correction method according to an embodiment of the present application.

[0022] FIG. 10 is a diagram of experimental data of the model coefficient correction method according to an embodiment of the present application.

[0023] FIG. 11 is a diagram of experimental data of the error correction method according to an embodiment of the present application.

[0024] FIG. 12 is a diagram of predicted experimental data of dual-drive regulation compared with basic regulation in the related art according to an embodiment of the present application.

[0025] FIG. 13 is a diagram of experimental data of various operating conditions of a data center according to an embodiment of the present application.

[0026] FIG. 14 is a comparison diagram of predicted data of a dual-drive regulation strategy compared with other regulation strategies in the related art according to an embodiment of the present application.

[0027] FIG. 15 is a schematic structural diagram of a thermal management control system for a data center according to an embodiment of the present application.

[0028] FIG. 16 is a schematic diagram of a hardware structure of an electronic device involved in an embodiment of the present application.

[0029] Description of Reference Numerals

Numeral	Name	Numeral	Name
100	Thermal management control system for data center	8	Second three-way valve
1	Cooling device	9	Third water pump
2	Heat exchanger	10	Server
3	First three-way valve	11	Filter
4	First water pump	21	First water inlet
5	Second water pump	22	First water outlet
6	Refrigeration device	23	Second water inlet
7	Fan	24	Second water outlet
31	Liquid inlet	32	First liquid outlet
33	Second liquid outlet	81	Water inlet end
82	First water outlet end	83	Second water outlet end

[0030] The implementation, functional features, and advantages of the objectives of the present application will be further described in conjunction with the embodiments and with reference to the accompanying drawings.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0031] It should be understood that the specific embodiments described herein are merely for

explaining the present application and are not intended to limit the present application.

[0032] The technical solutions in the embodiments of the present application will be clearly and completely described below with reference to the accompanying drawings in the embodiments of the present application. Obviously, the described embodiments are merely a part of the embodiments of the present application, rather than all embodiments. All other embodiments obtained by those of ordinary skill in the art based on the embodiments of the present application without exerting creative effort shall fall within the scope of the present application.

[0033] It should be noted that all directional indications in the embodiments of the present application (such as up, down, left, right, front, rear, etc.) are only used to explain the relative positional relationships and movement conditions among components under a specific posture (as shown in the drawings). If the specific posture changes, the directional indications shall also change accordingly.

[0034] In the present application, unless otherwise explicitly specified and defined, terms such as “connection” and “fixing” should be understood in a broad sense. For example, “fixing” may be a fixed connection, a detachable connection, or an integral formation; it may be a mechanical connection or an electrical connection; it may be a direct connection or an indirect connection through an intermediate medium; and it may be a communication between two elements or an interaction relationship between two elements, unless otherwise explicitly defined. For those of ordinary skill in the art, the specific meanings of the above terms in the present application may be understood according to specific circumstances.

[0035] In addition, in the present application, descriptions involving “first,” “second,” and the like are merely for descriptive purposes and cannot be understood as indicating or implying relative importance or implicitly indicating the number of technical features indicated. Accordingly, features defined by “first” and “second” may explicitly or implicitly include at least one such feature. In addition, technical solutions among various embodiments may be combined with each other, but the combination must be based on what can be realized by those of ordinary skill in the art. When the combination of technical solutions is contradictory or cannot be realized, it shall be considered that such combination of technical solutions does not exist and is not within the scope claimed by the present application.

[0036] In recent years, an increasing number of scholars have taken alternative approaches and continuously attempted to adopt data model methods for energy-saving optimization and control of the thermal management system of data centers. By adopting data-driven models for temperature prediction of data centers, the computational efficiency is high, which provides ideas for subsequent energy-saving optimization control. However, this type of modeling method

completely relies on the quality of collected data, has high data costs, lacks thermodynamic knowledge support, may exhibit “reverse logic” situations, and may even lead to system failures. With a small amount of early-stage data collection, the model accuracy is low and the energy-saving effect is poor.

[0037] That is, although both mechanism models and data models can describe the thermodynamic state of the thermal management system for a data center and provide mathematical expressions for system optimization control, the two types of models each have advantages and disadvantages. The mechanism model has high model accuracy but low computational efficiency, making real-time optimization difficult. The data model, while having high computational efficiency, lacks thermodynamic knowledge support, depends on the quality and quantity of data, has low model accuracy, and is prone to “reverse logic” situations.

[0038] Based on the above, the embodiments of the present application provide a thermal management control method for a data center. Referring to FIG. 1, FIG. 1 is a schematic flow chart of a thermal management control method for a data center according to an embodiment of the present application. In this embodiment, the thermal management control method for the data center includes:

[0039] Step S10: acquiring first data, the first data characterizing a plurality of actual operating conditions of the data center under operating conditions, and a control parameter and an operating mode under each actual operating condition.

[0040] In this embodiment, operating data of the data center under various operating conditions (the operating data including control parameters and operating modes) may be collected, the operating data may be preprocessed to obtain first data, and the preprocessing includes but is not limited to denoising processing or downsampling processing.

[0041] Exemplarily, acquiring first data includes:

[0042] Step A10: collecting the control parameter and the operating mode of the data center under each actual operating condition to obtain third data.

[0043] Step A20: performing data processing on the third data based on a preset data processing algorithm to obtain the first data, the preset data processing algorithm is at least one of a Latin hypercube sampling method, a wavelet threshold denoising method, an empirical mode decomposition denoising method, a k-nearest neighbor outlier removal method, a Mahalanobis distance outlier removal method, a linear interpolation data repair method, an expectation maximization numerical repair method, a Latin hypercube sampling interval division method, and a redundancy removal data reduction method.

[0044] In this embodiment, by collecting the control parameter and the operating mode of the

data center under each actual operating condition to obtain third data, and performing data processing on the third data based on a preset data processing algorithm to obtain first data, where the preset data processing algorithm is at least one of a Latin hypercube sampling method, a wavelet threshold denoising method, an empirical mode decomposition denoising method, a k-nearest neighbor outlier removal method, a Mahalanobis distance outlier removal method, a linear interpolation data repair method, an expectation maximization numerical repair method, a Latin hypercube sampling interval division method, and a redundancy removal data reduction method, abnormal data can be excluded and repaired for collected measured data, and data reduction is achieved to optimize the complexity of the sample library.

[0045] After the step S10, step S20 is executed: performing data supplementation on the first data based on a pre-trained mechanism model to obtain second data.

[0046] In this embodiment, those skilled in the art have conducted certain in-depth research on the training method or construction method of the mechanism model. For example, a mechanism model may be constructed according to the system operating mechanism, the accuracy of the mechanism model may be improved based on collected field data, and the sample library data may be supplemented through the accuracy-improved mechanism model.

[0047] In one example, the mechanism model is a system-level dual-drive model, in which components adopt data models with faster computation speed, and the system is constructed according to the actual mechanism. The overall computation speed is fast, but it has a certain degree of reverse logic.

