A DATA CENTER OPERATING SYSTEM BASED ON A DIGITAL TWIN OF A DATA CENTER

CROSS-REFERENCE TO RELATED APPLICATIONS

[01] This application claims priority from Korean Patent Application No. 10-2022-0092324, filed on July 26, 2022, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference in its entirety. This patent application was supported by funded Korea Institute of Energy Technology Evaluation and Planning & the Ministry of Trade, Industry and Energy.[Project Name : Development of a digital twin platform and business model linked to domestic and foreign technical standards that support energy management and optimization of energy-intensive buildings/ Project Number: 20212020900090]

BACKGROUND

Technical Field

[02] The present disclosure relates to an optimal operating system for air conditioning equipment of a data center based on a simulation of a digital twin, and more particularly to the disclosure of constructing a digital twin for a data center that actually exists, simulating the digital twin of the constructed data center, establishing an optimal operation plan of the air conditioning equipment in the data center based on the simulation, and

performing an operation according to the optimal operation plan.

Description of the Related Art

[03] A data center is a facility that collectively manages computers and includes power facilities, air conditioning equipment, and safety operation and management facilities for a computer operation.

[04] A server computer needs to be operated at an acceptable temperature (usually 28 degrees or less), and when the temperature is high, abnormalities such as device down may occur. Therefore, it is important to manage the temperature of an inlet at a server side in the data center that drives the server.

[05] To this end, in the data center, a thermo-hygrostat device for maintaining constant temperature and humidity is installed and operated.

[06] In the structure of a data center, servers are fixed and installed in racks, and multiple servers are usually installed in one rack. A server room has a plurality of racks, and a plurality of cooling devices (thermo-hygrostats) are operated for cooling.

[07] In management of the temperature of the server room, it is common to manage the temperature of an inlet of a rack, and air cooled by a cooling device enters the inlet of the rack and becomes hot through the server, and this air is circulated to the cooling device.

[08] In management of the temperature of the server room,

[09] 1. The cooling device needs to process the entire amount of heat

in the server room,

[10] 2. The cooling device needs to manage the server room such that hots pots are not generated by region.

[11] There are many reasons why hotspots are generated in the server room, but a main reason may be due to poor air circulation or high server load in a region.

[12] When a hotspot is generated locally in the server room, it may be resolved by increasing a cooling rate of a corresponding area by increasing an operation rate of the cooling device or air circulation device that affects the area.

[13] In the current method of controlling the temperature of a server room, an operation rate of the cooling device is adjusted based on temperature at a rack of a server or a return temperature at which air enters an inlet or a cooling device (thermo-hygrostat).

[14] Therefore, due to limitations in controlling hotspots and cold spots that are generated locally, the stability of maintaining the temperature of a data center is hindered, and energy is wasted due to an operation of a cooling device more than necessary.

[15] In this case, an optimal operation of air conditioning equipment such as the thermo-hygrostat in the server room of the data center described above corresponds to a necessary process for stable operation and power saving of the server.

[16] In this case, the optimal operation of the air conditioning equipment is affected by a structure of a top surface of the server room, layout of the server rack, layout and setting capacity of the thermo-hygrostat, a server load, or the like and an operation setting value of the air conditioning equipment according to each situation is required.

[17] However, in order to obtain a setting value necessary for an operation for an optimal operation of the air conditioning equipment, it is necessary to change an operation state of the air conditioning equipment and check a resulting effect. In this regard, in the case of a key data center, since a service is already operated, any change to the air conditioning operation setting value may adversely affect the already provided service.

[18] In addition, data that is previously accumulated in a monitoring system may be used to avoid the above-mentioned adverse effects, but from the past to the present, there is a problem in that noise is contained in data of a server due to installation and removal of a server on a server rack, unevenness of a server load, a change in power system or air conditioning equipment, and a change in air conditioning load based on seasonal factors.

[19] Korean Patent Publication No. No. 10-2020-0072765 of the present applicant discloses a method and system for evaluating an air conditioning state in a server room, Korean Patent Publication No. 10-2021-0076349 of the present applicant discloses a method and device for modeling a temperature simulation for a data center server room, and the previous patents

of the present applicant also provide a solution for performing an optimal operation.

