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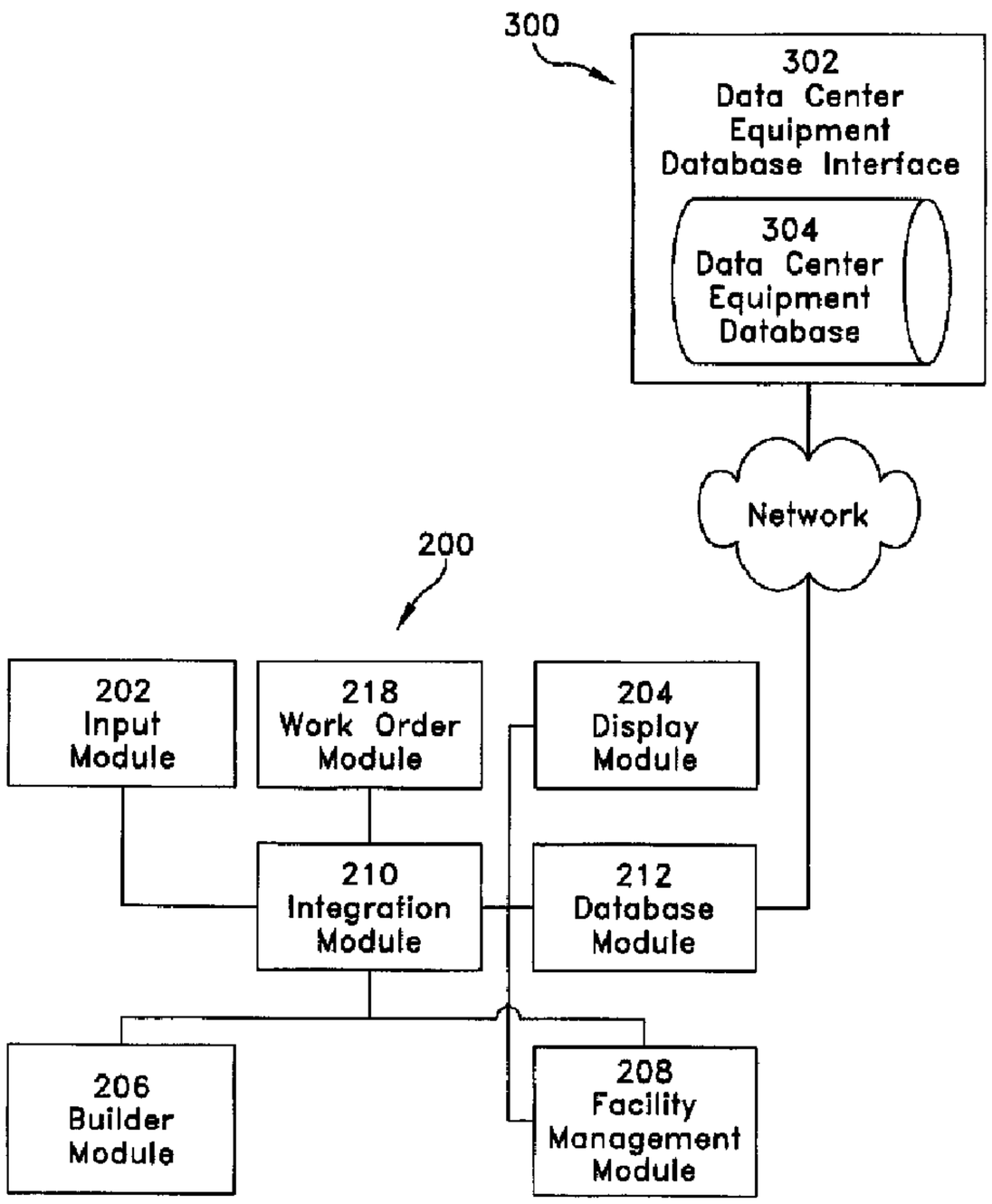


FIG. 3

(57) Abrégé/Abstract:
Systems and methods are provided for determining data center resource requirements, such as cooling and power requirements, and for monitoring performance of data center resource systems, such as cooling and power systems, in data centers. At least one

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(57) Abrégé(suite)/Abstract(continued):
aspect provides a system and method that enables a data center operator to determine available data center resources, such as power and cooling, at specific areas and enclosures in a data center to assist in locating new equipment in the data center.

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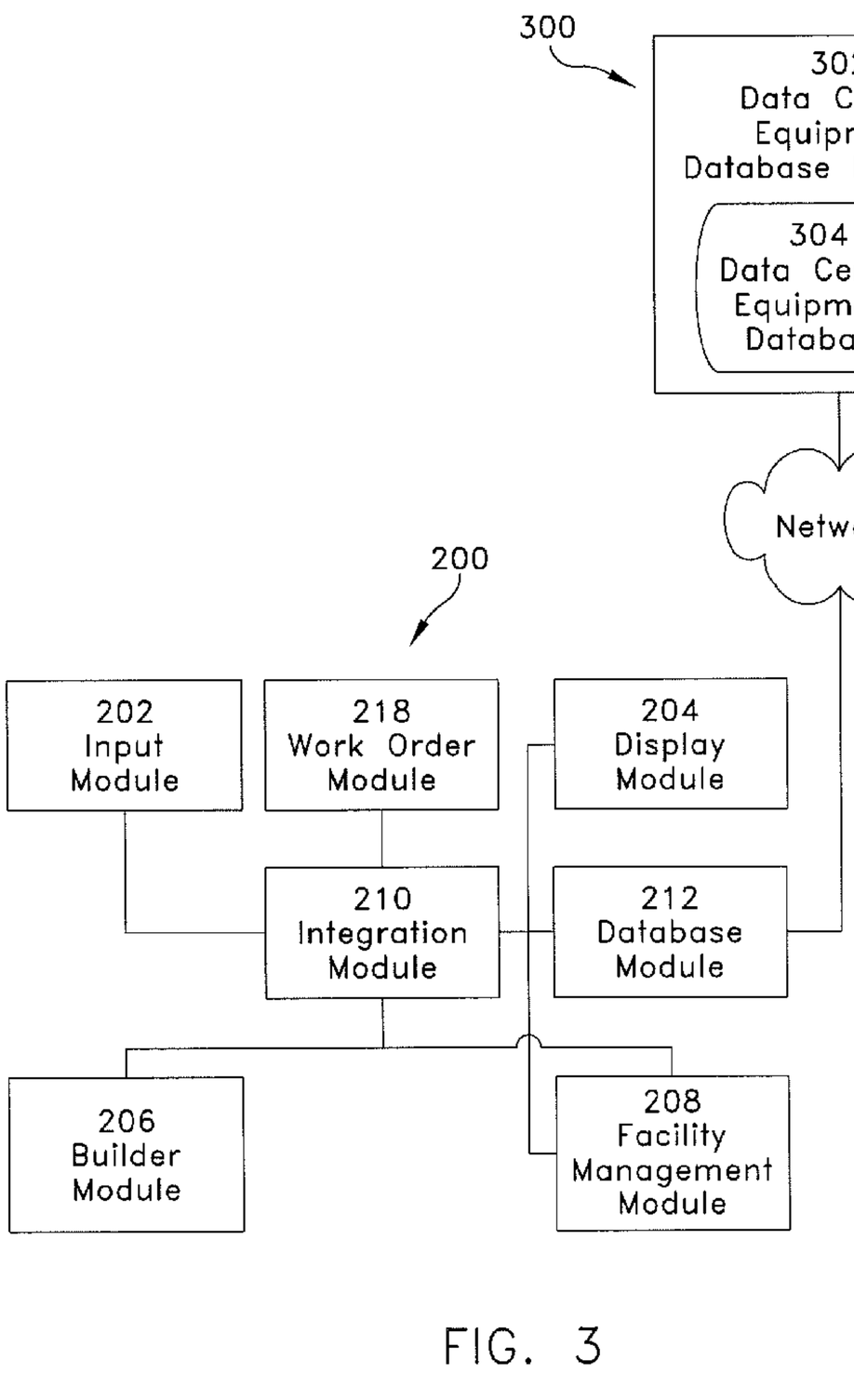


FIG. 3

(57) Abstract: Systems and methods are provided for determining data center resource requirements, such as cooling and power requirements, and for monitoring performance of data center resource systems, such as cooling and power systems, in data centers. At least one aspect provides a system and method that enables a data center operator to determine available data center resources, such as power and cooling, at specific areas and enclosures in a data center to assist in locating new equipment in the data center.

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METHODS AND SYSTEMS FOR MANAGING FACILITY POWER AND COOLING

BACKGROUND OF INVENTION

1. Field of Invention

Embodiments of the invention relate generally to entity management, and more specifically to methods and systems for managing facility power and cooling.

2. Discussion of Related Art

Centralized data centers for computer, communications and other electronic equipment have been in use for a number of years, and more recently with the increasing use of the Internet, large scale data centers that provide hosting services for Internet Service Providers (ISPs), Application Service Providers (ASPs) and Internet content providers are becoming more prevalent. Typical centralized data centers contain numerous racks of equipment that require power, cooling and connections to external communications facilities. In modern data centers and network rooms, the increased density of computing equipment used in these facilities has put strains on the cooling and power systems of the facilities. In the past, typical power consumption for each equipment enclosure in a data facility was on the order of 1kW. With the use of server blades and other high power density equipment in equipment racks, it is not uncommon for an equipment rack to have a power draw of 10kW or even as high as 25kW.

Typically, the power consumed by computer equipment is converted to heat and typically, the cooling requirements of a facility are determined based on the power requirements of the facility. Typical data centers utilize air plenums under raised floors to distribute cooling air through a data center. One or more computer room air conditioners (CRACs) or computer room air handlers (CRAHs) are typically distributed along the periphery of the data room, and these units draw return air from the room or a ceiling plenum and distribute cooling air beneath the raised floor. Perforated tiles may be placed in front or beneath racks of equipment to be cooled to allow the cooling air from beneath the floor to cool equipment within the racks.

Several tools are available to assist a data center designer in configuring a layout of a data center to provide necessary power and cooling to equipment to be located in the data center. These tools typically assist a designer in determining total power requirements and accordingly overall cooling requirements for a data center. In addition, these tools may assist a designer in determining optimum equipment layout and proper sizing of power cabling and circuit breakers.

While existing tools provide a designer with detailed layout information regarding power distribution, these tools typically provide far less help in determining cooling needs for a facility. Advanced programs that use computational fluid dynamics (CFD) may be used to model the cooling design of a facility, but the use of such programs is extremely limited due to the complexity of the programs, which results in their use being prohibitively expensive and time consuming. U.S. Patent Application US2003/0158718 A1 to Nakagawa et al describes an automated system for designing a cooling system for a facility. In the system of Nakagawa, the facility is divided into a number of pre-characterized cells (such as a cluster of racks) over which the response of various parameters, such as maximum temperature, are known based on key parameters. The system uses built-in cell to cell interaction rules to predict overall thermal performance and to optimize equipment layout. While this system may offer some improvements in speed over a full CFD analysis, it is limited to the use of pre-characterized cells, and does not provide analysis below the cell level. Also, the cells must be characterized using, for example, a CFD analysis or physical testing.

Programs and systems such as those described above provide idealized results for the cooling performance of a facility and often fail to account for situations which often occur in real life installations, which can dramatically affect the cooling performance of a data center. For example, in a facility using a raised floor, the absence of one or more floor panels, or the misplacement of one or more perforated floor panels can greatly affect the cooling performance of the data center and cause the actual performance to vary greatly from a calculated idealized performance.

Further, the degradation in performance of one or more air conditioning units can drastically change airflow and cooling characteristics of a facility.

The inability to properly analyze the cooling performance of a facility typically causes a data center designer to over design the facility from a cooling perspective, which results in the facility to be more expensive and less efficient.

In existing data centers, it is often desirable to replace equipment with upgraded equipment and/or add new equipment to existing enclosures in the facility. Several tools exist which enable a manager of a data center to monitor power usage in a facility. These tools include the InfrastruXure® Manager and/or InfrastruXure® Central product available from American Power Conversion Corporation of West Kingston, RI.

With the increasing cooling and power requirements of computer equipment, it is desirable for a data center manager to determine if there is adequate power and cooling available in the facility before new or replacement equipment may be added. Typically, a data center manager may know, or can determine, if the total cooling capacity of the data center is sufficient for the total power draw. However, hot spots in a facility may develop, particularly where high power density equipment is used, and it may not be enough to merely analyze cooling capacity at the facility level. To attempt to identify hot spots, a data center manager may resort to manual temperature measurements throughout a facility and try to implement fixes to correct the hot spots. Such fixes may involve a rearrangement or replacement of perforated floor panels, a rearrangement of enclosures, and/or adding additional cooling capacity. In any case, these fixes are typically done on a trial and error basis, and while some hot spots may be eliminated, the fixes may cause other hot spots to arise due to a redirection of the cooling air in the facility. This trial and error approach can lead to unexpected failures of equipment, which is unacceptable in critical data centers. To avoid such failures, data center managers typically over design facilities and fail to use facilities to their full capacity.

SUMMARY OF INVENTION

Aspects of the present invention relate generally to management of data center entities and their associated resources. Embodiments of the invention provide systems and methods for determining data center cooling and power requirements and for monitoring performance of cooling and power systems in data centers. At least one embodiment provides a system and method that enables a data center operator to determine available power and cooling at specific areas and enclosures in a data center to assist in locating new equipment in the data center.

One aspect of the invention is directed toward a computer-implemented method for managing data center equipment that includes presenting, to a user of a computer system, an interactive representation of a layout of a data center room that allows the user to provide an identifier of one or more element of data center equipment, receiving, from the user, an identifier of the one or more element of data center equipment to be placed in inactive storage and presenting, to the user, a representation of the one or more elements of data center equipment as placed in inactive storage.

The method may also include recording the one or more element of data center equipment as placed in inactive storage.

Another aspect of the invention is directed toward a computer-implemented method for navigating a representation of a data center on a mobile computing device that includes presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center that allows the user to provide an identifier of one or more element of data center equipment, receiving, from the user, an identifier of one or more element of data center equipment located in the data center and presenting, to the user, information regarding the identified one or more element of data center equipment.

In the method, the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center may include the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of a data center room. In the method, the act of

presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center may include the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of a rack. In the method, the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center may include the act of receiving information regarding one or more element of data center equipment represented in the interactive representation. In the method, the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center may include the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center that is updated based on the information received. In the method, the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center may include the act of presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space with a data center that is updated in near real-time based on the information received. In the method, the act of receiving, from the user, an identifier of one or more element of data center equipment may include the act of scanning a barcode associated with the one or more element of data center equipment using the mobile computing device. In the method, the act of presenting, to the user, information regarding the identified one or more element of data center equipment may include presenting, to the user, a representation of one or more element of data center equipment that is disposed within a rack.

Another aspect of the invention is directed toward a computer-implemented method for managing data center resource redundancy that includes determining the redundancy level of a data center resource specific to one or more element of data center equipment and providing the redundancy level of the data center resource as supplied to the one or more element of data center equipment.

In the method, the data center resource may include cooling provided to the one or more element of data center equipment. In the method, the data center

resource may include network connectivity provided to the one or more element of data center equipment. In the method, the data center resource may include power provided to the one or more element of data center equipment. In the method, the data center resource may include power distribution provided to the one or more element of data center equipment. In the method, the act of providing a representation of the redundancy level of the data center resource as supplied to the one or more element of data center equipment may include acts of presenting, to a user of a computer system, a representation of the one or more element of equipment within a representation of a rack, displaying the redundancy level in association with the representation of a rack.

Another aspect of the invention is directed toward a computer-implemented method for providing a representation of capacity of a data center resource that includes determining an amount of excess capacity of a first data center resource that is unusable due to insufficient associated capacity of one or more other data center resource and providing the amount of excess capacity of the first data center resource.

In the method, the act of determining the amount of excess capacity may include determining the amount of excess capacity at a U space position within a rack. In the method, the first data center resource may include U space and the one or more other data center resource includes power. In the method, the first data center resource may include power and the one or more other data center resource includes cooling. In the method, the first data center resource may include power distribution and the one or more other data center resource includes power available for distribution. In the method, the first data center resource may include physical space and the one or more other data center resource includes cooling. In the method, the first data center resource includes power distribution and the one or more other data center resource includes network connectivity. In the method, the first data center resource may include U space and the one or more other data center resource includes weight support.

Another aspect of the invention is directed toward a computer-implemented method for providing a representation of a data center resource that includes

determining a status of capacity for the data center resource provided to a rack and providing the status.

In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for power. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for cooling. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for physical space. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for weight support. In the method, the act of determining a status of capacity may include determining a status of available capacity. In the method, the act of determining a status of capacity may include determining a status of utilized capacity.

Another aspect of the invention is directed toward a computer-implemented method for providing a representation of a data center resource that includes determining a status of capacity for the data center resource provided to a U space position and providing the status.

In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for power. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for cooling. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for physical space. In the method, the act of determining a status of capacity for the data center resource may include determining a status of capacity for weight support. In the method, the act of determining a status of capacity may include determining a status of available capacity. In the method, the act of determining a status of capacity may include determining a status of utilized capacity.

Another aspect of the invention is directed toward a computer-implemented method for managing a data center equipment database that includes maintaining first, second and third sets of data, each describing a plurality of data center equipment

within one or more data center equipment database; wherein the third set includes a subset of the second set and the second set includes a subset of the first set.

In the method, the first set of data may include data regarding standard data center equipment. In the method, the first set of data may be disposed within a database hosted by a system provider. In the method, the second set of data may be disposed within a data center. In the method, the second set of data may include data regarding data center equipment that is approved for use within the data center. In the method, the second set of data may include data regarding non-standard data center equipment. In the method, the third set of data may include data preferred for use in a data center. In the method, the third set of data may be disposed within a mobile computing device. In the method, data stored in the data center equipment database may include one or more of the following: data center equipment manufacturer, data center equipment model, data center equipment power plug type, data center equipment number of plugs required, data center equipment power required, data center equipment airflow required, data center equipment network connectivity required, data center equipment weight support required, data center equipment cooling required and data center equipment physical space required.

The method may further include the act of transmitting the data regarding non-standard data center equipment to a database hosted by a system provider.

Another aspect of the invention is directed toward a computer-implemented method for maintaining a data center equipment database that includes transmitting, from one or more data center, data center configuration management information identifying the one or more data center and data center equipment disposed within the data center and receiving, at the data center equipment database, the data center configuration management information.

In the method, the data center configuration management information may include one or more of the following: data center physical dimensions, data center equipment location within the data center physical dimensions, data center equipment manufacturer and data center equipment model.

Another aspect of the invention is directed toward a computer-implemented method for maintaining a data center equipment database that includes transmitting, from one or more data center, data center resource consumption and production information associated with one or more element of data center equipment disposed within the one or more data center and receiving, at the data center equipment database, the data center resource consumption and production information associated with the one or more element of data center equipment.

In the method, transmitting, from one or more data center, data center resource consumption and production information associated with one or more element of data center equipment may include transmitting one or more of the following: data center equipment identity, data center equipment manufacturer, data center equipment model, data center equipment power plug type used, data center equipment number of plugs used, data center equipment power used, data center equipment airflow used, data center equipment network connectivity used, data center equipment weight support used, data center equipment cooling used and data center equipment physical space used. In the method, transmitting, from one or more data center, data center resource consumption and production information associated with one or more element of data center equipment may include transmitting one or more of the following: data center equipment identity, data center equipment manufacturer, data center equipment model, data center equipment power plug type provided, data center equipment number of plugs provided, data center equipment power provided, data center equipment airflow provided, data center equipment network connectivity provided, data center equipment cooling provided and data center equipment physical space provided.

Another aspect of the invention is directed toward a computer-implemented method for designing a data center that includes receiving one or more element of data center equipment to be provisioned in the data center and determining one or more location within the data center that satisfies data center resource requirements of the one or more element of data center equipment.

In the method, the act of determining one or more location may include the act of determining one or more location in near real-time. In the method, the act of receiving one or more element of data center equipment to be provisioned in the data center may include receiving one or more element of floor mounted data center equipment to be provisioned in the data center.

The method may further include the act of providing the one or more location and wherein the act of providing one or more location includes the act of providing the one or more location to a mobile computing device.

The method may further include the acts of receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment and determining one or more location within the data center that satisfies the one or more data center resource supply policy applicable to the one or more element of data center equipment. In the method, the act of determining one or more location may include determining a location that minimizes an amount of excess data center resource capacity that is unusable due to insufficient associated capacity of other data center resources. In the method, the one or more data center resource supply policy may include a redundancy level. In the method, the one or more data center resource supply policy may include a runtime requirement. In the method, the one or more data center resource supply policy may include a security requirement. In the method, the one or more data center resource supply policy may include a requirement of cooling. In the method, the one or more data center resource supply policy may include a requirement of network connectivity. In the method, the one or more data center resource supply policy may include a requirement of power. In the method, the one or more data center resource supply policy may include a requirement of power distribution.

The method may further include the act of providing the one or more location and wherein the act of providing the one or more location includes the act of providing a progression of locations starting from the location that minimizes the amount of excess data center resource capacity.

Another aspect of the invention is directed toward a computer-implemented method for designing a data center that includes receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receiving one or more location within the data center for one or more element of data center equipment and determining one or more element of data center equipment that satisfies applicable data center resource policy when located at the one or more location; wherein the one or more location satisfies data center resource requirements for the one or more element of data center equipment.

Another aspect of the invention is directed toward a computer-implemented method for designing a data center that includes receiving one or more element of data center equipment to be provisioned in the data center, receiving one or more location within a data center for the one or more element of data center equipment and determining a first compliance result that indicates whether the one or more location satisfies data center resource requirements of the one or more element of data center equipment.

The method may further include receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment and determining a second compliance result that indicates the first compliance result and whether the one or more location satisfies the one or more data center resource supply policy applicable to the one or more element of data center equipment.

Another aspect of the invention is directed toward a computer-implemented method for designing a data center that includes receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receiving a proposed change to a data center configuration and determining a compliance result that indicates whether the data center configuration, including the proposed change, complies with the one or more data center resource supply policy.

In the method, the one or more data center resource supply policy may include a redundancy level. In the method, the one or more data center resource supply policy may include a runtime requirement. In the method, the one or more data center resource supply policy may include a security requirement. In the method, the one or more data center resource supply policy may include a requirement of cooling. In the method, the one or more data center resource supply policy may include a requirement of network connectivity. In the method, the one or more data center resource supply policy may include a requirement of power. In the method, the one or more data center resource supply policy may include a requirement of power distribution.

Another aspect of the invention is directed toward a computer-implemented method for managing a work order that includes receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of an identified space within a data center, generating a work order describing a set of tasks required to complete the proposed change and presenting the set of tasks to a user of a computer system.

In the method, receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of an identified space within a data center may include receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of a data center room. In the method, receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of an identified space within a data center may include receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of a rack.

The method may further include detecting a change in the power demanded at power distribution device associated with the work order and recording the work order as completed based on the change in power demanded.

Another aspect of the invention is directed toward a computer-implemented method for providing an evaluation of data center resource that includes determining a rate of change of data center resource utilized capacity based on past changes to a data

center configuration and providing predicted data center resource utilization in the future based on the rate of change.

In the method, determining a rate of change of data center resource utilized capacity may include determining the rate of change using linear regression. In the method, the data center resource may include power. In the method, the data center resource may include cooling.

Another aspect of the invention is directed toward a system for managing data center equipment that includes an input to receive instructions from a user, an output to provide output data to a display device, a memory for storing data and a controller coupled to the input, the output and the memory. The controller may be configured to present, to a user, an interactive representation of a layout of a data center room that allows the user to provide an identifier of one or more element of data center equipment, receive, from the user, an identifier of the one or more element of data center equipment to be placed in inactive storage and present, to the user, a representation of the one or more element of data center equipment as placed in inactive storage.

Another aspect of the invention is directed toward a mobile computing device for navigating a representation of a data center that includes an input to receive instructions from a user, an output to provide output data to a display device, a memory for storing data and a controller coupled to the input, the output and the memory. The controller may be configured to present, to a user, an interactive representation of a layout of an identified space within a data center that allows the user to provide an identifier of one or more element of data center equipment, receive, from the user, an identifier of one or more element of data center equipment located in the data center and present, to the user, information regarding the identified one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for managing data center resource redundancy that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to determine the redundancy level of a data center resource specific to one or more element of data

center equipment and to provide the redundancy level of the data center resource as supplied to the one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for providing a representation of a capacity of a data center resource that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to determine an amount of excess capacity of a first data center resource that is unusable due to insufficient associated capacity of one or more other data center resource and to provide the amount of excess capacity of the first data center resource.

Another aspect of the invention is directed toward an apparatus for providing a representation of capacity of a data center resource that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to determine a status of capacity for the data center resource provided to a rack and provide the status.

Another aspect of the invention is directed toward an apparatus for providing a representation of a data center resource that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to determine a status of capacity for the data center resource provided to a U space position and provide the status.

Another aspect of the invention is directed toward an apparatus for maintaining a data center equipment database that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to maintain first, second and third sets of data, each describing a plurality of data center equipment within one or more data center equipment database. The third set may include a subset of the second set and the second set includes a subset of the first set.

Another aspect of the invention is directed toward an apparatus for maintaining a data center equipment database that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to transmit, from one or more data center, data center configuration management information identifying the one or more data center and data center equipment

disposed within the data center and receive, at the data center equipment database, the data center configuration management information.

Another aspect of the invention is directed toward an apparatus for maintaining a data center equipment database that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to transmit, from one or more data center, data center resource consumption and production information associated with one or more element of data center equipment disposed within the one or more data center and receive, at the data center equipment database, the data center resource consumption and production information associated with the one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for designing a data center that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to receive one or more element of data center equipment to be provisioned in the data center and determine one or more location within the data center that satisfies data center resource requirements of the one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for designing a data center that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to receive one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receive one or more location within the data center for one or more element of data center equipment and determine one or more element of data center equipment that satisfies applicable data center resource policy when located at the one or more location wherein the one or more location satisfies data center resource requirements for the one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for designing a data center that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to receive one or more element of data center equipment to be provisioned in the data center, receive one or more location

within a data center for the one or more element of data center equipment and determine a first compliance result that indicates whether the one or more location satisfies data center resource requirements of the one or more element of data center equipment.

Another aspect of the invention is directed toward an apparatus for designing a data center that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to receive one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receive a proposed change to a data center configuration and determine a compliance result that indicates whether the data center configuration, including the proposed change, complies with the one or more data center resource supply policy.

Another aspect of the invention is directed toward a system for managing a work order that includes an input to receive instructions from a user, an output to provide output data to a display device, a memory for storing data and a controller coupled to the input, the output and the memory. The controller may be configured to receive, from a user, a proposed change to a data center configuration though an interactive representation of a layout of an identified space within a data center, generate a work order describing a set of tasks required to complete the proposed change and present the set of tasks to a user.

Another aspect of the invention is directed toward an apparatus for providing an evaluation of data center resource that includes a memory for storing data and a controller coupled to the memory. The controller may be configured to determine a rate of change of data center resource utilized capacity based on past changes to a data center configuration and provide predicted data center resource utilization in the future based on the rate of change.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include presenting, to a user of a computer system, an interactive representation of a layout of a data center room that allows the user to

provide an identifier of one or more element of data center equipment, receiving, from the user, an identifier of the one or more element of data center equipment to be placed in inactive storage and presenting, to the user, a representation of the one or more element of data center equipment as placed in inactive storage.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include presenting, to a user of the mobile computing device, an interactive representation of a layout of an identified space within a data center that allows the user to provide an identifier of one or more element of data center equipment, receiving, from the user, an identifier of one or more element of data center equipment located in the data center and presenting, to the user, information regarding the identified one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include determining the redundancy level of a data center resource specific to one or more element of data center equipment and providing the redundancy level of the data center resource as supplied to the one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include determining an amount of excess capacity of a first data center resource that is unusable due to insufficient associated capacity of one or more other data center resource and providing the amount of excess capacity of the first data center resource.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include determining a status of capacity for the data center resource provided to a rack and providing the status.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to

perform operations that include determining a status of capacity for the data center resource provided to a U space position and providing the status.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include maintaining first, second and third sets of data, each describing a plurality of data center equipment within one or more data center equipment database; wherein the third set includes a subset of the second set and the second set includes a subset of the first set.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include transmitting, from one or more data center, data center configuration management information identifying the one or more data center and data center equipment disposed within the data center and receiving, at the data center equipment database, the data center configuration management information.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include transmitting, from one or more data center, data center resource consumption and production information associated with one or more element of data center equipment disposed within the one or more data center and receiving, at the data center equipment database, the data center resource consumption and production information associated with the one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include receiving one or more element of data center equipment to be provisioned in the data center and determining one or more location within the data center that satisfies data center resource requirements of the one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to

perform operations that include receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receiving one or more location within the data center for one or more element of data center equipment and determining one or more element of data center equipment that satisfies applicable data center resource policy when located at the one or more location; wherein the one or more location satisfies data center resource requirements for the one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include receiving one or more element of data center equipment to be provisioned in the data center, receiving one or more location within a data center for the one or more element of data center equipment and determining a first compliance result that indicates whether the one or more location satisfies data center resource requirements of the one or more element of data center equipment.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include receiving one or more data center resource supply policy describing one or more desired data center resource characteristic as supplied to the one or more element of data center equipment, receiving a proposed change to a data center configuration and determining a compliance result that indicates whether the data center configuration, including the proposed change, complies with the one or more data center resource supply policy.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include receiving, from a user, a proposed change to a data center configuration though an interactive representation of a layout of an identified space within a data center, generating a work order describing a set of tasks required to complete the proposed change and presenting the set of tasks to a user of a computer system.

Another aspect of the invention is directed toward a machine-readable medium that includes instructions which, when executed by a machine, cause the machine to perform operations that include determining a rate of change of data center resource utilized capacity based on past changes to a data center configuration and providing predicted data center resource utilization in the future based on the rate of change.

Another aspect is directed to a method that includes determining cooling capacity of a number of equipment enclosures in a data center, determining cooling requirements of each of the number of equipment enclosures, and providing an indication of remaining cooling capacity for each of the number of equipment enclosures.

The method may further include developing a floor plan model of the data center, wherein the floor plan model includes a floor plan that indicates location of each of the number of equipment enclosures in the data center, and for each of the number of equipment enclosures, displaying on the floor plan, the indication of remaining cooling capacity. The indication of remaining cooling capacity may include an indication of additional power that can be drawn by each of the number of equipment enclosures based on the remaining cooling capacity. Determining cooling capacity may include calculating a predicted cooling capacity based on the floor plan model. Determining cooling capacity may include measuring airflow at a first plurality of locations in the facility to obtain a measured cooling capacity. Determining cooling capacity may include measuring air temperature at a second plurality of locations in the facility. At least one of the first plurality of locations and the second plurality of locations includes at least one air vent of a raised floor. The method may further include comparing predicted cooling capacity with measured cooling capacity to obtain a comparison result and providing an indication when the comparison result is greater than a threshold. The method may further include adjusting the predicted cooling capacity based on measured airflow. The method may further include determining placement of new equipment in an equipment enclosure in the data center by comparing power ratings of the new equipment with cooling capacity of the equipment enclosure. The method may further include, for each of the

number of equipment enclosures, determining electrical power capacity and remaining electrical power availability, and displaying on the floor plan remaining electrical power availability. In the method, determining remaining electrical power availability may include measuring at least one parameter of electrical power provided to at least one of the number of equipment enclosures. In the method, determining cooling capacity of an equipment enclosure may include estimating available cooling air at the equipment enclosure using a weighted summation of available airflows from a plurality of airflow sources, the weights used in the weighted summation may decrease with distance from the equipment enclosure to each of the airflow sources, and the weights may be based on mechanical characteristics of the plurality of airflow sources. The method may further include determining available airflow of at least one of the plurality of airflow devices using at least one of specifications of the at least one of the plurality of airflow devices and measured data for the at least one of the plurality of airflow devices in the data center. The method may further include determining available airflow of at least a second one of the plurality of airflow devices based on the measured data for the at least one of the plurality of airflow devices. In the method, determining cooling capacity may include using superposition to combine airflows. In the method, determining airflow into and out of each of a plurality of sides of each control volume may include computing airflows using equations based on at least one of conservation of mass and conservation of momentum. Further, determining airflow into and out of each of a plurality of sides of each control volume may include determining airflows using empirical rules derived from CFD, physical measurement, or any other means.

Another aspect of the invention is directed to a system for managing a data center. The system includes at least one input to receive data related to equipment and equipment enclosures and to receive data related to cooling characteristics of the data center, a controller operatively coupled to the input and configured to determine cooling capacity of each equipment enclosure, and at least one output operatively coupled to the controller that provides an indication of remaining cooling capacity for each of the equipment enclosures.

The system may further include an output device coupled to the at least one output, wherein the system is configured to display a floor plan of at least a portion of the data center indicating location of at least one of the equipment enclosures in the data center and indicating the remaining cooling capacity for the at least one of the equipment enclosures. The output device may be configured to include an indication of additional power that can be drawn by the at least one of the equipment enclosures. The system may further include at least one airflow monitor operatively coupled to the controller to provide data related to at least one airflow in the data center. The system may further include at least one air monitor operatively coupled to the controller to provide data related to air temperature at a location in the data center. The controller may be configured to compare a predicted cooling capacity with a measured cooling capacity to obtain a comparison result and to provide an indication when the comparison result is greater than a threshold. The system may further include at least one power monitor operatively coupled to the controller, and at least one airflow controller operatively coupled to the controller and responsive to signals from the controller to alter cooling airflow in the data center. The system may further include at least one power controller operatively coupled to the controller and responsive to signals from the controller to alter at least one characteristic of power in the data center.

Another aspect of the invention is directed to a system for managing a data center. The system includes at least one input to receive data related to equipment and equipment enclosures and to receive data related to cooling characteristics of the data center, and means, coupled to the at least one input, for determining remaining cooling capacity for each of the number of equipment enclosures and providing an indication of remaining cooling capacity.

The system may further include means for providing an indication of additional power that can be drawn by each of the equipment enclosures and means for updating the indication of remaining cooling capacity based on measured airflows in the data center. The system may still further include means for determining placement of equipment in the data center based on remaining cooling capacity, and

means for estimating available cooling air of at least one of the equipment enclosures using a weighted summation of available airflows from a plurality of airflow sources.

Another aspect of the invention is directed to a computer-implemented method of managing power and cooling capacity of a data center. The method includes receiving data center parameters, determining an equipment layout in the data center, the equipment layout identifying a location of each of a plurality of devices in the data center, based on the location, determining available power and available cooling in the data center for each of the plurality of devices, comparing the available power and available cooling with power requirements and cooling requirements of each of the plurality of devices to obtain a cooling comparison result and a power comparison result for each of the plurality of devices.

The method may further include comparing each of the comparison cooling results and the power cooling results with thresholds and providing at least one recommendation for correcting an out of tolerance condition. The at least one recommendation may include adding an in-row cooling unit in a row of equipment of the data center along wit ha proposed location for the in-row cooling unit. The method may further include determining at least one of stranded cooling capacity and stranded power capacity in the data center and providing recommendations for reducing at least one of the stranded power capacity and the stranded cooling capacity in the data center. The method may further include displaying a floor plan model of the data center, wherein the floor plan model includes a floor plan that indicates a location of each of the plurality of devices in the data center, and for each of the plurality of devices, displaying on the floor plan an indication of remaining cooling capacity. The method may include displaying on the floor plan an indication of remaining power capacity for each of the plurality of devices. The method may still further include setting a redundancy level for at least some of the plurality of devices, and wherein the available power and available cooling are determined to meet the redundancy level. In the method, the act of determining the equipment layout may include arranging the plurality of devices in at least two substantially parallel rows with a hot aisle formed between the two rows, and the method may further include

conducting a cooling analysis by analyzing airflows in the hot aisle. The method may include selecting at least one in-row cooling unit to be placed in the layout in one of the at least two substantially parallel rows. At least one of the plurality of devices is an equipment rack, and the method may include determining a capture index for the at least one in-row cooling unit and the equipment rack. The method may further include on a display screen, simultaneously displaying a first floor plan model of the data center and a second floor plan model of the data center, wherein the first floor plan model includes at least a partial view of the data center and the second floor plan model includes a full view of the data center. The second floor plan model may include an indication of a portion of the data center that is shown in the first floor plan model. The method may further include displaying a three dimensional view of at least a portion of the data center. The method may include selecting a camera location for use in the data center and displaying a three dimensional view of a viewing area of the camera. The method may further include selecting a subset of the plurality of devices and defining a power zone for each device of the subset of the plurality of devices, wherein each power zone includes at least one UPS. In the method, each of the plurality of devices may be an equipment rack, and the method may further include selecting components for each of the plurality of devices from a displayed list of components. The method may further include determining operational power costs and operational cooling costs for a subset of the plurality of devices, and the operational power costs and operational cooling costs may be determined in terms of kilowatts. The method may further include transferring an electronic file containing data for the equipment layout from a design system to a management system. The method may also include displaying measured data for the data center on a display of a layout of the data center.

Another aspect of the invention is directed to a computer-implemented method for designing a layout of a data center. The method includes receiving information from a user regarding parameters of the data center, determining an equipment layout for the data center, the equipment layout identifying a location of each of a plurality of devices in the data center, and on a display screen, simultaneously displaying a first

floor plan model of the data center and a second floor plan model of the data center, wherein the first floor plan model includes at least a partial view of the data center and the second floor plan model includes a full view of the data center.

In the method, the second floor plan model may include an indication of a portion of the data center that is shown in the first floor plan model. The method may further include determining available power and available cooling in the data center for each of the plurality of devices, and comparing the available power and available cooling with power requirements and cooling requirements of each of the plurality of devices to obtain a cooling comparison result and a power comparison result for each of the plurality of devices. The method may include, for each of the plurality of devices, displaying on the first floor plan model an indication of remaining cooling capacity, and displaying on the first floor plan model an indication of remaining power capacity for each of the plurality of devices.

Another aspect of the invention is directed to a system for use with a data center. The system includes an input to receive instructions from a user, an output to provide output data to a display device, and a controller coupled to the input and to the output and configured to determine an equipment layout of a data center, the equipment layout identifying a location of each of a plurality of devices in the data center. The controller is further configured to, based on the location, determine available power and available cooling in the data center for each of the plurality of devices, and compare the available power and available cooling with power requirements and cooling requirements of each of the plurality of devices to obtain a cooling comparison result and a power comparison result for each of the plurality of devices.