[0048] In another example, the mechanism model is an equipment-level dual-drive model, which is refined from the system level to the equipment level, and the entirety is constructed by mechanism models, which can completely avoid “reverse logic,” but the simulation platform has a slower computation speed. These two examples are described in more detail in the following embodiments and will not be repeated here.

[0049] Step S30: performing, based on the second data, in combination with a preset optimization algorithm, optimization to obtain a target control parameter and a target operating mode for the data center, and performing thermal management control on the data center according to the target control parameter and the target operating mode.

[0050] The target control parameter refers to a control parameter for achieving the thermal management control target for the data center. The target operating mode refers to an operating mode for achieving the thermal management control target for the data center. The thermal management control target is that a system PUE of the data center is minimized or a total system energy consumption is minimized.

[0051] Exemplarily, the types of the operating mode include a first operating mode, a second operating mode, and a third operating mode, the first operating mode is an operating mode in which a refrigeration device is turned off and a cooling device supplies liquid to a liquid cooling side and an air cooling side, where the refrigeration device is a chiller or a refrigeration unit, and the cooling device is a cooling tower or an air cooler; the second operating mode is that the refrigeration device supplies liquid to the air cooling side, and the cooling device supplies liquid to the liquid cooling side; and the third operating mode is that both the refrigeration device and the cooling device supply liquid to the air cooling side and the liquid cooling side.

[0052] Exemplarily, the control parameters refer to operating control parameters of various power-consuming devices, and the power-consuming devices (i.e., the underlying controlled components described below) may include a fan, a water pump, a compressor, a cooling device, and a refrigeration device. The cooling device is a cooling tower or an air cooler, and the refrigeration device is a chiller or a refrigeration unit. The operating control parameters are fan frequency, water pump frequency, compressor frequency, valve opening degree, and the like.

[0053] In this embodiment, the preset optimization algorithm may be a genetic algorithm, a particle swarm optimization algorithm, a simulated annealing algorithm, or an ant colony algorithm.

[0054] The present application proposes a thermal management control method for a data center, an electronic device, and a readable storage medium. In the thermal management control method for the data center, the technical solution of the embodiments of the present application is to acquire first data, which characterizes a plurality of actual operating conditions of the data center, and control parameters and operating modes under each actual operating condition, and perform data supplementation on the first data based on a pre-trained mechanism model to obtain second data, so that the present application supplements data to intervals without valid measured data through the mechanism model, establishes a concise and effective data sample library, and through the fusion of the mechanism model sample library, can supplement super-region data for blank operating condition areas without measured data, improving the effective coverage of the sample library. That is, the embodiments of the present application can form a fused sample library of field data and mechanism model with high data quality, wide range, small quantity, and good effect, and based on the second data, in combination with a preset optimization algorithm, perform optimization to obtain target control parameter and a target operating mode for the data center, and perform thermal management control on the data center according to the target control parameter and the target operating mode, thereby achieving a fitted thermal management control strategy covering a wider range of operating conditions. The embodiments of the present application

construct a mechanism model according to the system operating mechanism, improve the accuracy of the mechanism model based on field-collected data, and supplement the sample library data through the accuracy-improved mechanism model, thereby facilitating real-time optimization calculation of optimal control parameter and optimal operating modes for thermal management control of the data center, so as to determine the thermal management control strategy for the server of the data center, thereby achieving thermal management control of the data center with high computational efficiency and high accuracy, and improving the stability and reliability of thermal management control of the data center.

[0055] The embodiments of the present application fuse the mechanism model with the data model, process field data through multiple methods and use the mechanism model to supplement intervals without valid data, forming a fused sample library of field data and mechanism model with high data quality, wide range, small quantity, and good effect (i.e., the second data). The data model fits the sample library data to form a comprehensive and effective system data model (i.e., a dual-drive model that fuses the data model and the mechanism model), and the data model can be combined with optimization algorithms to generate optimal control variables and operating modes in real time.

[0056] The embodiments of the present application fuse the mechanism model and the data model using a systematic method, complementing each other's strengths and weaknesses, thereby producing a dual-drive model with low computational cost, strong model logic, and comprehensive functions.

[0057] The embodiments of the present application disclose an energy-saving control method for a data center cooling system based on a mechanism and data dual-drive model, belonging to the field of data center energy-saving control. The main steps include: field-collected data are processed by the mechanism model to exclude or repair abnormal values; the mechanism model supplements data to intervals without valid measured data, establishing a concise, effective, and comprehensive sample library covering operating conditions; a data-driven method fits a comprehensive and accurate system PUE and energy consumption model; an optimization algorithm calculates the optimal control parameter and operating mode of the thermal management system and stores them into a knowledge base; and according to actual field operating conditions, the corresponding optimal control parameter and operating mode can be invoked in real time to avoid online optimization delay. PLC controls the operating state of the equipment according to the optimization decision, achieving real-time energy-saving optimization control of the system. The embodiments of the present application perform thermal management control of the data center with low computational cost, high accuracy, good logic, and low dependence on data

quality, and can achieve comprehensive energy saving of the thermal management system of the data center in the short, medium, and long term.

[0058] To facilitate understanding of the technical principles of the embodiments of the present application, a specific embodiment 1 is provided. Referring to FIG. 2, FIG. 2 is a flow chart of real-time energy-saving optimization and control of the thermal management system for a data center according to an embodiment of the present application. This embodiment connects a host computer intelligent computing platform, a Programmable Logic Controller (PLC), and terminal equipment systems to form an efficient control system process, specifically:

[0059] Host computer intelligent computing platform: Composed of a database and a dual-drive model. The database stores and manages data, and also implements functions such as data cleaning, data classification, and data updating. The mechanism and data dual-drive model performs real-time intelligent computation of the optimal working states of power-consuming components such as cooling towers, chillers, water pumps, and fans, and sends them to the PLC controller. Meanwhile, the PLC controller uploads field-collected data to the database.

[0060] PLC controller: Controls the working states of terminal equipment according to instructions from the host computer, and collects field real-time data through sensors.

[0061] Terminal equipment: The working states of terminal equipment of the thermal management system of the data center change in real time. Under the condition of meeting the temperature requirements of the server in the equipment room, the energy consumption of the thermal management system is reduced, achieving real-time energy-saving control functionality.

[0062] The above specific embodiment 1 is only used to help understand the technical concept of the embodiments of the present application and does not constitute a limitation on the present application. Simple transformations in more forms based on this technical concept shall all fall within the protection scope of the present application.

[0063] In a possible implementation, in step S30, performing, based on the second data, in combination with a preset optimization algorithm, optimization to obtain target control parameter and the target operating mode for the data center includes:

[0064] Step B10: performing model fitting on a thermal management control target based on the second data to obtain a fitted model.