[20] However, these solutions create a virtual model prior to installation of equipment and simulate the virtual model using a CFD rather than simulating equipment of an already installed data center, and accordingly, there is a problem that it is difficult to simulate equipment in an actually already installed data center.

[21] In fact, for the equipment in the data already installed, claims of Korean Patent Publication No. 10-2017-0036291 of the present applicant disclose a system and method for optimally controlling a thermo-hygrostat, but here, there is a problem in that control is performed with only temperature distribution obtained from a lower temperature sensor and an upper temperature sensor installed in a server rack and temperature distribution of return air and that it is impossible to perform simulation as a whole by turning the already installed equipment into a virtual object.

[22] 【Cited Reference】

[23] 【Patent Document】

[24] (Patent Document 0001) 1. Korean Patent Publication No. 10-2017-0036291 (published on April 3, 2017)

[25] (Patent Document 0002) 2. Korean Patent Publication No. 10-2020-0072765 (published on June 23, 2020)

[26] (Patent Document 0003) 3. Korean Patent Publication No. 10-

2021-0076349 (published on June 24, 2021)

SUMMARY

[27] The present disclosure is to resolve this problem and to provide an optimal operating system of an air conditioning equipment of a data center based on digital twin simulation that helps to operate the data center in an optimal state by constructing a digital twin for the data center that is actually operated and performing an operation simulation thereon to establish a predictive model and establishing an optimal operation plan based on the predictive model.

[28] According to the present disclosure, a optimal operating system for air conditioning equipment of a data center based on a simulation of a digital twin includes a database (DB) module configured to store information on a data center that actually exists, a data center digital twin construction module configured to implement the digital twin of the data center that actually exists based on information contained in the DB module, a digital twin simulation module configured to perform an air conditioning state simulation for the digital twin of the data center constructed by the data center digital twin construction module, a plan establishment module configured to establish an air conditioning plan of the data center to prevent a hotspot from being generated in a space of an actual data center based on information on the simulation performed by the digital twin simulation module, an operation

control module configured to operate the air conditioning equipment for the actual data center according to the plan established by the plan establishment module, a monitoring module configured to collect and monitor information on an operator derived from the actual data center operated by the operation control module, and an update module configured to provide the information collected by the monitoring module to the DB module.

[29] The digital twin simulation module may provide a predicted result from an operation of the air conditioning equipment at a specific point in future from a present time for the digital twin of the data center based on the information stored in the DB module.

[30] The DB module may include a spatial information DB of the data center, a device information DB, an operational information DB configured to contain operational information of the data center, including power consumption, temperature, or an operation rate, and a 3D model information DB configured to contain 3D model information of an actual object including a space or a device inside the data center.

[31] The spatial information DB may contain at least one of information on a lower structure of a floor of a server room, information on a double parquet layout structure, information on containment layout, or information on an upper structure of a ceiling, the device information DB may contain at least one of information on a rack, information on an IT device including a server, or information on air conditioning equipment, and the

operational information DB may contain at least one of information on power consumption by rack and thermo-hygrostat, information on cooling capacity of a thermo-hygrostat, information on temperature by rack, information on temperature of the server room, or information on humidity of the server room.

[32] The digital twin construct module may include an image analyzer configured to receive and analyze video or image information on a photo of a space or equipment of an actual data center, a 3D mapper configured to map equipment or a spatial object analyzed by the image analyzer to a 3D model, and a 3D model synchronizer configured to synchronize the object mapped by the 3D mapper with a current state of an actual object installed in the actual data center.

[33] According to the present disclosure, there is an advantage in that a simulation for an optimal operation is performed in an actual facility by implementing a data center that is actually implemented and operated to a cyberspace through a digital twin.

[34] There is an advantage in that an air conditioning system is more systematic than the existing air-conditioning operation policy operated in a rule-of-thumb manner based on temperature by establishing an optimal air conditioning operation plan through a simulation in order to implement an optimal operating environment.

[35] There is an advantage in that the accuracy of a simulation is continuously improved by comparing data obtained after an actual operation

with simulation data, analyzing a difference therebetween, correcting parameters for overcoming the difference, and updating the corrected parameters to a digital twin model.