In the system, the controller may be configured to compare each of the comparison cooling results and the power cooling results with thresholds, and based on at least one of the cooling comparison result and the power comparison result, provide at least one recommendation for correcting an out of tolerance condition. The at least one recommendation may include adding an in-row cooling unit in a row of equipment of the data center, and the at least one recommendation may include a

proposed location for the in-row cooling unit. The controller may be configured to determine at least one of stranded cooling capacity and stranded power capacity in the data center, and to provide recommendations for reducing at least one of the stranded power capacity and the stranded cooling capacity in the data center. The controller may be further configured to provide data to the output for displaying a floor plan model of the data center, wherein the floor plan model includes a floor plan that indicates a location of each of the plurality of devices in the data center, and provide data to the output for displaying on the floor plan an indication of remaining cooling capacity. The controller may be further configured to provide data to the output for displaying on the floor plan an indication of remaining power capacity for each of the plurality of devices, and the controller may be configured to determine the available power and available cooling based on a user-selected redundancy level. The controller may be configured to arrange the plurality of devices in at least two substantially parallel rows with a hot aisle formed between the two rows, and to conduct a cooling analysis by analyzing airflows in the hot aisle. The controller may be configured to select at least one in-row cooling unit to be placed in the layout in one of the at least two substantially parallel rows. At least one of the plurality of devices may be an equipment rack, and the controller may be configured to determine a capture index for the at least one in-row cooling unit and the equipment rack. The controller may be configured to provide data to the output to simultaneously display a first floor plan model of the data center and a second floor plan model of the data center, wherein the first floor plan model includes at least a partial view of the data center and the second floor plan model includes a full view of the data center. The second floor plan model may also include an indication of a portion of the data center that is shown in the first floor plan model. The controller may be configured to provide data to the output to display a three dimensional view of at least a portion of the data center, and to provide data to the output to display a three dimensional view of a viewing area of a camera to be located in the data center. The controller may be further configured to select a subset of the plurality of devices and define a power zone for each device of the subset of the plurality of devices, wherein each power

zone includes at least one UPS. The system may further include a database module containing data for components to be loaded into the plurality of devices, and the controller may be configured to provide data to the output for displaying a list of the components. The controller may be configured to determine operational power costs and operational cooling costs for a subset of the plurality of devices, and the operational power costs and operational cooling costs may be determined in terms of kilowatts. The controller may also be configured to provide an output electronic file containing data for the equipment layout. The controller may also be configured to, based on at least one of the cooling comparison result and the power comparison result, provide at least one recommendation for placement of rack mount equipment.

Another aspect of the invention is directed to a computer-implemented method for designing a layout of a data center. The method includes receiving information from a user regarding parameters of the data center, determining an equipment layout for the data center, the equipment layout identifying a location of each of a plurality of devices in the data center, including identifying a row location for each of a plurality of equipment racks with a first subset of the plurality of equipment racks being included in a first row; and on a display screen, displaying a rack view of the data center showing a front view of each of the plurality of equipment racks of the first subset in the first row.

In the method, displaying a rack view may include displaying a front view of a second subset of the plurality of equipment racks of a second row along with the front view of the first subset of the plurality of equipment racks. In the method, displaying a rack view may include displaying a front view of a second subset of the plurality of equipment racks of a second row along with the front view of the first subset of the plurality of equipment racks. The first row may include additional equipment, with the additional equipment not included in the rack view. The method may further include simultaneously displaying on the display screen the rack view and a full room view of the equipment layout for the data center. The method may also include, in response to selection of a selected equipment rack in the full room view by a user, displaying the selected equipment rack in the rack view, and displaying the selected

equipment rack in the rack view may include displaying a front view of the selected equipment rack.

Another aspect of the invention is directed to a computer-implemented method for evaluating the cooling performance of a cluster of equipment racks in a data center, wherein the cluster of equipment racks includes at least a first row of racks and a second row of racks separated by a cool aisle, with each of the equipment racks being configured to draw cooling air from the cool aisle. The method includes obtaining at least one of power data and airflow data for each of the equipment racks, obtaining cool airflow data for cool air supplied to the cool aisle from a source of cool air, and conducting an analysis of airflows in the cool aisle to determine a recirculation index for at least one of the equipment racks, wherein the recirculation index is indicative of a quantity of recirculated air included in an input airflow of the at least one equipment rack.

In the method, the recirculation index may be equal to a ratio of recirculated air to total air in the input airflow of the at least one equipment rack, and the method may further include determining a recirculation index for each of the equipment racks. In the method, the act of obtaining cool airflow data may include obtaining cool airflow data for an in-row cooling unit included in the cluster of racks. In the method, the act of obtaining cool airflow data may include obtaining cool airflow data of at least one perforated tile included in the cool aisle. In the method, the act of conducting an analysis may include defining a plurality of control volumes in the cool aisle, and the method may further include determining airflows in the cool aisle by determining airflow into and out of at least one of the control volumes. The method may further include comparing the recirculation index for each of the plurality of equipment enclosures with a threshold. The method may further include determining a cooling capacity for each of the equipment enclosures based on the recirculation index for each of the equipment enclosures, and displaying the cooling capacity for each of the equipment enclosures along with a representation of a data center containing the cluster. In the method, the act of conducting an analysis may include assigning different chemical concentration identifiers to the airflows for at least two

of the plurality of equipment racks. In the method, the act of conducting an analysis may include importing empirical data and determining end of aisle airflows using the empirical data. In the method, the act of conducting an analysis may include determining cool aisle airflows in isolation from the data center to obtain isolated results, and combining the isolated results with the empirical data.

Another aspect of the invention is directed to a computer-implemented method for evaluating the cooling performance of a cluster of equipment racks in a data center, wherein the cluster of equipment racks includes at least a first row of racks and a second row of racks separated by a hot aisle, with each of the equipment racks being configured to exhaust air into the hot aisle. The method includes obtaining at least one of power data and airflow data for each of the equipment racks, obtaining airflow data for at least one air removal unit contained in one of the first row of equipment racks and the second row of equipment racks, and conducting an analysis of airflows in the hot aisle to determine a capture index for at least one of the equipment racks, wherein the capture index is indicative of a fraction of air that is exhausted by the at least one of the equipment racks and captured by the at least one air removal unit.

In the method, the at least one air removal unit may include an in-row cooling unit, and the capture index may be equal to a ratio of captured air to total air exhausted by the at least one equipment rack. The method may further include determining a capture index for each of the equipment racks. In the method, the act of conducting an analysis may include defining a plurality of control volumes in the hot aisle, and the method may further include determining airflows in the hot aisle by determining airflow into and out of at least one of the control volumes. The method may further include comparing the capture index for each of the plurality of equipment enclosures with a threshold. The method may include determining a cooling capacity for each of the equipment enclosures based on the capture index for each of the equipment enclosures, and displaying the cooling capacity for each of the equipment enclosures along with a representation of a data center containing the cluster. In the method, the act of conducting an analysis may include assigning different chemical concentration identifiers to the airflows for at least two of the

plurality of equipment racks. In the method, the act of conducting an analysis may include importing empirical data and determining end of aisle airflows using the empirical data. The act of conducting an analysis may include determining hot aisle airflows in isolation from the data center to obtain isolated results, and combining the isolated results with the empirical data. In the method, the act of conducting an analysis may include importing empirical rules, and determining the capture index using the empirical rules, and the empirical rules may include coefficients for use in determining at least one capture index.

Another aspect of the invention is directed to a computer-readable medium encoded with instructions for execution on a computer system. The instructions, when executed, perform a method comprising acts of obtaining at least one of power data and airflow data for a plurality of equipment racks arranged in a cluster, wherein the cluster of equipment racks includes at least a first row of racks and a second row of racks separated by a cool aisle, with each of the equipment racks being configured to draw cooling air from the cool aisle, obtaining cool airflow data for cool air supplied to the cool aisle from a source of cool air, and conducting an analysis of airflows in the cool aisle to determine a recirculation index for at least one of the equipment racks, wherein the recirculation index is indicative of a quantity of recirculated air included in an input airflow of the at least one equipment rack.

The recirculation index may equal to a ratio of recirculated air to total air in the input airflow of the at least one equipment rack, and the acts may further include determining a recirculation index for each of the equipment racks. The act of obtaining cool airflow data may include obtaining cool airflow data for an in-row cooling unit included in the cluster of racks. The act of obtaining cool airflow data may include obtaining cool airflow data of at least one perforated tile included in the cool aisle. The act of conducting an analysis ma include defining a plurality of control volumes in the cool aisle, and wherein the method further includes determining airflows in the cool aisle by determining airflow into and out of at least one of the control volumes. The acts may further include comparing the recirculation index for each of the plurality of equipment enclosures with a threshold, and

determining a cooling capacity for each of the equipment enclosures based on the recirculation index for each of the equipment enclosures. The acts may further include displaying the cooling capacity for each of the equipment enclosures along with a representation of a data center containing the cluster. The act of conducting an analysis may include assigning different chemical concentration identifiers to the airflows for at least two of the plurality of equipment racks. The act of conducting an analysis may include importing empirical data and determining end of aisle airflows using the empirical data. The act of conducting an analysis may include determining cool aisle airflows in isolation from the data center to obtain isolated results, and combining the isolated results with the empirical data.

Another aspect of the invention is directed to a computer-readable medium encoded with instructions for execution on a computer system. The instructions when executed, perform a method comprising acts of obtaining at least one of power data and airflow data for a plurality of equipment racks arranged in a cluster, wherein the cluster of equipment racks includes at least a first row of racks and a second row of racks separated by a hot aisle, with each of the equipment racks being configured to exhaust air into the hot aisle, obtaining airflow data for at least one air removal unit contained in one of the first row of equipment racks and the second row of equipment racks, and conducting an analysis of airflows in the hot aisle to determine a capture index for at least one of the equipment racks, wherein the capture index is indicative of a fraction of air that is exhausted by the at least one of the equipment racks and captured by the at least one air removal unit.

In the method, the at least one air removal unit may be an in-row cooling unit, and the capture index may be equal to a ratio of captured air to total air exhausted by the at least one equipment rack. The acts may further include determining a capture index for each of the equipment racks. The act of conducting an analysis may include defining a plurality of control volumes, and wherein the method further includes determining airflows in the hot aisle by determining airflow into and out of at least one of the control volumes. The acts may further include comparing the capture index for each of the plurality of equipment enclosures with a threshold. The acts may

further include determining a cooling capacity for each of the equipment enclosures based on the capture index for each of the equipment enclosures, and displaying the cooling capacity for each of the equipment enclosures along with a representation of a data center containing the cluster. The act of conducting an analysis may include assigning different chemical concentration identifiers to the airflows for at least two of the plurality of equipment racks. The act of conducting an analysis may include importing empirical data and determining end of aisle airflows using the empirical data. The act of conducting an analysis may include determining hot aisle airflows in isolation from the data center to obtain isolated results, and combining the isolated results with the empirical data. The act of conducting an analysis may include importing empirical rules, and determining the capture index using the empirical rules. The empirical rules include coefficients for use in determining at least one capture index.

According to one aspect of the present invention, a computer-implemented method for providing a representation of capacity of a data center resource is provided. The method comprises acts of determining a first indication of excess capacity of a first data center resource that is unusable due to insufficient capacity of at least one other data center resource associated with the first data center resource, and providing the first indication of excess capacity of the first data center resource to an external entity. According to one embodiment of the present invention, the act of determining the first indication of excess capacity includes an act of determining an amount of excess capacity of the first data center resource that is unusable due to insufficient capacity of the at least one other data center resource associated with the first data center resource. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity at a location in a rack. According to another embodiment of the invention, the act of determining the first indication of excess capacity at the location in the rack includes an act of determining an indication of excess capacity at a U space position. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act

of determining an indication of excess capacity of rack space that is unusable due to insufficient capacity of power.

According to one embodiment of the present invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power that is unusable due to insufficient capacity of cooling. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power distribution that is unusable due to insufficient capacity of power available for distribution. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of physical space that is unusable due to insufficient capacity of cooling. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power distribution that is unusable due to insufficient capacity of network connectivity. According to another embodiment of the invention, the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of U space that is unusable due to insufficient capacity of weight support.

According to one embodiment of the present invention, the act of providing the first indication of excess capacity includes an act of providing the indication to another system element. According to another embodiment of the invention, the act of providing the first indication of excess capacity includes an act of presenting the first indication to a user of a computer system. According to another embodiment of the invention, the act of presenting the first indication to the user of the computer system includes an act of presenting, to the user of the computer system, an amount of excess capacity of the first data center resource that is unusable due to insufficient capacity of the at least one other data center resource associated with the first data center resource. According to another embodiment of the invention, the act of presenting, to the user of the computer system, the amount of excess capacity includes acts of presenting, to the user of the computer system, an identifier that identifies the

first data center resource and presenting, to the user of the computer system, an identifier that identifies the at least one other data center resource. According to another embodiment of the invention, the method further comprises determining a configuration of data center equipment that minimizes, relative to at least one other configuration, the excess capacity of the first data center resource, and providing the configuration of data center equipment to an external entity.

According to one embodiment of the present invention, determining the configuration of data center equipment includes determining a location for at least one element of data center equipment. According to another embodiment of the invention, the method further comprises determining a second indication of excess capacity of a second data center resource that is unusable due to insufficient capacity of at least one other data center resource associated with the second data center resource determining a configuration of data center equipment that minimizes, relative to at least one other configuration, an aggregate of the first indication and the second indication, and providing the configuration of data center equipment to an external entity.

According to one aspect of the present invention, a computer-implemented method for providing a representation of a data center resource is provided. The method comprises acts of determining a status of capacity for the data center resource provided to either a rack or a location in a rack, and providing the status to an external entity. According to another embodiment of the invention, determining the status of capacity for the data center resource includes determining a status for the data center resource provided to a U space position. According to one embodiment of the present invention, the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of power. According to another embodiment of the invention, the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of cooling. According to another embodiment of the invention, the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of physical space. According to another embodiment of the invention, the act

of determining the status of capacity for the data center resource includes an act of determining a status of capacity of weight support. According to another embodiment of the invention, the act of determining the status of capacity for the data center resource includes an act of determining a status of available capacity. According to another embodiment of the invention, the act of determining the status of capacity for the data center resource includes an act of determining a status of utilized capacity.

According to one aspect of the present invention, a computer-implemented method for providing a representation of a data center resource is provided. The method comprises acts of determining a rate of change of a utilized capacity of the data center resource based at least in part on changes to a data center configuration, and providing a predicted utilization of the data center resource based at least in part on the rate of change. According to another embodiment of the invention, determining the rate of change of utilized capacity of the data center resource includes determining the rate of change using linear regression. According to another embodiment of the invention, the data center resource includes power. According to another embodiment of the invention, the data center resource includes cooling.

According to one aspect of the present invention, a system for providing a representation of a capacity of data center resource is provided. The system comprises an input configured to receive a capacity of a first data center resource and a capacity of at least one other data center resource, an output configured to provide an amount of excess capacity of the first data center resource, and a controller coupled to the input and the output and configured to determine an amount of excess capacity of the first data center resource that is unusable due to insufficient capacity of the at least one other data center resource.

According to one aspect of the present invention, a system for providing a representation of a data center resource is provided. The system comprises an input configured to receive capacity information for a data center resource, an output configured to provide a status of capacity for the data center resource, and a controller coupled to the input and the output and configured to determine the status of capacity for the data center resource at either a rack or a location in a rack.

According to one aspect of the present invention, a system for providing an evaluation of a data center resource is provided. The system comprises an input configured to receive changes in a data center configuration, an output configured to provide a predicted utilization of the data center resource based on a rate of change of utilized capacity of the data center resource, and a controller configured to determine the rate of change of the utilized capacity of the data center resource based on the changes in a data center configuration.

According to one aspect of the present invention, a computer-implemented method for distributing data describing models of data center equipment is provided. The method comprises acts of indicating a first group of the data describing models of data center equipment, the first group identifying standard models of data center equipment, indicating a second group of the data describing models of data center equipment, the second group identifying models approved for use in a first data center, indicating a third group of the data describing models of data center equipment, the third group identifying models preferred for use in the first data center, providing the second group to a first remote computing device located in the first data center, and providing the third group to the first remote computing device located in the first data center. According to one embodiment of the present invention, the act of providing the second group comprises an act of providing data including at least one of the group comprising data center equipment manufacturer, data center equipment model, data center equipment power plug type, data center equipment number of plugs required, data center equipment power required, data center equipment airflow required, data center equipment network connectivity required, data center equipment weight support required, data center equipment cooling required, and data center equipment physical space required. According to another embodiment of the invention, the method further comprises an act of providing the third group from the first remote computing device to a second remote computing device.

According to one embodiment of the present invention, the act of providing the third group from the first remote computing device includes an act of providing the third group to a mobile computing device. According to another embodiment of

the invention, the act of indicating a first group includes storing an indicator of the first group in a database hosted by a system provider. According to another embodiment of the invention, the method further comprises an act of receiving first non-standard data describing models of data center equipment from the first remote computing device. According to another embodiment of the invention, the method further comprises an act of receiving non-standard data describing models of data center equipment from an external entity. According to another embodiment of the invention, the act of receiving non-standard data includes receiving additional data from a data center equipment manufacturer. According to another embodiment of the invention, the method further comprises acts of indicating a fourth group of the data describing models of data center equipment, the fourth group identifying models approved for use in a second data center, indicating a fifth group of the data describing models of data center equipment, the fifth group identifying models preferred for use in the second data center, providing the fourth group to a third remote computing device located in the second data center, and providing the fifth group to the third remote computing device located in the second data center. According to another embodiment of the invention, the method further comprises an act of receiving second non-standard data describing models of data center equipment from the third remote computing device.

According to one aspect of the present invention, a computer-implemented method for maintaining a data center equipment database is provided. The method comprises acts of receiving a set of configuration management data from each of a plurality of data centers, each set of configuration management data identifying one of the plurality data centers, a capacity for power of the identified data center, a capacity for cooling of the identified data center and at least one element of data center equipment disposed within the identified data center. According to one embodiment of the present invention, the acts of receiving include acts of receiving configuration management data including at least one of the group comprising data center physical dimensions, data center equipment location within the data center physical dimensions, data center power distribution provided to the data center equipment

location, data center cooling distribution provided to the data center equipment location, data center network connectivity provided to the data center equipment location, data center equipment manufacturer, and data center equipment model. According to another embodiment of the invention, the method further comprises acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers, each set of data center resource consumption and production data identifying one of the plurality of data centers and being associated with at least one element of data center equipment disposed within the identified data center.

According to one embodiment of the present invention, the acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers include acts of receiving data center resource consumption and production data including at least one from the group comprising data center equipment identity, data center equipment manufacturer, data center equipment model, data center equipment power plug type used, data center equipment number of plugs used, data center equipment power used, data center equipment airflow used, data center equipment network connectivity used, data center equipment weight support used, data center equipment cooling used, and data center equipment physical space used. According to another embodiment of the invention, the acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers include acts of receiving data center resource consumption and production data including at least one from the group comprising data center equipment identity, data center equipment manufacturer, data center equipment model, data center equipment power plug type provided, data center equipment number of plugs provided, data center equipment power provided, data center equipment airflow provided, data center equipment network connectivity provided, data center equipment weight support provided, data center equipment cooling provided, and data center equipment physical space provided.

According to one aspect of the present invention, a computer-implemented method for distributing data describing models of data center equipment is provided.

The method comprises acts of receiving, from a first remote computing device, a first group of the data describing models of data center equipment, the first group identifying models approved for use in a data center, receiving, from the first remote computing device, a second group of the data describing models of data center equipment, the second group identifying models preferred for use in the data center, and providing the second group to a second remote computing device. According to one embodiment of the present invention, the method further comprises acts of receiving, from an external entity, non-standard data describing models of data center equipment that are not approved for use in the data center, and providing the non-standard data to the first remote computing device.

According to one aspect of the present invention, a system for managing equipment data describing models of data center equipment is provided. The system comprises an input configured to receive data associated with the equipment data, an output configured to provide data associated with the equipment data, and a controller coupled to the input and the output and configured to allow an external entity to indicate that a first group of the equipment data describes standard models of data center equipment; to indicate that a second group of the equipment data describes models of data center equipment approved for use in a data center , to indicate that a third group of the equipment data describes models of data center equipment preferred for use in the data center and further configured to provide, via the output, the second group to a remote computing device located in the data center and to provide, via the output, the third group to the remote computing device located in the data center.

According to one aspect of the present invention, a system for managing equipment data describing models of data center equipment is provided. The system comprises a computer readable medium, an input configured to receive data associated with the equipment data, an output configured to provide data associated with the equipment data, and a controller coupled to the input, the output and the computer readable medium and configured to store, in the computer readable medium, an first indication that a first group of the equipment data describes models of data center equipment approved for use in a data center and to store a second indication

that a second group of equipment data describes models of data center equipment preferred for use in the data center and further configured to provide, via the output, the second group to a remote computing device located in the data center.

According to one aspect of the present invention, a system for maintaining a data center equipment database is provided. The system comprises an input configured to receive a set of configuration management data from each of a plurality of data centers, each set of configuration management data identifying one of the plurality data centers, a capacity for power of the identified data center, a capacity for cooling of the identified data center and at least one element of data center equipment disposed within the identified data center, and a controller coupled to the input and configured to store, in the data center equipment database, each set of configuration management data.

According to one aspect of the present invention, a computer-implemented method for managing a data center configuration is provided. The method comprises acts of receiving, from a user, a proposed change to the data center configuration though an interactive representation of a layout of an identified space in a data center, the proposed change including data identifying at least one element of data center equipment to be provisioned in the data center, the at least one element of data center equipment having a plurality of data center resource requirements, determining at least one location in the data center having a plurality of data center resources that satisfy the plurality of data center resource requirements of the at least one element of data center equipment, and storing the at least one location on a computer readable medium. According to one embodiment of the present invention, the act of receiving, from the user, the proposed change to the data center configuration includes an act of receiving data identifying at least one element of floor mounted data center equipment to be provisioned in the data center. According to another embodiment of the invention, the act of receiving, from the user, the proposed change includes an act of receiving, from the user, the proposed change to the data center configuration though an interactive representation of a layout of a data center room. According to another embodiment of the invention, the act of receiving, from the user, the proposed change

includes an act of receiving, from the user, the proposed change to the data center configuration though an interactive representation of a layout of a rack. According to another embodiment of the invention, the act of receiving, from the user, the proposed change to the data center configuration includes an act of receiving information regarding at least one element of data center equipment represented in the interactive representation.

According to one embodiment of the present invention, the act of receiving, from the user, the proposed change to the data center configuration includes an act of scanning a barcode. According to another embodiment of the invention, the act of determining the at least one location includes an act of determining at least one location in near real-time. According to another embodiment of the invention, the act of determining the at least one location includes an act of receiving, from an external entity, data identifying at least one location in the data center for the at least one element of data center equipment having a plurality of data center resources. According to another embodiment of the invention, the act of determining the at least one location includes an act of determining a location that minimizes, relative to at least one other location, an amount of excess data center resource capacity that is unusable due to insufficient associated capacity of at least one other data center resource, and the method further comprises providing the at least one location to an external entity. According to another embodiment of the invention, the act of providing the at least one location further includes an act of presenting the at least one location to a user of a computer system. According to another embodiment of the invention, the act of determining the at least one location includes an act of determining a series of locations arranged consecutively according to an amount of excess data center resource capacity that is unusable due to insufficient associated capacity of at least one other data center resource and the method further comprises providing the series of locations to an external entity.

According to one embodiment of the present invention, the act of providing the at least one location includes an act of presenting the series to a user of a computer system. According to another embodiment of the invention, the method further

comprises an act of presenting, to the user, information regarding the proposed change to the data center configuration, the information including a representation of at least one element of data center equipment that is disposed in a rack. According to another embodiment of the invention, the act of presenting, to the user, the information regarding the proposed change to the data center configuration includes an act of presenting, to the user, a representation of the at least one element of data center equipment as placed in inactive storage, and the method further includes an act of recording the at least one element of data center equipment as placed in inactive storage. According to another embodiment of the invention, the act of presenting, to the user, the information regarding the proposed change to the data center configuration includes an act of presenting, to the user, an interactive representation that is updated based on the proposed change. According to another embodiment of the invention, the act of presenting, to the user, the interactive representation that is updated based on the proposed change includes an act of presenting, to the user, the interactive representation updated in near real-time. According to another embodiment of the invention, the method further comprises generating a work order identifying a set of tasks required to complete the proposed change, and presenting the set of tasks via an output of a computer system. According to another embodiment of the invention, the method further comprises acts of detecting a change in the power demanded at power distribution device associated with the work order, and recording the work order as completed based on the change in power demanded. According to another embodiment of the invention, the method is performed using a remote computing device.

According to one aspect of the present invention, a computer-implemented method for managing a data center configuration is provided. The method comprises acts of receiving at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment, receiving a proposed change to the data center configuration, and determining a compliance result that indicates whether the data center configuration, including the proposed change, complies with the at least one policy. According to one embodiment of the

present invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a redundancy level. According to another embodiment of the invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a runtime requirement. According to another embodiment of the invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a security requirement. According to another embodiment of the invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of cooling. According to another embodiment of the invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of network connectivity. According to another embodiment of the invention, the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of power. According to another embodiment of the invention, the act of receiving the at least one policy identifying a requirement of power includes an act of receiving at least one policy identifying a requirement of power distribution.

According to one aspect of the present invention, a computer-implemented method for designing a data center is provided. The method comprises acts of receiving at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment, receiving data identifying at least one location in the data center for at least one element of data center equipment, the at least one location having a plurality of data center resources and the at least one element of data center equipment having a plurality of data center resource requirements, and determining at least one element of data center equipment that satisfies the policy when located at the at least one location, wherein the plurality of data center resources of the at least one location satisfy the plurality of data center resource requirements of the at least one element of data center equipment.

According to one aspect of the present invention, a system for managing a data center configuration comprising an input configured to receive, from a user, a proposed change to the data center configuration though an interactive representation

of a layout of an identified space in a data center, an output configured to provide a set of tasks to a user, and a controller coupled to the input and the output and configured to generate a work order identifying the set of tasks required to complete the proposed change and to provide the set of tasks to the output. According to one embodiment of the present invention, the system further comprises a computer readable medium coupled to the controller and wherein the input is further configured to receive status information associated with the work order and the controller is further configured to record the status information in the computer readable medium. According to another embodiment of the invention, the system further comprises an input configured to receive, from a user, status information associated with the work order and wherein the controller is further configured to provide the status information to the output.

According to one aspect of the present invention, a system for managing a data center configuration comprises a first input configured to receive at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment, a second input configured to receive a proposed change to the data center configuration, and a controller coupled to the first and second inputs and configured to determine a compliance result that indicates whether the data center configuration, including the proposed change, complies with the at least one policy.

According to one aspect of the present invention, a system for designing a data center is provided. The system comprises an first input configured to receive at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment, a second input configured to receive data identifying at least one location in the data center for at least one element of data center equipment, the at least one location having a plurality of data center resources and the at least one element of data center equipment having a plurality of data center resource requirements, and a controller coupled to the first and second inputs and configured to determine at least one element of data center equipment that satisfies the policy when located at the at least one location, wherein the plurality of data

center resources of the at least one location satisfy the plurality of data center resource requirements of the at least one element of data center equipment.

According to one aspect of the present invention, a remote computing device for navigating a representation of a data center is provided. The remote computing device comprises an interface configured to present, to a user, an interactive representation of a layout of an identified space in a data center and to receive, from the user, an identifier of at least one element of data center equipment located in the data center, a memory configured to store information regarding data center equipment represented by the interface, and a controller coupled to the interface and memory and configured to retrieve information regarding the identified at least one element of data center equipment from the memory and provide the information to the interface.

According to one aspect of the present invention, a computer-implemented method for managing data center resource redundancy is provided. The method comprises acts of determining a redundancy level of a data center resource at a location in a rack, and providing the redundancy level of the data center resource. According to one embodiment of the present invention, the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of cooling. According to another embodiment of the invention, the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of network connectivity. According to another embodiment of the invention, the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of power. According to another embodiment of the invention, the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of power distribution. According to another embodiment of the invention, the act of determining the redundancy level of the data center resource at a location in a rack includes an act of determining a redundancy level of a data center resource at a U space position. According to another embodiment of the invention, the act of providing the redundancy level includes an act of presenting, to a user of a

computer system, a representation of the at least one location in a rack. According to another embodiment of the invention, the act of presenting, to the user of the computer system, the representation of the at least one location in the rack includes an act of presenting, to a user of a computer system, a representation at least one U space position in a rack. According to another embodiment of the invention, the act of presenting, to the user of the computer system, the representation of the at least one location in the rack includes an act of presenting, to a user of a computer system, a representation of a redundancy relationship between elements disposed in a data center. According to another embodiment of the invention, the act of presenting, to the user of the computer system, a representation of a redundancy relationship between elements disposed in a data center includes an act of presenting, to a user of a computer system, a redundancy relationship between elements disposed in a rack.

According to one aspect of the present invention, a system for managing data center resource redundancy is provided. The system comprises a controller configured to determine the redundancy level of a data center resource at a location in a rack, and an output coupled to the controller and configured to provide a representation of the redundancy level of the data center resource. According to one embodiment of the present invention, the location in the rack includes a U space position in a rack. According to another embodiment of the invention, the system includes a remote computing device.

Further features and advantages of the present invention as well as the structure and operation of various embodiments of the present invention are described in detail below with reference to the accompanying drawings. In the drawings, like reference numerals indicate like or functionally similar elements. Additionally, the left-most one or two digits of a reference numeral identifies the drawing in which the reference numeral first appears.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings, are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various

figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings are not intended to be drawn to scale. In the drawings, each identical or nearly identical component that is illustrated in various figures is represented by a like numeral. For purposes of clarity, not every component may be labeled in every drawing. In the drawings:

FIG. 1 is a top view of a data center of the type with which embodiments of the present invention may be used;

FIG. 2 is a side view of the data center of FIG. 1.

FIG. 3 is a functional block diagram of a system in accordance with one embodiment of the present invention;

FIG. 4 is a flowchart of a process that may be implemented using the system of FIG. 3 in accordance with one embodiment of the invention;

FIG. 5 is a diagram showing facility information that can be displayed using at least one embodiment of the invention;

FIGS. 5A and 5B are diagrams showing additional information that can be displayed using embodiments of the invention;

FIGS. 5C and 5D show graphical user interface screens that exhibit various aspects of the present invention;

FIG. 6 is a functional block diagram of a management system in accordance with one embodiment of the invention;

FIG. 7 is a flow chart of a management process in accordance with one embodiment of the invention;

FIG. 8 shows a perspective view of a cluster of racks whose cooling performance can be analyzed using embodiments of the invention;

FIG. 9 shows a top view of a cluster of racks whose cooling performance can be analyzed using a control volume analysis technique of at least one embodiment;

FIG. 9A shows the cluster of racks of FIG. 9 along with staggered control volumes that may be used in the control volume analysis technique;

FIG. 10 is a flow chart of a control volume analysis technique in accordance with one embodiment of the invention;

FIG. 11 is a diagram demonstrating a principle of superposition used in one embodiment;

FIG. 12 is a graph used in determining airflows in one embodiment;

FIG. 13 is a diagram identifying airflows used with one analysis method of one embodiment;

FIG. 14 is a flow chart of a process for determining a recirculation index in one embodiment;

FIG. 15 is a schematic diagram showing a layout of equipment racks used in an analysis in one embodiment to determine a capture index;

FIG. 16 is a flowchart of a process for determining a capture index in accordance with one embodiment;

FIG. 17 is a functional block diagram of a computer system that may be used in embodiments of the invention;

FIG. 18 is a functional block diagram of a storage system that may be used with the computer system of FIG. 17;

FIG. 19 is a flowchart of a process that may be implemented using the system of FIG. 3 in accordance with one embodiment of the invention;

FIG. 20 shows graphical user interface screen that exhibits various aspects of the present invention;

FIG. 21 depicts another graphical user interface screens that exhibits various aspects of the present invention;

FIG. 22 illustrates another graphical user interface screen that exhibits various aspects of the present invention; and

FIG. 23 shows a representation used to analyze stranded capacity according to an aspect of the present invention.

DETAILED DESCRIPTION

This invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having," "containing," "involving," and variations thereof herein, is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

Embodiments of the present invention may be used to design, manage and retrofit a data center, such as data center 100 which is shown in FIGS. 1 and 2 with FIG. 1 showing a top view of the data center 100, and FIG. 2 showing a side view of the data center 100. As discussed further below, the design of the layout of the data center 100, including various data center resources such as power and cooling considerations may be performed using systems and processes of embodiments of the present invention. A data center resource may include, for example, any characteristic of a data center that supports and/or ensures data center equipment functionality. Examples of data center resources include power, cooling, physical space, weight support, remote equipment control capability, physical and logical security and physical and logical network connectivity. Power data center resources may include power distribution resources, such as transformers, PDUs and outlets, and power available for distribution, such as utility power supplied to the data center, power generated by an onsite generator and power supplied by UPSs. Physical space resources in a data center may include data center floor space and rack U space. Cooling resources in a data center may include cooling distribution capacity and cooling generation capacity. Physical security resources in a data center may include security cameras and door locks. Logical network connectivity resources in a data center may include Virtual Local Area Networks, Domain Name Services, and Dynamic Host Configuration Protocol Services. Physical network connectivity

resources may include network cabling and patch panels. Remote equipment control capability resources in a data center may include Keyboard Video Mouse services.

Embodiments of the invention, however, are not limited for use with data centers like that shown in FIGS. 1 and 2 and may be used with other facilities that do not include raised floors and may be used with facilities that house equipment other than computing equipment, including telecommunications facilities and other facilities. Further, embodiments of the invention may be used with raised floor and equipment layouts that are not neatly arranged in the manner shown in FIGS. 1 and 2. Embodiments of the present invention may use systems, devices and methods described in U.S. Patent Application No. 10/038,106, filed January 2, 2002, titled "Rack Power System and Method," incorporated herein in its entirety by reference.

The data center 100 includes rows of racks 102A, 102B, 102C and 102D, cooling units 104A and 104B, and a raised floor 106. Each of the rows includes racks 108, at least a number of which draw cool air from the front of the rack and return warm air to the rear or top or rear and top of the rack. Each rack may contain U space positions designed to house rack mounted data center equipment, such as, for example, servers, cooling equipment and network connectivity equipment.

As understood by those skilled in the art, to optimize cooling performance in a data center, rows of racks are often positioned to create alternating cold aisles and hot aisles. In the configuration shown in FIGS. 1 and 2, aisles 110A, 110B and 110C are hot aisles and aisles 112A and 112B are cold aisles. To provide cooling to the racks, in front of each of the racks in the cold aisle, perforated floor tiles 114 are used to provide cooling air from under the raised floor. In the data center 100, in addition to the perforated floor tiles shown, the raised floor may include solid floor tiles. The cooling units 104A and 104B are designed to provide cool air to the area under the raised floor and to receive return warm air from the space adjacent the ceiling of the data center. In other embodiments, in addition to or in place of the cooling units 104A and 104B, in-row cooling units, such as those available from American Power Conversion Corporation, may be used. Further, in at least one embodiment, half-rack in-row cooling units may be used, as described in co-pending U.S. Patent Application

Serial No. 11/335,901, entitled COOLING SYSTEM AND METHOD, Attorney Docket No. A2000-704819, by Neil Rasmussen et al., filed on January 19, 2006, and incorporated herein by reference. As described in the referenced application, the half-rack, in-row units have a width of twelve inches, which is approximately half of that of a standard data center rack.

One embodiment of the invention, directed to a system and a method for designing, monitoring, and upgrading the equipment installed in a data center, such as data center 100, will now be described with reference to FIG. 3. This equipment may include rack mounted equipment, such as servers, storage devices, and network connectivity equipment, and floor mounted equipment, such as three phase power distribution units and CRACs. FIG. 3 shows a functional block diagram of a design and management system 200. Embodiments of the invention are not limited to the functions provided by the functional blocks or the particular arrangement of the blocks. In addition, the functions provided by the system 200 need not be implemented on one computer system, but rather may be implemented using a number of networked devices as described further below that provide the functions described. Further, particular embodiments may have more or less functions and functional modules than those described below with reference to FIG. 3. In different embodiments, the functions described with reference to FIG. 3 may be performed on one processor or controller or may be distributed across a number of different devices.

The system 200 includes an input module 202, a display module 204, a builder module 206, a facility management module 208, an integration module 210, a database module 212, and a work order module 214. The input module 202 provides an interface to allow users to enter data into the system 200. The input module may include, for example, one of a number of known user input devices for computer systems, and in addition, in at least one embodiment, electronic data regarding a facility and/or equipment to be loaded into a facility may be entered into the system through a network interface or using an electronic media storage reader. Information may flow between these modules using any technique known in the art. Such techniques include passing the information over the network via TCP/IP, passing the

information between modules in memory and passing the information by writing to a file, database, or other storage entity, such as a storage device, disk or other type of storage entity.

The display module includes a display interface and may include a graphical display to display output data to a user. In addition, the display module may include an interface for one or more printers that provide a hard copy of output data.

The builder module 206 includes routines for designing optimal layout of equipment in a facility, determining data center resource requirements, such as power requirements and cooling requirements, for electronic enclosures and/or equipment racks, ensuring that the placement of equipment, cooling units and power distribution branches in the facility allow the data center resource requirements, such as power and cooling requirements, to be met, and calculating for each electronic enclosure, and/or equipment rack, the remaining data center resource capacity, such as power capacity and cooling capacity, available based on the layout of equipment in the facility.

In another embodiment, builder module 206 exposes interfaces that allow for entry of data center resource supply policies. These policies may detail additional desired characteristics of the data center resources as provided to data center equipment. For example, data center resource supply policies may specify desired data center resource redundancy levels and runtime requirements. Additionally, data center resource supply policies may specify security needs for data center equipment, such as, for example, the need to locate servers with financial data in racks that made be locked and/or under surveillance. As is discussed further below, both system and method embodiments may compare particular data center configurations to data center supply polices to determine whether the particular data center configuration complies with the data center policies. The result of this comparison may be stored on a computer readable medium for later use.

The facility management module 208 is used by the system 200 after equipment is installed in the facility. The management module includes routines to monitor data center resource characteristics, such as power and cooling

characteristics, of equipment in a facility. The management module may be coupled, either directly or through one or more networks, to measurement devices and control devices throughout the facility and may record their history for analysis, summarization and exportation. Based at least in part on methods discussed further below, the facility management module 208 may ascertain data center resources provided to a particular space or location in the data center.

According to one embodiment, the integration module 210 is the main module in the system and coordinates flow of data in the system to perform methods of embodiments of the present invention.

The database module is used to store data regarding various devices that may be used in a data center, such as servers, uninterruptible power supplies, power strips, network connectivity equipment (such as network cabling, hubs, routers, wireless routers, switches, patch panels, etc.), automatic transfer switches, power distribution units, air conditioning units, racks and any other data center equipment. The data stored may include data center resource supply policies for data center equipment. The data stored may also include data center resource consumption and production benchmarks for data center equipment such as physical parameters (e.g., dimensions/rack space requirements, power plug types, network cabling specifications, etc.) as well as power and cooling consumption data. In the case of data center equipment that provide data center resources such as network connectivity equipment, power supplies and air conditioning units, data center resource production benchmarks may include network connectivity, cooling and power output characteristics (e.g. total output capacity, number and type of connections/plugs available, etc.). It should be appreciated that benchmarks may indicate that certain data center equipment produce, and/or consume, data center resources. Examples of data center resource providing equipment include electrical generators and CRACs, among others. As described below, the database module may be used in embodiments of the invention to provide a complete bill of materials (BOM) for a completed design. In one embodiment, a centralized web-accessible database server

may be used to store equipment information and warnings and error messages, allowing easy access to the information for editing.

In another embodiment, a user may maintain data center equipment information, such as the information handled by database module 212, with the assistance of system 300. System 300 is also depicted in functional block diagram FIG. 3. System 300, which may be hosted by the system provider, includes data center equipment database 304 and data center equipment database interface 302. In general, interface 302 may be an interface to database 304 that may receive or provide any data appropriate for storage in database 304 including data center configuration, equipment or resource information. Database 304, in turn, may receive and store from interface 302 or retrieve and provide to interface 302 data center information including data center equipment resource requirements, data center configurations and data center resource redundancy and runtime requirements.