[0065] In this embodiment, the thermal management control target includes but is not limited to minimizing the system PUE of the data center or minimizing the total system energy consumption.

[0066] Step B20: performing, based on the fitted model, in combination with the preset optimization algorithm, optimization to obtain an optimal control parameter and an optimal

operating mode for each operating condition of the data center, and storing the optimal control parameter and the optimal operating mode of each operating condition into a knowledge base.

[0067] In this embodiment, the type of the preset optimization algorithm may be a genetic algorithm, a particle swarm optimization algorithm, a simulated annealing algorithm, or an ant colony algorithm. Those skilled in the art have conducted certain in-depth research on the genetic algorithm, particle swarm optimization algorithm, simulated annealing algorithm, and ant colony algorithm, which will not be repeated here.

[0068] Step B30: dynamically acquiring a real-time operating condition of the data center, and querying and invoking from the knowledge base to obtain the target control parameter and the target operating mode for the data center.

[0069] Exemplarily, in step B30, querying and invoking from the knowledge base to obtain the target control parameter and the target operating mode for the data center includes:

[0070] Step C10: querying and invoking from the knowledge base to obtain a control parameter corresponding to achieving the thermal management control target, and an operating mode corresponding to achieving the thermal management control target, where the thermal management control target is that a system PUE of the data center is minimized or a total system energy consumption is minimized.

[0071] Step C20: taking the control parameter corresponding to achieving the thermal management control target under the real-time operating condition as the target control parameter for the data center.

[0072] Step C30: taking the operating mode corresponding to achieving the thermal management control target under the real-time operating condition as the target operating mode for the data center.

[0073] In this embodiment, dynamically acquiring the real-time operating condition of the data center refers to periodically acquiring the real-time operating condition of the data center, or acquiring the real-time operating condition of the data center at preset time intervals.

[0074] The embodiments of the present application perform model fitting on the thermal management control target based on the second data to obtain a fitted model, and based on the fitted model, in combination with a preset optimization algorithm, perform optimization to obtain optimal control parameter and an optimal operating mode for each operating condition of the data center, store the optimal control parameter and the optimal operating mode of each operating condition into a knowledge base, and then dynamically acquire the real-time operating condition of the data center, and query and invoke from the knowledge base to obtain target control parameter and a target operating mode for the data center, thereby matching the real-time operating condition

with the full-range operating conditions in the knowledge base, and performing real-time fast invocation according to the matched operating condition in the knowledge base to select the corresponding optimal control parameter and optimal operating mode. In this embodiment, by traversing all possible operating conditions of the system, the optimization algorithm (i.e., the preset optimization algorithm described above) is used to pre-calculate the optimal control parameter and optimal operating mode corresponding to all operating conditions, and all of them are stored in a knowledge base. According to actual field operating conditions, the corresponding optimal control parameter and operating mode can be invoked in real time and quickly from the knowledge base, avoiding online optimization delay and eliminating the optimization process of the algorithm, thereby achieving fast real-time optimization.

[0075] For example, the regulation strategy in the related art: measured operating condition → system fitted model → genetic optimization algorithm → strategy issuance, which has delay. However, the regulation strategy of the embodiments of the present application: traverse operating conditions → system fitted model → genetic optimization algorithm → store strategy in knowledge base → measured operating condition → knowledge base invocation → strategy issuance. Compared with the regulation strategy in the related art, the embodiments of the present application establish a knowledge base, which can directly invoke the corresponding preferred regulation strategy from the knowledge base, eliminating the optimization delay.

[0076] Further, the fitted model is trained and stored in a cloud server, and the knowledge base is disposed locally at a user terminal.

[0077] The embodiments of the present application train and store the fitted model in a cloud server, and dispose the knowledge base locally at the user terminal, thereby achieving edge-cloud integration. Large-scale model training and verification are performed on the cloud, and control strategies for various operating conditions are calculated simultaneously. The calculation results are output as a knowledge base, which is stored in an edge data center and quickly invoked at the user terminal. That is, by establishing the knowledge base locally, the corresponding preferred regulation strategy is directly invoked from the local knowledge base to shorten the regulation response time.

[0078] In a possible implementation, the method further includes:

[0079] Step D10: in a case that the data center is in a risk operating condition, querying and invoking from the knowledge base to obtain a safety regulation strategy corresponding to the risk operating condition, where the safety regulation strategy includes control parameters and an operating mode for performing safety regulation on the risk operating condition.

[0080] In this embodiment, specifically, based on the fitted model, predictive analysis of risk operating conditions of the data center may be performed to obtain safety regulation strategies under risk operating conditions, i.e., optimal control parameter and optimal operating mode, which are all stored in the knowledge base. When the data center is in a risk operating condition, the safety regulation strategy corresponding to the risk operating condition is queried and invoked from the knowledge base to quickly respond to and execute the safety regulation strategy.

[0081] The embodiments of the present application query and invoke from the knowledge base to obtain the safety regulation strategy corresponding to the risk operating condition when the data center is in a risk operating condition, the safety regulation strategy includes control parameters and an operating mode for performing safety regulation on the risk operating condition, thereby performing pre-analysis on risk operating conditions, abnormal operating conditions, or extreme operating conditions, and obtaining corresponding safe and reliable regulation strategies in advance, which are stored in the knowledge base for reliable regulation and efficient emergency response when actually occurring, having a reliable risk prediction and risk response function.

[0082] In a possible implementation, performing model fitting on the thermal management control target based on the second data to obtain a fitted model includes:

[0083] Step E10: constructing a sample database according to the second data.

[0084] Step E20: performing feature selection on the sample database based on a principal component analysis method to obtain independent variable parameters that have an impact on the thermal management control target.

[0085] Step E30: performing model fitting on the thermal management control target according to the independent variable parameters that have an impact on the thermal management control target to obtain a fitted model.

[0086] In this embodiment, the thermal management control target includes but is not limited to minimizing the system PUE of the data center or minimizing the total system energy consumption. Those skilled in the art may set it according to actual circumstances, and this embodiment does not impose specific limitations.

[0087] The embodiments of the present application construct a sample database according to the second data, perform feature selection on the sample database based on a principal component analysis method to obtain independent variable parameters that have an impact on the thermal management control target, and perform model fitting on the thermal management control target according to the independent variable parameters that have an impact on the thermal management control target to obtain a fitted model, thereby achieving convergence of direct and indirect parameters that have the greatest impact on the target control quantity as required feature quantities

based on feature parameter selection methods such as principal component analysis, so as to greatly reduce the arrangement of system sensors, reduce the parameter complexity of the dual-drive model (i.e., the fitted model described above), and improve the fitting speed and accuracy of the dual-drive model.