[36] In addition, there is an advantage in that the reliability of the system is continuously increased through data accumulation and continuous update by periodically repeating the above operation.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[37] FIG. 1 is a diagram showing temperature distribution of a top surface of a server room.

[38] FIG. 2 is a schematic diagram of the present disclosure.

[39] FIG. 3 is a schematic control block diagram of the present disclosure.

[40] FIG. 4 is a control block diagram of a data center digital twin construction module and a data center digital twin DB.

[41] FIG. 5 shows examples of screens of states in which a digital twin of a data center is constructed.

[42] FIG. 6 shows a comparison between a simulation result and an actually operated result.

[43] FIGS. 7A and 7B show examples of screens of general status and monitoring of the entire data center.

[44] FIGS. 7C and 7D show examples of screens of energy management status and temperature distribution in a specific server room.

[45] FIGS. 8A and 8B show examples of screens of power peak and hotspot analysis.

[46] FIGS. 8C and 8D show examples of screens of power usage effectiveness (PUE) inquiry and analysis thereof.

[47] FIGS. 9A-9D show screens for respective operating states of a data center operating system according to the present disclosure.

[48] FIG. 10 shows a flow of a data center operating system according to the present disclosure.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[49] As the disclosure allows for various changes and numerous embodiments, particular embodiments will be illustrated in the drawings and described in detail in the written description.

[50] However, this is not intended to limit the present disclosure to particular modes of practice, and it is to be appreciated that all changes, equivalents, and substitutes that do not depart from the spirit and technical scope of the present disclosure are encompassed in the present disclosure.

[51] The terms such as "first" and "second" are used herein merely to describe a variety of constituent elements, but the constituent elements are not limited by the terms.

[52] The terms are used only for the purpose of distinguishing one constituent element from another constituent element.

[53] For example, a first element may be termed a second element and a second element may be termed a first element without departing from the teachings of the present disclosure.

[54] The term and/or includes a combination of a plurality of related recited items or any one of a plurality of related recited items.

[55] It will be understood that when an element, such as a layer, a region, or a substrate, is referred to as being “on”, “connected to” or “coupled to” another element, it may be directly on, connected or coupled to the other element or intervening elements may be present.

[56] In contrast, when an element is referred to as being “directly on,” “directly connected to” or “directly coupled to” another element or layer, there are no intervening elements or layers present.

[57] The terms used in the present specification are used for explaining a specific exemplary embodiment, not limiting the present disclosure.

[58] The singular expressions in the present specification include the plural expressions unless clearly specified otherwise in context.

[59] The terms such as "include" or "comprise" may be construed to denote a certain characteristic, number, step, operation, constituent element, or a combination thereof, but may not be construed to exclude the existence of or a possibility of addition of one or more other characteristics, numbers, steps, operations, constituent elements, or combinations thereof.

[60] Hereinafter, the embodiment will be described in detail with reference to the accompanying drawings, but the same or corresponding components regardless of reference numerals are given the same reference numerals, and overlapping descriptions thereof will be omitted.

[61] As shown in FIG. 1, in a server room 1, a plurality of server racks 10 may be spaced apart and arranged to face each other while defining one row.

[62] Since a lot of heat is generated due to the characteristics of the server, it is important to provide cooled air steadily such that the temperature of the server does not rise above a specific temperature in order to prevent a problem caused by overheating of the server.

[63] To this end, cooled air is supplied between a specific server rack row and an adjacent server rack row, and a space to which the cooled air is supplied is defined as a cold passage 20.

[64] In FIG. 1, an area marked with ⓒ is a cold passage, and an area marked with ⓗ is a heat passage 30 from which heat heated by exchanging heat with each server is dissipated.

[65] In order to increase cooling efficiency and concentration of cooled air, a confined room 200 may be implemented such that the cold passage 20 defines a confined space.

[66] Here, an area marked in red is called a hotspot and is defined as

an area with temperature higher than a reference temperature, and an area marked in blue is called a cold spot and is defined as an area with temperature lower than the reference temperature.

[67] When hotspots are continuously generated, cooling is reduced and serious problems such as damage to the server due to heat may occur, and accordingly, in order to prevent the problems in advance, it is necessary to optimize control such that hotspots are not generated inside the server room and cold spots are not generated due to excessive overcooling.