Database 304 may serve as a master database for the system provider and thus may include several types of information related to data centers. In one embodiment, database 304 includes a data center configuration management database (CMDB), which may encompass various configuration management data including one or more specific data center physical and logical configurations, and a data center equipment characteristics database, which may include theoretical and actual data center resource production and consumption information for data center equipment. More particularly, database 304 may accept and store specific CMDB information for the system provider's installed base of data centers or a subset thereof. This information may include the entire physical layout of a data center, e.g. its physical dimensions, the location and identity of data center equipment, and data center resource capacity, redundancy and runtime requirements, among other information that may have relevance to the design and performance of a data center. The source of this information may include the initial design on the data center as discussed with regard to method 300 below.

The type of information stored by database 304 for data center equipment characteristics may include the information discussed above with regard to database

module 212, e.g. nameplate values as referred to in the art. Additionally, database 304 may also store data center resource consumption and production history for data center equipment and may use this information to maintain a set of benchmarks that are specific to the manufacturer and model of data center equipment. These specific historical measurements may be summarized into various forms to establish a benchmark that is specific to the manufacturer and model of data center equipment and that is based on actual, practical usage of the data center equipment rather than theoretical values (e.g. nameplate values). These data center resource consumption and production summaries may include, among others, minimum, maximum and average data center resource consumption or production, data center resource consumption or production as a function of time, e.g. power or cooling consumption or production by day of week, week of year, etc., actual data center resource consumption or production when a change in either is requested, and data center resource consumption or production as a function of data center equipment utilization. The source of this information may include the initial design on the data center, including customer or system provider entered benchmarks, and ongoing parameter measurement as discussed with regard to method 300 below. According to one aspect, it is appreciated that these benchmarks, in turn, may be more accurate than the nameplate values and may be used for simulation purposes during the design and retrofitting processes discussed below.

Interface 302 may expose both user interfaces (UIs) and system interfaces to exchange database 304 information with external entities. These external entities may include systems and/or users. Interface 302 may both restrict input to a predefined information domain and validate any information entered prior to using the information or supplying the information to other modules. For instance, in one embodiment, interface 302 may include a Structured Query Language (SQL) interface to enable a user or application program to interrogate database 304. This SQL interface may include graphical elements that a user may actuate to build SQL statements and may also include elements that enable a user to simply input SQL statement directly.

In other embodiments, interface 302 may include more complex grouping, translation, validation and/or restriction logic. For instance, interface 302 may validate that a SQL statement entered by a user conforms to proper SQL syntax prior to executing it against database 304. In one embodiment, interface 302 may expose a UI with characteristics similar to those of builder module 206 to enable users to create database information representing various data center configurations. In another example, interface 302 may expose a user interface allowing a user to enter new data center equipment resource information, including manufacturer, model and data center resource consumption and production benchmarks. Interface 302 may restrict entry of resource consumption and production benchmarks to predefined data center resources, such as power, cooling, physical space, etc. In still another embodiment, a user may establish groups of data center equipment through interface 302 and approve these equipment groups for use within a set of data centers or upon certain types of computing devices, such as remote or mobile computing devices. Furthermore, interface 302 may enable a user to designate a hierarchical relationship between groups of equipment. As discussed further in regard to method 300 below, arrangement of this information into a hierarchy of groups may ease database maintenance and distribution.

In one embodiment, interface 302 may expose a system interface that imports data center configuration and measured parameter information from a system provider's installed base of data centers or data center equipment providers. Interface 302 may utilize a standard protocol, such as, for example, SQL or SQL wrapped in SOAP, to implement such a system interface and may include non-standard protocol elements that are parsed and resolved to commands to be executed by database 304. Interface 302 may validate database commands prior to execution on database 304. Any customer specific data center equipment, e.g. data center equipment entered by a customer that is not present in the database 304, may be imported into database 304 by interface 302 if any applicable validation is successful. Similarly, equipment not present in database 304 that is made available by data center equipment providers may be imported into database 304 by interface 302 if any applicable validation is

successful. These features enable system 300 to easily add new data center equipment to its set of managed elements.

Furthermore, importation of measure parameters may trigger a parameter summarization process that updates data center equipment resource consumption and production benchmarks to reflect actual usage history. The summarization process may include updating, among others, minimum, maximum and average power consumed or produced benchmarks, benchmarks for power consumption or production as a function of time, e.g. power consumed or produced by day of week, week of year, etc., benchmarks for power actually consumed or produced when a change in either is requested, and/or benchmarks for power consumed or produced as a function of data center equipment utilization.

In still another embodiment, interface 302 may expose a system interface that exports data center equipment information, or catalogs, to external storage. This external storage may reside at various locations on various computing devices. Furthermore, as discussed below, the particular information that is exported to these locations and computing devices may be relegated to specific groups of data center equipment.

It should be appreciated that in at least one embodiment, the functionality of system 300 may be included in database module 212 of system 200.

In yet another embodiment, the work order module 214 may enable management of changes to the configuration of the data center, such as those resulting from a data center retrofit process as discussed below with regard to process 600. In general, work order module 214 analyzes any changes made to the data center configuration by the other modules in system 200. Then work order module 214 generates a set of tasks that, once complete, will implement those changes. Next, work order module 214 translates the set of tasks to a set of work orders in human-readable form. Lastly, work order module 214 facilitates tracking of those work orders to completion. To accomplish these objectives, work order module 214 may expose various UIs and system interfaces to enable communication and interoperation with external entities.

In one embodiment, work order module 214 exposes a system interface through which integration module 210 may supply any changes made to the data center configuration. Work order module 214 may also expose a user interface including elements that enable a user, such as a data center manager, to modify and dispatch work orders to other users, such as technicians, for implementation. Work order module 214 may also expose a user interface to enable a user to configure a set of automatic dispatching rules. Further, work order module 214 may expose other user interfaces that enable users, such as technicians, to modify the details, including status information, of work orders. These user interfaces may reside on various computing devices, including remote or mobile computing devices.

Implementing such a user interface on a remote or mobile computing device may allow users, such as technicians, to update the CMDB of the data center as configuration changes are made. This may produce several benefits including increased accuracy of the CMDB, due to the increased compliance with, and promptness of, configuration change updates. Another benefit may be increased productivity for users, such as technicians, because configuration changes may be entered while working on data center equipment, rather than entering changes at a workstation as a separate activity.

Work order module 214 may also implement modification and assignment system interfaces to interoperate with other systems. For example, work order module 214 may, through a system interface, utilize an external email system to notify users of a work order assignments. Lastly, work order module 214 may utilize a system interface that enables it to detect changes in data center resource demands and may use this information, when appropriate, to modify the status information of a work order.

A flow chart of a method 300 in accordance with one embodiment that may be performed using the system 200 will now be described with reference to FIG. 4. Initially, and optionally, at stage 301 of the method 300, a user may create groups of data describing data center equipment. These groups may enable management of multiple types and/or models of data center equipment as a single collective entity.

For example, inclusion of data describing data center equipment in a group may designate such equipment as approved for use within all of the data centers owned by a customer or specific subsets thereof. Any data center equipment approved for use within a data center may be used during the design or retrofit of the data center.

Moreover, the user may arrange these groups in a hierarchical fashion. In one embodiment, a first group is created that includes all of the data center equipment supported by the system, a second group is created that is a subset of the first group and that designates equipment that is approved for use within the data centers of a particular customer, and a third group is created that is a subset of the second group and that designates equipment that is preferred for use within a particular customer data center. In one embodiment, a user may target specific groups for exportation to specific customers, customer data centers or specific computing devices within a customer data center, such as remote or mobile computing devices.

Fashioning groups of equipment data may ease maintenance and distribution of electronic data center equipment catalogs, which may include data describing characteristics of data center equipment. For example, specific inclusion of data center equipment data in a group that is lower in the hierarchy, e.g. a group designated for distribution to a remote or mobile computing device within a specific data center, may require that the data be present in ancestor groups. This inclusion may be performed automatically by the system. These groups may also be employed to enforce standardization of data center equipment within the customer organizational hierarchy by requiring that equipment be approved for use by the customer before it is allowed to be used to retrofit a specific customer data center.

In another embodiment, the system provider may create a group of data describing standard data center equipment. A group of the standard data center equipment data may be approved for use in customer data centers. An equipment catalog including data associated with the standard and/or approved data center equipment may be delivered with the initial system installation in a data center. The standard and/or approved equipment data may then be supplemented with customer

specific, non-standard equipment data used in a customer data center, as discussed with regard to stage 304 below.

Approved equipment may be further grouped into a preferred set for use with one or more customer data centers. The creation of these preferred groups may be explicitly performed by the user or may be implicitly performed by the system based on usage of specific equipment by a customer or within a customer data center during data center design or retrofit.

In stage 302 of the method 300, information regarding the facility is loaded into the system. The information includes, for example, dimensions of the facility, number of rooms, locations of doors, support columns, other obstructions, parameters of data center resource capabilities, such as available power, cooling capabilities of the facility, whether a raised floor or drop ceiling is in use, and characteristics of any such floor and roof. Data center resource supply policies may also be entered in this stage. For data center resource providing equipment, such as electrical generators or CRACs, capability information may be loaded by receiving data center equipment information from interface 302 of system 300. Thus, this stage of method 300 collects information helpful in determining the data center resources provided to particular data center locations and spaces. In at least one embodiment, as discussed further below with regard to cooling, this information may be further processed to determine the data center resources provided to particular data center locations and spaces.

In stage 304 of the method, information regarding equipment to be installed in the facility is entered. The information includes, for example, the number of racks of equipment, maximum power draw for each of the racks, dimensions of the racks, and cooling requirements for the racks. The need for backup power sources and multiple power sources for equipment and or racks may also be entered at stage 304. In one embodiment, data center resource consumption and production characteristics of individual pieces of equipment that are to be loaded into racks may also be entered. Also, the weight of equipment (including equipment loaded into racks) may be used to ensure that the weight of the installed equipment is within any facility constraints.

These characteristics may include, in addition to network connectivity, power and cooling requirements, the amount of rack space that the equipment needs to occupy and the type and/or number of electrical plugs that the equipment requires. In one embodiment, the database module 212 contains information regarding a number of devices, such as uninterruptible power supplies, equipment racks, cooling units, generator systems, power distribution units, automatic transfer switches, electrical routing devices, including cables, and servers and other computer equipment. In this embodiment, when a particular model number of a device is entered, characteristics of the device are retrieved from the database module. In one embodiment, interface 302 of system 300 provides these device/equipment characteristics to database module 212. Equipment related to fire protection and security may also be included in the design. Further, in at least one version, all equipment and components within equipment racks may include RFID tags, which can be used by systems of the invention to track location of equipment and racks. In another embodiment, any data center equipment characteristics that are added or changed by a user at this or the previous stage may be transmitted to interface 302 of system 300 for importation into database 304.

Once all of the information is entered into the system, at stage 306, the system in one embodiment determines a layout for the equipment in the facility, taking into account the data center resource requirements, such as power and cooling requirements, of the equipment as well as other characteristics of the equipment that were entered at stage 304 or retrieved from the database module. In another embodiment, the user may create the layout graphically, adding racks and other equipment where desired, and in this embodiment, the system will provide feedback during the layout process, disallowing some choices and making intelligent suggestions. These rules may include, for example: a standard alternating hot aisle/cold aisle layout must be specified, the plenum must be greater than some minimum value, the total room cooling capacity must exceed total room cooling load, aisles must be wide enough for access purposes and to meet building codes, distance between PDU and IT racks served by the PDU must not exceed some maximum

value, PDU must be located immediately adjacent to a UPS, where a cable ladder spans an aisle, the aisle cannot exceed a maximum width, one or more data center resource capacities must be at a level sufficient to support target data center resource redundancy and/or runtime requirements, etc.

Next, at stage 308, a cooling analysis is conducted to determine if the design provides adequate cooling for each of the racks and the equipment installed in the racks. As described further below, in different embodiments of the present invention one of a number of different methods may be used to conduct the cooling analysis. In one embodiment, if the results of the cooling analysis indicate that one or more devices and/or racks are not receiving adequate cool air, then the procedure may return to stage 306 to change the layout of the equipment based on feedback provided from the analysis conducted at stage 308.

At the completion of the cooling analysis, at stage 310, a room model is displayed showing the locations of the equipment in one or more rooms of the facility. The room model may include, for each equipment rack, or for individual data center equipment, information regarding the total data center resources, such as power and cooling, being consumed or produced as well as an indication of total available data center resources, such as power and cooling, to the rack or data center equipment. In one embodiment actual data center resource data, such as power and cooling data, may be displayed, while in other embodiments colors may be used, either alone or in combination with data, to display different levels of data center resource availability, such as power and cooling availability. For example, if a rack is operating with sufficient cooling air with a margin above a threshold, the rack may be indicated in green on the display, if the cooling air availability is closer to the threshold, the rack may be indicated in yellow, and if the rack does not have sufficient cooling air it may be indicated in red. Still further, the results of the analysis may indicate that adequate data center resources, such as power and/or cooling, are being provided for equipment, but that specified redundancy levels and/or runtime margins are not being met, either at the room level, a row level, a rack level, or at a specific piece/element of data center equipment.

In one embodiment, the system may display multiple room models and may allow the user to find one or a series of alternate satisfactory locations for the equipment based on the data center resource requirements of the equipment and any applicable redundancy and/or runtime requirements. Another embodiment may allow the user to find an optimum location followed by a series of alternate satisfactory locations for the equipment. Each series of locations may be arranged consecutively according to an order of preference, such as in order of decreasing excess or stranded capacity. As discussed further below, stranded capacity includes excess capacity that is nominally available, but unusable, due to insufficient associated capacity of another data center resource required by data center equipment.

Yet another embodiment may allow the user to specify both the data center equipment and location and may validate whether the location provides sufficient data center resources to satisfy the requirements of the equipment and any applicable data center supply policies. This validation may be performed by comparing the data center resources provided to the location, the data center requirements of the equipment and any applicable data center resource supply policies. The result of this comparison, a compliance result, may be stored for later use. In still another embodiment, the system may suggest data center equipment to be placed at a user specified location. In this case, the system may ensure that applicable data center resource supply policies, and data center resource requirements of the suggested equipment, are met by comparing the polices, the data center resources provided to the location and the data center resource requirements of the equipment prior to suggesting the equipment based on a compliance result. Specific example details regarding the room model are described further below with reference to FIGS. 5 through 5D.

At decision block 312, a determination may be made by, for example, a facility designer as to whether the layout generated in stage 310 is satisfactory. The determination may be based on additional criteria of importance to the designer that was not included during the design of the original layout. For example, it may be desirable to have certain racks near each other or to have certain racks isolated from

one another. At stage 314, additional criteria or other feedback can be provided and the process then returns to stages 306 and 308 where the room model can be refined. Stages 306 to 312 may be repeated until a satisfactory model is achieved at stage 312. In at least one embodiment, at the completion of the design stage, a bill of materials is generated and may be used to provide the cost of the equipment to be installed in the facility and may also be used to generate a sales order for the equipment, providing a simple solution for ordering all equipment associated with a new data center. Further, CAD drawings and electronic files that capture the designed layout may also be generated. In another embodiment, this data center configuration is transmitted to interface 302 of system 300 for storage in database 304 in the form of a CMDB for the installed data center.

At stage 316, the equipment is installed in the facility according to the layout generated at stages 306 to 314. In one embodiment, measurement equipment to measure cooling characteristics and power characteristics, may be installed with the equipment. The measurement equipment is described further below, and may include, for example, devices for measuring power, airflow, humidity and temperature at various locations in the facility and within equipment racks located in the facility.

At stage 318 of the process 300, power and cooling parameters are measured using the measurement equipment. Additional temperature measurements may also be provided by devices, such as servers, that have the capability to detect internal temperatures. The parameters measured may be used continuously by the management module of the system 200 to detect error conditions and to monitor trends that may lead to an error condition. Further, in the process 300, the measured parameters can be compared with predicted parameters calculated during the design process in stages 306 and 308. For example, in one embodiment, the airflow through a perforated floor tile of a raised floor is used to determine the available cooling air of a rack located adjacent the floor tile. The airflow through the perforated tile may be determined in stage 308 using one of a number of computational methods that are described further below, or the airflow may be determined using data from related physical measurements or simulations. Once the equipment is installed in the facility,

the perforated floor tile may be instrumented to measure the actual airflow through the tile. The actual measured value may then be compared with the calculated value at stage 320. If the two differ by more than a predetermined threshold, then an indication or warning may be provided and the calculations conducted in stage 308 may be conducted once again at stage 322 using measured values in place of calculated values as appropriate to obtain updated parameters. In another embodiment, measured parameters are transmitted to interface 302 of system 300 for storage in database 304. As discussed above, the storage of these measure parameters by interface 302 may trigger further analysis and summarization of the measure parameters into data center equipment consumption and production benchmarks.

After stage 322, the model of the facility described above with reference to stage 310 may be displayed with values of power and cooling availability and consumption updated to reflect any differences between measured parameters and calculated parameters. Any out of tolerance conditions (for either cooling or power) may be indicated on the display using, for example, a color coded scheme as described above. In one embodiment, a user may be provided with a number of available options to correct an out of tolerance condition. The options may include upgrading or adding facility equipment (i.e., an air conditioning unit or an uninterruptible power supply) or may include moving equipment and/or racks. Stages 318 to 322 of the process may be performed continuously as part of a management system of the data facility.

In one embodiment of the invention, stages 302 to 314 of the process 300 are implemented using a build-out system accessible by a user over the Internet. In this embodiment, the user provides the requested information, and the build-out system provides the processing described above, provides outputs to the user over the Internet, and stores results locally. After the equipment has been installed in the facility, the management system 500 (described below) may access the build-out system to download information related to the equipment. In addition, when a retrofit of the facility is to occur, the management system may contact the build-out system to coordinate the design of the retrofit. In at least one embodiment, electronic files may

be imported/exported between the systems to provide a complete transfer of all information related to a data center's design.

FIG. 5 shows an example of a display of a room model that may be generated using the system 200 and the process 300 and shown on a computer display. It should be appreciated that this computer display may be any be coupled to, or included in, any sort of computing device including a remote or mobile computing device. The room model shown in FIG. 5 is essentially the data center 100 previously discussed above with reference to FIGS. 1 and 2. However, in FIG. 5, additional data related to the power and cooling consumption and capacity of each rack, U space positions, and/or elements of data center equipment housed within each rack may be included in an informational block, such as informational blocks 120A and 120B shown on two of the racks 108A and 108B in FIG. 5. Informational blocks may be included on data center equipment, each rack, or on less than all racks, for example, by row, zone, or cluster.

FIGS. 5A and 5B show enlarged views of respectively racks 108A and 108B that may also be shown on a computer display of systems of embodiments of the invention. In the views of FIGS. 5A and 5B, specific information regarding the racks and U space positions is included in the informational block. In the embodiment shown, the information in the block includes a rack identifier 122, a rack type 124, power capacity 126, power usage 128, cooling capacity 130, cooling usage 132, contents of the rack 134, power redundancy 136, cooling redundancy 138, and UPS runtime 140. In other embodiments, such as the embodiment depicted in FIG. 20 discussed below, information for each rack may be included in tabular form, or in the form of columnar bars, on a graphical display showing the room layout. Data center information that may be displayed includes runtime measurements, data center resource redundancy measurements, including relationships between data center equipment working in combination to providing redundancy, and capacity measurements, such as available capacity, utilized capacity, and stranded capacity.

The rack identifier 122 includes a row number and a rack number, however, in other embodiments, the rack identifier may also include an indicator of the type of

rack, membership of the rack to a particular row, zone, group, or cluster, manufacturer of the rack, as well as other information. The rack type 124 identifies the particular type of rack, i.e., server rack, router rack or telecommunications rack. The power capacity 126 indicates the maximum power capacity of the rack, and the power usage indicator 128 indicates the percentage of maximum capacity at which the rack is expected to operate. In different embodiments, the power usage indicator may be calculated based on manufacturer supplied data for equipment contained in the rack and/or based on actual power measurements of equipment. The power capacity for a rack, in at least one embodiment, is determined based on limitations of devices and/or power cables that supply power to the rack, such as circuit breakers, UPSs or any other devices. The contents of the rack 134 includes a list of the equipment contained in the rack and may include an indication of remaining space in the rack displayed, for example, in terms of rack units, which are typically referred to as "U" with 1U equal to 1.75 inches. Details regarding the equipment in the rack, including operational status and network addresses, such as an IP address for a device may also be included.

The cooling capacity indicator 130 and cooling usage indicator 132 identify respectively the quantity of cooling air available to the rack and the percentage of that cooling air that is being used by equipment in the rack. In other embodiments power and cooling usage may be indicated using various types of graphical gauges, such as a bar graph, that indicates power and cooling usage and capacity. In the embodiment shown in FIGS. 5A and 5B, the cooling capacity is shown in terms of kilowatts (kW). As known to those skilled in the art, for typical data center applications, many equipment racks typically require approximately 160 cfm (cubic feet per minute) of cooling air per kilowatt of power used by the rack. All the power consumed by computing type devices is typically converted to heat, such that the required cooling (in terms of kW) for a rack can be assumed to be equal to the power consumption of the rack. Accordingly, in one embodiment, the cooling usage indicator is equal to the power consumed by the rack. In other embodiments, depending on the type of equipment that is installed in the racks, the cooling required by a rack may not be

equal to that consumed by the rack and may be calculated based on manufacturer's data for the equipment, based on test results, or in any other manner.

The cooling capacity of an equipment rack is determined based on a number of different factors. For example, for a raised-floor environment, these factors may include: location of the rack in the facility, proximity of perforated tiles to the rack, the amount and temperature of cooling air provided through any such perforated tile, the physical or geometric layout of the racks and building, and the cooling requirements of other equipment in the facility located near the rack. The cooling capacity of one rack in a facility may be affected by the cooling usage of nearby racks, and accordingly, in one embodiment, the cooling capacity of a rack is adjusted when the cooling usage of a nearby rack is changed. In at least one embodiment of the present invention, calculations for determining cooling capacity of a rack are based in part on the ability of one rack to borrow cooling air available to adjacent racks. Particular methods for determining cooling capacity for racks in embodiments of the present invention are described further below. In one embodiment, when the cooling usage of one rack is changed, the cooling capacity of that rack, and all racks located near the changed rack is recalculated.

In embodiments of the present invention, during the design as well as during the management of a data center, the true available capacity of a data center can be determined at U space position level, the rack level, at the row level and at the room level. In determining available capacity (including unused capacity), data center resources including both cooling and power capacity are used, and the true available capacity can be determined using the lowest data center resource capacity. In situations where data center resource capacities are not equal, the excess capacity can be considered wasted or stranded capacity that can not be used in the present design. In other words, while stranded capacity is nominally available, it is unusable due to insufficient associated capacity. In embodiments of the present invention, the stranded capacity can be determined at the U space position level or rack level and can be totaled to determine stranded capacity at the row level and at the room level.

In one embodiment, as depicted in FIG. 21, this data resource information may be displayed to the user in the form of graphs. For example, FIG 21 depicts total capacity 2102, space capacity 2104, cooling capacity 2106 and power capacity 2108, each as a function of time. Each of these representations may include total data center capacity specific to the data center resource shown. In addition, the representations may include data center capacity specific to a specific location in the data center, e.g. high density or medium density racks. Still further, these capacities may be projected into the future to enable a user, such as a data center manager, to predict when capacity may need expansion.

FIG. 23 illustrates an embodiment that a user, such as a data center manager, may reference to assess stranded data center capacity and ascertain the root cause of the stranded capacity. More specifically, FIG. 23 depicts report 2302 which includes rows and columns under various data center resource headings. The intersection of these rows and columns may indicate how much excess capacity of the data resource listed in column 2304 is unusable due to insufficient capacity of the data resource listed in row 2306. For example, intersection 2308 may indicate that 20% of the weight support capacity of the data center is unusable due to insufficient power capacity. In another embodiment, the actual amount of stranded capacity may be used to articulate these relationships and the meaning ascribed to the rows and columns may be transposed. As will be apparent to one of ordinary skill in the art, other embodiments illustrating this relationship are possible without departing from the present invention.

Recommendations are provided for reducing stranded capacity during the design phase as well as during the management phase. The recommendations may include reducing capacity of data center resources, such as power and cooling resources, (thereby reducing operational costs) or adding data center resource capacity, such as cooling capacity or power capacity, appropriately to reduce the stranded capacity. Warnings may be generated when the stranded capacity is greater than preset thresholds, and in addition, recommendations for more optimal locations of equipment, including power and cooling equipment, may also be provided to

minimize the amount of stranded capacity. Further, costs of the stranded capacity may be calculated.

In management systems and methods of embodiments of the invention, as described above, data center resource capacity and availability, such as power and cooling capacity and availability, may be monitored in real time. In one version, changes to the availability rate (or the utilization rate) are monitored and based on these changes, the growth rate of a data center may be determined, and predictions of dates when additional capacity will be required can be provided. In one embodiment the forecasting method used to make these determinations is linear regression. Other forecasting methods are possible without departing from the scope of the present invention. The ability to monitor capacity and predict future capacity needs allows data center operators to control costs and plan for upcoming expenses. Further, determinations may be made as to the additional expenses that will be incurred if new equipment is added. The total cost (for example per kilowatt) can also be determined during the design phase or during operation.

In embodiments of the invention described herein, data center layouts may be designed to provide specific redundancy levels (i.e., n, n+1 or 2n) for data center resource design, such as both the power design and the cooling design. In data centers in the past, additional room cooling units are typically provided to include some redundancy in a data center, such that an overall cooling capacity of the data center can be maintained, even when one or more of the room cooling units fails or must be powered down to conduct maintenance. One problem with these past solutions is that the cooling redundancy is designed at the room level and not the rack level, and while overall cooling capacity may meet redundancy requirements, cooling at the rack level may not meet the desired redundancy requirements. In embodiments described herein, the ability to provide accurate airflow data at the rack level and U space position level allows true cooling redundancy to be designed into a solution.

As discussed above, graphical user interfaces may be used with embodiments of the present invention to assist in the design and management of data centers. In one embodiment, these graphical user interfaces may be used to present an interactive

representation of a layout of a various spaces in the data center. In another embodiment, interactive representations may be tailored to particular spaces within the data center, such as the entire data center, data center floors, rooms, racks and U spaces. Further these interfaces may be displayed on a local or remote computing device. Remote computing devices may include general computer systems, mobile computing devices and computing devices that are included with, embedded in, or affixed to, another physical structure or device, such as a wall, ceiling, another computer system or an enclosure, e.g. a rack enclosure, etc.

For example, particular user interface screens used in one embodiment to design a layout in a data center will now be described further with reference to FIGS. 5C and 5D. FIG. 5C shows a floor editor interface 402 used in one embodiment to layout equipment in a data center, while FIG. 5D shows a rack editor interface 404 used in one embodiment to provide further details of the contents of equipment in the data center. In one embodiment of a data center design system, tutorials are provided for a user to assist the user by providing best practice design guidelines. The tutorials may be accessed by a user as desired or may be configured to be displayed as a user is taking a particular action.

The floor editor interface includes a main menu 403, a tool bar 406, a configuration box 408, a generic components box 410, a floor layout box 412, a status box 414 a full-image viewing box 416, and an unplaced equipment box 418. The main menu 403 provides a drop-down menu in a format known to those skilled in the art, and allows a user to perform various functions, including the ability to "undo" and/or "redo" changes that are made to the layout. The tool bar 406 provides short hand access to functions of the design system, and in one embodiment includes a floor editor button 406A and a rack editor button 406B. Activation of the floor editor button results in the display of the screen shown in FIG. 5C, while activation of the rack editor button results in display of the screen shown in FIG. 5D.

The floor editor box 412 shows the layout of equipment in a data center being designed and provides text that identifies the equipment contained in the layout. A room perimeter 412A shows the exterior walls of the room along with dimensions of

the room that can be set by a user. In one embodiment, when a new design is started, the user is presented with a screen showing a number of basic room configurations that can be selected. Further, the walls of the room can be moved by a user by selecting one of buttons 412B, and additional buttons can be added where needed to expand or shrink an area of the room. In one embodiment, the room size may be changed as equipment is added to the layout. Three rows 412C, 412D and 412E are outlined in the room shown in FIG. 5C. In other embodiments, more or less rows may be included. As shown in FIG. 5C, the rows are configured in a manner to provide alternating hot and cold aisles. Row 412D includes three equipment racks (identified by "R"), two half-rack cooling units (identified by "C") a UPS ("U") and a power distribution unit ("P"). Row 412E includes one rack, and row 412C as presently configured does not include any equipment. During the design phase additional equipment may be added to each of the rows. The room also includes an automatic transfer switch (ATS) 412G and a cooling distribution unit (CDU) 412F. Hatched areas are shown on the display around the ATS and CDU to indicate that these areas should be kept clear of equipment. Each piece of equipment in the room may include identifiers that indicate the type of rack as well as the rack's location in the room and the power source for the rack. Further, as discussed above, each rack may include information regarding data center resource use and availability, such as power and cooling use and availability. Still further, text may be provided on each row to indicate total data center resource information, such as power and cooling information for each row.

The configuration box 408 includes eight configuration options for designing a data center. A room properties configuration option, when selected, allows a user to identify data center resource values, such as physical, power, and cooling values, that affect the data center design as a whole including dimensions of the room, aisle widths and total anticipated power density for the data center. Data center resource redundancy and/or runtime requirements, such as power redundancy requirements (i.e. N, N+1, 2N), cooling redundancy requirements and runtime requirements for UPS systems may also be set. The number of data troughs that will be used and

location of power distribution and cooling line distribution (i.e. overhead or under a raised floor) can also be configured. In one embodiment, only in-row cooling is provided, however, in other embodiments other types of cooling solutions may be used as well. In at least one embodiment, individual rows may be rotated to different angles in the data center. Further, while only one room is shown in FIG. 5C, at least one embodiment allows a data center to include multiple rooms. These rooms may be active rooms, which hold active data center equipment, and inactive rooms for storage of spare or decommissioned equipment.

An add rack configuration option in the configurations box 408 is used to add equipment racks to the data center design. When this option is selected, a user is presented with choices of various types of racks to add to the data center. When racks are selected, an indicator is provided in the unplaced equipment box 418, indicating that the racks still need to be placed into the room layout.

An add in-row cooling option in the configuration box is used to add in-row cooling units to the data center design. When this option is selected, a user is presented with various types of cooling units that can be added in the rows. As with equipment racks, when a cooling unit is selected, an indicator is provided in the unplaced equipment box 418, indicating that the cooling unit still needs to be placed in the room layout.

A power zone option in the configuration box is used to identify and select PDUs and UPSs and to indicate which equipment will be powered from the UPSs and PDUs. Characteristics of the PDUs and UPSs may also be selected. Once selected, an indicator is provided in the unplaced equipment box 418 for the UPSs and PDUs. In one embodiment, multiple racks may be included in a selection on the layout to identify the equipment that belongs to a particular power group, also known as power zone. In still another embodiment, after selection of equipment and UPSs and PDUs, an automatic power zone option may be implemented in which the system matches equipment power requirements (i.e., redundancy levels, runtime durations, voltages, phasing) to those of the UPSs and PDUs and assigns power zones automatically and determines lengths of power cables that are needed to power equipment from the

assigned PDU. In automatically determining power zones, the system may also identify the need for additional UPSs and PDUs.

A power generation option in the configuration box 408 is used to identify and select an automatic transfer switch (ATS) and generator. Again, once these are selected, an indicator is provided in the unplaced equipment box 418.

An emergency power off option in the configuration box is used to select an emergency power off (EPO) solution for the data center design, and once selected, an indicator for the EPO solution will be added in the unplaced equipment box.

A management option in the configuration box 408 allows a data center manager, such as the InfrastruXure® Manager and/or InfrastruXure® Central discussed above, to be added. In one embodiment, when selecting the manager, a rack location for the manager is also selected.

A service option in the configuration box 408 allows a user to select a level of service to be provided to the data center by a data center services organization.

Other configuration options may include a row planning configurator that allows a user to plan how many racks a row can support by defining the power and cooling settings for the row, prior to placing equipment in a row. In one embodiment, the row planning configurator may provide an estimate on the number of racks that can be supported based on the power components and in-row cooling units contained in the row. In one embodiment, the row planning configurator may provide a complete layout based on design best practices.

The generic components box 410 includes a number of icons to designate pre-existing equipment in a data center. The components may be selected and "dragged" into position in the layout. In one embodiment, the generic components include blocks and gaps. The gaps can be used to identify areas over which cables and conduits can be routed (i.e. a walkway), while the blocks are used to identify areas over which cables and conduits can not be routed (i.e. a column). Once dragged onto the layout, the blocks and gaps can be sized appropriately.

As discussed above, when equipment is selected for use in the data center, an icon appears in the unplaced equipment box 418. To place the equipment in the

layout, the icon is selected and dragged into the appropriate location in the layout. Existing equipment may be repositioned using this same method. For example, existing equipment may be dragged from an active room and dropped in an inactive storage room, thus enabling the system to track unutilized equipment available for provisioning elsewhere. In one embodiment, when adding an in-row cooling unit, the icon for the cooling unit can be placed between two adjacent racks and released, and the racks will then move in the row to allow the cooling unit to be inserted between the racks. Further, in one embodiment, a snap-to feature is employed to align equipment properly in rows and along walls, and in addition, rows and equipment may be aligned along and "snapped to" floor tiles when, for example, a raised floor is in use. Using this feature, a user does not need to precisely align objects.

The full-image viewing box 416 provides a "bird's eye" view of the layout contained in the floor layout box 412. In one embodiment, the zoom button on the tool bar can be used to enlarge the view of the data center layout in the floor layout box 412. When the view is enlarged, the entire layout may not appear in the floor layout box. The full-image box 416 still displays the full image of the layout for the user. In one embodiment, when the full layout does not appear in the floor layout box, an overlay is used in the full-image box to indicate on the full-image, the portion of the layout that is displayed in the floor layout box. In one embodiment, when the full image is not displayed in the floor layout box 412, the overlay may be selected and dragged within the full-image viewing box to select which part of the layout is displayed in the floor layout box.

The status box 414 is used to display warnings, errors and other conditions to the user. The warnings may vary in severity and may include indications that design guidelines are being violated and may also include more severe warnings indicating that data center resource capacities, such as power and cooling capacities, have been exceeded, or that redundancy and/or runtime requirements are no longer met. In one embodiment, when the status box indicates that there is an error or warning associated with a particular piece of equipment in the layout, the piece of equipment may be highlighted with a color such as red or yellow. In at least one embodiment, when an

error or warning occurs, guidelines for correcting the error or warning are provided by either selecting a highlighted piece of equipment or the error or warning message directly.

The rack editor interface 404 will now be described further with reference to FIG. 5D. The rack editor interface includes the tool bar 406, the status box 414 and the full-image viewing box 416 discussed above. Further, the rack editor interface 404 also includes a rack editor box, a product catalog box 422 and a rack content section 424.

The rack editor box 420 shows the front face of each of the equipment racks in the data center layout with the racks being arranged by row. In FIG. 5, two rows of racks 420A and 420B are shown. As shown in FIG. 5, in one embodiment, only the equipment racks are shown in the rack editor box. When a particular rack is selected in the rack editor box, then the contents of the rack appear in the rack content box 424, and components may be added to the selected rack. Racks may be selected in the rack editor box or may also be selected in the full-image view box 416. When a rack is selected in the full-image view box, then the image in the rack editor box will shift, if necessary, to provide a view that includes the selected rack.

The product catalog box 422 provides a comprehensive listing of components that may be used in equipment racks in data centers. The user may select equipment to be included in each rack, and as equipment is selected, it is included in the rack content box 424. The list may include only equipment of a particular manufacturer or may include equipment from several manufacturers. In one embodiment, all necessary hardware and cabling associated with rack equipment may be selected from the product catalog box.

In one embodiment depicted in FIG. 20, a user may review and manage data center resource capacity and available supplied to data center equipment. Many of the features of this embodiment are similar to those described in reference to FIG.5C above. In addition, FIG. 20 includes capacity group explorer 2002, which presents a logical grouping of data center equipment, such as racks, based on common capacity requirements. This grouping enables a user, such as a data center designer, to manage

sets of data center equipment as one collective entity for capacity planning purposes. Representations of individual elements of data center equipment, such as UPS 2004, Rack 2006, and PDU 2008 may present the user with columnar bars depicting various data center resource redundancy and/or runtime measurements and capacity measurements, such as available capacity, utilized capacity, stranded capacity. For example, Rack 2006 has an as-configured potential power and cooling demand of 28.8 kW and a current actual power and cooling demand of 7.92 kW. In other embodiments, these demand or consumption measurements may be matched against as-configured potential power and cooling supply capacity and actual power and cooling capacity to ensure all capacity, consumption, redundancy and runtime requirements are met.

In another embodiment depicted in FIG. 22, rack editor interface 404 may be displayed on a remote or mobile computing device. Rack editor interface 404 includes user interface elements that allow for adding equipment 2202, deleting equipment 2204, editing equipment 2206 and moving equipment 2208. This embodiment further includes data center explorer 2210 and rack editor box 2212. Because rack editor interface 404 may be provided on a remote or mobile computing device, users, such as technicians, may document as-built conditions, verify rack installations, troubleshoot installation in a more efficient manner and perform other rack-oriented activities.

In the depicted embodiment, equipment racks are shown in data center explorer 2210. The rack editor box 2212 shows the front face of the equipment rack currently selected in data center explorer 2210. In another embodiment, rack editor box 2212 may display the rear face of the rack and/or the front face of the rack. In FIG. 22, rack Front is selected in data center explorer 2210 and houses data center equipment sss, PowerEdge 2650, PowerEdge 6650, etc.. When a particular rack is selected in data center explorer 2210, the equipment it houses may be modified using user interface elements 2202 through 2208.

The user may add data center equipment to the currently selected rack by actuating user element 2202 and selecting the desired equipment and position with the

rack. The user may delete or edit data center equipment associated with the currently selected rack by selecting the desired equipment from data center explorer 2210 and actuating user element 2204 or 2206, respectively. The user may move data center equipment associated with the currently selected rack by selecting the desired equipment from data center explorer 2210, actuating user element 2208 and selecting the desired position within the rack. In another embodiment, the system may recommend a satisfactory or optimum position. It should be appreciated that the user may select particular data center equipment by drilling down in data center explorer 2210 or by searching the data center using a unique identifier, such as a barcode scanned by the remote or mobile computing device. These methods of searching may allow a user, such as a technician, to quickly obtain information concerning specific data center equipment or modify the CMDB while physically located near the equipment.

According to other embodiments, an interactive representation of an identified space within a data center may be implemented using other interface technology. For example, in another embodiment, in addition to the graphical user interface screens shown above, a three-dimensional option is available allowing a user to view the design of a data center in 3D. In one embodiment, a design system includes software code programmed in Java that is used to generate 3D models that are rendered via OpenGL to allow for hardware acceleration. Further, 3D models may be exported from the design system to CAD tools such as AutoCAD, available from AutoDesk of San Rafael, CA. As described above, security cameras can be implemented into data centers designed using embodiments of the present invention. In one version that has 3D viewing capabilities, security cameras may be included in the design and the 3D view may be used to view a simulation of a camera's view after installation. In one embodiment, networked cameras and other security monitoring devices available from Netbotz Corporation of Austin, Texas may be used.