[0088] To facilitate understanding of the technical principles of the embodiments of the present application, a specific embodiment 2 is provided. Referring to FIG. 3, FIG. 3 is a schematic diagram of a dual-drive flow of the thermal management system for a data center according to an embodiment of the present application, specifically including:

[0089] (1) Sample library construction:

[0090] First, after collecting field data, data preprocessing is performed: wavelet threshold denoising, empirical mode decomposition, and other methods are used for data denoising to remove sensor data noise, shield interference, and ensure the authenticity of signals; data processing methods such as empirical mode decomposition denoising method, k-nearest neighbor outlier removal method, or Mahalanobis distance outlier removal method are used for data filtering and outlier removal to retain valid data; and methods such as linear interpolation and expectation maximization algorithm are used to learn and analyze historical information data, completing the repair of missing data or faulty data.

[0091] Further, in the subsequent stage when the mechanism model has relatively high accuracy, the mechanism model simulation data may be used to exclude or repair abnormal values in the field-collected data.

[0092] Then, this embodiment uses Latin hypercube sampling to determine the interval of the sample library and remove redundant data, ensuring that the data is concise and effective, and uses the mechanism model to supplement data to intervals without valid data, establishing a fused sample library of field data and mechanism model with high data quality, wide range, small quantity, and good effect.

[0093] (2) Data model training:

[0094] The principal component analysis (PCA) method is used to perform feature selection on the dual-drive sample library data, selecting the parameters that have the greatest impact on the total system power consumption and PUE as independent variables. The most representative parameters of this data center thermal management system are ambient temperature and humidity, air and liquid heat loads, control parameters of various power-consuming devices, and operating modes, with output parameters being system power consumption and PUE.

[0095] After the input parameters and output parameters of the neural network function are determined, data-driven algorithms such as BPNN, LSTM, SVM, XGBoost, or LightGBM are

used to continuously and iteratively fit the system model until the RMSE and MAPE meet the accuracy requirements. Various data-driven algorithms are compared and analyzed in terms of accuracy and fitting effect, and the best data-driven algorithm for this data center is selected to improve the system control effect.

[0096] (3) Optimization calculation:

[0097] The internal thermal environment of the data center changes with ambient temperature, ambient humidity, and heat load. If the operating parameters of the thermal management system of the data center are improperly selected, the server may experience overheating or overcooling. Severe overheating may cause server downtime, while severe overcooling may lead to low refrigeration efficiency and significant power consumption waste. Therefore, in order to maintain the server within a safe temperature range and minimize energy consumption, it is necessary to calculate the optimal system control parameters and operating mode under different ambient temperatures, environmental humidities, and heat loads in real time.

[0098] Optimization algorithms such as genetic algorithms can achieve the above requirements. Taking the lowest system PUE as the thermal management control target as an example, the optimal system control parameters and operating mode under any given ambient temperature and humidity and air-liquid heat load at any moment are calculated.

[099] (4) Knowledge base construction:

[0100] All possible operating conditions of the thermal management system are traversed, and the optimal control parameter and optimal operating mode corresponding to all operating conditions are pre-calculated using optimization algorithms and all stored in the knowledge base.

[0101] (5) Optimization strategy issuance and execution:

[0102] There are two modes for the source of optimization strategies.

[0103] Mode 1: According to actual field operating conditions, the corresponding optimal control parameter and operating mode can be invoked in real time and quickly from the knowledge base, avoiding online optimization delay.

[0104] Mode 2: Based on the high-precision system energy consumption fitted model and actual operating condition parameters, an optimization algorithm is used to perform real-time optimization. After the optimization is completed, the optimal control parameter and operating mode under the operating condition can be output, which requires a certain optimization time, the optimization algorithm may be, for example, a particle swarm optimization algorithm, a simulated annealing algorithm, or an ant colony algorithm, etc. This embodiment does not impose specific limitations on this.

[0105] The optimization results (optimization strategies) are issued by control equipment to

underlying controllable components to achieve system energy-saving optimization control, maintaining the server within a safe temperature range and minimizing energy consumption, the control equipment may be, for example, PLC or Direct Digital Control (DDC) system, etc.

[0106] The above specific embodiment 2 is only used to help understand the technical concept of the embodiments of the present application and does not constitute a limitation on the present application. Simple transformations in more forms based on this technical concept shall all fall within the protection scope of the present application.

[0107] Based on the first embodiment of the present application described above, a second embodiment of the thermal management control method for the data center is proposed, the method further includes:

[0108] Step F10: constructing a model error function based on the target control parameter and the target operating mode corresponding to the real-time operating condition, and predicted data of the fitted model under the real-time operating condition.

[0109] Step F20: performing iterative optimization on model coefficients of the fitted model based on the model error function.

[0110] Referring to FIG. 7, FIG. 7 is a schematic diagram of mutual calibration and optimization between a data model and a mechanism model according to an embodiment of the present application. In this embodiment, by constructing a model error function based on the target control parameter and the target operating mode corresponding to the real-time operating condition, and the predicted data of the fitted model under the real-time operating condition, and performing iterative optimization on the model coefficients of the fitted model based on the model error function, the data model and the mechanism model are effectively calibrated against each other for accuracy, continuously improving the model accuracy during operation, and thereby continuously improving the accuracy, reliability, and energy-saving effectiveness of the intelligent regulation strategy.

[0111] In addition, referring to FIG. 8 and FIG. 9, FIG. 8 is a flow chart of model calibration and optimization using a model coefficient correction method according to an embodiment of the present application, and FIG. 9 is a flow chart of model calibration and optimization using an error correction method according to an embodiment of the present application. The embodiments of the present application, based on the model coefficient correction method, use the model prediction error as the optimization target to optimize the model coefficients of the fitted model, improving the accuracy of the mechanism model and safeguarding the dual-drive sample library. In another example, the embodiments of the present application may also be based on the error correction method, improving the accuracy of the mechanism model by fitting the prediction error with a data

model and superimposing the error data model onto the mechanism model.

[0112] Referring to FIG. 10 and FIG. 11, FIG. 10 is a diagram of experimental data of the model coefficient correction method according to an embodiment of the present application, and FIG. 11 is a diagram of experimental data of the error correction method according to an embodiment of the present application. It can be seen that compared with the model calibration and optimization process of the model coefficient correction method, the model calibration and optimization process of the error correction method has higher mechanism model prediction accuracy.

[0113] As an implementable manner, the performing data supplementation on the first data based on a pre-trained mechanism model to obtain second data includes:

[0114] Step G10: performing exclusion or correction on abnormal data in the first data based on the pre-trained mechanism model to obtain third data.

[0115] Step G20: performing data supplementation on the third data based on the pre-trained mechanism model to obtain second data.

[0116] The embodiments of the present application perform exclusion or correction on abnormal data in the first data based on the pre-trained mechanism model to obtain third data, and perform data supplementation on the third data based on the pre-trained mechanism model to obtain second data, thereby excluding and repairing abnormal data for collected measured data, achieving data reduction, and optimizing the complexity of the sample library.