[68] The purpose of the present disclosure is to construct a digital twin of a data center through optimal control of a server room in a data center that is actually operated, perform a simulation thereon, and help optimal control based thereon.

[69] FIG. 2 is a schematic diagram of the present disclosure.

[70] As shown in FIG. 2, a digital twin of a data center includes 3D space information of a server room and information on a heating source and cooling source on a top surface of the server room.

[71] The digital twin is a technology that predicts the result in advance by creating a three-dimensional object with the same characteristics as an object in a real world and simulating a situation that may occur in the real world using a computer.

[72] In the present disclosure, an actual operating data center is implemented as a 3-dimensional data center digital twin on a computer. The 3-

dimensional data center digital twin may refer to a 3D model that models a data center using view data about the structure and equipment of the data center, material table data including structure and equipment information, and document data including drawings of the structure and equipment and manuals thereof.

[73] The 3D data center digital twin is modeled by matching space information, structure information, equipment information, equipment manual information, and various operation-related information in response to each component included in the data center that actually exists.

[74] For example, the drawing information of the server room may be matched to the server room of the 3D model of the data center, or drawing information, equipment information, manual information, power usage information, temperature/humidity information, or layout information may be matched to the server room of the 3D model of the data center.

[75] Accordingly, when a user selects a component in the 3D data center digital twin, drawing information, manual information, specification information, and the like corresponding to the selected component may be output on a computer screen.

[76] As shown in FIG. 2, 3D spatial information of the server room of the digital twin of the data center may include various space-related information as well as information on a lower structure of a floor of the server room, a double parquet layout structure, a containment layout structure, and an

upper structure of a ceiling.

[77] The information on the heating source and cooling source of the top surface of the server room may include layout information of rack/IT equipment (e.g., server), power consumption per rack, layout information of a thermo-hygrostat, and cooling capacity of the thermo-hygrostat.

[78] The present disclosure may contribute to energy saving used when using air conditioning equipment in a data center by utilizing digital twin simulation technology.

[79] In other words, when simulation is performed using resources constituting the digital twin of the data center and information on the characteristic thereof (e.g., power consumption, cooling capacity, layout information, space information), a risk of controlling the temperature of the top surface of the server room (e.g., hotspots) may be analyzed, and an operating method for the use of a thermo-hygrostat to contain such a risk, or the amount of use strategy may be analyzed.

[80] Through this, it is possible to generate an optimal air conditioning plan that may use the optimal amount of power without excessively using the amount of power consumed without generating a hotspot.

[81] Based on the current power consumption of the rack, the operation rate of the air conditioner, and the current temperature of the top surface at the present time, temperature distribution of the top surface and the amount of power used by the air conditioner in the future may be predicted.

[82] The purpose of management of a cooling device for temperature control on the top surface of the server room of the data center is to minimize energy consumption without hotspots. Therefore, it may be possible to select an optimal plan among several plans by making and simulating plans for operating methods of several air conditioners.

[83] That is, an expected environment after a predetermined time based on the current environment of the digital twin of the data center may be simulated, energy consumption may be predicted, and a minimum energy plan may be generated and may be applied to an operation of energy of air conditioning.

[84] When the optimal plan is selected, the server room is actually operated based thereon, and the air conditioner is controlled in real time. Through this, a wind speed, an air volume, an air temperature, and a flow rate are controlled.

[85] According to control of the air conditioner, an operating environment monitoring is performed to monitor temperature distribution and energy consumption in the server room.

[86] Operational data obtained during monitoring (e.g., real-time power consumption, real-time cooling device utilization rate, or real-time top surface temperature) is provided to the digital twin of the data center, and thus simulation may be performed more realistically using real-time operation data.

[87] Hereinafter, each "module" or "unit" may be any one of a

personal computer (PC), a smart phone, a tablet PC, a mobile Internet device (MID), an Internet tablet, and an Internet of things (IoT) device, an Internet of Everything (IoE) device, a desktop computer, a laptop computer, a workstation computer, a Wireless Broadband Internet (Wibro) terminal, and a Personal Digital Assistant (PDA), but is not limited thereto, and may be implemented as a server that accesses a separate database and write or read data as a device for hosting an online network and specifying a network address.