As discussed above, with reference to the process shown in FIG. 4, the system 200, and other systems of the present invention, may be used as part of a data center management system. The management system may include the system 200 described

above with the management module containing routines to perform management functions, or in other embodiments, the management functions may be performed by a designated manager controller contained in the data center and implemented, for example, in a computer server located in one of the racks of equipment and accessible by a user using a management console.

FIG. 6 shows a block diagram of a management system 500 that may be used in embodiments of the present invention. The management system includes the manager controller 502, the manager console 504, power measurement devices 506, and airflow, humidity and temperature measurement devices 508. It should be appreciated that manager console 504 may be implemented as any computing device, including a remote or mobile computing device. Implementing manager console 504 on a remote or mobile computing device may allow a user, such as a data center manager, to, for example, dispatch work orders to technicians while physically inspecting, installing, moving, and/or changing data center equipment. In addition, in one embodiment, the management system may include power control devices 520 to control application of power to one or more individual devices or racks contained within a data center, and the system may include airflow controllers 521 to control the airflow or supply temperature of an air conditioning unit or to control, for example, perforated tile dampers. As discussed above, the management system may also include one or more security devices 523, including security cameras. The devices of the management system 500 may be directly coupled to the manager controller or may be coupled to the manager controller using a network 522 that may be a dedicated network, may include the Internet, or may include a LAN or WAN contained in the data center. The manager controller may communicate with one or more servers 524 to obtain information from and control operation of the servers.

In one embodiment, the management controller 502 may be implemented at least in part using an InfrastruXure® Manager and/or InfrastruXure® Central available from American Power Conversion Corporation (APC) of West Kingston, RI., and devices may be coupled to the manager using, for example a controller area network (CAN) bus or an Ethernet network. The power controllers and airflow

controllers may be implemented using available known devices that monitor and/or control power and airflow in facilities. Further, in at least one embodiment, the management system 500 may include systems and methods for monitoring and controlling power as described in U.S. Patent No. 6,721,672 to Spitaels et al, which is incorporated by reference herein. Further, in at least one embodiment that uses in-row cooling devices, the management controller may communicate with the cooling units to control the units to ensure that adequate cooling at specified redundancy levels is being met. Further details regarding the control of in-row cooling units that can be used with embodiments of the invention are discussed in copending U.S. Patent Application serial no. 11/335,901, discussed above and filed on January 19, 2006.

One aspect of the present invention, which will now be described, is directed to a retrofit system and method that is particularly useful for adding new equipment to a facility. The addition of new equipment may include adding equipment to existing racks or may include adding other data center equipment, such as racks or other floor mounted equipment, to a facility. The retrofit system may be a standalone computer system configured to perform processes described herein, or in one embodiment, the retrofit system is implemented using the system 200 described above. Specifically, the builder module 206 of the system 200 may include routines to assist in retrofitting a data center. A process 600 for using the system 200 (or some other system) to retrofit or upgrade a data center will now be described with reference to FIG. 7, which shows a flow chart of the process 600.

In a first stage 602 of the process 600, data related to a present configuration of a data center to be retrofitted is provided to the builder module. The data related to the present configuration may include the data displayed in the room model of FIG. 5 along with additional data that was generated during design of the data center. Further, in one embodiment, the data related to the present configuration may include data generated during an initial design as updated by actual measurements conducted in a facility. For example, the cooling capacity of individual racks may be calculated in an initial design and then updated by the management module once the system is installed and operating. Cooling capacity data may be updated based on actual

measurements of airflow from, for example, perforated floor tiles, while the original data may have been calculated based on predicted airflows. In one embodiment, interface 302 of system 300 provides this data center configuration and measured parameter information from database 304.

Information related to the retrofit is then provided in stage 604. The information related to the retrofit may include information similar to that input at stage 304 of process 300 described above, such as type of equipment, characteristics of equipment, number of racks, as well as other information. In addition, a user may designate one or more desired locations in the data center for the installation of new equipment. For example, a user may desire to add five additional servers to the data center, where the servers are similar to and have a related function to existing servers in the data center. The user may choose one or more preferred locations based on power specifications, cooling specifications and physical dimensions of the servers, and based on power capacity, power plug type and/or number, cooling capacity and contents of existing racks displayed on a floor model of the data center. In addition, the user may indicate whether it is acceptable to move existing equipment to accommodate the installation of new equipment. In another example, a user may desire to replace three servers in the data center. The user may choose the servers targeted for replacement and may make other data center modifications with these replacement servers in mind. In addition, the user may indicate whether the replaced equipment should be removed from the data center or moved into an inactive storage room. Tracking inactive equipment may allow a user, such as a data center manager, to quickly ascertain equipment available for provisioning within the data center.

At stage 606, an updated layout for the data center is generated and cooling and power calculations are performed at stage 608 on the updated layout in the manner discussed above at stage 308 of process 300. If the user has designated specific locations for equipment in the data center, the layout may first be determined using these locations, and if problems arise as a result of the desired layout (i.e., lack of cooling for a rack based on equipment or supply policy requirements), then the user will be able to note any such problems once the layout is displayed and can then

choose to change the layout. In one embodiment, the system may suggest one or more elements of data center equipment to be placed at one or more locations. In this case, the system may ensure that applicable data center resource supply policies, and data center resource requirements of the suggested equipment, are met. In another embodiment, the system may provide the user with one or a series of satisfactory locations for the equipment based on the data center resource requirements of the equipment and any applicable data center resource redundancy and/or runtime requirements. In another embodiment, the system may provide the user with an optimum location, followed by other satisfactory locations in a decreasing order of preference, for the new equipment based on the data center resource requirements of the equipment and any applicable data center resource redundancy and/or runtime requirements. If a particular layout is not designated by a user, then the system 200 will determine the layout in the manner discussed above with respect to stage 306 of process 300.

At stage 610, an updated floor model is displayed (for example, in the manner shown in FIGS. 5C and 5D), and at stage 612, a user can review the model and either provide feedback (stage 614) or indicate that the design is satisfactory. Once the floor model has been approved by a user, the retrofit design process is complete, and the equipment may be installed, relocated, or removed and parameters of the data center may be measured and updated in the manner described above in stages 318 to 322 of process 300 using for example a data center management system.

In one embodiment, changes to the configuration of the data center such as those designed by retrofit process 600 may be implemented by work order process 1900 as illustrated by the flowchart in FIG. 19. Initially, at stage 1900, a data center configuration change may be made using a graphical user interface such as those discussed with regard to FIGS. 5C and 5D above. Details of the change may be used to construct a set of tasks to carry out the change. These tasks may be grouped together into work orders. Work orders may be human-readable and may include textual instructions as well as pictorial representations. It should be appreciated that a

single configuration change, initiated using a visual editor, may be translated into multiple work orders.

At stage 1902, a work order is dispatched to a user for implementation. In one embodiment, this dispatching may be automatic or manual. Automatic dispatching may occur based on a set of preconfigured rules. These rules may consider characteristics of both the work to be performed and the user to whom the work order may be dispatched. Characteristics of the user that may be considered include the user's physical location, physical area of responsibility, recent and current work load, remaining schedule availability and area of expertise. Alternatively, a work order may be automatically dispatched to one or more users in a "round robin" fashion. In another embodiment, a user, such as a data center manager, may access the dispatch UI exposed by work order module 214, discussed in relation to FIG. 3 above, to modify and/or dispatch work orders to users. In still another embodiment, a user, such as a technician, may access the dispatch UI exposed by work order module 214 to modify and/or dispatch work orders to himself.

At stage 1904, a user performs the work dictated by the work order and modifies the work order appropriately. Modification of the work order may include, for example, changing the details of the work performed such as recording installation of an alternative model of equipment, rearrangement of the order of equipment within the rack, reconfiguration of the flow of a data center's resources, such as power, to the equipment, etc.. Modification may also include changing the status of the work order. When a user modifies a work order using a remote or mobile computing device, certain information required to complete the modification may be entered using any interface supported by the remote or mobile computing device, including barcode scanning.

In one embodiment, work order module 214 may monitor a data center resource provider, such as power outlet, that is targeted as part of the work order for a change in demand. When a change in demand is detected, such as an increase in the power demanded at a power outlet, the work order may be marked as complete. In another embodiment, the work order is not marked as complete until the data center

resource consumption or production benchmark, such as the power consumption benchmark, of the data center equipment specified on the work order is recognized. For example, if a work order calls for the installation of a particular model of blade server, the system may not mark the work order as complete after initial activation of the blade server, but instead may wait until the power consumption history of the blade server matches a known power consumption benchmark for the model of blade server called for in the work order.

In the processes 300 and 600 described above, design and analysis stages are performed after all data is entered as part of an initial design or a retrofit of a facility. In another embodiment, analysis is performed real-time, and user displays are updated as the user enters data into the system.

In embodiments of the present invention, using the processes described above, data center operators are able to determine, in essentially real-time, whether additional equipment may be added to a data center and may also determine locations for the equipment, where data center resource requirements, such as both power and cooling requirements, of the equipment may be met. Further, reports may be generated that indicate to a user or data center manager how much capacity, redundancy and/or runtime is available for each row, for each rack , for each U space position, for each piece of data center equipment and for the facility in its entirety. Still further, as discussed above, in determining overall capacity, systems and methods are able to identify and display stranded capacity, and provide suggestions for reducing the stranded capacity.

In the processes and systems described above, cooling calculations for a data center and for equipment in the data center are performed as part of the design process for the data center, during operation of the data center, and during an upgrade or retrofit of the data center. In embodiments of the present invention, in determining equipment layout and performing cooling calculations, initial information on characteristics of the facility itself are identified to determine if there is sufficient cooling at the facility level. These characteristics include, for example, whether a raised floor or drop ceiling is used as an air plenum, the location and characteristics of

air conditioning units (including in-row cooling units), dimensions of the room that are to house the data center, and total power draw of the data center. Based on this information, an initial determination may be made as to whether there is sufficient cooling provided by the air conditioning units for the expected power draw in the room, and if not, a recommendation may be made for additional air conditioning units. For some facilities, desired redundancy and operating margins may be included in this determination.

Once the determination has been made that there is sufficient cooling at the facility level, an analysis is conducted to determine if there is adequate cooling at each rack in the facility and/or at individual pieces of equipment. In at least one embodiment, the cooling capacity of a rack may be determined by increasing the power level of the rack to determine at what additional power level the airflow to the rack becomes inadequate. This can be performed individually for each of the racks in a data center. In different embodiments of the present invention, one or more of a number of different methods may be used to perform the cooling calculations. These methods include, but are not limited to, a computational fluid dynamics (CFD) analysis, a Coarse-Grid CFD analysis (designated as CGCFD), a control volume analysis (designated as CVA), and an analysis based on empirical rules and/or borrowing concepts. Further, in some embodiments, a combination of two or more of the above methods may be used to conduct portions of an overall analysis. In one embodiment, the principle of superposition is used to combine results of portions of an analysis. In particular, in many applications the airflows may be considered to be ideal, where an ideal airflow is inviscid, incompressible, irrotational without any other forces, such as buoyancy. With such an ideal airflow, a complex application can be reduced to a number of less complex applications, analysis of the less complex applications can be performed using one of the methods described herein, and superposition can be used to combine the results of each of the less complex applications to obtain analysis results for the complex application.

A computational fluid dynamics analysis can be used in one embodiment in association with the design and retrofit of a data center to provide detailed results of

the cooling performance of a facility, including determining the availability of adequate cooling air at racks and individual pieces of equipment in the facility and determining cooling capacity for each rack. The techniques for implementing a CFD analysis of a data center are known. A CFD analysis must typically be performed by someone particularly skilled in the art, typically requires detailed information regarding the facility and the layout of equipment in the facility, and depending on the complexity of the analysis conducted, and the computing equipment used to conduct the analysis, may take hours or days to run one iteration of the analysis.

In another embodiment, an improved technique for conducting the cooling analysis is used. The improved technique has been developed based on computational fluid dynamics techniques. The improved technique is referred to herein as a Coarse-Grid CFD or simply CGCFD. In a typical CFD analysis, a data center to be analyzed is typically divided into non-uniform cells in the range of one to eight inches on a side. In at least one embodiment, in the CGCFD analysis, a Cartesian grid system of cells that are one foot cubes are used. The use of uniform one foot cells typically reduces the number of cells used in the calculations from a traditional CFD analysis by at least an order of magnitude. Further, uniform grid cells generally make the CFD analysis faster and more reliable relative to a comparable non-uniform cell analysis. Further, other techniques are employed in the CGCFD analysis to improve the computational efficiency of the analysis. These techniques include: the use of simple turbulence models, initializing the analysis with data obtained from the results from a prior similar solution, using two dimensional or partial two dimensional representations when possible to simplify calculations, and tailoring a CGCFD routine for a specific application. The use of two dimensional representations may be used, for example, in a raised floor or ceiling plenum, where pressure gradients in the depth direction can be neglected in the computations.

The tailoring of a CGCFD routine can be used in embodiments of the present invention to significantly improve computational efficiency and improve robustness (for example, so the tool can be made to work reliably in an autonomous way) of the total analysis, and multiple tailored routines may be used in combination to produce a

complete analysis. For example, a first CGCFD routine may be tailored for use with different raised floor configurations to determine the output airflow at each perforated floor tile of a raised floor in a data center, and a second CGCFD routine may be tailored for use with a cluster of racks that include two rows of racks with a cold aisle between the rows. The first CGCFD routine may be run to determine the output air at perforated tiles in the cold aisle of the rack cluster, and the second CGCFD routine may use the results of the first routine to determine the airflows and temperatures at inlets and outlets of the racks. The second routine may be run a number of times to account for all of the clusters of racks located in a data center. As equipment is moved, and as different configurations are established within a cluster to optimize cooling performance, the second routine may be run to obtain new cooling data without the need to repeat the first routine, as the airflows from the perforated tiles generally would not change. In some cases, for perforated floor tiles having a large percentage of open area (for example, greater than 50%), it may be desirable to repeat the first routine as air flows may change based on room configuration.

Embodiments of the invention that utilize the CGCFD approach to conduct the analyses of a data center provide advantages over embodiments that utilize a traditional CFD approach. These advantages include computational efficiency and simplification of use. Iterations of cooling calculations using the CGCFD approach may be conducted in a matter of seconds or minutes versus hours or days with a full CFD analysis. Further, the CGCFD routines may be designed to operate with a limited set of input variables, allowing a less-skilled user to conduct analyses using the CGCFD approach. For example, for a CGCFD routine that is tailored to analyze only the raised floor plenum, the input variables may be limited to the height of the floor, location and type of perforated tiles, length and width of the floor, and the locations and characteristics of air conditioning units that provide cooling air to the raised floor. For a CGCFD routine that is tailored to conduct an analysis on a cluster of racks, the input data may be limited to airflow per tile (could be obtained automatically from the output of a separate CGCFD routine or using other methods), the number of racks in the cluster, the power draw of each of the racks, and room

environmental details including the temperature of the surrounding environment, ceiling height, the presence of nearby walls, etc. The output data for a cluster of racks may include the input temperature at each server, or other piece of equipment in a rack. In other embodiments, the output data may simply be a measure of the amount of warm recirculated air drawn into each rack. The data may be expressed as an absolute number (e.g. in terms of cfm) or expressed as a fraction of the total air consumed by the rack. A system, such as system 200 described above, may use the output data to determine if the cooling performance of the cluster is satisfactory.

In another embodiment, another improved technique for conducting the cooling analysis is used. The improved technique is referred to herein as a control volume analysis or simply CVA. The control volume analysis may be used in conjunction with a CFD analysis and/or a CGCFD analysis, or may be used as a stand alone process. The CVA technique is similar in some aspects to the CGCFD technique described above, however, further simplification of the analysis process is provided. As will be discussed below, the CVA technique is a computationally efficient technique that is particularly effective for computing the three-dimensional airflow, pressure and temperature distributions in the cold aisle of a raised floor data center. However, the CVA technique is not limited in its use to this application and may be used for other applications as well. The CVA technique can provide output data in essentially real-time, allowing a user to try various locations for equipment as part of an initial design or a retrofit and obtain cooling data for the different locations in real-time.

The CVA technique will be described with reference to FIG. 8, which shows a subsection 700 of a data center. The subsection of the data center includes a cluster of racks that includes a first row of racks 702, and a second row of racks 704, which are located on a raised floor and separated by two rows of perforated tiles 706, 708.

In data centers that have clusters of racks arranged like those in FIG. 8, it is not uncommon for undesirable hot spots to develop even though the total supply of cool air to the cluster should be sufficient to meet the needs of the racks. For example, if the airflow rate through one or more perforated tiles is too great, a rack

may be unable to capture all of the tile airflow and some of the cooling air may escape the cold aisle. Racks will generally draw their required air, and in this situation, if a rack can not capture cool air, it may draw hot exhaust air over the top of the rack creating a hot spot. Further, due to widely varying cooling airflow requirements, racks may compete with one another for cooling airflow. In particular, a high-power rack may borrow underutilized air from an adjacent rack, or in some cases from a rack separated by several tiles. With several racks contained in a cluster, with each having different cooling needs, the airflow patterns and temperature distribution in the cold aisle are complex functions. The CVA technique can be used to simplify the solutions to these complex functions.

In the CVA analysis for the rack cluster of FIG. 8, the airflow and temperature analysis is conducted on the volume of air contained in the cold aisle, between the racks, from the perforated tiles up to a height equal to the top height of the racks. The volume of air is divided into a number of control volumes equal to the number of racks in the cluster. Each control volume is defined as the volume above one of the perforated tiles extending from the perforated tile to the top of the racks. The control volume analysis includes determining for each control volume, the airflow through each of the six faces of the control volume. Once the airflows are known, temperatures and mass species concentrations can be determined for each of the control volumes. In the CVA technique, the temperature analysis can be decoupled from the airflow analysis because, as discussed above, buoyancy forces in the control volumes can be ignored. Similarly, mass species concentrations are not coupled to the airflow solution and may also be computed separately if desired in order to compute the fraction of recirculated air ingested by each rack.

In conducting a CVA analysis in the embodiment described herein, there are several initial assumptions made to simplify the analysis. In other embodiments, the analysis could be changed if these assumptions would not apply. The first assumption is that airflow across each face of a control volume (and therefore into the front face of a rack) is considered uniform. Resulting airflow and temperature values effectively represent an average of the airflow and temperature at each face.

The second assumption is that buoyancy forces within each control volume are negligible. Unless a significant hot spot develops, then there is insufficient heating of the air in a cold aisle to substantially affect airflow patterns, and even if some heating occurs, any buoyancy effects are small compared to the momentum of the airflow from typical perforated tiles.

The third initial assumption is that viscosity and turbulence within each control volume are negligible. In the control volumes, air is introduced through the perforated tiles and is pulled into the racks. The air is not required to change direction rapidly and there is no flow of air parallel to solid objects. Accordingly, viscosity and turbulence may be ignored and the competition of forces driving the airflow reduces to an interplay between pressure and momentum.

The CVA analysis may be further simplified by dividing a cluster of racks into slices of two racks separated by two perforated tiles 718A, 718B. FIG. 9 shows a cluster of six racks 710 that can be divided into three two-rack slices 712, 714, 716. The nomenclature used for identifying racks, and airflows in FIG. 9 is defined in Table 1 below, along with other variables that will be used herein in the description of the CVA technique.

TABLE 1

A_s, A_t	Control volume side and perforated tile area
C_1, C_2	Dimensionless empirical constants in the y and x-momentum equations
C	Species Concentration
CV	Control volume
N	Number of 2-rack slices in cluster
$\hat{n}$	Outward unit normal vector
PA_i, PB_i	Pressure in control volume above perforated tiles A_i and B_i
P_{amb}	Ambient reference pressure
M_L, M_R, M_T	z-direction momentum flux terms through left, right, and top surfaces of staggered CV at slice i

TA_i, TB_i	Temperature in control volume above perforated tiles A_i and B_i
Q_t	Airflow rate through each perforated tile
QA_i, QB_i	Airflow rate through racks A_i and B_i
QAx_i, QBx_i	Airflow rates in the x-direction above perforated tiles A_i and B_i
Qz_i	Airflow rates in the z-direction above perforated tiles between tiles A_i and B_i
$QAtop_i$, $QBtop_i$	Airflow rates in the y-direction above perforated tiles A_i and B_i at top-of-rack height
$\vec{V}$	Velocity Vector
α	Linear relaxation factor
ρ	Density of air

At the start of the CVA analysis, the rack airflows QA_i, QB_i and the tile airflows are known. The tile airflows can be estimated based on the mean perforated tile airflow for the entire facility or determined using a CFD analysis, a CGCFD analysis, physical measurement, or using one of a number of known programs. The rack airflows can be determined based on characteristics of equipment installed in the rack. In one embodiment, each rack airflow is determined on the basis of the power usage of the rack and using the relationship of 160 cfm per kilowatt of power as discussed above. To determine the airflow patterns, all airflows QAx_i, QBx_i, Qz_i, $QAtop_i$, and $QBtop_i$, and pressures PA_i, and PB_i are computed based on the principle of conservation of mass and momentum. To perform this computation, a total of 7n-2 unknowns (5n-2 internal airflows plus 2n pressures) may be determined using a total of 7n-2 equations, where n is the number of 2-rack slices (or length of cluster expressed in tile or rack widths). Optionally, an energy balance or mass species balance can then be used to compute the 2n temperatures or 2n species concentrations based on the airflows.

In one embodiment, rather than solve all equations simultaneously, a semi-simultaneous approach is taken. In this embodiment, the five unknowns for each two-rack slices of a rack cluster, airflows Qz_i, $QAtop_i$, and $QBtop_i$, and pressures PA_i, and PB_i, are first determined simultaneously. During these initial computations, each two-rack slice is considered in isolation, which is the equivalent of having the ends of the slices blocked, such that QAx_i and QBx_i are equal to zero. After an initial sweep through each two-rack slice is complete, the side-to-side airflows (QAx_i, QBx_i,) can be computed based on the calculated pressures within each control volume. The side-to-side airflows affect the pressures, and after computing the side to side airflows, a second computation of the airflows and pressures is conducted for each of the two-rack slices. This process is repeated until there are no significant changes in the computed variables. Once all airflows are known, all temperatures or mass species concentrations can be computed directly without the need to do multiple iterations.

The fundamental equations used to compute the unknowns described above, assuming steady state, incompressible and inviscid fluid flow rely on conservation of mass (m), conservation of momentum (M) conservation of energy (e) and conservation of species concentration (C), and can be written as follows:

$$\int_A \left(\vec{V} \cdot \hat{n}\right) dA = 0 \qquad \text{(m)}$$

$$\int_A \left(\rho \vec{V} \cdot \hat{n}\right) \vec{V} dA = -\int_A p \hat{n} dA \qquad \text{(M)}$$

$$\int_A T\left(\vec{V} \cdot \hat{n}\right) dA = 0 \qquad \text{(e)}$$

$$\int_A C\left(\vec{V} \cdot \hat{n}\right) dA = 0 \qquad \text{(C)}$$

Applying the conservation of mass equation (m) to the two-rack slices for the conditions described above results in the following equations:

$$Q_t + QA_i + QAx_{i-1} = Qz_i + QAx_i + QAtop_i \quad (1)$$

$$Q_t + Qz_i + QBx_{i-1} = QB_i + QBx_i + QBtop_i \quad (2)$$

Where QA_i is always negative based on the sign convention of FIG. 9.

As will now be described, staggered control volumes are used to formulate the z-momentum equations. Three staggered control volumes 730A, 730B and 730C are shown in FIG. 9A. The number of staggered control volumes is equal to the number of 2-rack slices. The staggered control volumes are the same size as the main control volumes, but are shifted so that they are located midway between opposing racks. The staggered control volumes allow pressure to be considered more easily for each face which is normal to the z-direction. If the original control volumes are used, then each control volume would have one face coplanar with a rack inlet, which is a face over which the pressure is not known and need not be known in the calculations. Applying the conservation of momentum equation (M) in the z-direction to the staggered control volume in slice *i* results in the following equation:

$$PA_i - PB_i = (\rho/(4\ A_s^2))\ \{(Qz_i+QB_i)^2-(\ QA_i+Qz_i)^2\} + M_L + M_R + M_T \quad (3)$$

In equation (3), the first term on the right hand side of equation (3) is generally dominant, as it accounts for the effect of rack airflow rates on control volume pressures. M_L, M_R and M_T account for losses or gains in z-momentum through the sides and the top of the control volume.

Using an "upwind" estimate for incoming/outgoing z-momentum and assuming that the velocity of the air in the z-direction is negligible above the racks, M_L, M_R and M_T are determined using the equations of Table 2 below

TABLE 2

IF	THEN	ELSE
$QAx_{i-1} + QBx_{i-1} \geq 0$	$M_L=-(\rho/(2\ A_s^2))\ (QAx_{i-1} + QBx_{i-1})\ Qz_{i-1}$	$M_L=-(\rho/(2\ A_s^2))\ (QAx_{i-1} + QBx_{i-1})\ Qz_i$
$QAx_i + QBx_i \geq 0$	$M_R=(\rho/(2\ A_s^2))\ (QAx_i + QBx_i)\ Qz_i$	$M_R=(\rho/(2\ A_s^2))\ (QAx_i + QBx_i)\ Qz_{i+1}$
$QAtop_i + QBtop_i \geq 0$	$M_T=(\rho/(4\ A_s^2))\ (QAtop_i + QBtop_i)\ Qz_i$	$M_T = 0$

The relationship between Y-momentum and pressure may be written using equations (4) and (5) as follows:

$$PA_i - P_{amb} = = (\rho/A_t^2)\{C1\ [Q_t + \tfrac{1}{2}\ (QAi + QAx_{i-1} - QAx_i - Qz_i)]^2 - \tfrac{1}{2}\ QAtop_i^2\} \quad (4)$$

$$PB_i - P_{amb} = = (\rho/A_t^2)\{C1\ [Q_t + \tfrac{1}{2}\ (Qzi + QBx_{i-1} - QBx_i - QB_i)]^2 - \tfrac{1}{2}\ QBtop_i^2\} \quad (5)$$

In one embodiment, equations (1) through (5) are solved simultaneously for each 2-rack slice of a cluster sequentially using the process 800 shown in FIG. 10. In the first stage 802 of process 800, the user defines Q_T (the airflow through the perforated tiles), the number of 2-rack slices in the cluster, and the power draw of each of the racks. As discussed above, Q_T may be estimated as the mean perforated tile airflow rate for the entire facility or determined separately using, for example, a CFD or CGCFD analysis or other analysis or physical measurement. At stage 804, all airflow variables (except Q_T and the rack inlet airflows) are initialized to zero. At stage 806, equations (1) through (5) are solved simultaneously for each slice. At decision block 808 a determination is made as to whether the equations have been solved for all slices, and if not, stage 806 is repeated. Once the equations have been solved for all slices, then at stage 810, the x-direction airflow variables are updated based on the computed pressures in the control volumes, PA_i and PB_i as discussed below. At stage 812, a determination is made as to whether the computed pressures have changed by more than a predetermined threshold since the previous iteration and if so, stages 806 to 812 are repeated. Once there is no significant change in the

computed variables, the process 800 stops at stage 814, at which point the pressures and airflows for all of the control spaces have been determined.

In the process 800, at stage 810, new x-direction airflow values (QA_{xi} and QB_{xi}) are determined based on the assumption that the pressure drop between adjacent cells is proportional to the square of the airflow rate using the equations in Table 3.

TABLE 3

IF	**THEN**	***ELSE***
$PA_i \geq PA_{i+1}$	$QAx_i = A_s\{(PA_i - PA_{i+1})/(\rho C_2)\}^{1/2}$	$QAx_i = -A_s\{(PA_{i+1} - PA_i)/(\rho C_2)\}^{1/2}$
$PB_i \geq PB_{i+1}$	$QBx_i = A_s\{(PB_i - PB_{i+1})/(\rho C_2)\}^{1/2}$	$QBx_i = -A_s\{(PB_{i+1} - PB_i)/(\rho C_2)\}^{1/2}$

In one embodiment, because of non-linearities of the equations, adjustments to the x-direction airflow values at stage 810 are achieved gradually by introducing damping into the iterative process and updating the values of QAx_i and QBx_i using the following equations (6) and (7).

$$QAx_i = \alpha\, QAx_i^{new} + (1-\alpha)\, QAx_i^{old} \qquad (6)$$

$$QBx_i = \alpha\, QBx_i^{new} + (1-\alpha)\, QBx_i^{old} \qquad (7)$$

In equations (6) and (7), α is a linear relaxation factor. If α is set to zero, then no changes will occur from iteration to iteration. If α is set to 1, then there will be no damping introduced. For smaller values of α, more iterations will be required, however, the chances of obtaining a stable solution increase. The particular optimum choice of α is problem specific, however, it has been found that values of α around 0.05 work well in the process described above. Once the airflows are computed using the process above, temperatures and mass species concentrations can be calculated, if desired. It should be noted that control volumes may be used to compute

temperatures or concentrations regardless of the method used to initially compute airflows.

The CVA technique described above can be conducted separately, one for each cluster of racks in a facility to obtain a complete cooling analysis of the facility. When a retrofit of a facility is to be done, the control volume analysis may be done for all clusters, or only for those in the vicinity of any changes to the facility.

Three different methods, CFD, CGCFD and CVA, have been described above for determining cooling data in embodiments of the present invention to determine placement of location of equipment in data centers. In still another embodiment, empirical rules are used either alone or in combination with one of the methods described above to determine proper placement of equipment and the adequacy of cooling air. The empirical rules that are used may take a number of different forms, and programs incorporating the empirical rules may be updated as more data is generated to support the empirical rules. In one embodiment, empirical rules are based, at least in part, on the ability of equipment racks to borrow unused capacity from surrounding neighbors. The amount that may be borrowed may be limited to an allowable fraction (or weight) of the unused capacity and the particular allowable fraction may differ depending on a number of variables such as borrower-donor separation distance, tile flow rate, and the total power draw of both the borrower and the donor.

In one particular embodiment, the cooling air available to a given rack is computed based on a weighted summation of the available airflows from airflow sources (i.e., supply devices, including in-row cooling units, or vents), net of airflows computed to be used by other racks, where the weights associated with the available airflows for a given rack decrease with distance between the rack and the air supply devices or vents. For example, with reference to FIG. 9, the cooling air available to each rack may initially be set equal to the cooling air supplied by the perforated tile in front of the rack, or to reflect possible losses, and provide safety margin, the cooling air available may be set equal to some amount (i.e. 90%) of the total air from the perforated tile. The cooling load for each rack is then subtracted from the available

air to provide a net available cooling air figure for each perforated tile and to provide an initial indication of a lack of cooling air for any equipment rack. For each equipment rack, the available cooling air is then increased by assigning to each rack, a percentage of the net available cooling air from nearby perforated tiles. For example, the cooling air available may include 10% of the net available cooling air from a perforated tile associated with either an adjacent rack or a rack across an aisle, and 5% of the net available cooling air from a perforated tile of a diagonal rack or a rack two positions over in a row. The particular percentages or weights used may be changed based on actual results or as a result of analyses conducted. The loads of each rack may then be compared with the total available cooling air to determine remaining cooling capacity and to identify any potential problem racks.

In at least one embodiment, empirical rules may be used in combination with superposition to analyze data centers and provide recommended equipment layouts. Using superposition, complex problems may be broken down into simpler problems that can then be solved using empirical rules.

In one embodiment, empirical rules are established by initially performing a number of CFD analyses on typical rack layouts, and the results of these analyses are used to produce simple equations or look-up tables that can be used in real-time to design layouts of equipment. In such an analysis, the side-to-side airflows, such as those shown in FIG. 9 may be determined for each rack one at a time with one rack turned "on" and all other racks turned "off". The airflows at the ends of a cluster for a number of different configurations may also be determined using CFD. The airflows may be determined for a number of different air intake values for each rack and a number of different values of air flow from the perforated tiles. The total air flows for different configurations can then be determined in real-time using superposition and the stored results. The airflows through the top (in or out) of the volume in front of each rack may then be determined based on conservation of mass. In one embodiment, when the airflow into the top of one of the volumes exceeds some percentage (i.e., 20%) of the total air flow into the rack associated with the volume, then an overheating problem may exist requiring a design around. In other

embodiments, mass species concentration analyses may be used in combination with empirical rules to determine what percentage of the total air entering a control volume is recirculated air to determine when an overheating problem may exist.

In determining the airflows for each rack of a cluster, symmetry of the clusters can be used to reduce the number of CFD analyses that need to be performed, and the control volumes discussed above with respect to FIG. 9 may be used to establish a reference grid for the analysis. For example, with reference to the cluster of racks 710 of FIG. 9, CFD analyses need only be performed for Rack A_{i-1} and Rack A_i, and the results for each other rack may be determined based on the resulting airflows and the relative position of the racks. For example, the airflows in the cluster associated with Rack B_{i+1} are the same as those associated with Rack A_{i-1} with the direction of some of the airflows changed for corresponding Rack A and Rack B inlet airflow and tile airflow rates.

In one example, which will now be described, the concepts of symmetry and superposition are used in conjunction with CFD analyses and empirical rules to provide a practical real-time solution for determining air flows in a cool aisle. Further, air flows are used to determine a recirculation index (RI) for a row of racks, which can be used to identify potential "hot spots" in a data center. As discussed above, one cooling objective in a data center is to manage the equipment rack inlet air temperatures. The rack inlet air temperatures are dominated by the airflow patterns within the cold aisle and the temperatures within and around the cold aisle. Air drawn in from outside the cold aisle is generally heated to some degree by the rack exhaust and will be hereafter referred to as "recirculated air". While the temperature of the recirculated air is highly application dependent, air that passes directly from a perforated tile to a rack inlet will be very near the supply temperature. Thus, good cooling performance can be achieved if all of the airflow ingested by a rack comes directly from the perforated tiles.

A cluster of racks, which receives its required cooling air exclusively from the perforated tiles within the cluster, represents an autonomous scalable unit from which a larger facility with predictable cooling performance may be constructed. A

reasonable requirement is therefore to ensure that racks are adequately cooled by air originating from the racks own cold aisle. Conversely, it is acceptable for the rack to ingest no more than a small fraction of recirculated air.

With the above in mind, the recirculation index (ri) is defined as the fraction of recirculated air ingested by the rack. An ri of 0% implies that all of the rack inlet air was drawn directly from the perforated tiles while an ri of 100% implies that all of the rack inlet air was drawn from outside of the cold aisle. Note that a low ri is sufficient to guarantee cool inlet temperatures; however, a high ri does not guarantee excessively high inlet temperatures.

The concepts of control volumes, symmetry and superposition are used in the present example to determine air flows and ultimately RI for a cold aisle. In using superposition, a sum of velocity potentials (or actual velocity components or total airflows over a consistent area) of simpler, elemental flow solutions is used to obtain a new, composite flow solutions. For example, assume we know the airflow pattern associated with only Rack A1 "on" subject to a particular tile airflow rate and we also know the airflow pattern with Rack B3 "on" subject to the same perforated tile airflow rate. The relevant horizontal airflow components can be added to obtain a solution, which approximates the airflow pattern resulting from Racks A1 and B3 both "on" simultaneously. The airflow pattern resulting from the superposition of the two separate airflow patterns is not exactly the same as the full solution – even for an ideal flow. Using superposition two solutions are added together which individually (and when added together) satisfy conservation of mass criteria. The use of superposition does not guarantee that the combined solution will be the unique solution and the difference is in the boundary conditions. As an illustration of this, consider a 2-rack example. In using superposition, the top airflow condition floats freely as a constant-pressure boundary condition in all cases. In reality, the airflow pattern constructed from superposition may not provide a perfect match to air velocity over the top surface of the cold aisle. Also, when one rack is off, an assumption is made that the face (inlet) of the rack is a symmetry boundary condition (which is consistent with an inviscid analysis). This result creates the opportunity for some

flow parallel to the face of the rack, which would probably not exist when the rack is actually drawing air.

In the example, superposition is used to establish only the 3n-2 internal horizontal airflows (n being equal to the length of the row in terms of racks) while end-of-row horizontal airflows are computed based on separate empirical correlations. Vertical airflow components are computed from a mass balance performed on each control volume. The horizontal airflows clearly depend on tile airflow. For example, a rack of a given airflow rate may be able to draw cooling air from a distance of many tile-widths when the perforated tile airflow rate is very low. However, this range of influence is much less as the tile flow rate is substantially increased. (As we know from the non-dimensional argument, the results would be identical if all airflows are scaled by the tile flow rate.) Therefore, the tile airflow rate is included in the analysis; the floor tiles should be "turned on" in the CFD analysis used to correlate airflow patterns. However, if the floor tiles are left "on" and the effect of each rack is considered individually, when the flows for each rack are summed, the sum would have more airflow leaving the top of the cold aisle than in reality. The answer is to correlate only the horizontal airflows and then simply compute the correct airflow into or out of the top of each control volume based on conservation of mass.

It is worth emphasizing that the use of the non-dimensional airflow and, in particular, superposition, simplifies the method. Without these simplifications, there would be many combinations of rack and tile airflows to evaluate and store empirically to cover a range of practical applications.

Based on the above discussion, the complete airflow solutions to any rack layout of interest can be constructed using superposition. Elemental building-block airflow patterns are associated with each rack and each of the four end-of-row airflows are turned on individually as illustrated in FIG. 11 for the case of a 2-rack cluster 1002. It is important to stress that FIG. 11 illustrates which airflow boundary conditions are turned on and off in each of the elemental airflow solution to yield the total solution with all airflow boundary conditions "on". Each of arrows 1004a to 1004f represents one of the airflows. It is the airflow components internal to the cold

aisle that are actually being combined. There are, in general, a total of 2n+4 elemental solutions for any layout, which makes up a complete airflow solution. Obviously, fewer elemental solutions are required if some racks have zero airflow and the ends of the cold aisle are sealed (e.g. with doors).

The elemental airflows used with superposition may be determined in any manner including physical testing. In the present example, CFD modeling for the cold aisle is performed using the following boundary conditions:

- Fixed velocity of air leaving the computational domain over the area of a rack face for any rack which is "on"
- Fixed velocity entering or leaving the domain over the area of the end of the rows for any end-of-row flow "on".
- The top of the solution domain is "open" for air to enter or exit to the surrounding environment held at constant pressure.
- All other surfaces are "symmetry" surfaces.

As stated above, there are in general 2n+4 elemental solutions for each row length; 2n elemental solutions associated with each rack turned on plus four end-of-row elemental solutions. Each elemental solution covers a range of dimensionless flow rates so that any arbitrary, but practical, rack or end airflow rate can be considered. So, the task is reduced to determining and storing the 3n-2 internal horizontal control volume airflows over an appropriate range of dimensionless airflow rates.

Because of the geometric symmetry of a cluster of racks, only the 3n-2 internal airflows for approximately one quarter of the 2n+4 rack and end-of-row boundary conditions are considered and stored; n/2+1 boundary conditions if n is even and (n+1)/2+1 if n is odd. The remaining internal airflows are determined from an appropriate reinterpretation of the smaller data set by changing variable indices and signs. In addition to being efficient, this use of symmetry, forces the final output from the rack cooling performance tool to be perfectly symmetric. Each of these boundary conditions are driven individually through a range of dimensionless airflow rates while keeping track of all of the "response" airflow rates internal to the cluster. The

result can be summarized in a plot of "response" airflow rates; one plot for each elemental boundary condition.