[0117] In a possible implementation, performing thermal management control on the data center according to the target control parameter and the target operating mode includes:

[0118] Step H10: controlling operating parameters of underlying controlled components of the data center according to the target control parameter and the target operating mode, so as to perform thermal management control on the data center.

[0119] The underlying controlled components include a fan, a water pump, a compressor, and a valve, and the operating parameters of the underlying controlled components include a fan frequency, a water pump frequency, a compressor frequency, and a valve opening degree.

[0120] As an example, the pre-trained mechanism model is a system-level dual-drive mechanism model, and the method further includes:

[0121] Step I10: acquiring, from a preset component model library, trained component data models corresponding to respective underlying controlled components.

[0122] Step I20: performing system-level mechanism model construction for the data center based on each component data model to construct the system-level dual-drive mechanism model.

[0123] Referring to FIG. 5, FIG. 5 is a schematic diagram of an operating mechanism of a

system-level dual-drive mechanism model according to an embodiment of the present application. In this embodiment, the system-level dual-drive mechanism model is configured to: acquire component data models corresponding to respective underlying controlled components; perform system-level mechanism model construction and analysis for the data center based on each component data model, which is the system-level dual-drive mechanism model; and obtain an optimal operating parameter and an optimal operating mode of the data center under each operating condition based on the system-level dual-drive mechanism model.

[0124] The embodiments of the present application adopt a system-level dual-drive mechanism model as the mechanism model, in which components adopt data models with faster computation speed, and the system is constructed according to the actual mechanism. The overall computation speed is fast, but it has a certain degree of reverse logic.

[0125] Further, the performing system-level mechanism model construction for the data center based on each component data model to construct the system-level dual-drive mechanism model includes:

[0126] Step J10: constructing the system-level dual-drive mechanism model based on each component data model in a first preset building block stacking manner.

[0127] The embodiments of the present application construct the system-level dual-drive mechanism model based on each component data model in a first preset building block stacking manner, thereby performing mechanism modeling on typical components and devices separately to form a mechanism model component library. When constructing the system-level dual-drive mechanism model, corresponding elements are preferentially selected from the mechanism model component library to reduce the secondary construction time of component/device models, and the system-level dual-drive mechanism model is quickly formed in a building block stacking manner through library selection. This embodiment simplifies the construction efficiency of the system-level dual-drive mechanism model through the component library and building block stacking manner, and also improves the scalability of the system mechanism model.

[0128] As another example, the pre-trained mechanism model is an equipment-level dual-drive mechanism model, based on each component data model, the method further includes:

[0129] Step K10: acquiring, from a preset component model library, trained component mechanism models corresponding to respective underlying controlled components.

[0130] Step K20: performing system-level mechanism model construction for the data center based on each component mechanism model to obtain the equipment-level dual-drive mechanism model.

[0131] Referring to FIG. 6, FIG. 6 is a schematic diagram of an operating mechanism of an

equipment-level dual-drive mechanism model according to an embodiment of the present application. In this embodiment, the equipment-level dual-drive mechanism model may be configured to: acquire component mechanism models corresponding to each underlying controlled component; perform system-level mechanism model construction and analysis for the data center based on each component mechanism model, which is the equipment-level dual-drive mechanism model; and obtain an optimal operating parameter and an optimal operating mode of the data center under each operating condition based on the equipment-level dual-drive mechanism model.

[0132] The embodiments of the present application adopt an equipment-level dual-drive mechanism model as the mechanism model, which is refined from the system level to the equipment level, and the entirety is constructed by mechanism models, which can completely avoid “reverse logic,” but the simulation platform has a slower computation speed. Meanwhile, relying on the high accuracy, low computational complexity and cost of the equipment-level dual-drive mechanism model, it does not depend on the quality and quantity of data, the data cost is low, and the advantages of the dual-drive model are significant, with a good energy-saving effect.

[0133] Further, the pre-trained mechanism model is an equipment-level dual-drive mechanism model. Performing system-level mechanism model construction for the data center based on each component mechanism model to obtain the equipment-level dual-drive mechanism model includes:

[0134] Step L10: constructing the equipment-level dual-drive mechanism model based on each component mechanism model in a second preset building block stacking manner.

[0135] The embodiments of the present application construct the equipment-level dual-drive mechanism model based on each component mechanism model in a second preset building block stacking manner, thereby performing mechanism modeling on typical components and devices separately to form a mechanism model component library. When constructing the equipment-level dual-drive mechanism model, corresponding elements are preferentially selected from the mechanism model component library to reduce the secondary construction time of component/device models, and the system-level mechanism model is quickly formed in a building block stacking manner through library selection. This embodiment simplifies the construction efficiency of the equipment-level dual-drive mechanism model through the component library and building block stacking manner, and also improves the scalability of the equipment-level dual-drive mechanism model.

[0136] To facilitate understanding of the technical concept of the embodiments of the present application, a specific embodiment 3 is provided. Referring to FIG. 4, FIG. 4 is a schematic scenario diagram of thermal management control of a data center according to an embodiment of

the present application, including the following main process steps:

[0137] In this embodiment, 1 represents field data (i.e., first data) after multiple data processing such as data denoising, data filtering, and data repair. The data is redundant, disordered, and unevenly distributed, resulting in slow computation and poor accuracy of the data-driven fitting function.

[0138] In this embodiment, Latin hypercube sampling is used to determine the optimal data interval and size of this database, and field data are filled in to form the sample library of form 2. The data in this sample library is still redundant, disordered, and unevenly distributed, requiring further processing.

[0139] Data reduction is performed on each data interval, deleting redundant data, to form a concise and effective sample library of form 3 (i.e., third data). Although this database solves the data redundancy problem, the data distribution is still uneven, requiring further processing.

[0140] The mechanism model supplements intervals without valid data to form a comprehensive, concise, and effective mechanism and data dual-drive fused sample library of form 4 (i.e., second data). This database is concise and uniform, which can greatly improve the computation speed and result accuracy of the data-driven fitting function.

[0141] The above disclosed content is merely an optional embodiment of the present application, and certainly cannot be used to limit the scope of the present application. Those of ordinary skill in the art can understand and implement all or part of the processes of the above embodiments, and equivalent variations made according to the claims of the present application shall still fall within the scope covered by the present application.

[0142] That is, the above specific embodiment 3 is only used to help understand the technical concept of the embodiments of the present application and does not constitute a limitation on the present application. Simple transformations in more forms based on this technical concept shall all fall within the protection scope of the present application.

[0143] Referring to FIG. 12, FIG. 12 is a diagram of predicted experimental data of dual-drive regulation compared with basic regulation in the related art according to an embodiment of the present application. It can be seen that compared with the basic regulation prediction in the related art, the power consumption prediction accuracy of the dual-drive regulation by fitting the mechanism model and the data model in the embodiments of the present application is higher, that is, the prediction effect is better. The embodiments of the present application supplement data through the dual-drive model, and the intelligent regulation has high safety, good accuracy, high robustness, and good generalization ability.