[88] As shown in FIG. 3, the present disclosure largely includes a data center digital twin construction module 110, a data center digital twin DB 120, a simulation module 130, an analysis module 140, and an operating plan establishment module 150.

[89] A monitoring module 200 measures various parameters (e.g., electric power consumption, temperature, humidity, wind volume, wind speed, or power consumption) in equipment (e.g., thermo-hygrostat, lighting device, or IT device/server rack) in a server room that actually exists and a space of the server room and transmits the monitored contents to the data center digital twin DB 120 to repeatedly use and update the monitored contents in future simulations.

[90] FIG. 4 shows specific components of the data center digital twin construction module 110. The data center digital twin construction module 110 includes an image analyzer 111, a storage 112, a 3D modeller 113, a 3D model mapper 114, a 3D model synchronizer 115, and a verifier 116.

[91] When a data center digital twin is constructed, 3D modeling needs to be performed based on visual data (drawings, photos, and video) of structures constituting the server room in the data center (e.g., lower structure of floor, upper structure of ceiling, double parquet layout information, and containment layout information) and visual data (drawings, photos, and videos) of racks and IT equipment, and accordingly, an image analysis unit 111 is required to identify the external and visual features of each structure or equipment shown from these data before modeling .

[92] The image analyzer 111 may analyze the characteristics of each area by dividing each data into a plurality of pieces (e.g., mesh segmentation), and further compare drawing data, video data, and photographic data for one object (e.g., rack) to clearly refine the characteristics of the object.

[93] The 3D modeller 113 implements each object as a 3D model based on photo data, video data, or drawing data.

[94] The 3D model mapper 114 may match analysis information generated by the image analyzer with pre-stored model types of an object and determine a model type having the most similar value to the analysis information as a model type of a specific object.

[95] Here, model types are state information generated by assuming virtual situations that may occur in each object, and each model type includes information about the location and number of feature point distributions.

[96] That is, the model type stores information about the distribution

of feature points for virtual situations that may occur in an object. For example, information on situations in which cracks occur in an upper structure of a ceiling or a lower structure of a floor or parts thereof are incompletely maintained may be stored as a model type.

[97] For example, when parquet has an intact structure in the drawing data, but a part of the parquet has cracks in the recently taken photo, the 3D model is mapped by reflecting the current state.

[98] The 3D model synchronizer 115 plays a role in assembling such that 3D models of each object implemented by the 3D modeller and the 3D mapper actually match in one completed space. That is, when there are a ceiling model, a floor model, a containment model, a server rack model, a thermo-hygrostat model, a piping model, and a wiring model constituting one server room, each of them may be implemented the same as the actual implementation of the server room while maintaining a relative layout relationship with each other. An example of implementation of a digital twin model inside the entire server room by the 3D model synchronizer is shown in FIG. 5.

[99] The storage 112 stores information analyzed by the image analyzer 111, and information implemented by the 3D modeler, the 3D mapper, and the 3D model synchronizer 115.

[100] Th verifier 116 determines whether the 3D models for each implemented object completely reflect an object that actually exists, and compares and analyzes a difference and the same point by dividing the

implemented 3D model into a plurality of areas or zones and comparing the areas and the zones with collected data (drawings, photos, and video).

[101] The data center digital twin DB 120 serves as a library, and in detail, includes a spatial information DB 121, a device information DB 122, an operational information DB 123, a simulation information DB 124, and a digital twin model storage 125.

[102] The spatial information DB 121 contains information on a ceiling, a floor, a containment, and a parquet constituting the server room, and the device information DB 122 contains information on a server rack, an IT device, and air conditioning equipment.

[103] The operational information DB 123 contains information on power consumption, temperature, humidity, wind volume, and generation of hotspot/cold spot for each device/time zone.

[104] The simulation information DB 124 stores various histories of simulations performed in the simulation module, and the digital twin model storage 125 stores the contents of a combination of the characteristic parameters of various devices/spaces in the digital twin implemented as a 3D model.

[105] In FIG. 3, the simulation module 130 performs simulation to implement an optimal temperature condition in the server room while preventing hotspots from being generated as much as a possible when a specific input value (outside temperature, power rate, type and number of

servers and IT devices to be operated, location of servers and IT devices to be operated, and type/number/location of thermo-hygrostat to be operated) for the digital twin of the implemented data center is input through the input module.