As an example, internal horizontal airflows associated with boundary condition Rack A1 for an n=2 cluster are shown in FIG. 12. There are 4 curves in FIG. 12 because there are 4 horizontal internal airflows associated with an n=2 cluster of racks. All of these curves can be conveniently approximated with a least-squares fit to a cubic polynomial of the generic form

$$Q^*=c_1 (QRA_1^*) + c_2 (QRA_1^*)^2 + c_3 (QRA_1^*)^3 \quad (8)$$

so that only the coefficients c_1, c_2, and c_3 must be stored for all airflows associated with all unique boundary conditions for all n's. Storing the "response" airflow as an equation offers the additional benefit compared to a simple look-up table in that results outside the domain of FIG. 12 are automatically interpolated.

The process involved in compiling the curves in FIG. 12 and the constants of Equation 8 is repeated for all unique boundary conditions for all n's considered. Determining all internal airflow correlations, for example, up to n=30 requires several hundreds of CFD runs. Therefore, in at least one embodiment, the process of converting the raw CFD data into the curve-fit constants of Equation 8 is automated. In at least some examples above, the flow in the cold aisle is considered to be ideal with no viscosity or turbulence. To verify this assumption, sample CFD cases were run with turbulence and viscosity included, and little difference was detected between models that included viscosity and turbulence and those that did not.

The discussion above describes a process for all internal cold-aisle airflows for any row length, perforated tile airflow, and rack airflow distribution assuming that that the end airflow is known. A process for predicting the end airflow will now be described. Unlike the airflow within the cold aisle, the end airflow is strongly coupled to the airflow in the surrounding room environment. Buoyancy forces can be significant; direct superposition of rack-induced airflows may not work well and the end airflows do not depend simply on the dimensionless rack airflow rates. The end airflow can

still be determined using empirical correlations of CFD data; however, a relatively large number of CFD simulations typically should be performed in order to achieve reasonable accuracy over a useful range of actual layouts. A comprehensive model for end airflow, which takes into account different geometric and thermal environments, may be included in other embodiments. In one embodiment, described herein, a method includes predicting end airflow as a function of rack power and airflow distribution for any row length and perforated tile flow rate while assuming a fixed room environment. The example environment is large and free of other racks or objects. Air is supplied at 60°F and is exhausted uniformly over a 14 ft-high ceiling. As discussed above, under ideal-flow conditions, we can expect air velocity at points near the racks to scale with the dimensionless rack inlet velocities. Further, as discussed above these "response" velocities vary nearly linearly with dimensionless rack flow rate (or velocity). It is, therefore, reasonable to estimate the dimensionless end airflows based on the following expression:

$$QAx_0^* = a_0 + a_{A1}\,QRA_1^* + a_{A2}\,QRA_2^* + \ldots + a_{An}\,QRA_n^* + a_{B1}\,QRB_1^* + a_{B2}\,QRB_2^* + \ldots + a_{Bn}\,QRB_n^* \quad (9)$$

where QAx_0^* is one of four dimensionless end airflows for a cluster and the coefficients a_{Ai} and a_{Bi} effectively weight the relative importance of each rack on the end airflow. The weighting coefficients associated with racks located near the end of the row will be much larger than those associated with more interior racks. Further, empirically it is found that only racks in the first four or five positions nearest the end of the row need be retained in Equation 9. For the fixed conditions considered, the constant a_0 is negative, implying that the flow is "out" (driven by buoyancy) when there is zero rack airflow.

To determine the values of the coefficients in Equation 9 for a particular set of room environment and cluster geometry, many (on the order of 100) CFD simulations may be performed at a number of different perforated tile flow rates. A large pool of rack

power values may be created from which the many CFD simulations draw rack power and airflow data from, either randomly or systematically. The rack power values may be based on the frequency distribution of actual data center racks as determined from a survey. The rack power and airflow values used in the CFD simulations may be scaled as necessary to achieve practical total supply-to-equipment airflow ratios in the range of, for example, 0.9 to 3 for each perforated tile flow rate considered. The CFD data is then used to determine a least-squares fit of the coefficients in Equation 9 for each tile flow rate considered.

In summary, a simple end airflow model has been described which accurately accounts for a non-uniform distribution of rack airflow and power for a fixed set of room conditions. In at least one embodiment, the model is generalized to include the effects of geometric environment, the thermal environment, and supply airflow rate. The effects of the end airflow penetrate only a few rack distances down the row; for longer row lengths predictions for the majority of the racks in the cluster will be good even if the end airflow model is not as accurate as desired.

The airflow into or out of the top of each control volume has been left "floating" as necessary degrees of freedom in the above example. Now, with all of the horizontal airflows computed as discussed above, the airflow at the top of each control volume is computed based on the conservation of mass. With reference to FIG. 13, using dimensional quantities, the equations for A-row and B-row control volumes are determined using equations 9(a) and 9(b).

$$QAtop_i = Q_T - QRA_i + QAx_{i-1} - Qz_i - QAx_i \quad (10a)$$

$$QBtop_i = Q_T - QRB_i + QBx_{i-1} + Qz_i - QBx_i \quad (10b)$$

Applied to all control volumes, equations 9a and 9b represent a total of 2n equations. At this stage, there is only one unknown per equation ($QAtop_i$ and $QBtop_i$) so they may be solved sequentially.

At this point, all airflows within the cold aisle are known for the example. What remains is to track the airflow into each rack so that its origin may be identified and

the recirculation index (RI) can be calculated for each rack. As discussed above, RI is the fraction of recirculated air ingested by a rack. The recirculated air can enter the cold aisle at any point where there is inflow at the ends of the rows or along the top of the cold aisle. Further, the warm recirculated air need not directly enter the cold aisle via the control volume immediately adjacent to a rack of interest; it may enter anywhere, travel anywhere the airflow patterns take it, and end up at the inlet of any rack.

To compute RI for each rack the cool supply air is distinguished from the warm recirculated air at all points in the cold aisle. Mathematically, this is accomplished by defining the concentration of recirculated air at any point in the cold aisle using Equation 11.

$$C_{recirc} = (\text{mass of recirculated air})/(\text{total mass of air}) \quad (11)$$

It follows from Equation 11 that the supply airflow emerging from the tiles has a $C_{recirc}=0$ and that anywhere the recirculated air enters the cold aisle along the sides or top of the cold aisle and C_{recirc} may be set equal to 1. In practice, C_{recirc} may be set to a value less than 1 for the ends of the cold aisle recognizing that, on average, the top is generally much warmer than the ends of the cold aisle. Accordingly, in one embodiment, $C_{recirc}=0.5$ for any inflow at the ends of the cold aisle.

The recirculated air can be assumed to have the same physical properties as the cool supply air so that it has no effect, e.g. due to a density difference, on the airflow patterns in the cold aisle.

Now consider a small volume just covering a rack inlet. Equation 11 applied to this volume represents the average C_{recirc} over this volume. Dividing the numerator and denominator by a small time increment Δt and taking the limit as $\Delta t \rightarrow 0$, demonstrates that the average C_{recirc} over a rack inlet is precisely the rack recirculation index. Thus, to determine the RR's for each rack the average C_{recirc} over each rack inlet is determined. Referring back to FIG. 8, we can estimate the RR for each rack as the average C_{recirc} of the control volume immediately adjacent to the rack of interest.

C_{recirc} over all 2n control volumes can be computed from the conservation of mass of the recirculated air using Equation 12.

$$\sum_{\substack{All\ CV \\ Faces}} C_{recirc} Q = 0 \qquad (12)$$

where Q is the total airflow rate through each control volume face and is a known value at this stage of the calculation.

FIG. 13, shows control volumes 1008 and 1010 of a transverse section of a cold aisle 1006. Equation 12 is applied to the control volumes 1008 and 1010. For convenience, we label the C_{recirc} crossing each control volume surface with same convention used for airflows while dropping the "recirc" subscript. The result is

$$C_T Q_T + (CAx_{i-1})(QAx_{i-1}) = (CRA_i)(QRA_i) + (CAx_i)(QAx_i) + (Cz_i)(Qz_i) + (CAtop_i)(QAtop_i) \qquad (13a)$$

$$C_T Q_T + (CBx_{i-1})(QBx_{i-1}) + (Cz_i)(Qz_i) = (CRB_i)(QRB_i) + (CBx_i)(QBx_i) + (CBtop_i)(QBtop_i) \qquad (13b)$$

Equations 13a and 13b are not solved directly because the number of C_{recirc} values exceeds the number of equations. Estimating each C_{recirc} as the average C_{recirc} from the "upwind" control volume, results in a proper balance of 2n unknown C_{recirc}'s and 2n equations. Based on this "upwind" approach, the appropriate C_{recirc} values are inserted into Equations 13a and 13b after the airflow patterns in the cold aisle have been computed thereby establishing the direction of airflow crossing each face of each control volume.

TABLE 4

C_{recirc} Settings Based on Airflow Direction

Airflow	Upwind Value of C_{recirc}

	Airflow≥0	Airflow<0
Q_t	0	0
QAx_i	CA_i	CA_{i+1}
QBx_i	CB_i	CB_{i+1}
Qz_i	CA_i	CB_i
$QAtop_i$	CA_i	1
$QBtop_i$	CB_i	1

Table 4 shows the appropriate upwind values of C_{recirc} to be used in Equations 13a and 13b where the CA_i and CB_i are the average C_{recirc} over the relevant "A" or "B" control volumes respectively. Not shown in the table are the settings for QAx_i and QBx_i at the end of the row, i.e. Qax_0, QBx_0, QAx_n, and QBx_n. In this case C_{recirc}may be set to 0.5 as discussed above for any "inflow".

With the values of C_{recirc} taken from Table 4, the 2n Equations represented by 13a and 13b may be solved simultaneously for the 2n CA_i and CB_i values. These simple linear equations can be solved without iteration virtually instantaneously for any practical row length using common computing hardware. Finally, as discussed above, the computed CA_i and CB_i values may be directly interpreted as the recirculation index of the adjacent "A" and "B" racks respectively.

In other embodiments, because of the similarity between the energy and concentration equations, bulk average temperature could be determined over each control volume instead of RI following a very similar procedure.

A summary of a process 1050 for determining recirculation index for a cluster of racks using the methodology described above will now be provided with reference to FIG. 14. In a first stage 1052 of the process, the row length, tile airflow, rack airflow and rack power are defined for a cold aisle to be analyzed. Next, in stage 1054, empirical data used for computing airflows is imported from a CFD analysis as described above. The end airflows are then determined at stage 1056 based on details of the cluster and details of the room environment. All horizontal airflows are then determined at stage 1058. At stage 1060, horizontal airflows induced by the 4 end

airflows are computed, and at stage 1062, complete horizontal airflows are computed by adding the airflows from stages 1058 and 1060. Vertical airflows are computed at stage 1064, and then at stage 1066, the recirculation index may be determined for each rack by solving a set of conservation equations for the recirculated air as described above.

In one embodiment, to determine cooling capacity for a given rack based on the recirculation index, a threshold recirculation index is first established, below which a design is considered unsatisfactory. For each rack, after a satisfactory design is achieved, the power of the rack is increased until the recirculation index of the that rack (or any other rack) reaches the threshold level, and the power at which that occurs represents the maximum cooling capacity for the rack. A similar method for determining cooling capacity can be used with other analyses described herein, including the analysis using capture index values described below.

In other embodiments, the control volume and superposition methods described above may be modified. These modifications may include the use of more complex statistical methods (e.g., the use of neural networks) to determine end airflow conditions from large pools of CFD data. Further, the number of control volumes may be substantially increased to improve accuracy and resolution of computed variables. In particular, the latter improvement would allow airflow variations at various rack elevations (e.g., due to a variety of equipment installed in a rack) to be considered. The basic methodology could further be modified to include layouts beyond the scope discussed above including layouts involving an arbitrary number of perforated tiles of arbitrary flow rate, an arbitrary cold aisle width, arbitrary rack dimensions or other such variations from examples discussed above.

In processes described above, cooling analyses of a data center have focused primarily on determining airflows in the cool aisle for a cluster of racks located in a data center having a raised floor. Embodiments described above, however, are not limited for use in data centers having raised floors, and aspects of the embodiments are also applicable to data centers that do not include raised floor cooling systems. At least one embodiment described above provides a decoupling of the cold aisle from the

remainder of the data center to compute airflows in the cold aisle. The effect of the room environment is then built back into the analysis using end-of-row airflows that are computed, for example, in separate CFD calculations that may be computed offline and made available through look-up tables or empirical correlations. As described below, in a similar manner to that described above, a hot aisle in a data center can be analyzed by decoupling the aisle from the remainder of the room and later building the effects of the room environment back into the analysis.

In additional embodiments that will now be described, processes are provided for evaluating a cluster of racks based on airflows that occur in a hot aisle for a cluster of racks. In at least one version of the additional embodiments, a raised floor data center is not used, but rather, cooling is provided using in-row cooling units as described above. In one particular process of one embodiment, a capture index (CI) is calculated and used to analyze a cluster of racks in a data center. The capture index is used in one embodiment with a row or cluster of racks having one or more in-row cooling units, and the capture index is defined as the percentage of air released by a rack into a hot aisle, which is captured by cooling units bounding the hot aisle. The CI may be considered as a complementary metric to the RI described above for use with the hot aisle. However, CI techniques may also be used with cold aisle analysis as discussed further in U.S. Provisional Application 60/897,076, filed on January 24, 2007 which is hereby incorporated herein for all purposes. The CI is useful when the focus of a design is to keep the hot air within the hot aisle. As discussed above, rack inlet temperatures are typically the ultimate cooling metric, however, if all of the hot air is captured in the hot aisle, the rest of the data center (including rack inlets) can be designed and controlled to remain at "room temperature."

The cold-aisle capture index is defined as the fraction of air ingested by the rack which originates from local cooling resources (e.g., perforated floor tiles or local coolers). The hot-aisle capture index is defined as the fraction of air exhausted by a rack which is captured by local extracts (e.g., local coolers or return vents). CI therefore varies between 0 and 100% with better cooling performance generally indicated by greater CI values. In a cold-aisle analysis, high CI's ensure that the bulk

of the air ingested by a rack comes from local cooling resources rather than being drawn from the room environment or from air which may have already been heated by electronics equipment. In this case, rack inlet temperatures will closely track the perforated-tile airflow temperatures and, assuming these temperatures are within the desired range, acceptable cooling will be achieved. In a hot-aisle analysis, high CI's ensure that rack exhaust is captured locally and there is little heating of the surrounding room environment.

While good (high) CI values typically imply good cooling performance; low CI values do not necessarily imply unacceptable cooling performance. For example, consider a rack in a raised-floor environment which draws most of its airflow from the surrounding room environment rather than from the perforated tiles. The rack's cold-aisle CI will be low; however, if the surrounding room environment is sufficiently cool, the rack's inlet temperature will be acceptable anyway. However, in this case, the rack's cooling needs are met by the external room environment rather than perforated tiles within the rack's cluster. If this process is repeated many times across the data center, facility cooling will be complex and unpredictable. Thus, high CI values lead to inherently scalable cluster layouts and more predictable room environments.

Note that, although CI has been defined above as a rack-level quantity relative to local cooling resources, the definition of CI could be extended to any grouping of inlets and outlets, for example, a single server with reference to a single perforated tile. In this case, the metric would indicate the fraction of airflow ingested by the server which originated from the single perforated tile.

In one embodiment, the use of chemical concentrations with, for example a CFD analysis, can be used to quantitatively determine CI for both a hot aisle and a cold aisle. For the hot aisle, the exhaust of each rack is identified in such an analysis as a separate species having the same properties as air, so as not to change the physics of airflow. The fraction of hot air released from $rack_i$ (identified as C^i) which is captured by an in-row cooler identified as $cooler_j$ may be computed using Equation 14 below.

$$f_{ij}=C_j^i(Q_{coolerj})/Q_{racki}) \quad (14)$$

where:

C_{ji} is the concentration of C^i at the inlet of cooler j

$Q_{coolerj}$ is the airflow rate (e.g. in cfm) through coolerj

Q_{racki} if the airflow rate (e.g. in cfm) through racki

As an example, if the cooler and rack airflow are equal, and the concentration of exhaust air C^i from rack i at the cooler inlet is measured to be 0.5, then this implies that half of the exhaust air from rack i is captured by cooler j. In a hot aisle having N coolers, then the capture index (CI) is the sum of all of the f_{ij}'s over all N coolers and can be expressed using Equation 15 below.

$$CI_i = \sum_{j=1}^{N} C_j^i \frac{Q_{coolerj}}{Q_{racki}} \quad (15)$$

As will now be described, with reference to FIG. 15, which shows a cluster of racks 1080, a set of empirical rules can be used to determine the CI for each rack 1082 of the cluster. As shown in FIG. 15, the resulting CI values may be displayed on a display with the associated racks. In one example, racks having a CI less than 60% are identified in red indicating a warning, racks having a CI between 60% and 80% are indicated in yellow as a caution, and racks having a CI greater than 80% are indicated in green indicating that the CI is satisfactory.

In one embodiment, a large pool of CFD runs can be performed to establish and refine empirical rules. In other embodiments, neural networks and other techniques may be used to refine rules. The cluster 1080 includes two rows (row A and row B) of parallel racks that exhaust air to a common hot aisle 1084. Each Rack is labeled A1-A6 and B1-B7, identifying the row and position in the row of the rack, and for the example shown each rack has a power draw of 2 kW. The cluster also includes in-row cooling units 1086. In FIG. 15, a number of half-rack cooling units 1086 are shown, but embodiments of the invention may also be used with full-width

rack cooling units or other devices. The half-rack cooling units used in the example associated with FIG. 15 have a nominal cooling capacity of 17 kW. Also shown in FIG. 15 is the CI in terms of percentage for each rack. The CI is shown as a percentage and indicates for each rack, the percentage of its exhaust air that is captured by one of the cooling units.

The CI is determined based on the concept that all rack-cooling unit interactions depend only on the magnitude of airflow associated with the racks and cooling units and their relative geometric positions. Each rack location can be thought of as having a certain potential to supply airflow to other rack locations. This potential varies inversely with the distance of separation. For example, rack A1 in FIG. 15 could potentially supply a large portion of its airflow to the area near rack A2. However, much less of rack A1's airflow could make its way to position A6. Further, the amount of airflow a rack can supply to other locations is in direct proportion to its own total airflow. The net airflow which can be supplied to a particular rack location A1 can be represented using Equation 16 below.

$$(Q_{Ai})_{net} = (Q_{Ai})_{self} + \sum_{all\ other\ racks\ j} (Q_{Aj})_{self} Ae^{-B\Delta x} + c\{(Q_{Bi})_{self} + \sum_{all\ other\ racks\ j} (Q_{Bj})_{self} Ae^{-B\Delta x}\} \quad (16)$$

where

$(Q_{Ai})_{net}$=The net maximum airflow that can be supplied to location Ai including contributions from all other racks.

$(Q_{Ai})_{self}$=The actual airflow supplied by the rack at location Ai.

A=empirical constant.

B=empirical constant.

C=empirical "coupling" constant for accounting for effects from opposite row.

The net maximum airflow that can be supplied to various locations in the B row is computed using a similar expression. Finally, the same expression is used to

compute the net maximum airflow, which can be captured at any rack location – with the sum over all coolers instead of racks. The CI is then estimated as the ratio of net airflow captured and net airflow supplied at any location expressed as a percentage and with values capped at 100%. The constants A, B, and C are selected to provide the best statistical fit to benchmark CFD data. Different values of the constants may be used to account for alternative configurations including different cooler types, different average rack power or peak-to-average power ratios and alternative hot-aisle spacing, row lengths, or room environments. As an example, consider a cluster of average power racks with modest rack-to-rack power variations. The cluster is 14 ft. long, contains a 3 ft. wide hot aisle, and is assumed to be in a fairly tightly packed data center environment with a 12 ft. ceiling height. In this case, reasonable predictions are made with the empirical constants taken as A=0.56, B=0.33, and C=0.65.

In the embodiment described above, the CI is calculated for a cluster of racks having uniform depth and width. In other embodiments, the same processes may be used for racks of non-uniform depth and width. In one embodiment, the CI calculations described above are programmed into a Microsoft Excel Spreadsheet program that allows a user to add and move cooling units to see the effect of different numbers of cooling units and their placements. In other embodiments, the process for determining CI described above may be incorporated into data center design and management systems, such as system 200 discussed above.

In the embodiment above, an exponential expression is used for modeling the rack and cooler interactions. In other embodiments, other expressions may be used, such as a polynomial or any other mathematical expression which contains a number of parameters which may be tuned to provide the best fit to benchmark performance data. Further, different curves and/or different coefficients may be used for the portion of the calculation associated with determining air supplied by racks than used in the portion of the calculation used for determining air captured by cooling units. In another embodiment, the rules may be further refined to address specific situations. For example, a Rack A may have no effect on another Rack B where a third rack C is

located between Rack A and Rack B and has greater airflow than either Rack A or Rack B.

In still another embodiment, the effects of the ends of rows may be accounted for explicitly in hot aisle and cold aisle CI analysis. Separate CFD simulations may be conducted to determine the net inflow or outflow of air at each end of a row for given layouts of racks and cooling units. The results of the CFD simulations may be incorporated into the empirical methods described above to determine CI for racks in a cluster. The results of the CFD simulations can be used to provide correct airflow estimates at the ends of the row, while one of the algorithms discussed above may be used to determine CI at more interior portions of the row. Similarly, the effects of a missing rack or racks may be simulated using CFD with the results incorporated into the empirical methods.

The capture index method of analysis discussed above provides a rack-by-rack, or local, cooling performance metric for equipment racks in a data center. In addition to using CI as a rack-level metric in a hot aisle analysis or cold aisle analysis, in another embodiment, cluster-wide performance metrics are determined, and the overall cooling performance of the cluster may be determined based on both the CI metric and the global metric. The cluster-wide performance metrics indicate whether the cluster as a whole will have adequate cooling performance. The CI identifies which racks are not having their exhaust airflow adequately captured. If a rack having a low CI is a low power rack, this may not result in a problem. Furthermore, a rack may have a relatively high CI, yet still cause problems if it is a high power rack with a high outlet temperature. In one embodiment, for a hot aisle analysis the global metric that is used is a determination of the net power which escapes the hot aisle. The net escaped power can be determined using equation 17.

$$\sum_{all\ racks\ i}(1-CI_i)P_i \qquad (17)$$

where,

CI_i=the capture index for rack i expressed as a fraction (rather than percentage), and

P_i=the power of rack i.

The net escaped power determined by equation 17 may be correlated to maximum cluster inlet temperatures (e.g., a net escaped power of 25 kW may imply a maximum cluster rack inlet temperature of seventy-nine degrees F) for clusters of particular geometric layouts (e.g., hot aisle width, row length, etc.), room environments and rack and cooler details (e.g., cooling unit flow rate and rack airflow/power (cfm/kW)). Accordingly, the net escaped power may be used to determine the highest rack inlet temperature.

In other embodiments, other techniques described above for calculating airflows in a cool aisle may be applied to a hot aisle or cold aisle analysis to determine CI, including the use of CFD, CGCFD and control volumes. The use of superposition may be less applicable in hot aisle analyses because the airflow patterns are not ideal. In still another embodiment, a process 1100 is provided for determining CI in a hot aisle using a CFD analysis. The CFD analysis is performed only on the hot aisle itself and end of row airflows are determined separately and may be patched into the CFD solution. Common computer hardware can be used to conduct such a CFD analysis in 10 to 20 seconds. The process 1100 is shown in flowchart form in FIG. 16. In a first stage 1102 of the process 1100 data related to the layout is loaded either manually, read from a database, or in any other manner. The data related to the layout may include row length, power draw and airflow for each rack, rack dimensions, cooling unit types, locations and flow rates, hot aisle widths and room environment details (i.e., size, temperatures).

At stage 1104 of the process 1100, hot-aisle end of row airflows are determined using best-fit curves, or look-up tables based on prior CFD studies. Hot aisle end of row calculations may be performed using the same techniques used to determine cold aisle end of row airflows with the input rack airflow provided as a positive value and the cooling units airflow input as a negative value. At stage 1106, a CFD analysis of just the hot aisle is performed using results of the end airflow analysis of stage 1104 and with the top of the hot aisle taken as a constant-pressure boundary. In the analysis, the exhaust air for each rack is "tagged" with a particular concentration. At stage 1108, the CI for each rack is determined based on the ratio of captured and

supplied airflows computed by equation 16 and the results of stage 1106. The global cluster cooling metric may also be determined at this point using equation 17. At stage 1110, the rack CI's and the global cluster cooling metric can be used to determine if cooling for the cluster is adequate.

In addition to the cooling analysis methods discussed above, which provide real-time analysis of data centers, additional cooling analysis methods may be used in embodiments of the invention. These additional methods include a panel method, a potential analysis method, flow network/zonal modeling, principal component analysis or a combination of any of these and the methods discussed above. These additional cooling analysis methods are generally known to those of skill in the art.

Various embodiments according to the invention may be implemented on one or more computer systems as discussed above. These computer systems may include cellular phones, personal digital assistants and/or other types of mobile computing devices. Moreover, a computer system may include any sort of computing device such as a personal computer, a workstation, a mainframe, a networked client, a server, media servers and application servers. For example, system 200 may be implemented in a single computer system or in multiple computer systems. These computer systems may be, for example, general-purpose computers such as those based on Intel PENTIUM-type processor, Motorola PowerPC, Sun UltraSPARC, Hewlett-Packard PA-RISC processors, or any other type of processor.

For example, various aspects of the invention may be implemented as specialized software executing in a general-purpose computer system 900 such as that shown in Figure 17. The computer system 900 may include a processor 903 connected to one or more memory devices 904, such as a disk drive, memory, or other device for storing data. Memory 904 is typically used for storing programs and data during operation of the computer system 900. The computer system 900 may also include a storage system 906 that provides additional storage capacity. Components of computer system 900 may be coupled by an interconnection mechanism 905, which may include one or more busses (e.g., between components that are integrated within a same machine) and/or a network (e.g., between components that reside on

separate discrete machines). The interconnection mechanism 905 enables communications (e.g., data, instructions) to be exchanged between system components of system 900.

Computer system 900 also includes one or more input devices 902, for example, a keyboard, mouse, trackball, microphone, touch screen, and one or more output devices 907, for example, a printing device, display screen, speaker. In addition, computer system 900 may contain one or more interfaces (not shown) that connect computer system 900 to a communication network (in addition or as an alternative to the interconnection mechanism 905).

The storage system 906, shown in greater detail in Figure 18, typically includes a computer readable and writeable nonvolatile recording medium 911 in which signals are stored that define a program to be executed by the processor or information stored on or in the medium 911 to be processed by the program to perform one or more functions associated with embodiments described herein. The medium may, for example, be a disk or flash memory. Typically, in operation, the processor causes data to be read from the nonvolatile recording medium 911 into another memory 912 that allows for faster access to the information by the processor than does the medium 911. This memory 912 is typically a volatile, random access memory such as a dynamic random access memory (DRAM) or static memory (SRAM). It may be located in storage system 906, as shown, or in memory system 904. The processor 903 generally manipulates the data within the integrated circuit memory 904, 912 and then copies the data to the medium 911 after processing is completed. A variety of mechanisms are known for managing data movement between the medium 911 and the integrated circuit memory element 904, 912, and the invention is not limited thereto. The invention is not limited to a particular memory system 904 or storage system 906.

The computer system may include specially-programmed, special-purpose hardware, for example, an application-specific integrated circuit (ASIC). Aspects of the invention may be implemented in software, hardware or firmware, or any combination thereof. Further, such methods, acts, systems, system elements and

components thereof may be implemented as part of the computer system described above or as an independent component.

Although computer system 900 is shown by way of example as one type of computer system upon which various aspects of the invention may be practiced, it should be appreciated that aspects of the invention are not limited to being implemented on the computer system as shown in FIG. 17. Various aspects of the invention may be practiced on one or more computers having a different architecture or components shown in FIG. 17. Further, where functions or processes of embodiments of the invention are described herein (or in the claims) as being performed on a processor or controller, such description is intended to include systems that use more than one processor or controller to perform the functions.

Computer system 900 may be a general-purpose computer system that is programmable using a high-level computer programming language. Computer system 900 may be also implemented using specially programmed, special purpose hardware. In computer system 900, processor 903 is typically a commercially available processor such as the well-known Pentium class processor available from the Intel Corporation. Many other processors are available. Such a processor usually executes an operating system which may be, for example, the Windows 95, Windows 98, Windows NT, Windows 2000 (Windows ME) or Windows XP operating systems available from the Microsoft Corporation, MAC OS System X operating system available from Apple Computer, the Solaris operating system available from Sun Microsystems, or UNIX operating systems available from various sources. Many other operating systems may be used.

The processor and operating system together define a computer platform for which application programs in high-level programming languages are written. It should be understood that embodiments of the invention are not limited to a particular computer system platform, processor, operating system, or network. Also, it should be apparent to those skilled in the art that the present invention is not limited to a specific programming language or computer system. Further, it should be appreciated

that other appropriate programming languages and other appropriate computer systems could also be used.

One or more portions of the computer system may be distributed across one or more computer systems coupled to a communications network. For example, as discussed above, a computer system that performs build-out functions may be located remotely from a system manager. Remote computer systems also may include remote general-purpose computer systems and/or remote computing devices. For example, various aspects of the invention may be distributed among one or more computer systems configured to provide a service (e.g., servers) to one or more client computers, or to perform an overall task as part of a distributed system. For example, various aspects of the invention may be performed on a client-server or multi-tier system that includes components distributed among one or more server systems that perform various functions according to various embodiments of the invention. These components may be executable, intermediate (e.g., IL) or interpreted (e.g., Java) code which communicate over a communication network (e.g., the Internet) using a communication protocol (e.g., TCP/IP). For example, one or more database servers may be used to store device data that is used in designing layouts, and one or more servers may be used to efficiently perform cooling calculations associated with embodiments of the present invention.

It should be appreciated that the invention is not limited to executing on any particular system or group of systems. Also, it should be appreciated that the invention is not limited to any particular distributed architecture, network, or communication protocol.

Various embodiments of the present invention may be programmed using an object-oriented programming language, such as SmallTalk, Java, C++, Ada, or C# (C-Sharp). Other object-oriented programming languages may also be used. Alternatively, functional, scripting, and/or logical programming languages may be used. Various aspects of the invention may be implemented in a non-programmed environment (e.g., documents created in HTML, XML or other format that, when viewed in a window of a browser program, render aspects of a graphical-user

interface (GUI) or perform other functions). Various aspects of the invention may be implemented as programmed or non-programmed elements, or any combination thereof.

A variety of system elements including inputs, outputs and interfaces may exchange information with various external entities that may be information providers and/or information consumers. These external entities may include users and/or systems. Each of these system elements may both restrict exchanged information to a predefined set of values and validate any information exchanged prior to using the information or providing the information to other components.

In embodiments of the invention discussed above, systems and methods are described that provide indications of remaining cooling capacity for equipment enclosures. The indication of remaining cooling capacity may be a direct indication of remaining cooling in terms of, for example, kilowatts or BTU per hour, or the indication may be indirect such as providing the total capacity of cooling available to an enclosure along with an indication of how much cooling is being used, for example, in terms of percentage. Further, calculated values, including the capture index and the recirculation index may be used to determine the sufficiency of a particular design and to determine additional cooling capacity before a warning or error condition will result.

Embodiments of a systems and methods described above are generally described for use in relatively large data centers having numerous equipment racks, however, embodiments of the invention may also be used with smaller data centers and with facilities other than data centers. Further, as discussed above, embodiments of the present invention may be used with facilities having raised floors as well as with facilities that do not have a raised floor.

In embodiments of the present invention discussed above, results of analyses are described as being provided in real-time. As understood by those skilled in the art, the use of the term real-time is not meant to suggest that the results are available immediately, but rather, are available quickly giving a designer the ability to try a number of different designs over a short period of time, such as a matter of minutes.

Having thus described several aspects of at least one embodiment of this invention, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

CLAIMS

1. A computer-implemented method for providing a representation of capacity of a data center resource, the method comprising acts of:

determining an first indication of excess capacity of a first data center resource that is unusable due to insufficient capacity of at least one other data center resource associated with the first data center resource; and

providing the first indication of excess capacity of the first data center resource to an external entity.

2. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an amount of excess capacity of the first data center resource that is unusable due to insufficient capacity of the at least one other data center resource associated with the first data center resource.

3. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity at a location in a rack.

4. The method according to claim 3, wherein the act of determining the first indication of excess capacity at the location in the rack includes an act of determining an indication of excess capacity at a U space position.

5. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of rack space that is unusable due to insufficient capacity of power.

6. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power that is unusable due to insufficient capacity of cooling.

7. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power distribution that is unusable due to insufficient capacity of power available for distribution.

8. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of physical space that is unusable due to insufficient capacity of cooling.

9. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of power distribution that is unusable due to insufficient capacity of network connectivity.

10. The method according to claim 1, wherein the act of determining the first indication of excess capacity includes an act of determining an indication of excess capacity of U space that is unusable due to insufficient capacity of weight support.

11. The method according to claim 1, wherein the act of providing the first indication of excess capacity includes an act of providing the indication to another system element.

12. The method according to claim 1, wherein the act of providing the first indication of excess capacity includes an act of presenting the first indication to a user of a computer system.

13. The method according to claim 12, wherein the act of presenting the first indication to the user of the computer system includes an act of presenting, to the user of the computer system, an amount of excess capacity of the first data center resource

that is unusable due to insufficient capacity of the at least one other data center resource associated with the first data center resource.

14. The method according to claim 13, wherein the act of presenting, to the user of the computer system, the amount of excess capacity includes acts of:

presenting, to the user of the computer system, an identifier that identifies the first data center resource; and

presenting, to the user of the computer system, an identifier that identifies the at least one other data center resource.

15. The method according to claim 1, further comprising:

determining a configuration of data center equipment that minimizes, relative to at least one other configuration, the excess capacity of the first data center resource; and

providing the configuration of data center equipment to an external entity.

16. The method according to claim 15, wherein determining the configuration of data center equipment includes determining a location for at least one element of data center equipment.

17. The method according to claim 1, further comprising:

determining a second indication of excess capacity of a second data center resource that is unusable due to insufficient capacity of at least one other data center resource associated with the second data center resource;

determining a configuration of data center equipment that minimizes, relative to at least one other configuration, an aggregate of the first indication and the second indication; and

providing the configuration of data center equipment to an external entity.

18. A computer-implemented method for providing a representation of a data center resource, the method comprising acts of:

determining a status of capacity for the data center resource provided to either a rack or a location in a rack; and

providing the status to an external entity.

19. The method according to claim 18, wherein determining the status of capacity for the data center resource includes determining a status for the data center resource provided to a U space position.

20. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of power.

21. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of cooling.

22. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of physical space.

23. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of capacity of weight support.

24. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of available capacity.

25. The method according to claim 18, wherein the act of determining the status of capacity for the data center resource includes an act of determining a status of utilized capacity.

26. A computer-implemented method for providing a representation of a data center resource, the method comprising the acts of:

determining a rate of change of a utilized capacity of the data center resource based at least in part on changes to a data center configuration; and

providing a predicted utilization of the data center resource based at least in part on the rate of change.

27. The method according to claim 26, wherein determining the rate of change of utilized capacity of the data center resource includes determining the rate of change using linear regression.

28. The method according to claim 26, wherein the data center resource includes power.

29. The method according to claim 26, wherein the data center resource includes cooling.

30. A system for providing a representation of a capacity of data center resource, the system comprising:

an input configured to receive a capacity of a first data center resource and a capacity of at least one other data center resource;

an output configured to provide an amount of excess capacity of the first data center resource; and

a controller coupled to the input and the output and configured to determine an amount of excess capacity of the first data center resource that is unusable due to insufficient capacity of the at least one other data center resource.

31. A system for providing a representation of a data center resource, the system comprising:

an input configured to receive capacity information for a data center resource;

an output configured to provide a status of capacity for the data center resource; and

a controller coupled to the input and the output and configured to determine the status of capacity for the data center resource at either a rack or a location in a rack.

32. A system for providing an evaluation of a data center resource, the system comprising:

an input configured to receive changes in a data center configuration;

an output configured to provide a predicted utilization of the data center resource based on a rate of change of utilized capacity of the data center resource; and

a controller configured to determine the rate of change of the utilized capacity of the data center resource based on the changes in a data center configuration.

33. A computer-implemented method for managing a data center configuration, the method comprising acts of:

receiving, from a user, a proposed change to the data center configuration though an interactive representation of a layout of an identified space in a data center, the proposed change including data identifying at least one element of data center equipment to be provisioned in the data center, the at least one element of data center equipment having a plurality of data center resource requirements;

determining at least one location in the data center having a plurality of data center resources that satisfy the plurality of data center resource requirements of the at least one element of data center equipment; and

storing the at least one location on a computer readable medium.

34. The method according to claim 33, wherein the act of receiving, from the user, the proposed change to the data center configuration includes an act of receiving data identifying at least one element of floor mounted data center equipment to be provisioned in the data center.

35. The method according to claim 33, wherein the act of receiving, from the user, the proposed change includes an act of receiving, from the user, the proposed change to the data center configuration though an interactive representation of a layout of a data center room.

36. The method according to claim 33, wherein the act of receiving, from the user, the proposed change includes an act of receiving, from the user, the proposed change to the data center configuration though an interactive representation of a layout of a rack.

37. The method according to claim 33, wherein the act of receiving, from the user, the proposed change to the data center configuration includes an act of receiving information regarding at least one element of data center equipment represented in the interactive representation.

38. The method according to claim 33, wherein the act of receiving, from the user, the proposed change to the data center configuration includes an act of scanning a barcode.

39. The method according to claim 33, wherein the act of determining the at least one location includes an act of determining at least one location in near real-time.

40. The method according to claim 33, wherein the act of determining the at least one location includes an act of receiving, from an external entity, data identifying at

least one location in the data center for the at least one element of data center equipment having a plurality of data center resources.

41. The method according to claim 33, wherein the act of determining the at least one location includes an act of determining a location that minimizes, relative to at least one other location, an amount of excess data center resource capacity that is unusable due to insufficient associated capacity of at least one other data center resource, and the method further comprises providing the at least one location to an external entity.

42. The method according to claim 41, wherein the act of providing the at least one location further includes an act of presenting the at least one location to a user of a computer system.

43. The method according to claim 33, wherein the act of determining the at least one location includes an act of determining a series of locations arranged consecutively according to an amount of excess data center resource capacity that is unusable due to insufficient associated capacity of at least one other data center resource and the method further comprises providing the series of locations to an external entity.

44. The method according to claim 43, wherein the act of providing the at least one location includes an act of presenting the series to a user of a computer system.

45. The method according to claim 33, further comprising an act of presenting, to the user, information regarding the proposed change to the data center configuration, the information including a representation of at least one element of data center equipment that is disposed in a rack.

46. The method according to claim 45 wherein the act of presenting, to the user, the information regarding the proposed change to the data center configuration includes an act of presenting, to the user, a representation of the at least one element of data center equipment as placed in inactive storage, and the method further includes an act of recording the at least one element of data center equipment as placed in inactive storage.

47. The method according to claim 45, wherein the act of presenting, to the user, the information regarding the proposed change to the data center configuration includes an act of presenting, to the user, an interactive representation that is updated based on the proposed change.

48. The method according to claim 47, wherein the act of presenting, to the user, the interactive representation that is updated based on the proposed change includes an act of presenting, to the user, the interactive representation updated in near real-time.

49. The method according to claim 33, further comprising:

generating a work order identifying a set of tasks required to complete the proposed change; and

presenting the set of tasks via an output of a computer system.

50. The method according to claim 49, further comprising acts of:

detecting a change in the power demanded at power distribution device associated with the work order; and

recording the work order as completed based on the change in power demanded.