[0144] In addition, referring to FIG. 13 and FIG. 14, FIG. 13 is a diagram of experimental data

of various operating conditions of a data center according to an embodiment of the present application, and FIG. 14 is a comparison diagram of predicted data of the dual-drive regulation strategy compared with other regulation strategies in the related art according to an embodiment of the present application. It can be seen that the optimization effect of the dual-drive regulation strategy of the embodiments of the present application is better. Other regulation strategies, due to not fitting the mechanism model to supplement data, result in poor energy-saving effect of the data model, huge early-stage fluctuations, and a tendency toward "reverse logic." Through data comparative analysis, the data model regulation strategy saves 80.14% energy compared with the basic regulation strategy, and the dual-drive model regulation strategy of the embodiments of the present application saves 73.31% energy compared with the data model regulation strategy.

[0145] In addition, referring to FIG. 15, the embodiments of the present application further propose a thermal management control system 100 of a data center. The thermal management control system 100 is applied to the thermal management control method for the data center as described above. The thermal management control system 100 includes: a liquid cooling system, an air cooling system and a server.

[0146] The liquid cooling system includes a cooling device 1, a heat exchanger 2, a first three-way valve 3, a first water pump 4, and a second water pump 5. The heat exchanger 2 includes a first pipeline and a second pipeline. The first pipeline is provided with a first water inlet 21 and a first water outlet 22. The second pipeline is provided with a second water inlet 23 and a second water outlet 24. The first three-way valve 3 includes a liquid inlet 31, a first liquid outlet 32, and a second liquid outlet 33. The cooling device 1 is a cooling tower or an air cooler. The air cooling system includes a refrigeration device 6, a fan 7, a second three-way valve 8, and a third water pump 9. The second three-way valve 8 includes a water inlet end 81, a first water outlet end 82, and a second water outlet end 83. The refrigeration device 6 is a chiller or a refrigeration unit. An outlet end of the cooling device 1, the first water inlet 21, the first water outlet 22, the liquid inlet 31, the first liquid outlet 32, and an inlet end of the cooling device 1 form a liquid cooling circuit, and the first water pump 4 is disposed in the liquid cooling circuit. A coolant outlet of the server 10, the second water inlet 23, the second water outlet 24, and a coolant inlet of the server 10 form a heat exchange circuit, and the second water pump 5 is disposed in the heat exchange circuit. A fluid in the heat exchange circuit is configured to exchange heat with a fluid in the liquid cooling circuit in the heat exchanger 2. A liquid outlet end of the refrigeration device 6, the water inlet end 81, the first water outlet end 82, a liquid cooling inlet of the fan 7, a liquid cooling outlet of the fan 7, and a liquid inlet end of the refrigeration device 6 form an air cooling circuit, and the third water pump 9 is disposed in the air cooling circuit. The fan 7 is configured to blow cold air to the

server 10. The air cooling circuit is in communication with the liquid cooling circuit through the second water outlet end 83, and the liquid cooling circuit is in communication with the air cooling circuit through the second liquid outlet 33.

[0147] Exemplarily, in a case that the operating mode is the first operating mode, the cooling device 1 is turned on, the refrigeration device 6 is turned off, a valve at the second water outlet end 83 and a valve at the second liquid outlet 33 are both opened, and a valve at the water inlet end 81 is closed, so that the cooling device 1 supplies liquid to the liquid cooling circuit and the air cooling circuit simultaneously. In a case that the operating mode is the second operating mode, both the cooling device 1 and the refrigeration device 6 are turned on, the valve at the second water outlet end 83 and the valve at the second liquid outlet 33 are both closed, and the valve at the water inlet end 81 is opened, so that the cooling device 1 supplies liquid to the liquid cooling circuit and the refrigeration device 6 supplies liquid to the air cooling circuit.

[0148] In a case that the operating mode is the third operating mode, both the cooling device 1 and the refrigeration device 6 are turned on, the valve at the second water outlet end 83, the valve at the second liquid outlet 33, and the valve at the water inlet end 81 are all opened, so that the cooling device 1 and the refrigeration device 6 simultaneously supply liquid to the air cooling circuit and the liquid cooling circuit.

[0149] In a possible implementation, the thermal management control system 100 further includes a filter 11, and the air cooling circuit, the liquid cooling circuit, and the heat exchange circuit are each provided with at least one filter 11.

[0150] The present application proposes a thermal management control system 100 for a data center. In the thermal management control method for the data center, the technical solution of the embodiments of the present application is to configure the thermal management control system 100 to include a liquid cooling system and an air cooling system. The liquid cooling system includes a cooling device 1, a heat exchanger 2, a first three-way valve 3, a first water pump 4, and a second water pump 5. The heat exchanger 2 includes a first pipeline (not shown) and a second pipeline (not shown). The first pipeline is provided with a first water inlet 21 and a first water outlet 22. The second pipeline is provided with a second water inlet 23 and a second water outlet 24. The first three-way valve 3 includes a liquid inlet 31, a first liquid outlet 32, and a second liquid outlet 33. The cooling device 1 is a cooling tower or an air cooler. The air cooling system includes a refrigeration device 6, a fan 7, a second three-way valve 8, and a third water pump 9. The second three-way valve 8 includes a water inlet end 81, a first water outlet end 82, and a second water outlet end 83. The refrigeration device 6 is a chiller or a refrigeration unit. An outlet end of the cooling device 1, the first water inlet 21, the first water outlet 22, the liquid inlet 31, the

first liquid outlet 32, and an inlet end of the cooling device 1 form a liquid cooling circuit, and the first water pump 4 is disposed in the liquid cooling circuit. A coolant outlet of the server 10, the second water inlet 23, the second water outlet 24, and a coolant inlet of the server 10 form a heat exchange circuit, and the second water pump 5 is disposed in the heat exchange circuit. A fluid in the heat exchange circuit is configured to exchange heat with a fluid in the liquid cooling circuit in the heat exchanger 2. A liquid outlet end of the refrigeration device 6, the water inlet end 81, the first water outlet end 82, a liquid cooling inlet of the fan 7, a liquid cooling outlet of the fan 7, and a liquid inlet end of the refrigeration device 6 form an air cooling circuit, and the third water pump 9 is disposed in the air cooling circuit. The fan 7 is configured to blow cold air to the server 10. The air cooling circuit is in communication with the liquid cooling circuit through the second water outlet end 83, and the liquid cooling circuit is in communication with the air cooling circuit through the second liquid outlet 33, thereby enabling that in a low-temperature mode (i.e., the first operating mode), the refrigeration device 6 is turned off and the cooling device 1 supplies liquid to the liquid cooling side and the air cooling side; in a normal-temperature mode (i.e., the second operating mode), the refrigeration device 6 supplies liquid to the air cooling side and the cooling device 1 supplies liquid to the liquid cooling side; and in a high-temperature mode (i.e., the third operating mode), the refrigeration device 6 supplements cooling to the liquid cooling side through the three-way valve. This enables the working states of the terminal equipment of the thermal management system of the data center to change in real time, reducing the energy consumption of the thermal management system while meeting the temperature requirements of the server 10 in the equipment room, achieving real-time energy-saving control functionality, and facilitating real-time optimization calculation of optimal control parameter and optimal operating modes for thermal management control of the data center, so as to determine the thermal management control strategy for the server 10 of the data center, thereby achieving thermal management control of the data center with high computational efficiency and high accuracy, and improving the stability and reliability of thermal management control of the data center.