[106] The simulation module 130 may visually implement a distribution change trend of temperature of a top surface in the server room using a computational fluid dynamics (CFD) simulation based on the value input by the input module 160.

[107] The simulation module 130 may simulate a situation at that time when an actual server room is operated at a specific time in the future, not at present, in consideration of time conditions and power rate conditions.

[108] The analysis module 140 of FIG. 3 may suppress hotspots/cold spots from being generated as much as possible in the simulation implemented through the simulation module, or when there is none, the analysis module 140 may analyze an operating state of air conditioning equipment including the thermo-hygrostat at that time and wind speed, air volume, temperature distribution, and humidity distribution at that time for each local location.

[109] The analysis module may select a thermo-hygrostat and predict or analyze a target temperature for the thermo-hygrostat and the amount of power consumed accordingly using a change in temperature of a top surface of the server room, an analysis technology of big data of influence on air conditioning equipment, temperature information by location, thermo-hygrostat operational information, and IT equipment power consumption

information.

[110] The analysis module 140 analyzes optimization model data based on artificial intelligence. In order to implement an artificial intelligence-based optimization model, extraction of input variables for explaining a relationship between input and output values or reduction of a strong correlation between input variables may have a direct effect on improving performance.

[111] The analysis module 140 analyzes the optimization model data through an optimal model after evaluating the performance of a model via development of an AI-based optimization model and a method of evaluating various learning models by understating a pattern of energy consumption based on difference analysis and results using analysis and extraction of variables with a high coefficient through correlation analysis, one-dimensional vectorization and two-dimensional vectorization of input variables through pattern analysis according to climate, season, and building users of input variables and predicted values, resolution of multi-collinearity problem through feature analysis between input variables, and various statistics such as a mean squared error (MSE) between energy consumption and actual energy consumption predicted via normalization of input variables.

[112] The operating plan establishment module 150 may establish an operation plan for air conditioning equipment for each case based on contents analyzed by the analysis module.

[113] That is, the operating plan establishment module 150 establishes an overall operation plan in consideration of the number of operating thermo-hygrostats, individual operation modes and operating time of a thermo-hygrostat for each location, and the like to minimize a power rate or strategic usage while satisfying a condition to prevent a hotspot or a cold stop from being generated or suppress generation as much as possible.

[114] Not only one plan established by the operating plan establishment module 150 is established, but Plan A, Plan B, Plan C, and the like may be established in preparation for various situations, and an operator may select one of them and reflect the selected plan to an operation of the actual server room.

[115] As shown in FIG. 3, the server room of the actual data center includes at least one row of server racks 310, at least one thermo-hygrostat 320, and an IT device mounted on each server rack (e.g., server) 330.

[116] The monitoring module 200 collects information on temperature, humidity, and power usage inside the server room according to an operation of the IT device 330 and the thermo-hygrostat 320. The monitoring module 200 includes a server rack heat temperature sensor, a humidity sensor, an air flow sensor, a thermo-hygrostat return temperature sensor, a server room temperature sensor, and a power usage meter.

[117] Temperature sensors are provided at the top and bottom of each server rack constituting a server rack row 310 to measure the temperature of

air emitted from the server rack.

[118] After a plan suitable for a specific situation/load among the plans established by the operating plan establishment module 150 is established, when the situation/load is realistically reached, the entire air conditioning equipment such as the thermo-hygrostat in the server room is operated according to the plan.

[119] The monitoring module 200 monitors the temperature, humidity, wind volume, wind speed, and power consumption of the entire server room. The monitored actual operational information is transferred to the data center digital twin DB 120 to update information in the DB.

[120] Then, the simulation result and the actual operation result are analyzed by a comparison module 180.

[121] As shown in FIG. 6, for example, predictive data of power usage and predictive data of a top surface environment (temperature environment; whether hotspot/cold spot is generated and temperature distribution) are provided via simulation according to a specific operation plan, and then, based thereon, actual operation result data, that is, power consumption detailed data and top surface environment operation data are written by the monitoring module.

[122] Examples of data collected and written by the monitoring module 200 are shown in FIGS. 7 and 8. FIGS. 7A and 7B show examples of screens of general status and monitoring of the entire data center, and FIGS.