51. The method according to claim 33, wherein the method is performed using a remote computing device.

52. A computer-implemented method for managing a data center configuration, the method comprising acts of:

receiving at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment;

receiving a proposed change to the data center configuration; and

determining a compliance result that indicates whether the data center configuration, including the proposed change, complies with the at least one policy.

53. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a redundancy level.

54. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a runtime requirement.

55. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a security requirement.

56. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of cooling.

57. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of network connectivity.

58. The method according to claim 52, wherein the act of receiving the at least one policy includes an act of receiving at least one policy identifying a requirement of power.

59. The method according to claim 58, wherein the act of receiving the at least one policy identifying a requirement of power includes an act of receiving at least one policy identifying a requirement of power distribution.

60. A computer-implemented method for designing a data center, the method comprising acts of:

receiving at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment;

receiving data identifying at least one location in the data center for at least one element of data center equipment, the at least one location having a plurality of data center resources and the at least one element of data center equipment having a plurality of data center resource requirements; and

determining at least one element of data center equipment that satisfies the policy when located at the at least one location, wherein the plurality of data center resources of the at least one location satisfy the plurality of data center resource requirements of the at least one element of data center equipment.

61. A system for managing a data center configuration comprising:

an input configured to receive, from a user, a proposed change to the data center configuration though an interactive representation of a layout of an identified space in a data center;

an output configured to provide a set of tasks to a user; and

a controller coupled to the input and the output and configured to generate a work order identifying the set of tasks required to complete the proposed change and to provide the set of tasks to the output.

62. The system according to claim 61, further comprising a computer readable medium coupled to the controller and wherein the input is further configured to receive status information associated with the work order and the controller is further configured to record the status information in the computer readable medium.

62. The system according to claim 61, further comprising an input configured to receive, from a user, status information associated with the work order and wherein the controller is further configured to provide the status information to the output.

63. A system for managing a data center configuration comprising:

a first input configured to receive at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment;

a second input configured to receive a proposed change to the data center configuration; and

a controller coupled to the first and second inputs and configured to determine a compliance result that indicates whether the data center configuration, including the proposed change, complies with the at least one policy.

64. A system for designing a data center, the system comprising:

an first input configured to receive at least one policy identifying at least one characteristic of a data center resource as provided to at least one element of data center equipment;

a second input configured to receive data identifying at least one location in the data center for at least one element of data center equipment, the at least one location having a plurality of data center resources and the at least one element of data center equipment having a plurality of data center resource requirements; and

a controller coupled to the first and second inputs and configured to determine at least one element of data center equipment that satisfies the policy when located at the at least one location, wherein the plurality of data center resources of the at least

one location satisfy the plurality of data center resource requirements of the at least one element of data center equipment.

65. A remote computing device for navigating a representation of a data center, the remote computing device comprising:

an interface configured to present, to a user, an interactive representation of a layout of an identified space in a data center and to receive, from the user, an identifier of at least one element of data center equipment located in the data center;

a memory configured to store information regarding data center equipment represented by the interface; and

a controller coupled to the interface and memory and configured to retrieve information regarding the identified at least one element of data center equipment from the memory and provide the information to the interface.

66. A computer-implemented method for managing data center resource redundancy, the method comprising acts of:

determining a redundancy level of a data center resource at a location in a rack; and

providing the redundancy level of the data center resource.

67. The method according to claim 66, wherein the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of cooling.

68. The method according to claim 66, wherein the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of network connectivity.

69. The method according to claim 66, wherein the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of power.

70. The method according to claim 66, wherein the act of determining the redundancy level of the data center resource includes an act of determining a redundancy level of power distribution.

71. The method according to claim 66, wherein the act of determining the redundancy level of the data center resource at a location in a rack includes an act of determining a redundancy level of a data center resource at a U space position.

72. The method according to claim 66, wherein the act of providing the redundancy level includes an act of presenting, to a user of a computer system, a representation of the at least one location in a rack.

73. The method according to claim 72, wherein the act of presenting, to the user of the computer system, the representation of the at least one location in the rack includes an act of presenting, to a user of a computer system, a representation at least one U space position in a rack.

74. The method according to claim 72, wherein the act of presenting, to the user of the computer system, the representation of the at least one location in the rack includes an act of presenting, to a user of a computer system, a representation of a redundancy relationship between elements disposed in a data center.

75. The method according to claim 74, wherein the act of presenting, to the user of the computer system, a representation of a redundancy relationship between elements disposed in a data center includes an act of presenting, to a user of a computer system, a redundancy relationship between elements disposed in a rack.

76. A system for managing data center resource redundancy, the system comprising:

a controller configured to determine the redundancy level of a data center resource at a location in a rack; and

an output coupled to the controller and configured to provide a representation of the redundancy level of the data center resource.

77. The system according to claim 76, wherein the location in the rack includes a U space position in a rack.

78. The system according to claim 77, wherein the system includes a remote computing device.

79. A computer-implemented method for distributing data describing models of data center equipment, the method comprising acts of:

indicating a first group of the data describing models of data center equipment, the first group identifying standard models of data center equipment;

indicating a second group of the data describing models of data center equipment, the second group identifying models approved for use in a first data center;

indicating a third group of the data describing models of data center equipment, the third group identifying models preferred for use in the first data center;

providing the second group to a first remote computing device located in the first data center; and

providing the third group to the first remote computing device located in the first data center.

80. The method according to claim 79, wherein the act of providing the second group comprises an act of providing data including at least one of the group comprising:

data center equipment manufacturer;

data center equipment model;

data center equipment power plug type;

data center equipment number of plugs required;

data center equipment power required;

data center equipment airflow required;

data center equipment network connectivity required;

data center equipment weight support required;

data center equipment cooling required; and

data center equipment physical space required.

81. The method according to claim 79, further comprising an act of providing the third group from the first remote computing device to a second remote computing device.

82. The method according to claim 81, wherein the act of providing the third group from the first remote computing device includes an act of providing the third group to a mobile computing device.

83. The method according to claim 79, wherein the act of indicating a first group includes storing an indicator of the first group in a database hosted by a system provider.

84. The method according to claim 79, further comprising an act of receiving first non-standard data describing models of data center equipment from the first remote computing device.

85. The method according to claim 79, further comprising an act of receiving non-standard data describing models of data center equipment from an external entity.

86. The method according to claim 85, wherein the act of receiving non-standard data includes receiving additional data from a data center equipment manufacturer.

87. The method according to claim 79, further comprising acts of:

indicating a fourth group of the data describing models of data center equipment, the fourth group identifying models approved for use in a second data center;

indicating a fifth group of the data describing models of data center equipment, the fifth group identifying models preferred for use in the second data center;

providing the fourth group to a third remote computing device located in the second data center; and

providing the fifth group to the third remote computing device located in the second data center.

88. The method according to claim 87, further comprising an act of receiving second non-standard data describing models of data center equipment from the third remote computing device.

89. A computer-implemented method for maintaining a data center equipment database, the method comprising acts of receiving a set of configuration management data from each of a plurality of data centers, each set of configuration management data identifying one of the plurality data centers, a capacity for power of the identified data center, a capacity for cooling of the identified data center and at least one element of data center equipment disposed within the identified data center.

90. The method according to claim 89, wherein the acts of receiving include acts of receiving configuration management data including at least one of the group comprising:

data center physical dimensions;

data center equipment location within the data center physical dimensions;

data center power distribution provided to the data center equipment location;

data center cooling distribution provided to the data center equipment location;

data center network connectivity provided to the data center equipment location;

data center equipment manufacturer; and

data center equipment model.

91. The method according to claim 89, further comprising acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers, each set of data center resource consumption and production data identifying one of the plurality of data centers and being associated with at least one element of data center equipment disposed within the identified data center.

92. The method according to claim 91, wherein the acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers include acts of receiving data center resource consumption and production data including at least one from the group comprising:

data center equipment identity;

data center equipment manufacturer;

data center equipment model;

data center equipment power plug type used;

data center equipment number of plugs used;

data center equipment power used;

data center equipment airflow used;

data center equipment network connectivity used;

data center equipment weight support used;

data center equipment cooling used; and

data center equipment physical space used.

93. The method according to claim 91, wherein the acts of receiving a set of data center resource consumption and production data from each of the plurality of data centers include acts of receiving data center resource consumption and production data including at least one from the group comprising:

data center equipment identity;

data center equipment manufacturer;

data center equipment model;

data center equipment power plug type provided;

data center equipment number of plugs provided;

data center equipment power provided;

data center equipment airflow provided;

data center equipment network connectivity provided;

data center equipment weight support provided;

data center equipment cooling provided; and

data center equipment physical space provided.

94. A computer-implemented method for distributing data describing models of data center equipment, the method comprising acts of:

receiving, from a first remote computing device, a first group of the data describing models of data center equipment, the first group identifying models approved for use in a data center;

receiving, from the first remote computing device, a second group of the data describing models of data center equipment, the second group identifying models preferred for use in the data center; and

providing the second group to a second remote computing device.

95. The method according to claim 94, further comprising acts of:

receiving, from an external entity, non-standard data describing models of data center equipment that are not approved for use in the data center; and

providing the non-standard data to the first remote computing device.

96. A system for managing equipment data describing models of data center equipment, the system comprising:

an input configured to receive data associated with the equipment data;

an output configured to provide data associated with the equipment data; and

a controller coupled to the input and the output and configured to allow an external entity to indicate that a first group of the equipment data describes standard models of data center equipment; to indicate that a second group of the equipment data describes models of data center equipment approved for use in a data center, to indicate that a third group of the equipment data describes models of data center equipment preferred for use in the data center and further configured to provide, via the output, the second group to a remote computing device located in the data center and to provide, via the output, the third group to the remote computing device located in the data center.

97. A system for managing equipment data describing models of data center equipment, the system comprising:

a computer readable medium;

an input configured to receive data associated with the equipment data;

an output configured to provide data associated with the equipment data; and

a controller coupled to the input, the output and the computer readable medium and configured to store, in the computer readable medium, an first indication that a first group of the equipment data describes models of data center equipment approved for use in a data center and to store a second indication that a second group of equipment data describes models of data center equipment preferred for use in the data center and further configured to provide, via the output, the second group to a remote computing device located in the data center.

98. A system for maintaining a data center equipment database, the system comprising:

an input configured to receive a set of configuration management data from each of a plurality of data centers, each set of configuration management data identifying one of the plurality data centers, a capacity for power of the identified data center, a capacity for cooling of the identified data center and at least one element of data center equipment disposed within the identified data center; and

a controller coupled to the input and configured to store, in the data center equipment database, each set of configuration management data.

99. The remote computing device according to claim 65, wherein the remote computing device is included in a rack.

100. The remote computing device according to claim 65, wherein the remote computing device is affixed to a wall.

101. The method according to claim 45, wherein the act of presenting, to the user, the information regarding the proposed change includes an act of presenting, to the user; the information on a remote computing device.

102. The method according to claim 101, wherein the act of presenting, to the user, the information on the remote computing device includes an act of presenting, to the user, the information on a remote computing device that is located on the data center equipment.

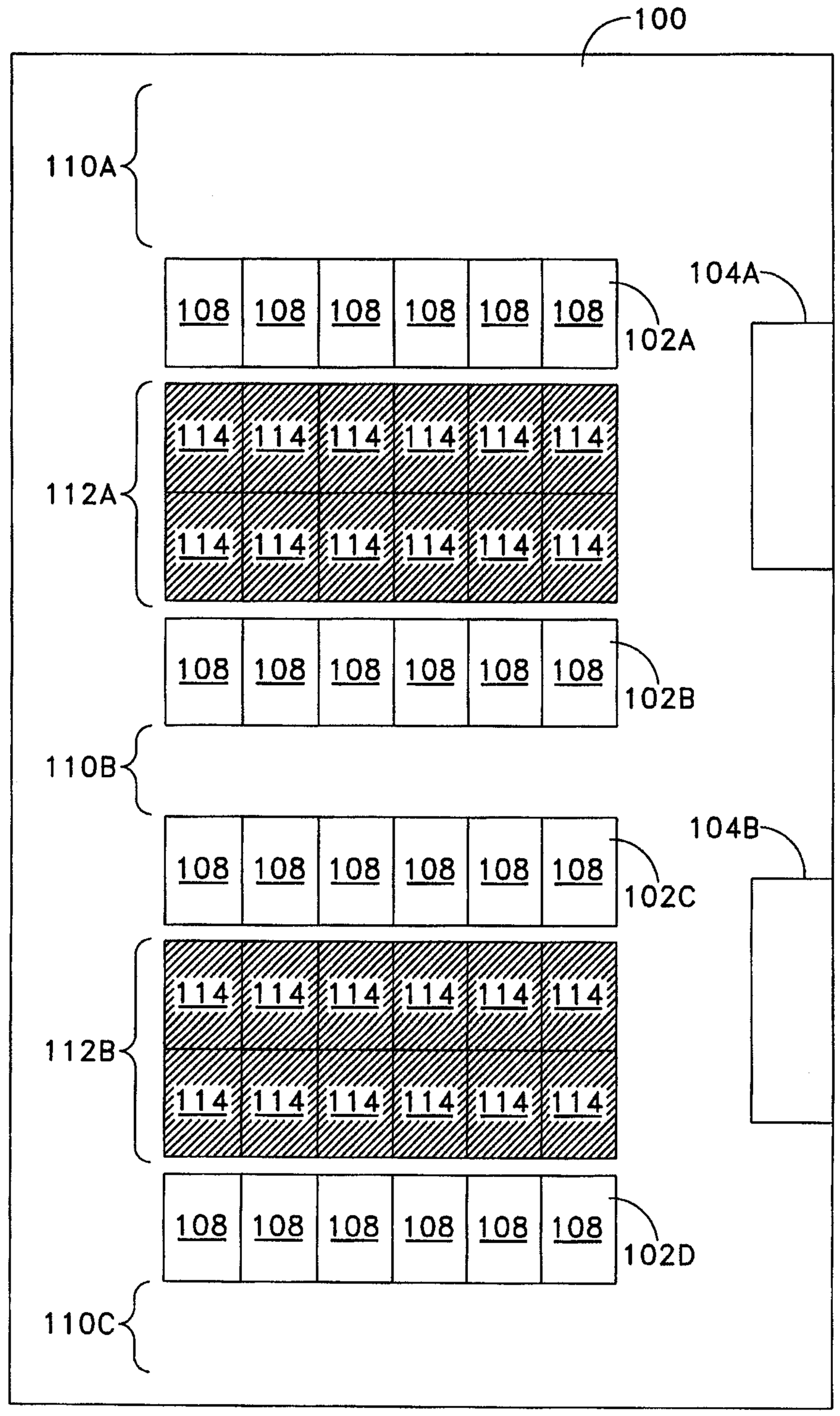

100
110A
108 108 108 108 108 108
104A
102A
112A
114 114 114 114 114 114
114 114 114 114 114 114
108 108 108 108 108 108
102B
110B
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102D
110C

FIG. 1

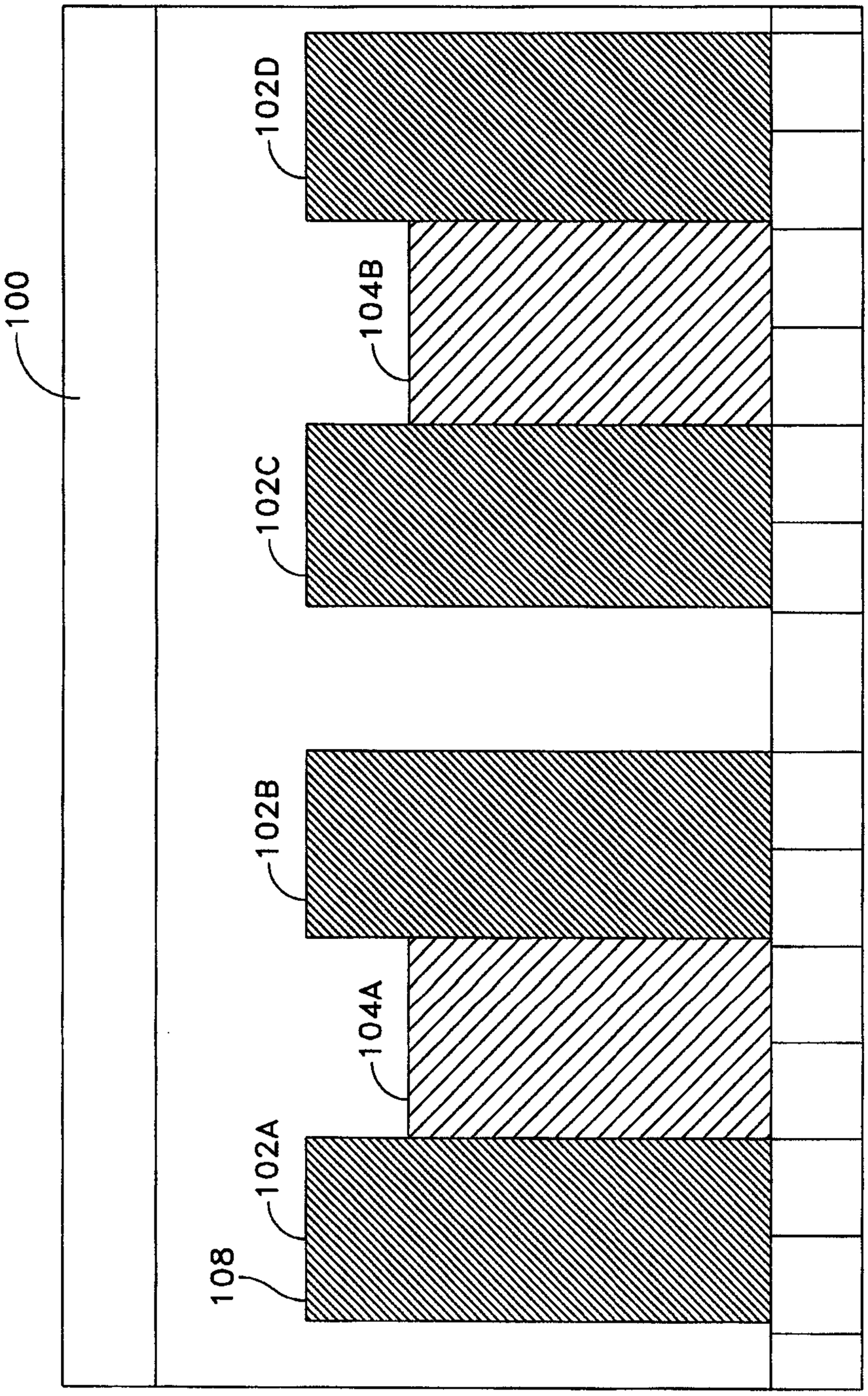


FIG. 2

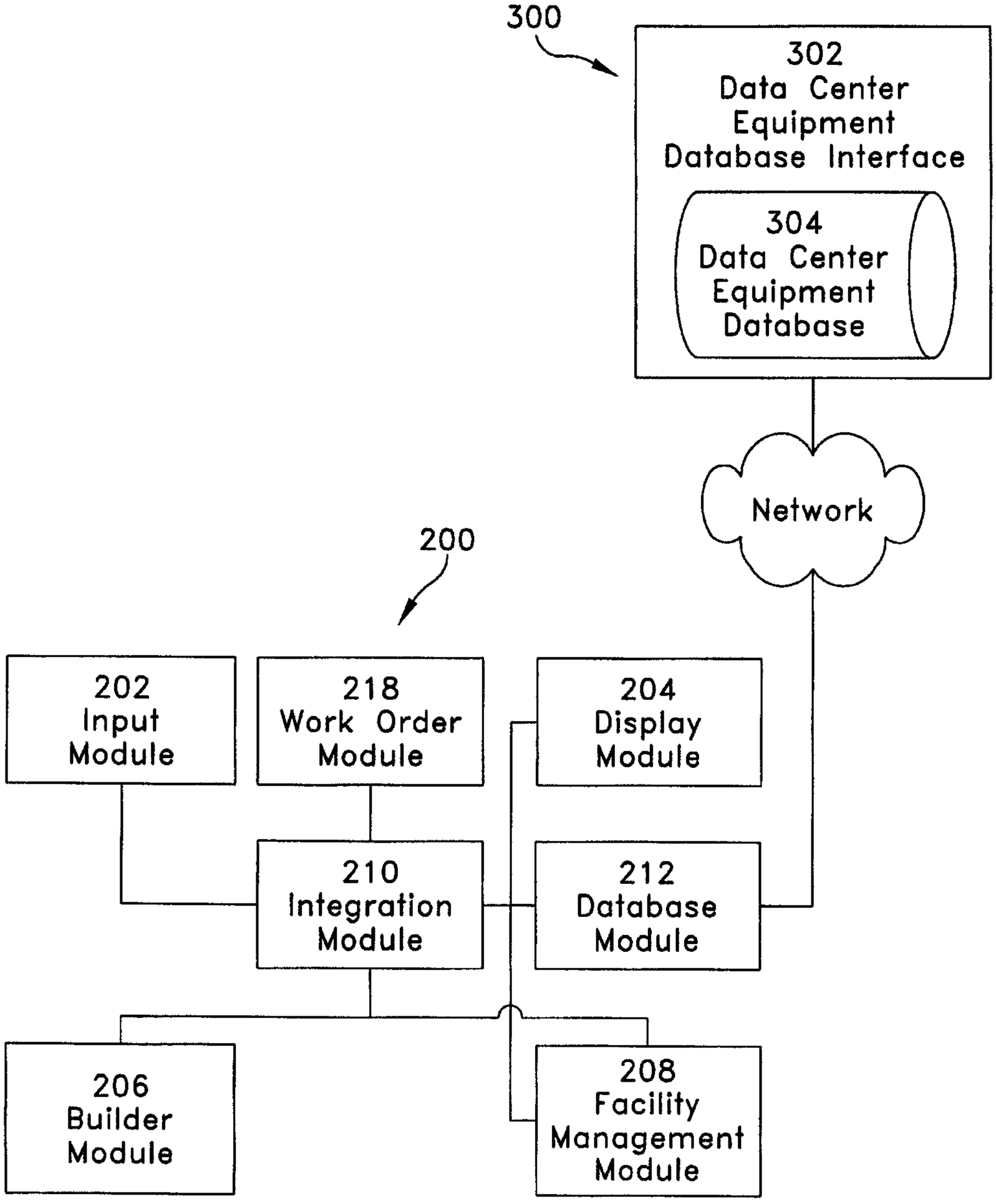

300
302
Data Center
Equipment
Database Interface
304
Data Center
Equipment
Database
Network
200
202
Input
Module
218
Work Order
Module
204
Display
Module
210
Integration
Module
212
Database
Module
206
Builder
Module
208
Facility
Management
Module

FIG. 3

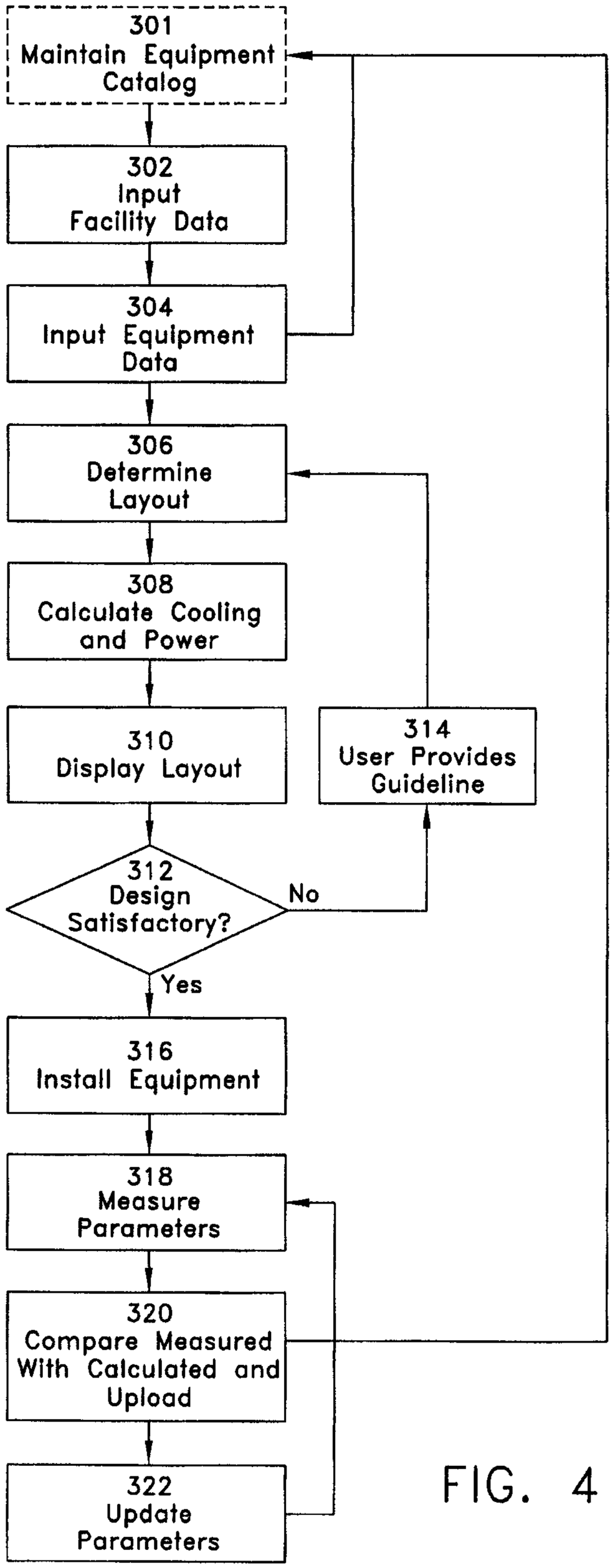

301
Maintain Equipment Catalog
302
Input Facility Data
304
Input Equipment Data
306
Determine Layout
308
Calculate Cooling and Power
310
Display Layout
312
Design Satisfactory?
No
Yes
314
User Provides Guideline
316
Install Equipment
318
Measure Parameters
320
Compare Measured With Calculated and Upload
322
Update Parameters

FIG. 4

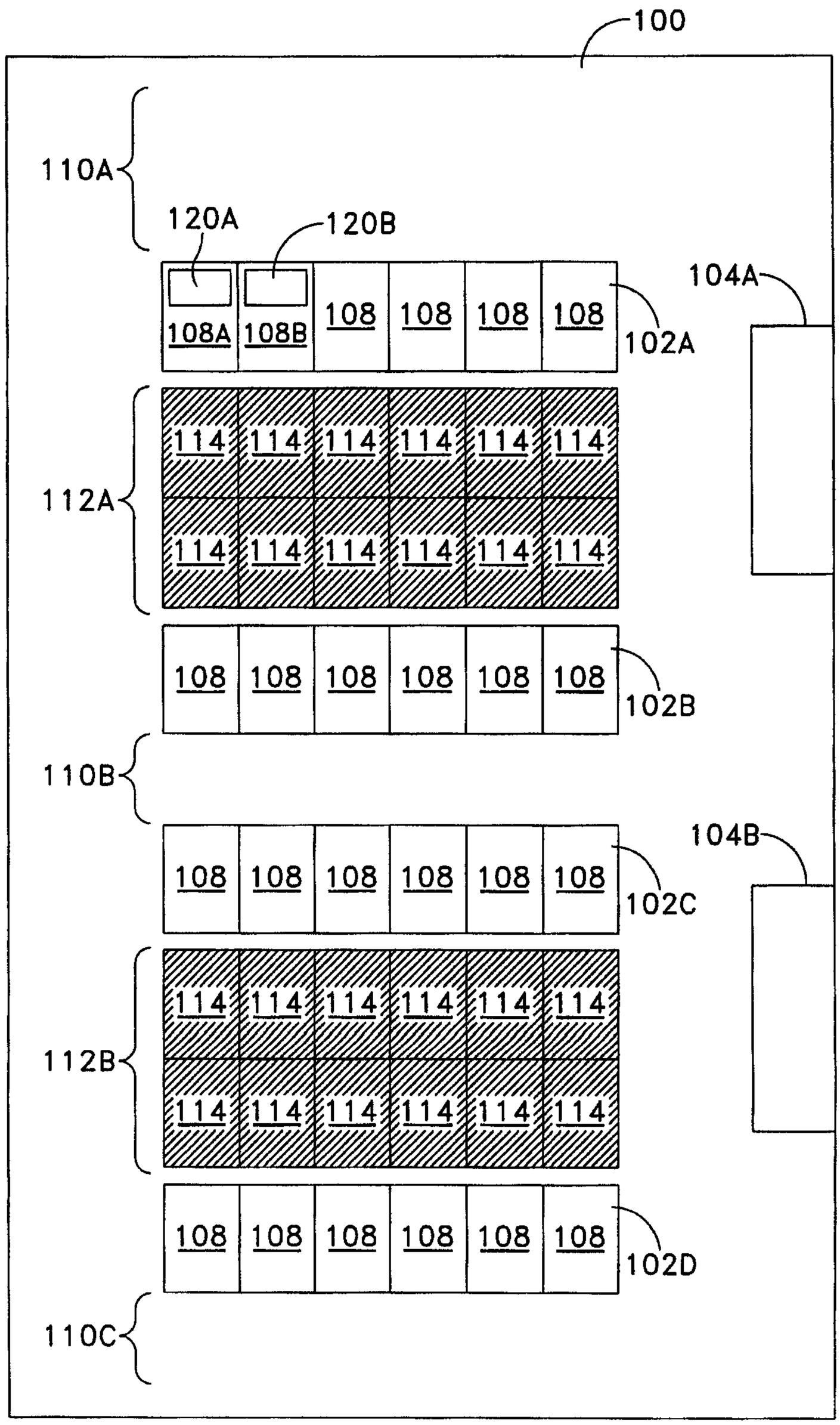

100
110A
120A
120B
108A
108B
108
102A
104A
112A
114
102B
110B
104B
102C
112B
102D
110C

FIG. 5

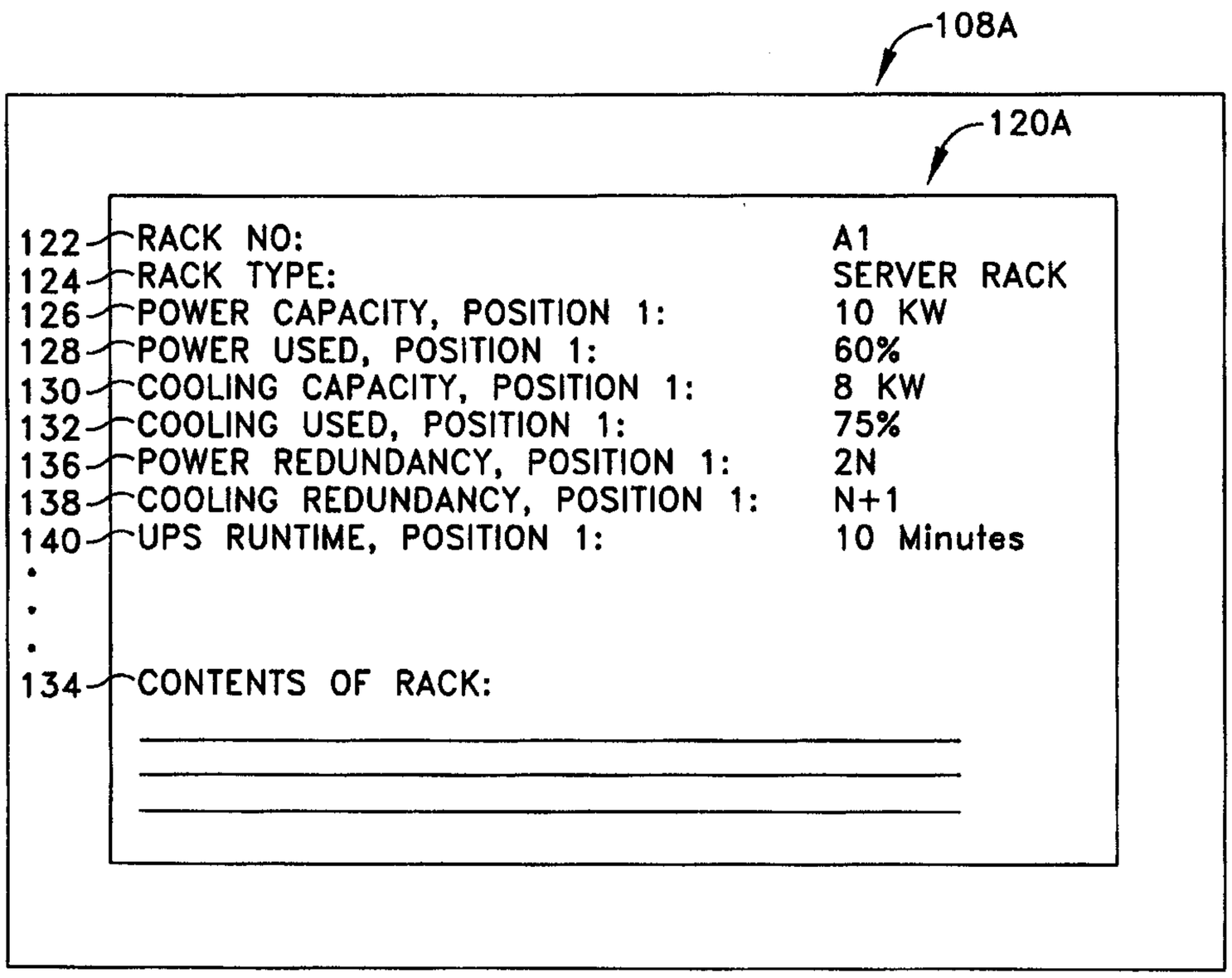

108A
120A
122 RACK NO: A1
124 RACK TYPE: SERVER RACK
126 POWER CAPACITY, POSITION 1: 10 KW
128 POWER USED, POSITION 1: 60%
130 COOLING CAPACITY, POSITION 1: 8 KW
132 COOLING USED, POSITION 1: 75%
136 POWER REDUNDANCY, POSITION 1: 2N
138 COOLING REDUNDANCY, POSITION 1: N+1
140 UPS RUNTIME, POSITION 1: 10 Minutes
134 CONTENTS OF RACK:

FIG. 5A

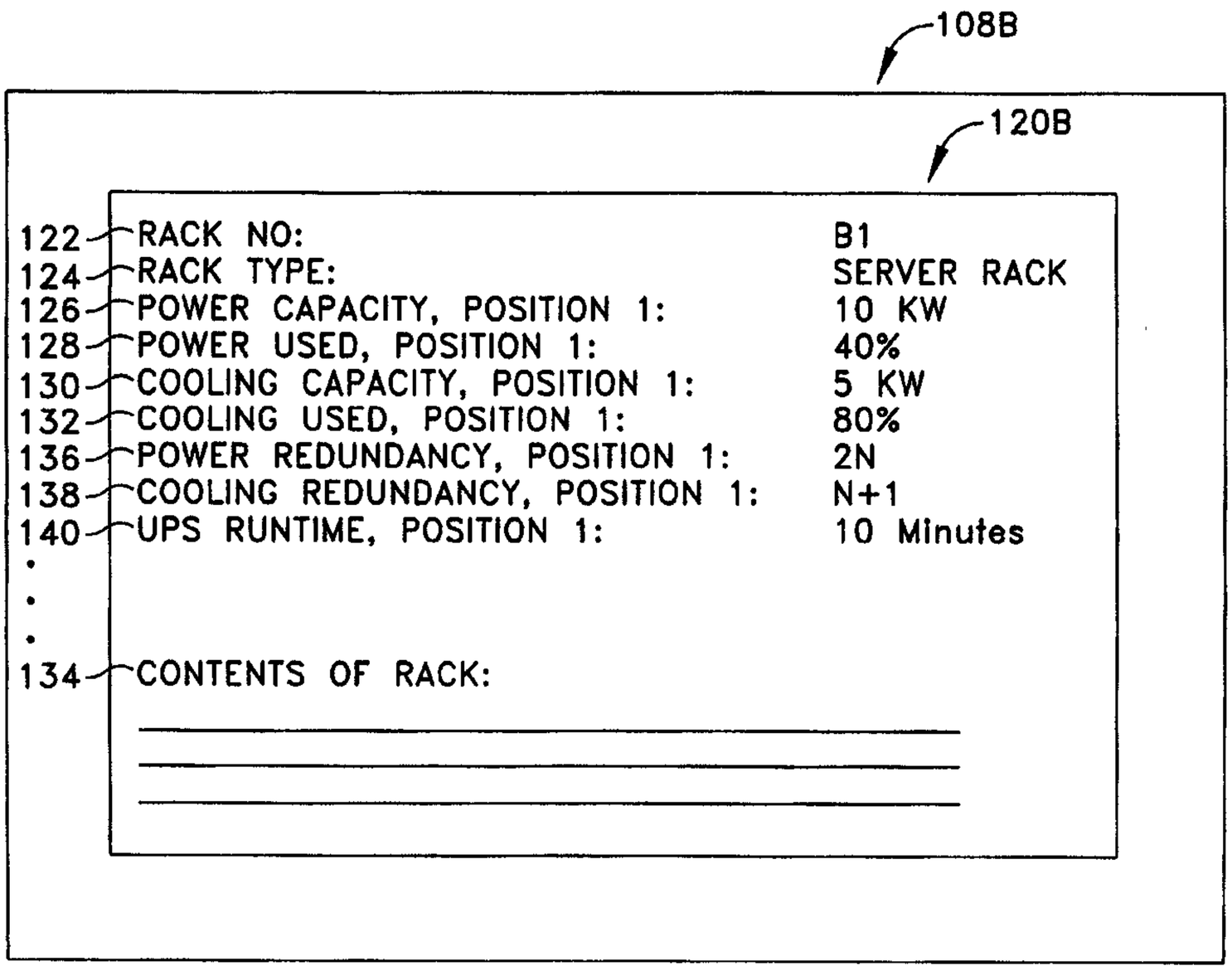

108B
120B
122 RACK NO: B1
124 RACK TYPE: SERVER RACK
126 POWER CAPACITY, POSITION 1: 10 KW
128 POWER USED, POSITION 1: 40%
130 COOLING CAPACITY, POSITION 1: 5 KW
132 COOLING USED, POSITION 1: 80%
136 POWER REDUNDANCY, POSITION 1: 2N
138 COOLING REDUNDANCY, POSITION 1: N+1
140 UPS RUNTIME, POSITION 1: 10 Minutes
134 CONTENTS OF RACK:

FIG. 5B

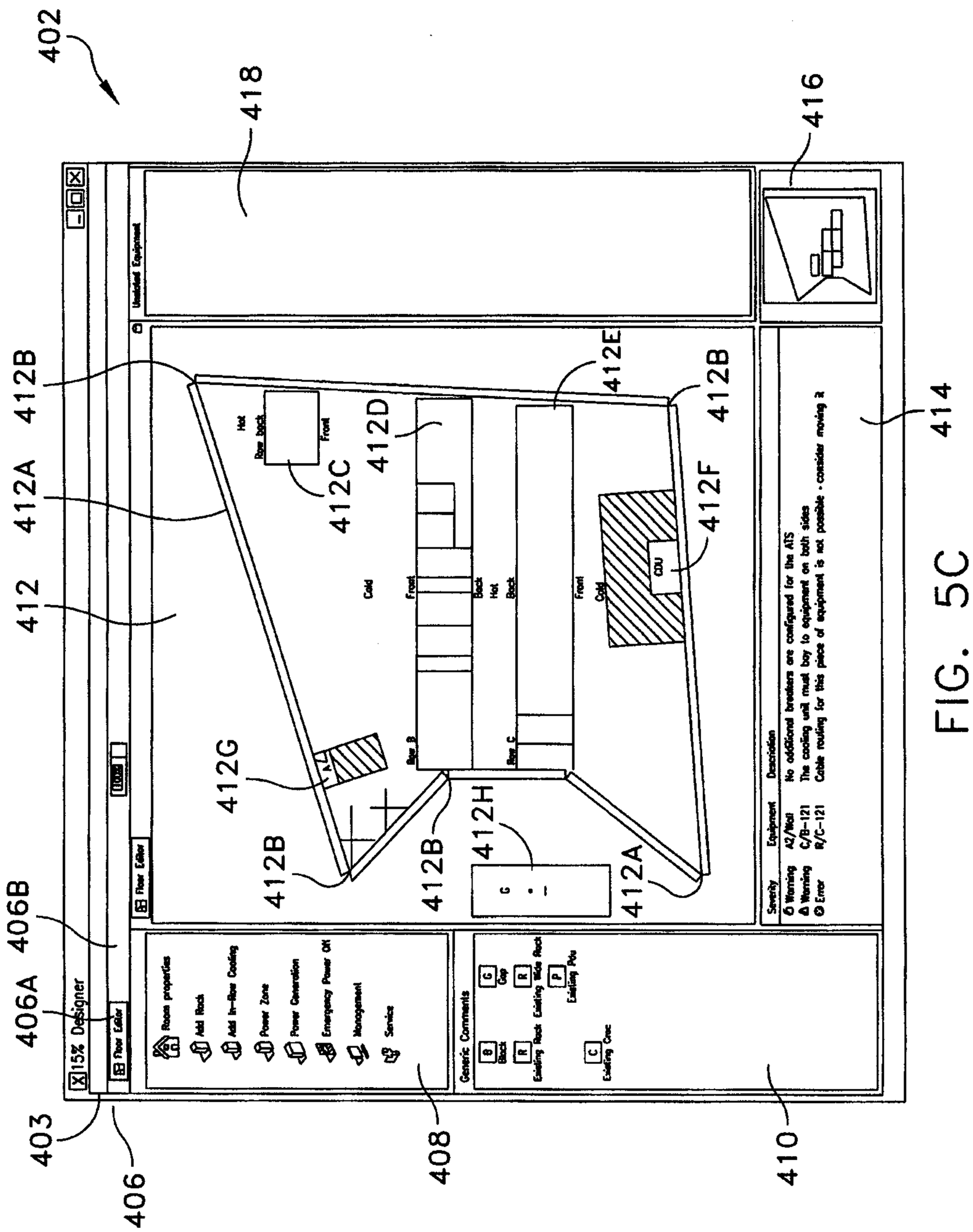

400
418
416
412B
412A
412
412C
412D
412E
412F
412G
412H
414
406B
406A
403
408
410
Unlocked Equipment
Floor Editor
15% Designer
Room properties
Add Rack
Add In-Row Cooling
Power Zone
Power Generation
Emergency Power Off
Management
Service
Generic Comments
Existing Rack
Existing Wide Rack
Existing Pdu
Existing Crac
Hot
Row back
Front
Cold
Back
CDU
Row B
Row C
Severity
Equipment
Description
Warning
A2/Wall
No additional breakers are configured for the ATS
Warning
C/B-121
The cooling unit must bay to equipment on both sides
Error
R/C-121
Cable routing for this piece of equipment is not possible - consider moving it

FIG. 5C

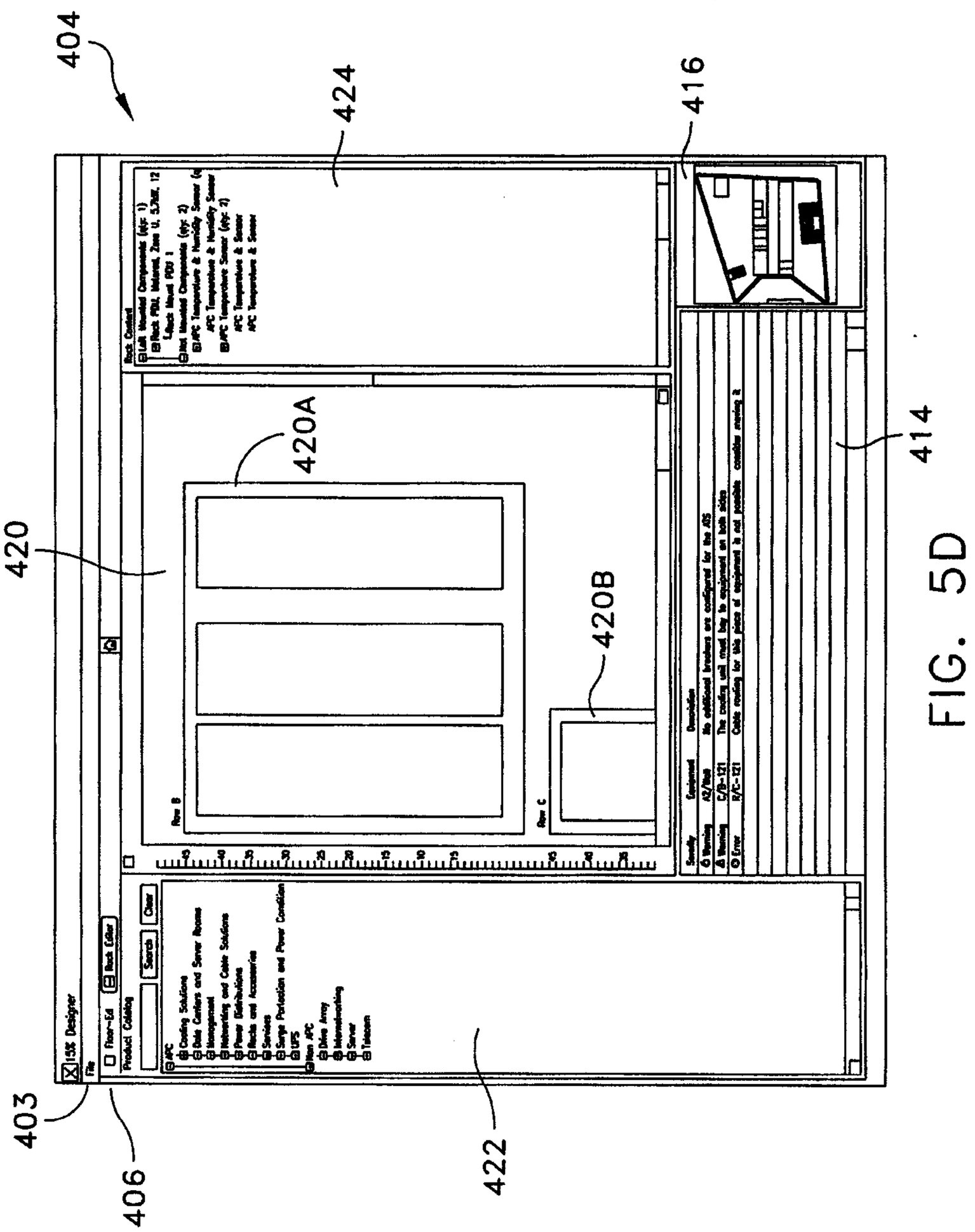

400
424
416
420A
420
420B
414
422
403
406
Rack Content
LAN Mounted Components (qty: 1)
Rack PDU, Metered, Zero U, 5.7kW, 12
Rack Mount PDU 1
Net Mounted Components (qty: 2)
AFC Temperature & Humidity Sensor
AFC Temperature & Humidity Sensor
AFC Temperature Sensor (qty: 2)
AFC Temperature & Sensor
AFC Temperature & Sensor
Row B
Row C
15K Designer
File
Floor-64
Rack Editor
Product Catalog
Search
Clear
APC
Cooling Solutions
Data Centers and Server Rooms
Management
Networking and Cable Solutions
Power Distributions
Racks and Accessories
Services
Surge Protection and Power Condition
UPS
Non APC
Dell Army
Interconnecting
Server
Telecom
Severity
Component
Description
Warning
A2/Net
No additional breakers are
Warning
C/B-121
The cooling unit must be
Error
R/C-121
Cable routing for this piece

FIG. 5D

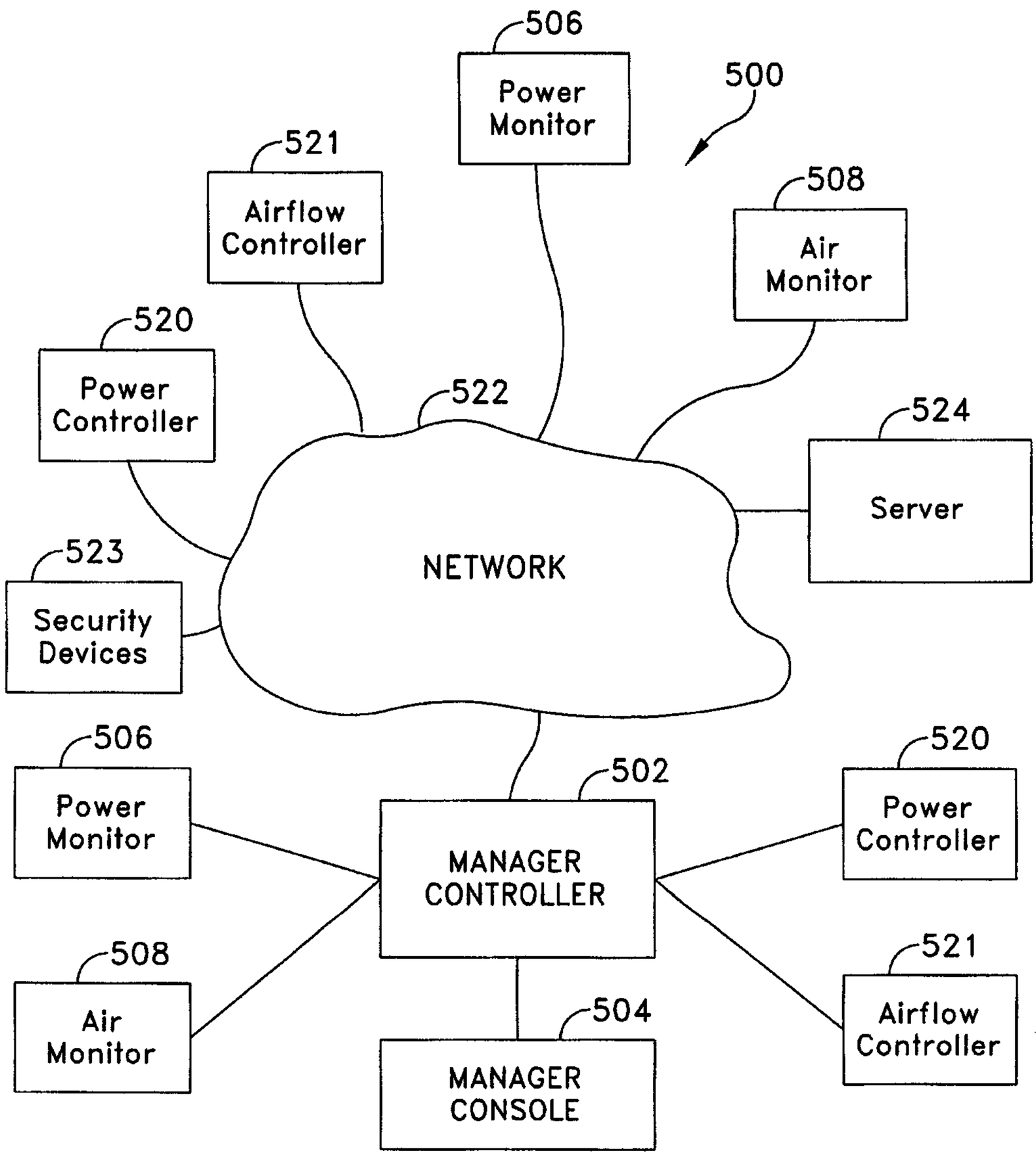

506
Power Monitor
500
521
Airflow Controller
508
Air Monitor
520
Power Controller
522
524
Server
NETWORK
523
Security Devices
506
Power Monitor
502
MANAGER CONTROLLER
520
Power Controller
508
Air Monitor
504
MANAGER CONSOLE
521
Airflow Controller

FIG. 6

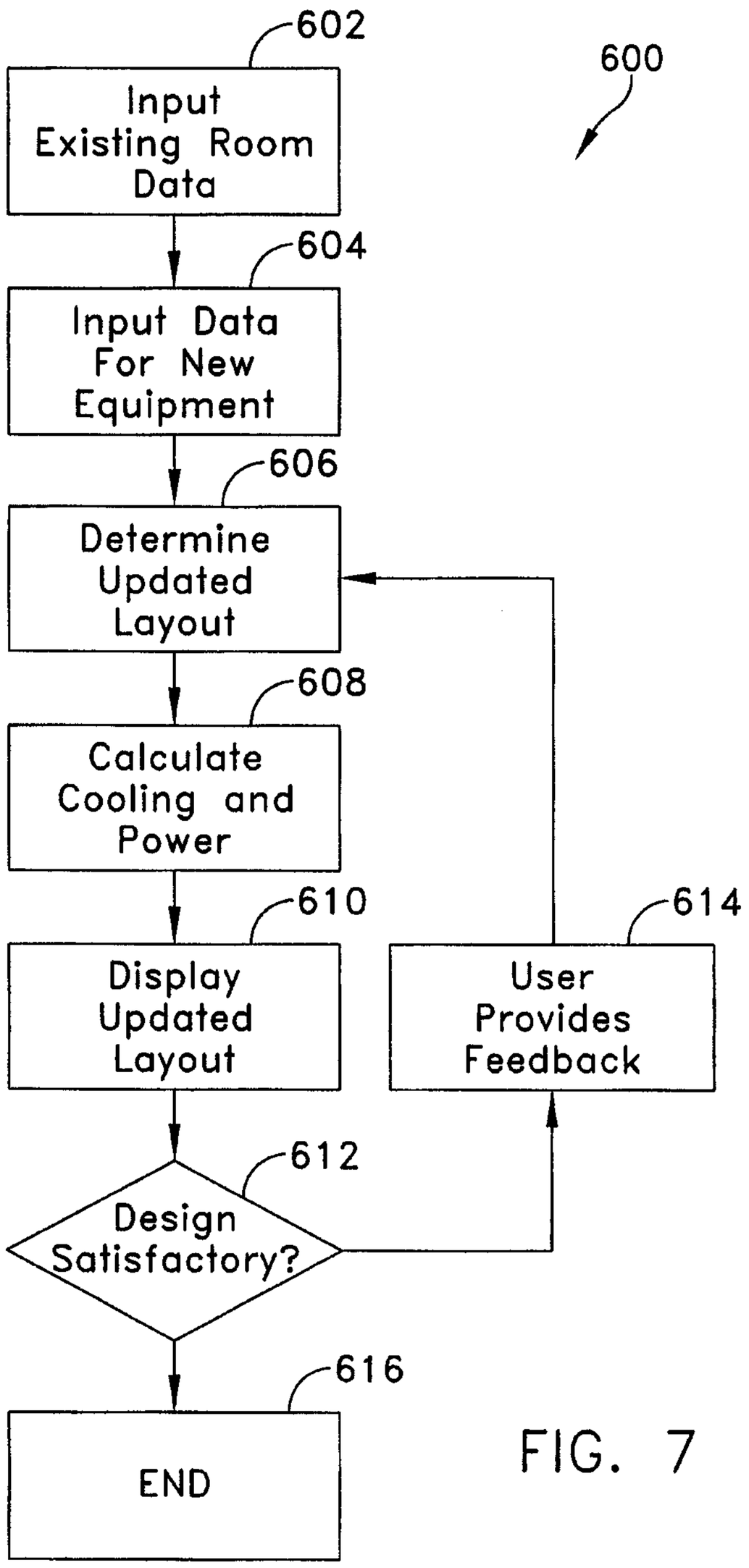

602
600
Input Existing Room Data
604
Input Data For New Equipment
606
Determine Updated Layout
608
Calculate Cooling and Power
610
Display Updated Layout
614
User Provides Feedback
612
Design Satisfactory?
616
END

FIG. 7

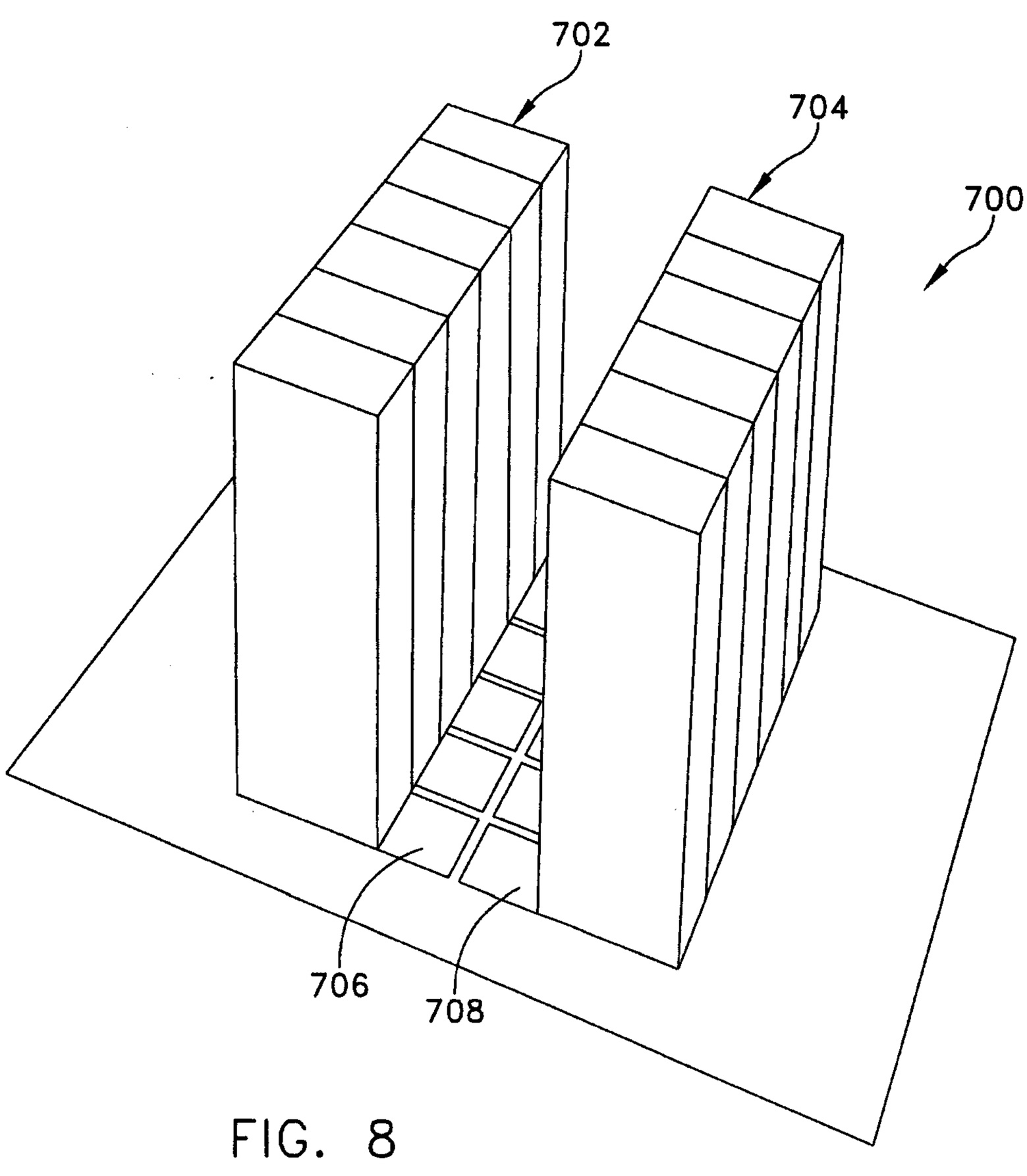


FIG. 8

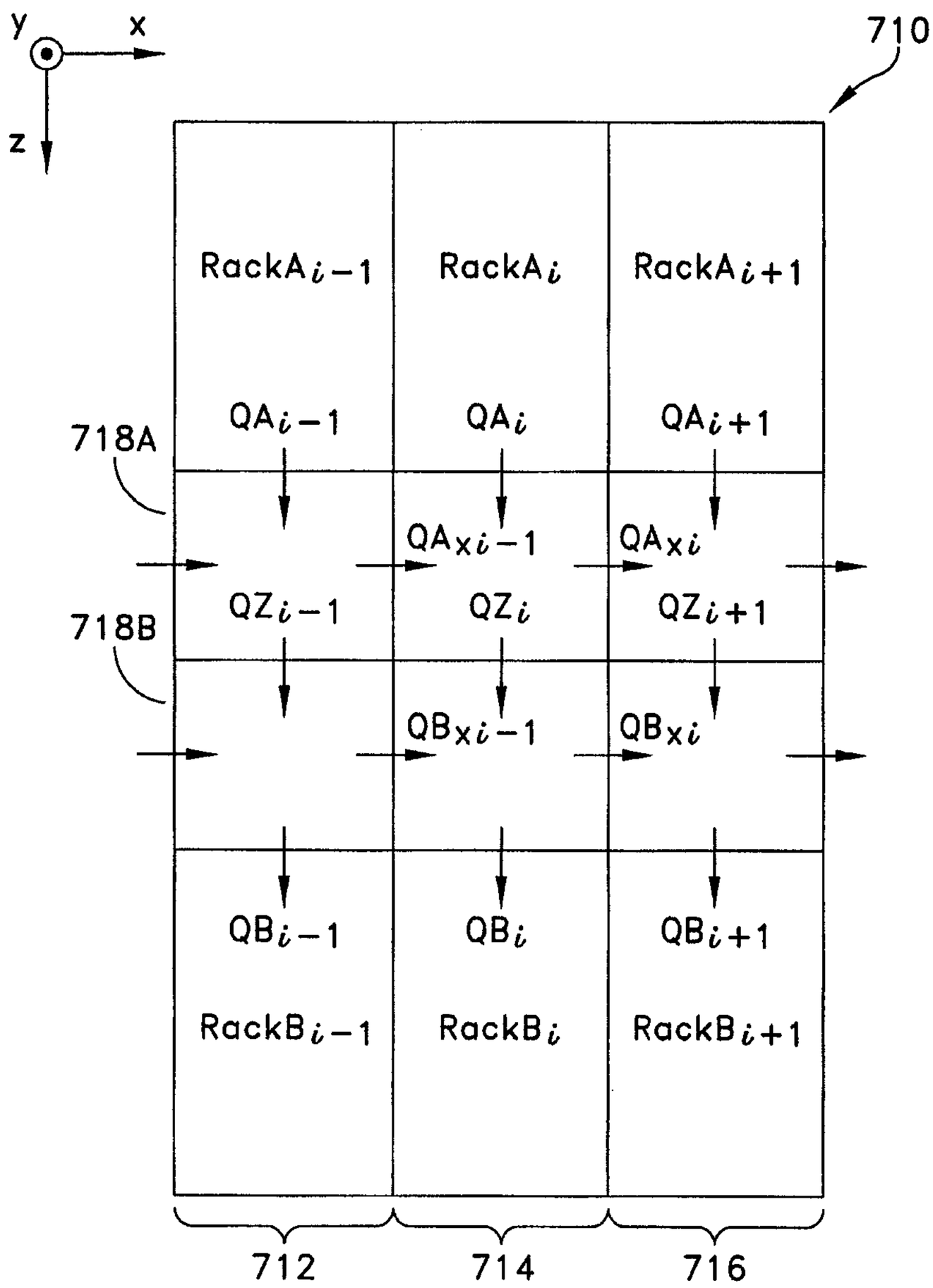

y
x
z
710
RackA$_{i-1}$
RackA$_i$
RackA$_{i+1}$
718A
QA$_{i-1}$
QA$_i$
QA$_{i+1}$
QA$_{xi-1}$
QA$_{xi}$
QZ$_{i-1}$
QZ$_i$
QZ$_{i+1}$
718B
QB$_{xi-1}$
QB$_{xi}$
QB$_{i-1}$
QB$_i$
QB$_{i+1}$
RackB$_{i-1}$
RackB$_i$
RackB$_{i+1}$
712
714
716

FIG. 9

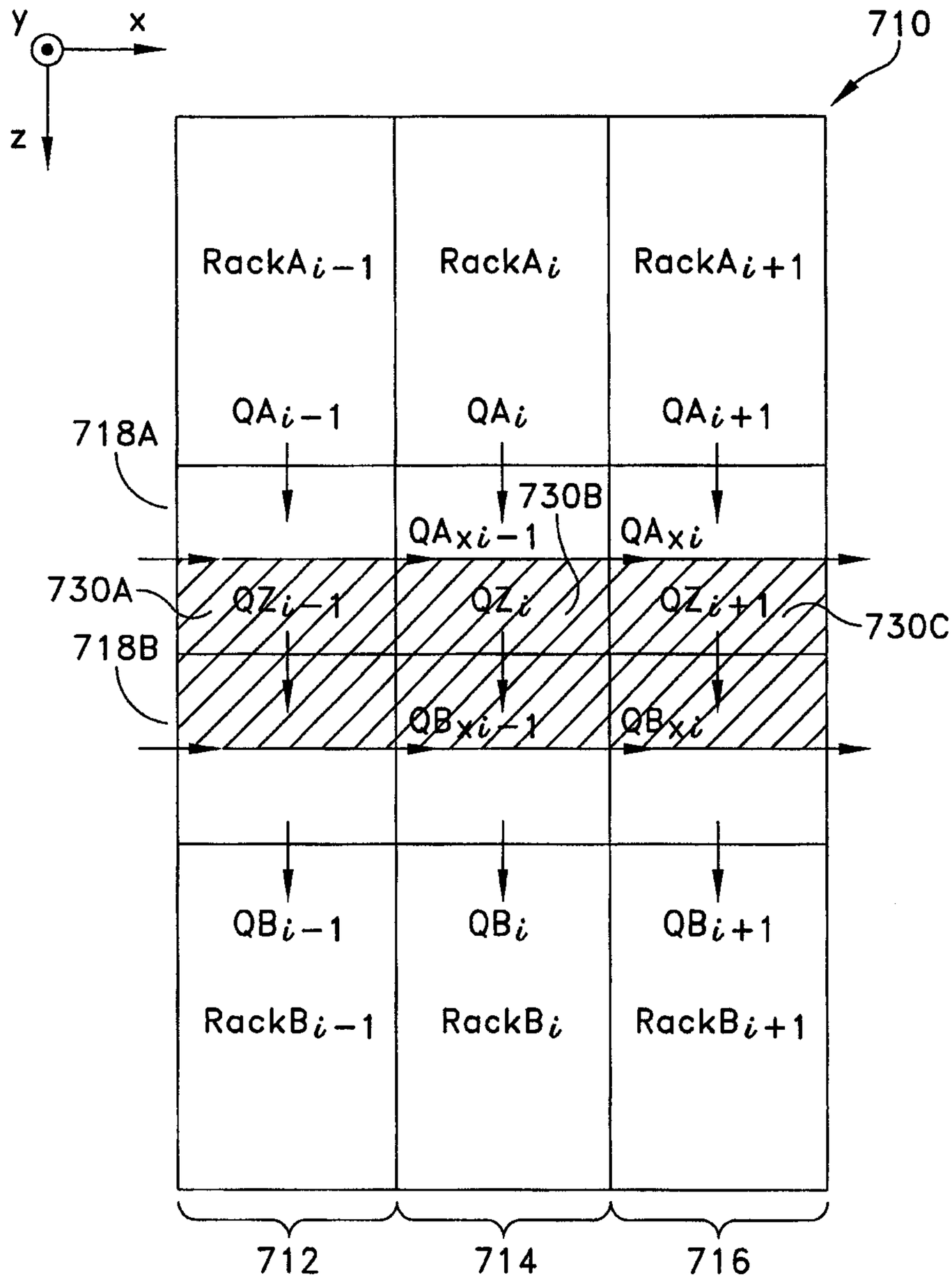

y
x
z
710
RackA$_{i-1}$
RackA$_i$
RackA$_{i+1}$
718A
QA$_{i-1}$
QA$_i$
QA$_{i+1}$
730B
QA$_{xi-1}$
QA$_{xi}$
730A
QZ$_{i-1}$
QZ$_i$
QZ$_{i+1}$
730C
718B
QB$_{xi-1}$
QB$_{xi}$
QB$_{i-1}$
QB$_i$
QB$_{i+1}$
RackB$_{i-1}$
RackB$_i$
RackB$_{i+1}$
712
714
716

FIG. 9A

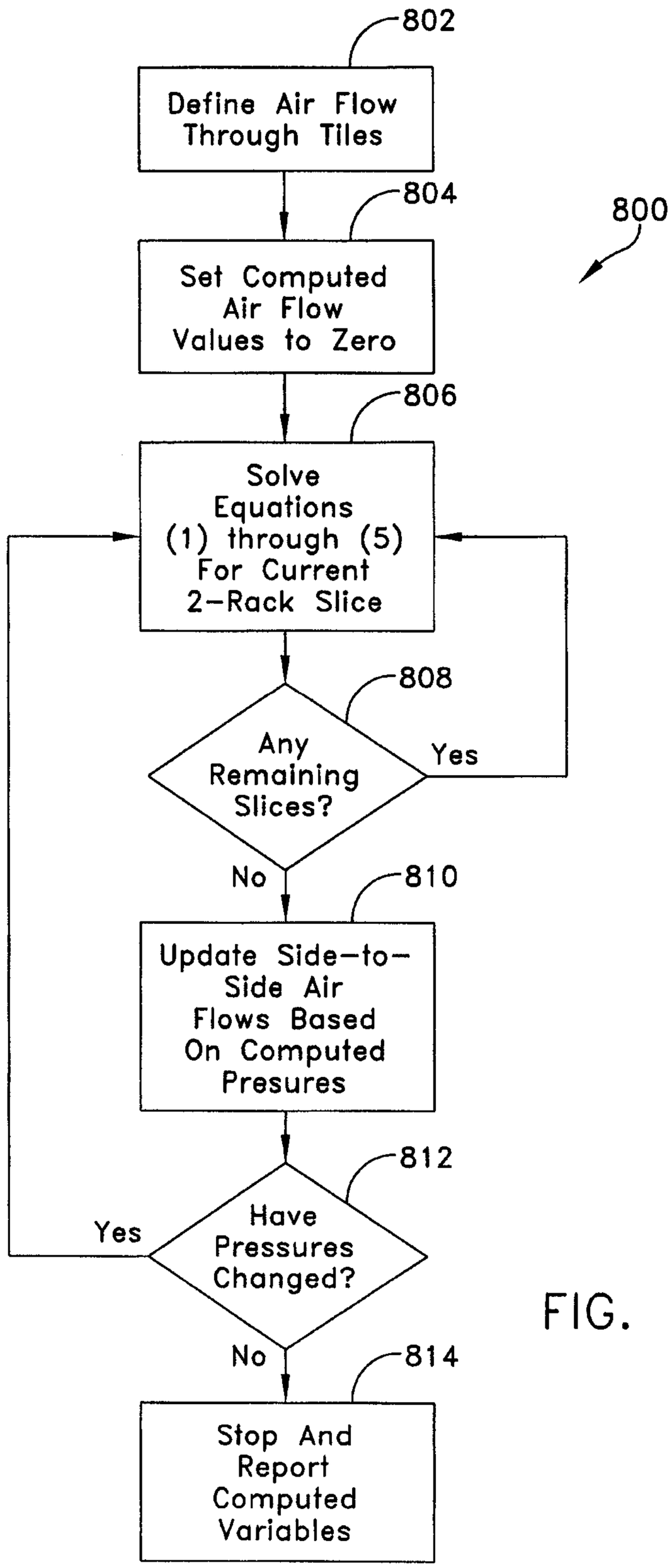

802
Define Air Flow Through Tiles
804
Set Computed Air Flow Values to Zero
800
806
Solve Equations (1) through (5) For Current 2-Rack Slice
808
Any Remaining Slices?
Yes
No
810
Update Side-to-Side Air Flows Based On Computed Presures
812
Have Pressures Changed?
Yes
No
814
Stop And Report Computed Variables

FIG. 10

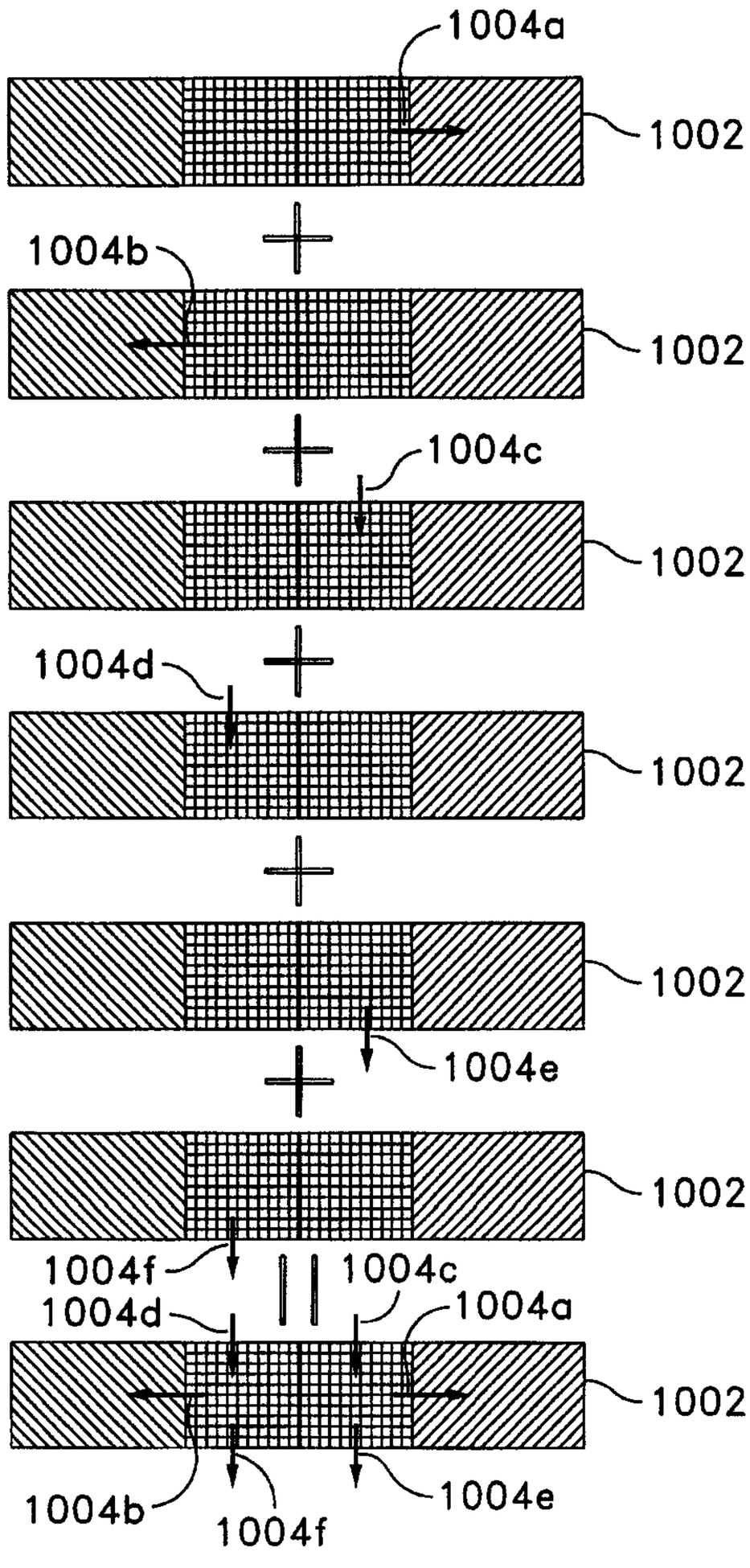

1004a
1002
1004b
1002
1004c
1002
1004d
1002
1002
1004e
1002
1004f
1004c
1004d
1004a
1002
1004b
1004f
1004e

FIG. 11

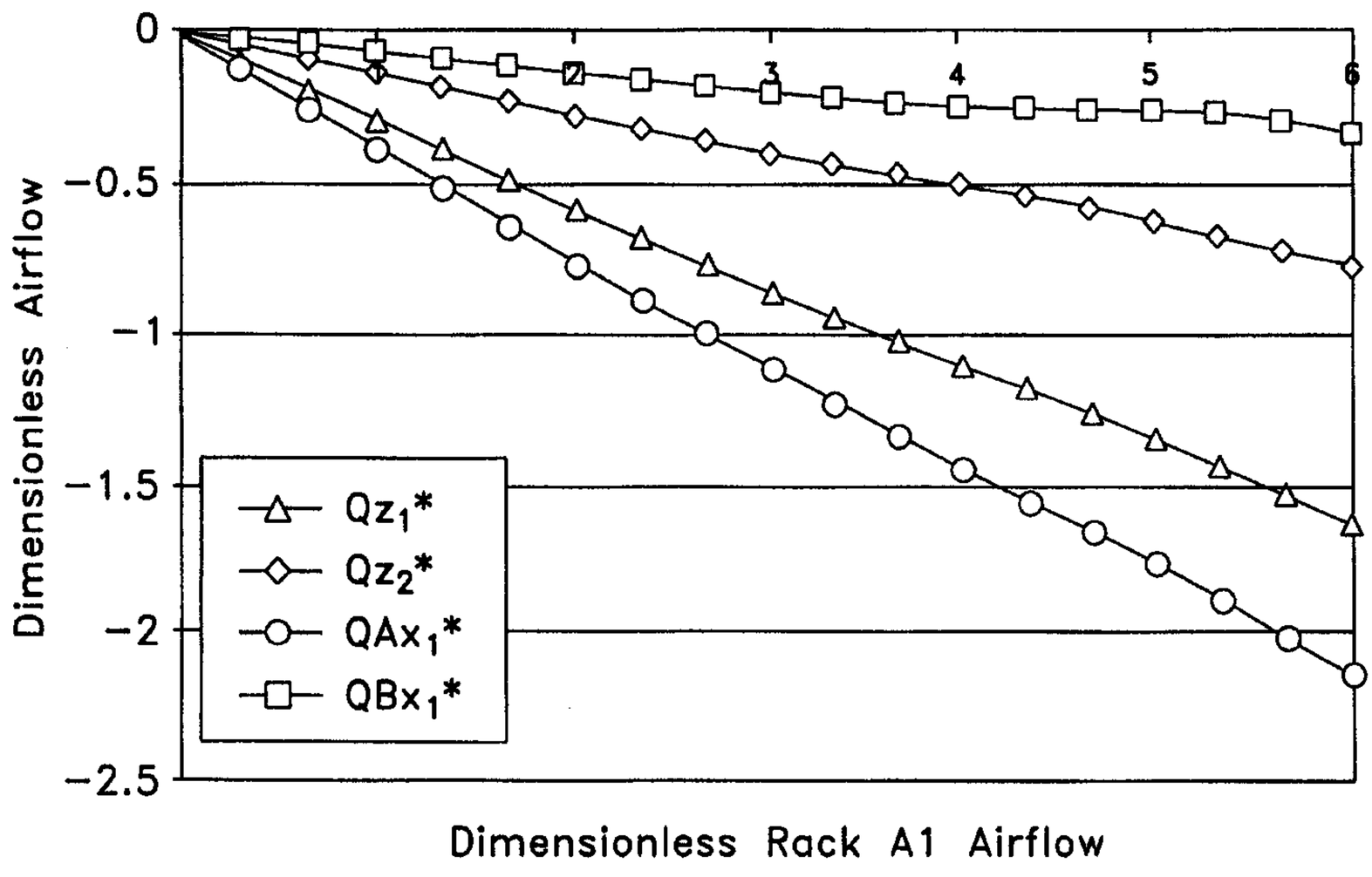

0
−0.5
−1
−1.5
−2
−2.5
Dimensionless Airflow
2
3
4
5
6
Qz_1*
Qz_2*
QAx_1*
QBx_1*
Dimensionless Rack A1 Airflow