[0151] The thermal management control system 100 for the data center provided in this embodiment and the thermal management control method for the data center provided in the above embodiments belong to the same inventive concept. Technical details not described in detail in this embodiment may be found in the embodiments of the thermal management control method for the data center, and this embodiment has the same beneficial effects as those of the respective embodiments of the thermal management control method for the data center, which will not be repeated here.

[0152] The system embodiments described above are merely illustrative, in which units

described as separate components may or may not be physically separated, that is, may be located in one place, or may be distributed across multiple network units. Some or all of the modules may be selected as needed to achieve the objectives of the solutions of this embodiment.

[0153] In addition, the embodiments of the present application further provide an electronic device. Referring to FIG. 16, FIG. 16 is a schematic diagram of a hardware structure of an electronic device according to an embodiment of the present application. As shown in FIG. 16, the electronic device may include: a processor 1001, such as a Central Processing Unit (CPU), a communication bus 1002, a user interface 1003, a network interface 1004, and a memory 1005. The communication bus 1002 is used to implement connection communication among these components. The user interface 1003 may include a display and an input unit such as a keyboard, and the user interface 1003 may further include a standard wired interface and a wireless interface. The network interface 1004 may include a standard wired interface and a wireless interface (such as a Wireless-Fidelity (WI-FI) interface). The memory 1005 may be a high-speed Random Access Memory (RAM) or a stable Non-Volatile Memory (NVM), such as a disk memory. The memory 1005 may alternatively be a storage device independent of the aforementioned processor 1001.

[0154] Those skilled in the art can understand that the structure shown in FIG. 16 does not constitute a limitation on the electronic device, and may include more or fewer components than those shown, or some components may be combined, or different component arrangements may be used. As shown in FIG. 16, as a storage medium, the memory 1005 may include an operating system, a data storage module, a network communication module, a user interface module, and a thermal management control program for a data center.

[0155] In the electronic device shown in FIG. 16, the network interface 1004 is mainly used for data communication with other devices; the user interface 1003 is mainly used for data interaction with a user; the processor 1001 and the memory 1005 in this embodiment may be disposed in a communication device, and the communication device invokes, through the processor 1001, the thermal management control program for a data center stored in the memory 1005, and executes the thermal management control method for the data center applied in any of the above embodiments.

[0156] The terminal proposed in this embodiment and the thermal management control method for the data center applied according to the above embodiments belong to the same inventive concept. Technical details not described in detail in this embodiment may be found in any of the above embodiments, and this embodiment has the same beneficial effects as those of executing the thermal management control method for the data center.

[0157] In addition, the embodiments of the present application further provide a storage

medium. The storage medium is a computer storage medium. The computer-readable storage medium may be a non-volatile computer-readable storage medium. The computer-readable storage medium has stored thereon a thermal management control program for a data center, and the thermal management control program for a data center, when executed by a processor, implements the thermal management control method for the data center according to the present application as described above.

[0158] For the respective embodiments of the electronic device and the computer-readable storage medium of the present application, reference may be made to the respective embodiments of the thermal management control method for the data center of the present application, which will not be repeated here.

[0159] It should be noted that, in this document, the terms “comprise”, “include,” or any other variant thereof are intended to cover a non-exclusive inclusion, such that a process, method, article, or system that includes a series of elements includes not only those elements but also other elements not explicitly listed, or elements inherent to such process, method, article, or system. Without further limitation, an element defined by the phrase “including a ...” does not exclude the presence of additional identical elements in the process, method, article, or system that includes that element.

[0160] The sequence numbers of the embodiments of the present application are merely for description and do not indicate the quality of the embodiments.

[0161] Through the description of the above embodiments, those skilled in the art can clearly understand that the methods of the above embodiments may be implemented by means of software plus necessary general hardware platforms, or may also be implemented by hardware, but in many cases the former is a better implementation. Based on this understanding, the technical solutions of the present application, or the part that contributes to the related art, may be embodied in the form of a software product. The computer software product is stored in a storage medium (such as ROM/RAM, magnetic disk, optical disk) as described above, and includes several instructions for causing an electronic device (which may be a mobile phone, a computer, a server, an air conditioner, or a network device, etc.) to execute the methods described in the various embodiments of the present application.

[0162] The above are merely optional embodiments of the present application and are not intended to limit the scope of the present application. Any equivalent structural or equivalent process transformations made using the specification and drawings of the present application, or any direct or indirect application in other related technical fields, shall likewise be included within the scope of the present application.

CLAIMS

What is claimed is:

1. A thermal management control method for a data center, comprising:

acquiring first data, the first data characterizing a plurality of actual operating conditions of the data center under operating conditions, and a control parameter and an operating mode under each actual operating condition;

performing data supplementation on the first data based on a pre-trained mechanism model to obtain second data; and

performing, based on the second data, in combination with a preset optimization algorithm, optimization to obtain a target control parameter and a target operating mode for the data center, and performing thermal management control on the data center according to the target control parameter and the target operating mode.

2. The thermal management control method for the data center according to claim 1, wherein the performing, based on the second data, in combination with the preset optimization algorithm, optimization to obtain the target control parameter and the target operating mode for the data center comprises:

performing model fitting on a thermal management control target based on the second data to obtain a fitted model;

performing, based on the fitted model, in combination with the preset optimization algorithm, optimization to obtain an optimal control parameter and an optimal operating mode for each operating condition of the data center, and storing the optimal control parameter and the optimal operating mode of each operating condition into a knowledge base; and

dynamically acquiring a real-time operating condition of the data center, and querying and invoking from the knowledge base to obtain the target control parameter and the target operating mode for the data center.

3. The thermal management control method for the data center according to claim 2, further comprising:

constructing a model error function based on the target control parameter and the target operating mode corresponding to the real-time operating condition, and predicted data of the fitted model under the real-time operating condition; and

performing iterative optimization on model coefficients of the fitted model based on the model error function.

4. The thermal management control method for the data center according to claim 2, wherein the querying and invoking from the knowledge base to obtain the target control parameter and the target operating mode for the data center comprises:

querying and invoking from the knowledge base to obtain a control parameter corresponding to achieving the thermal management control target, and an operating mode corresponding to achieving the thermal management control target, wherein the thermal management control target is that a system PUE of the data center is minimized or a total system energy consumption is minimized;

taking the control parameter corresponding to achieving the thermal management control target under the real-time operating condition as the target control parameter for the data center; and

taking the operating mode corresponding to achieving the thermal management control target under the real-time operating condition as the target operating mode for the data center.