7C and 7D show examples of screens of energy management status and temperature distribution in a specific server room.

[123] FIGS. 8A and 8B show examples of screens of power peak and hotspot analysis, and FIGS. 8C and 8D show examples of screens of power usage effectiveness (PUE) inquiry and analysis thereof.

[124] In this way, the monitoring module also performs a function of combining/analyzing and displaying data while collecting data.

[125] The comparison module 180 shown in FIG. 3 compares and analyzes simulation results and actual operation results for a specific operation plan, and writes and provides a comparison report such as air conditioning power, top surface temperature distribution, wind speed, and the like according to the plan and actual load, and accordingly, the analysis module analyzes suitability evaluation of the plan/operation and the actual return on investment (ROI).

[126] In order to analyze the accuracy of simulation standardized evaluation methods of foreign countries (American ASHRAE, DOE) in which advanced technology has been established, and in this regard, suitability of a predicted value of a simulation model may be verified using Cv (RMSE) and the suitability of the predicted value of the simulation model may be verified using MBE.

[127] The MBE means the total quantitative error of simulation and measurement data during a measurement period and is expressed in %, and Cv

(RMSE) means distributional error of simulation and measurement data during a measurement period and is expressed in %.

$$MBE(\%) = \frac{\sum_{Period} (S-M)_{\text{interval}}}{\sum_{Period} M_{\text{interval}}} \times 100 \quad (1)$$

$$RMSE_{Period} = \sqrt{\frac{\sum (S-M)^2_{interval}}{N_{interval}}} \quad (2)$$

$$A_{Period} = \frac{\sum_{Period} M_{interval}}{N_{interval}} \quad (3)$$

$$Cv(RMSE_{Period}) = \frac{RMSE_{Period}}{A_{Period}} \times 100 \quad (4)$$

[128] S represents a result value of simulation, and M represents measured energy consumption and corresponds to gas or electricity consumption depending on an energy source. N is the number of data intervals and corresponds to 11 when 12 months of data are used. Such errors have an appropriate level of calibration tolerances by respective guidelines, and Table 1 below shows the calibration tolerances.

[129] When an error is smaller than a value in Table 1, this may be applied as a Baseline model at an appropriate level. Energy savings through a completed Baseline model is calculated as a difference between energy consumption of the Baseline model and energy consumption of a building after renovation.

Table 1 Calibration tolerances by guideline

Index(%)	ASHRAE 14	IPMVP	FEMP
MBE_{month}	± 5	± 20	± 5
$Cv(RMSE)_{month}$	15	-	15

[130] The main characteristics of an environment in a server room may be effectively derived by optimizing a location of each sensor node in a virtual sensor lattice network configured in a simulation for correlation analysis between the result of simulation of an environment (temperature, humidity, air flow, or pressure) in the server room and the actual measurement result measured by a sensor.

[131] Analysis of a simulation error is performed by the comparison module 180, and thus there is an advantage in that the accuracy of a future simulation may be increased through learning about such an error or modification of a related parameter.

[132] Hereinafter, an operation of the present disclosure will be described with reference to FIGS. 9 and 10.

[133] As shown in FIGS. 9A and 10A, a data center digital twin is constructed, and temperature information by location of a server room in the digital twin, thermo-hygrostat operational information, IT device power consumption information, IT device usage information, and the like may be contained.

[134] In this state, on the premise that specific future situations such

as outside temperature, weather, season, climate, and other unexpected situations will occur, when external situation and usage of IT devices are input and the digital twin of the data center is simulated, temperature distribution and power consumption in the server room are displayed, and further, a plan for optimal control for achieving optimal temperature distribution (no or minimized hotspot/cold spot) is established, as shown in FIGS. 9B and 10B. In this state, the energy consumption and temperature distribution of a top surface to be achieved in optimal control may be predicted.

[135] Based on the established optimal operation plan, as shown in FIGS. 9C and 10C, an air conditioning operation is performed for the server room of the actual data center. An optimal operating environment may be maintained to eliminate hotspots (overheating point) and cold spot (supercooling point) and save energy and costs through optimal control.