5. The thermal management control method for the data center according to claim 1, wherein the performing data supplementation on the first data based on the pre-trained mechanism model to obtain the second data comprises:

performing exclusion or correction on abnormal data in the first data based on the pre-trained mechanism model to obtain third data; and

performing data supplementation on the third data based on the pre-trained mechanism model to obtain the second data.

6. The thermal management control method for the data center according to claim 1, wherein the performing thermal management control on the data center according to the target control

parameter and the target operating mode comprises:

controlling operating parameters of underlying controlled components of the data center according to the target control parameter and the target operating mode, to perform thermal management control on the data center;

wherein the underlying controlled components comprise a fan, a water pump, a compressor, and a valve, and the operating parameters of the underlying controlled components comprises a fan frequency, a water pump frequency, a compressor frequency, and a valve opening degree.

7. The thermal management control method for the data center according to claim 6, wherein the pre-trained mechanism model is a system-level dual-drive mechanism model, and the method further comprises:

acquiring, from a preset component model library, component data models corresponding to each trained underlying controlled component; and

performing system-level mechanism model construction for the data center based on each component data model to construct the system-level dual-drive mechanism model.

8. The thermal management control method for the data center according to claim 7, wherein the performing system-level mechanism model construction for the data center based on each component data model to construct the system-level dual-drive mechanism model comprises:

constructing the system-level dual-drive mechanism model based on each component data model in a first preset building block stacking manner.

9. The thermal management control method for the data center according to claim 6, wherein the pre-trained mechanism model is an equipment-level dual-drive mechanism model, and the method further comprises:

acquiring, from a preset component model library, component mechanism models corresponding to each trained underlying controlled component; and

performing system-level mechanism model construction for the data center based on each component mechanism model to obtain the equipment-level dual-drive mechanism model.

10. The thermal management control method for the data center according to claim 9, wherein the performing system-level mechanism model construction for the data center based on each component mechanism model to obtain the equipment-level dual-drive mechanism model comprises:

constructing the equipment-level dual-drive mechanism model based on each component mechanism model in a second preset building block stacking manner.

11. The thermal management control method for the data center according to any one of claims 1 to 10, wherein the preset optimization algorithm is a genetic algorithm, a particle swarm optimization algorithm, a simulated annealing algorithm, or an ant colony algorithm.

12. The thermal management control method for the data center according to any one of claims 7 to 10, wherein types of the operating mode comprise a first operating mode, a second operating mode, and a third operating mode, wherein,

the first operating mode is an operating mode in which a refrigeration device is turned off and a cooling device supplies liquid to a liquid cooling side and an air cooling side, wherein the refrigeration device is a chiller or a refrigeration unit, and the cooling device is a cooling tower or an air cooler;

the second operating mode is that the refrigeration device supplies liquid to the air cooling side, and the cooling device supplies liquid to the liquid cooling side; and

the third operating mode is that both the refrigeration device and the cooling device supply liquid to the air cooling side and the liquid cooling side.

13. A thermal management control system, wherein the thermal management control system is applied to the thermal management control method for the data center according to any one of claims 1 to 12, and the thermal management control system comprises:

a liquid cooling system, comprising a cooling device, a heat exchanger, a first three-way valve, a first water pump, and a second water pump, wherein the heat exchanger comprises a first pipeline and a second pipeline, the first pipeline is provided with a first water inlet and a first water outlet, the second pipeline is provided with a second water inlet and a second water outlet, the first

three-way valve comprises a liquid inlet, a first liquid outlet, and a second liquid outlet, and the cooling device is a cooling tower or an air cooler;

an air cooling system, comprising a refrigeration device, a fan, a second three-way valve, and a third water pump, wherein the second three-way valve comprises a water inlet end, a first water outlet end, and a second water outlet end, and the refrigeration device is a chiller or a refrigeration unit; and

a server;

wherein an outlet end of the cooling device, the first water inlet, the first water outlet, the liquid inlet, the first liquid outlet, and an inlet end of the cooling device form a liquid cooling circuit, and the first water pump is disposed in the liquid cooling circuit; a coolant outlet of the server, the second water inlet, the second water outlet, and a coolant inlet of the server form a heat exchange circuit, the second water pump is disposed in the heat exchange circuit, and a fluid in the heat exchange circuit is configured to exchange heat with a fluid in the liquid cooling circuit in the heat exchanger;

a liquid outlet end of the refrigeration device, the water inlet end, the first water outlet end, a liquid cooling inlet of the fan, a liquid cooling outlet of the fan, and a liquid inlet end of the refrigeration device form an air cooling circuit, the third water pump is disposed in the air cooling circuit, and the fan is configured to blow cold air to the server; and

the air cooling circuit is in communication with the liquid cooling circuit through the second water outlet end, and the liquid cooling circuit is in communication with the air cooling circuit through the second liquid outlet.

14. The thermal management control system according to claim 13, wherein the system comprises:

in a case that the operating mode is the first operating mode, the cooling device is turned on, the refrigeration device is turned off, a valve at the second water outlet end and a valve at the second liquid outlet are both opened, and a valve at the water inlet end is closed, so that the cooling device supplies liquid to the liquid cooling circuit and the air cooling circuit simultaneously;

in a case that the operating mode is the second operating mode, both the cooling device and the refrigeration device are turned on, the valve at the second water outlet end and the valve at the

second liquid outlet are both closed, and the valve at the water inlet end is opened, so that the cooling device supplies liquid to the liquid cooling circuit and the refrigeration device supplies liquid to the air cooling circuit.

15. The thermal management control system according to claim 13, wherein the system comprises:

in a case that the operating mode is the third operating mode, both the cooling device and the refrigeration device are turned on, the valve at the second water outlet end, the valve at the second liquid outlet, and the valve at the water inlet end are all opened, so that the cooling device and the refrigeration device simultaneously supply liquid to the air cooling circuit and the liquid cooling circuit.

16. The thermal management control system according to any one of claims 13 to 15, further comprising a filter, wherein the air cooling circuit, the liquid cooling circuit, and the heat exchange circuit are each provided with at least one filter.

17. An electronic device, comprising: a memory, a processor, and a thermal management control program for a data center stored on the memory and executable on the processor, wherein the thermal management control program for the data center, when executed by the processor, implements the thermal management control method for the data center according to any one of claims 1 to 12.

18. A storage medium, wherein the storage medium is a computer-readable storage medium, a thermal management control program for a data center is stored on the computer-readable storage medium, and the thermal management control program for the data center, when executed by a processor, implements the thermal management control method for the data center according to any one of claims 1 to 12.