[136] In addition, data obtained through an actual air conditioning operation is collected by the monitoring module, the performance of each facility is analyzed, risk determination, energy consumption analysis, and the efficiency of facilities are analyzed, the analyzed data and analysis of an error between the simulation result and the result of the actual operation are returned to the digital twin of the data center and becomes a learning target, and the learned contents are updated to contribute to increasing the accuracy of future simulations.

[137] The method according to embodiments may include a computer

readable medium including program commands for executing operations implemented through various computers. The computer readable medium may store program commands, data files, data structures or combinations thereof. The program commands recorded in the medium may be specially designed and configured for the present disclosure or be known to those skilled in the field of computer software.

[138] Examples of a computer readable recording medium include magnetic media such as hard disks, floppy disks and magnetic tapes, optical media such as CD-ROMs and DVDs, magneto-optical media such as floptical disks, or hardware devices such as ROMs, RAMs and flash memories, which are specially configured to store and execute program commands. Examples of the program commands include a machine language code created by a compiler and a high-level language code executable by a computer using an interpreter and the like. The hardware devices described above may be configured to operate as one or more software modules to perform the operations of the embodiments, and vice versa.

[139] Software may include a computer program, code instructions, or a combination of one or more of them, and may configure a processing device to operate as desired or command the processing device independently or collectively. Software and/or data may be permanently or temporarily embodied in any type of machine, component, physical device, virtual equipment, computer storage medium or device, or a transmitted signal wave

in order to be interpretated by the processing device or to provide instructions or data to the processing device. Software may be distributed on a networked computer system and stored or executed in a distributed manner. Software and data may be stored on one or more computer readable media.

[140] As described above, the present disclosure has been described with reference to the embodiments shown in the drawings, but this is only for explaining the disclosure, and one of ordinary skill in the art to which the present disclosure belongs would understand that various modifications or equivalent embodiments are possible from the detailed description of the present disclosure.

[141] Therefore, the authentic scope of the present disclosure needs to be determined by the technical spirit of the claims.

WHAT IS CLAIMED IS:

1. A data center operating system based on a digital twin of a data center, comprising:

a database (DB) module configured to store information on a data center that actually exists;

a data center digital twin construction module configured to implement the digital twin of the data center that actually exists based on information contained in the DB module;

a digital twin simulation module configured to perform an air conditioning state simulation for the digital twin of the data center constructed by the data center digital twin construction module;

a plan establishment module configured to establish an air conditioning plan of the data center to prevent a hotspot from being generated in a space of an actual data center based on information on the simulation performed by the digital twin simulation module;

an operation control module configured to operate the air conditioning equipment for the actual data center according to the plan established by the plan establishment module;

a monitoring module configured to collect and monitor information on an operator derived from the actual data center operated by the operation control module; and

an update module configured to provide the information collected by the monitoring module to the DB module.

2. The data center operating system of claim 1, wherein the digital twin simulation module provides a predicted result from an operation of the air conditioning equipment at a specific point in future from a present time for the digital twin of the data center based on the information stored in the DB module.

3. The data center operating system of claim 1, wherein the DB module includes:

a spatial information DB of the data center;

a device information DB;

an operational information DB configured to contain operational information of the data center, including power consumption, temperature, or an operation rate; and

a 3D model information DB configured to contain 3D model information of an actual object including a space or a device inside the data center.

4. The data center operating system of claim 3, wherein:

the spatial information DB contains at least one of information on a lower structure of a floor of a server room, information on a double parquet

layout structure, information on containment layout, or information on an upper structure of a ceiling;

the device information DB contains at least one of information on a rack, information on an IT device including a server, or information on air conditioning equipment; and

the operational information DB contains at least one of information on power consumption by rack and thermo-hygrostat, information on cooling capacity of a thermo-hygrostat, information on temperature by rack, information on temperature of the server room, or information on humidity of the server room.

5. The data center operating system of claim 1, wherein the digital twin construct module includes:

an image analyzer configured to receive and analyze video or image information on a photo of a space or equipment of an actual data center;

a 3D mapper configured to map equipment or a spatial object analyzed by the image analyzer to a 3D model; and

a 3D model synchronizer configured to synchronize the object mapped by the 3D mapper with a current state of an actual object installed in the actual data center.