FIG. 12

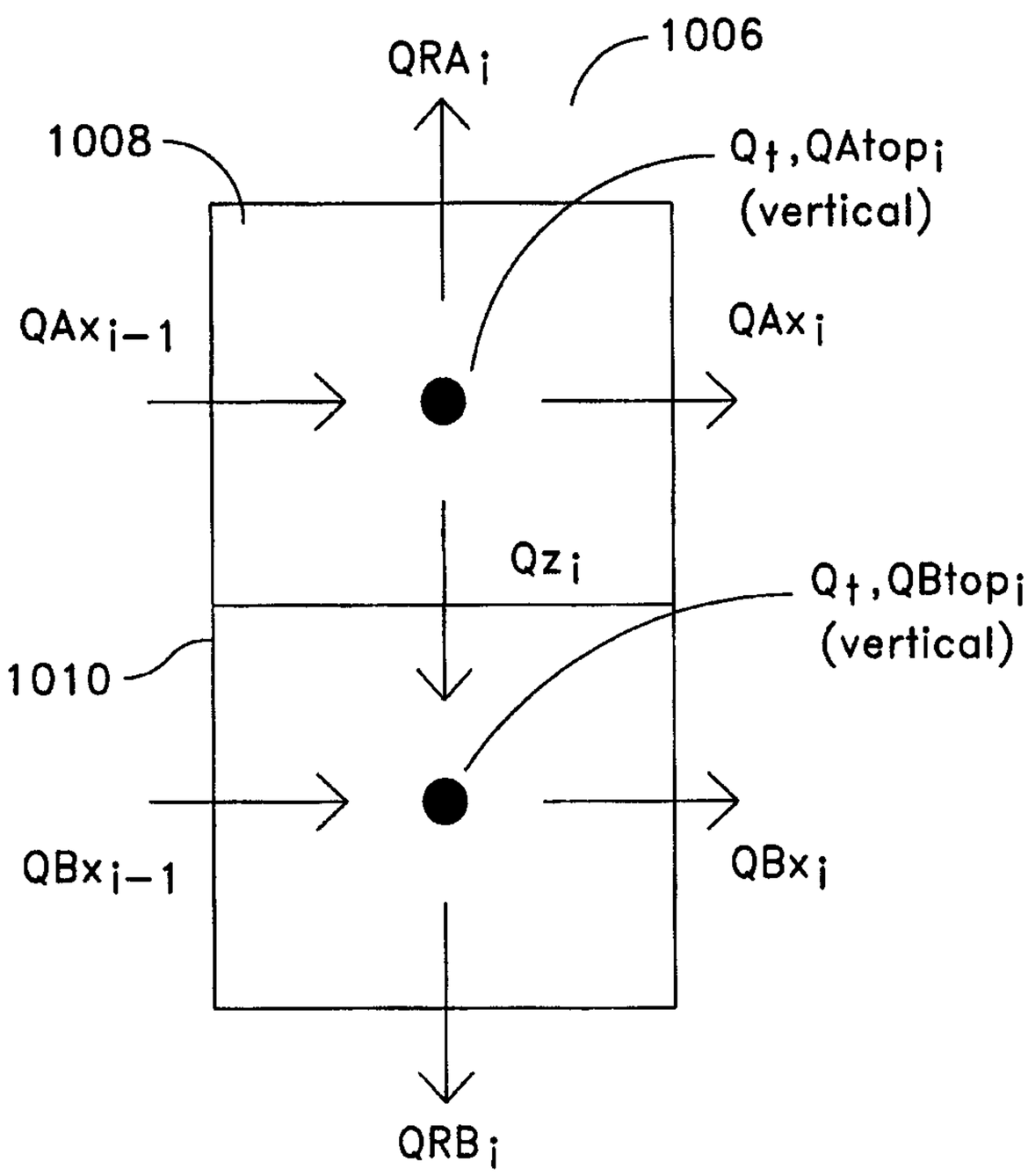

QRA i
1006
1008
Q t , QAtop i
(vertical)
QAx i−1
QAx i
Qz i
Q t , QBtop i
(vertical)
1010
QBx i−1
QBx i
QRB i

FIG. 13

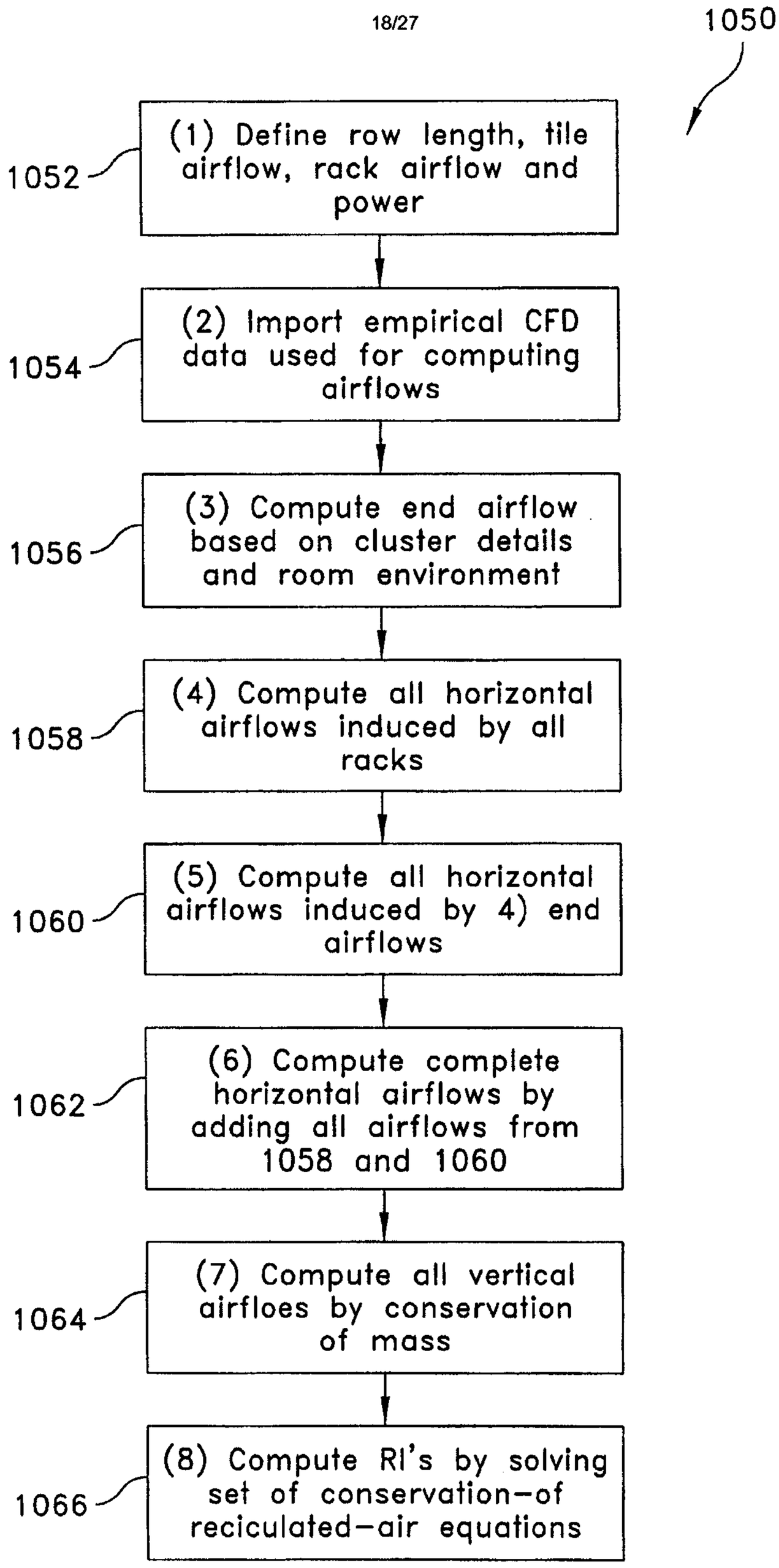

1050
1052
(1) Define row length, tile airflow, rack airflow and power
1054
(2) Import empirical CFD data used for computing airflows
1056
(3) Compute end airflow based on cluster details and room environment
1058
(4) Compute all horizontal airflows induced by all racks
1060
(5) Compute all horizontal airflows induced by 4) end airflows
1062
(6) Compute complete horizontal airflows by adding all airflows from 1058 and 1060
1064
(7) Compute all vertical airfloes by conservation of mass
1066
(8) Compute RI's by solving set of conservation-of reciculated-air equations

FIG. 14

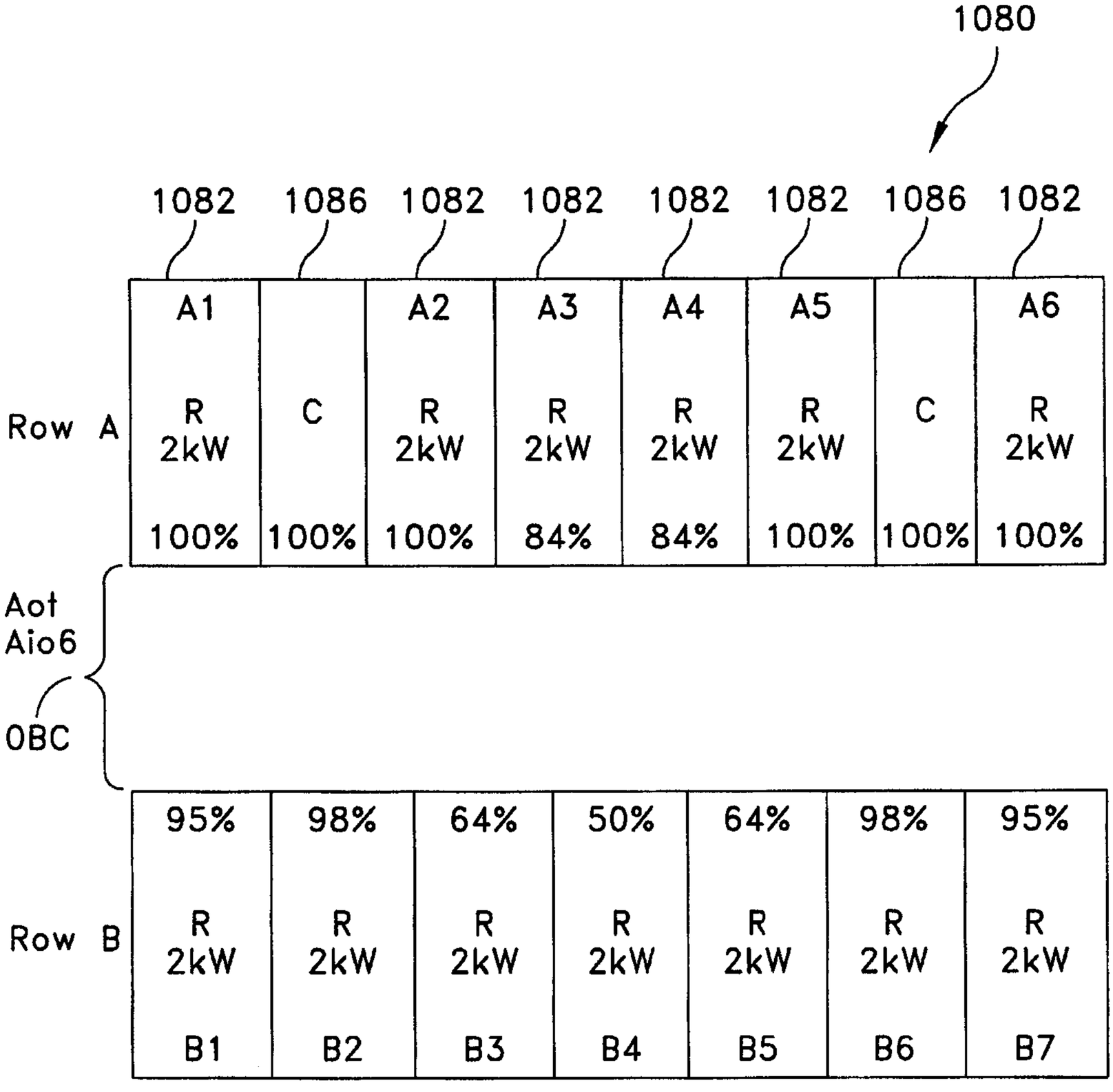

1080
1082
1086
1082
1082
1082
1082
1086
1082
Row A
A1
R
2kW
100%
C
100%
A2
R
2kW
100%
A3
R
2kW
84%
A4
R
2kW
84%
A5
R
2kW
100%
C
100%
A6
R
2kW
100%
Aot
Aio6
OBC
Row B
95%
R
2kW
B1
98%
R
2kW
B2
64%
R
2kW
B3
50%
R
2kW
B4
64%
R
2kW
B5
98%
R
2kW
B6
95%
R
2kW
B7

FIG. 15

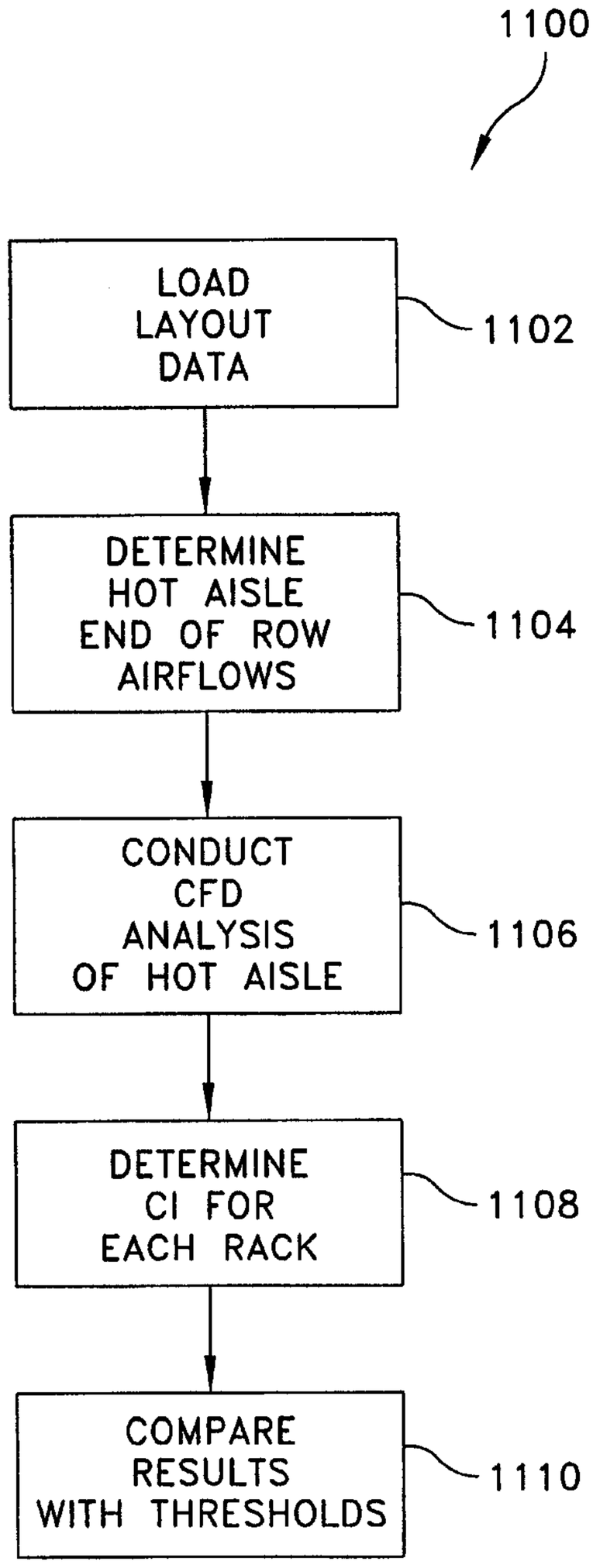

1100
LOAD LAYOUT DATA
1102
DETERMINE HOT AISLE END OF ROW AIRFLOWS
1104
CONDUCT CFD ANALYSIS OF HOT AISLE
1106
DETERMINE CI FOR EACH RACK
1108
COMPARE RESULTS WITH THRESHOLDS
1110

FIG. 16

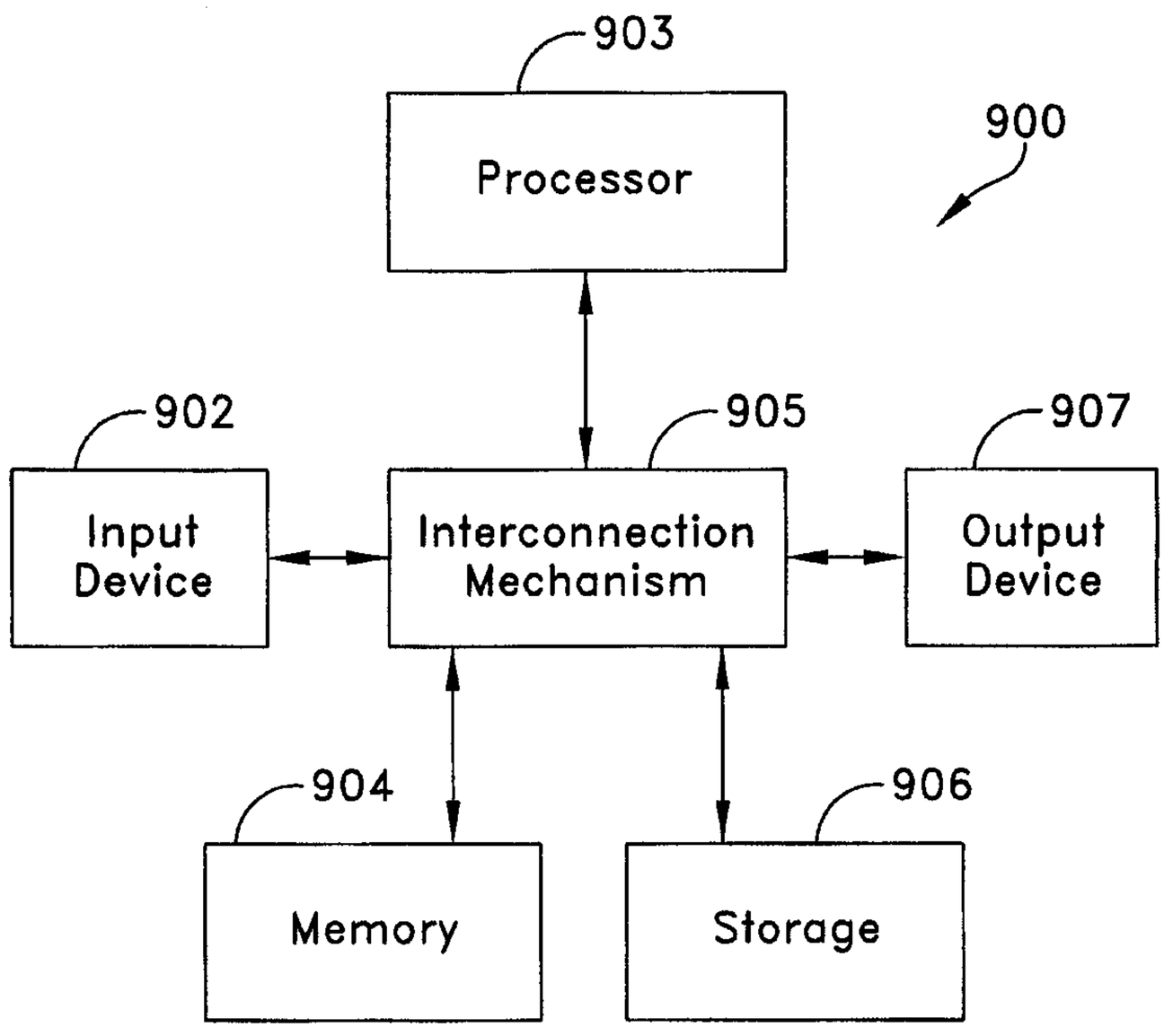

903
Processor
900
902
905
907
Input Device
Interconnection Mechanism
Output Device
904
906
Memory
Storage

FIG. 17

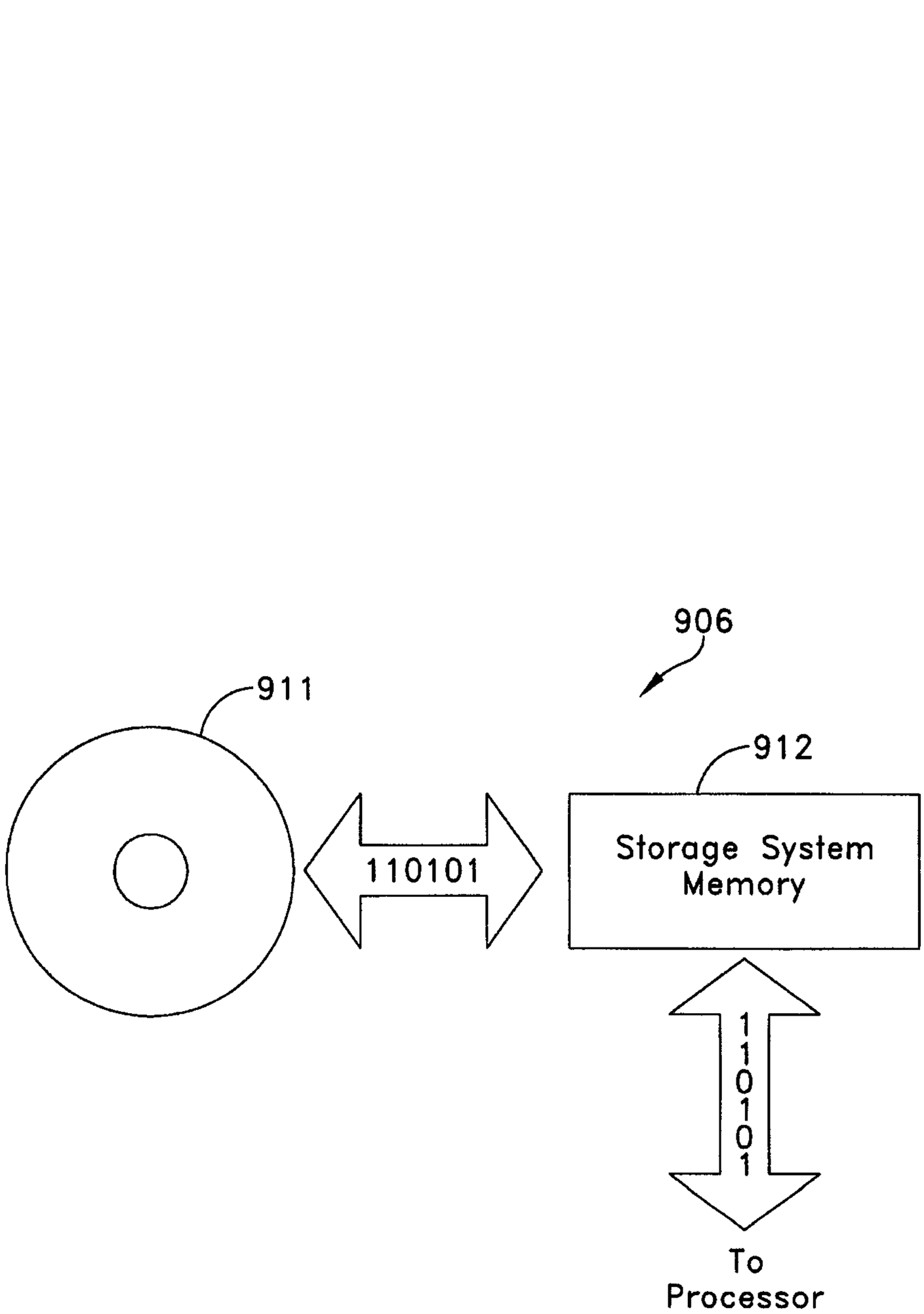

906
911
912
110101
Storage System Memory
1 1 0 1 0 1
To Processor

FIG. 18

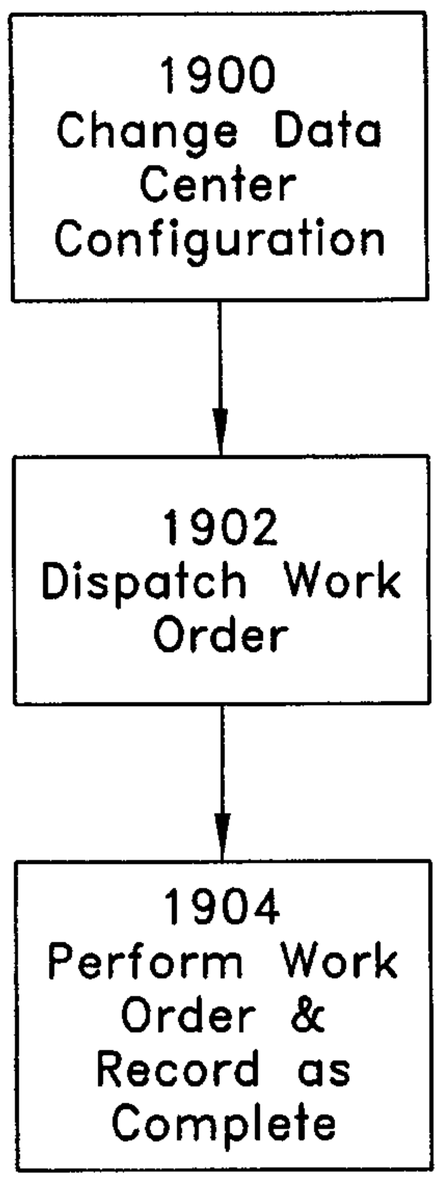

1900
Change Data Center Configuration
1902
Dispatch Work Order
1904
Perform Work Order & Record as Complete

FIG. 19

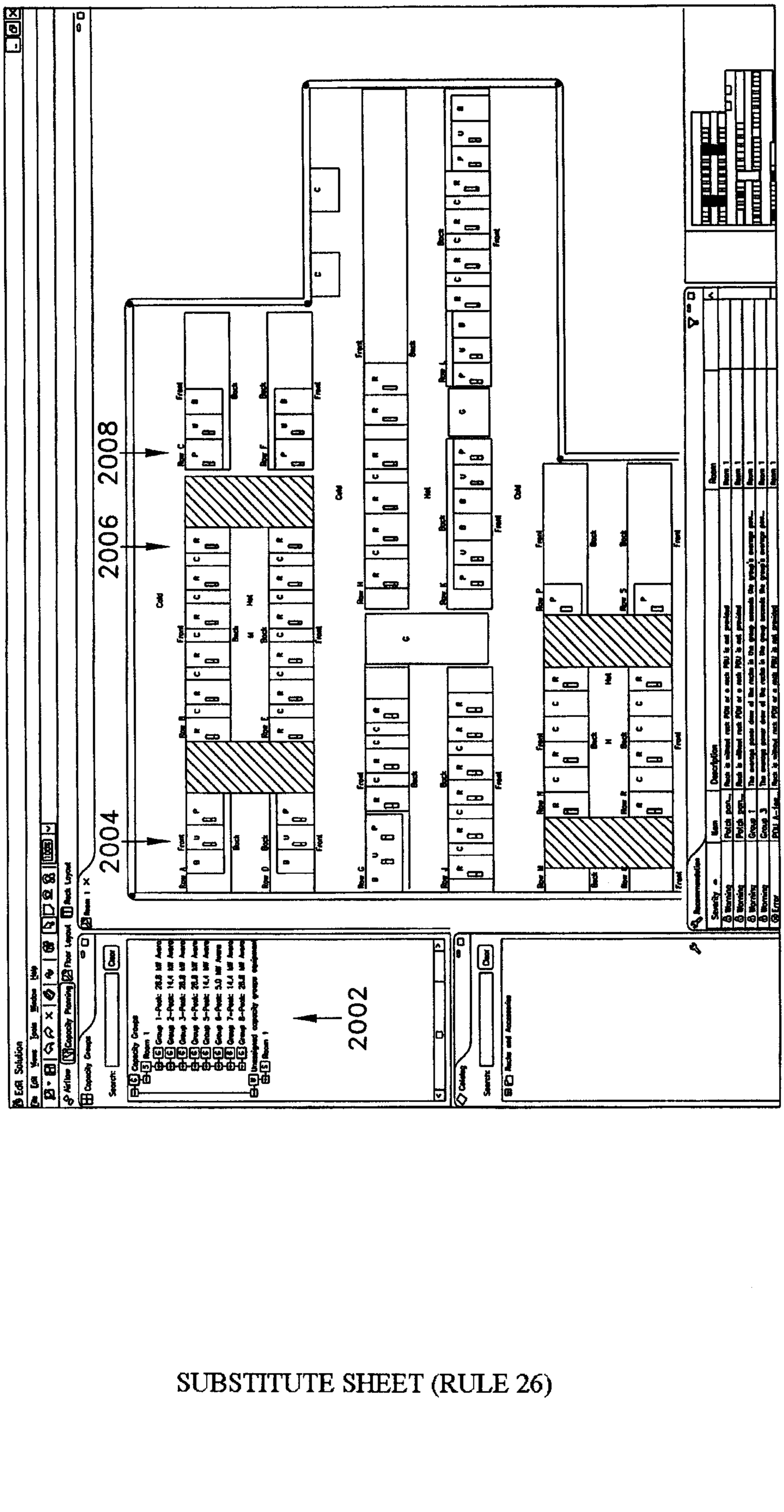

2002
2004
2006
2008
Front
Back
Cold
Hot
Aisle
Row A
Row B
Row C
Row D
Row E
Row F
Row G
Row H
Row J
Row K
Row P
Row S
Capacity Groups
Room 1
Description
Severity
Main
Racks and Accessories
Catalog
Search:
Clear
Capacity Planning
Floor Layout
Rack Layout
Airflow
EGR Solution

FIG. 20

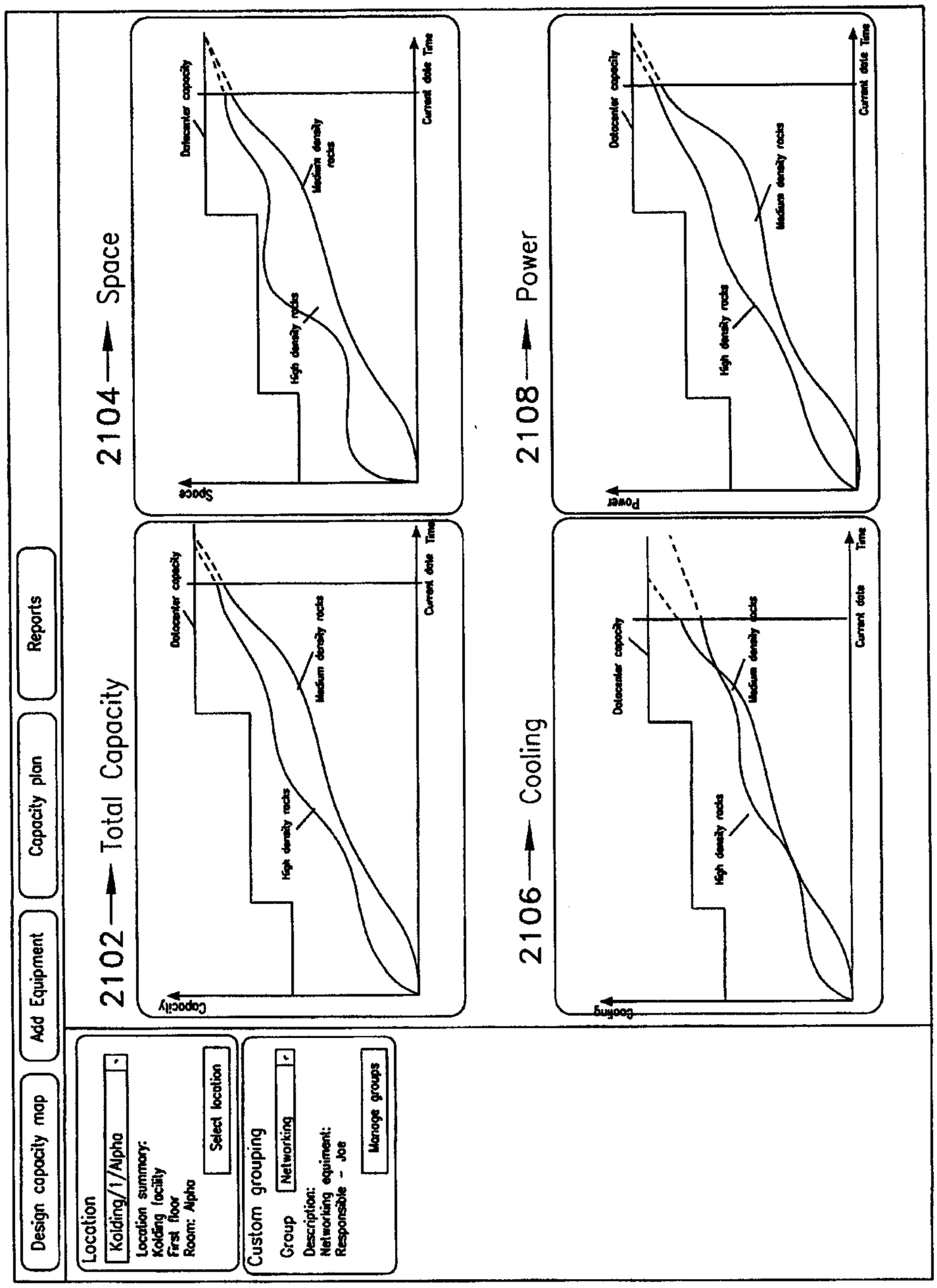

Design capacity map
Add Equipment
Capacity plan
Reports
Location
Kolding/1/Alpha
Location summary:
Kolding facility
First floor
Room: Alpha
Select location
Custom grouping
Group
Networking
Description:
Networking equipment:
Responsible - Joe
Manage groups
2102 Total Capacity
2104 Space
2106 Cooling
2108 Power
Datacenter capacity
Medium density rocks
High density rocks
Current date
Time
Capacity
Space
Cooling
Power

FIG. 21

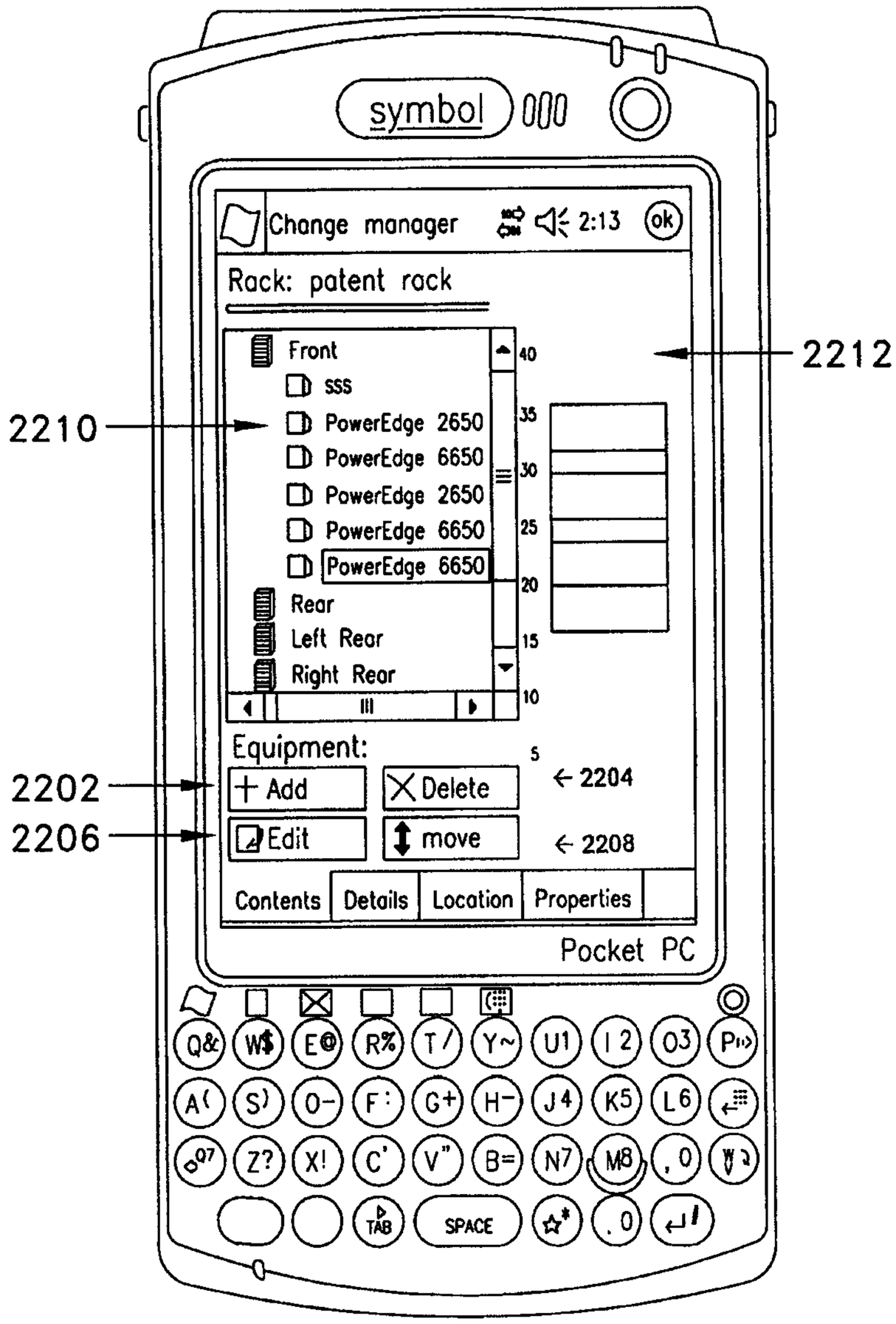

symbol
Change manager
2:13
ok
Rack: patent rack
Front
sss
PowerEdge 2650
PowerEdge 6650
PowerEdge 2650
PowerEdge 6650
PowerEdge 6650
Rear
Left Rear
Right Rear
40
35
30
25
20
15
10
Equipment:
5
Add
Delete
Edit
move
Contents
Details
Location
Properties
Pocket PC
2210
2212
2202
2206
2204
2208

FIG. 22

2304

2306

Report 2302

Effects of Stranded Condition	Causes of Stranded Condition			
	Power	Cooling	Rack U Space	Rack Pa
Power	N/A	0%	10%	
Cooling	20%	N/A	0%	
Rack U Space	0%	10%	N/A	
Rack PDU Outlets	10%	5%	10%	
Floor Space	10%	10%	10%	
Patch Panel Ports	5%	5%	10%	
Weight Support Capacity	20%	20%	10%	

2308

	Total	30%	30%	20%	35%	40%	30%	50%
Rack PDU Outlets	15%							
Floor Space	0%	0%	5%	0%	0%	0%	0%	0%
Patch Panel Ports	5%	5%	0%	0%	10%	5%	N/A	0%
Weight Support Capacity	0%	0%	0%	0%	0%	0%	0%	N/A

FIG. 23

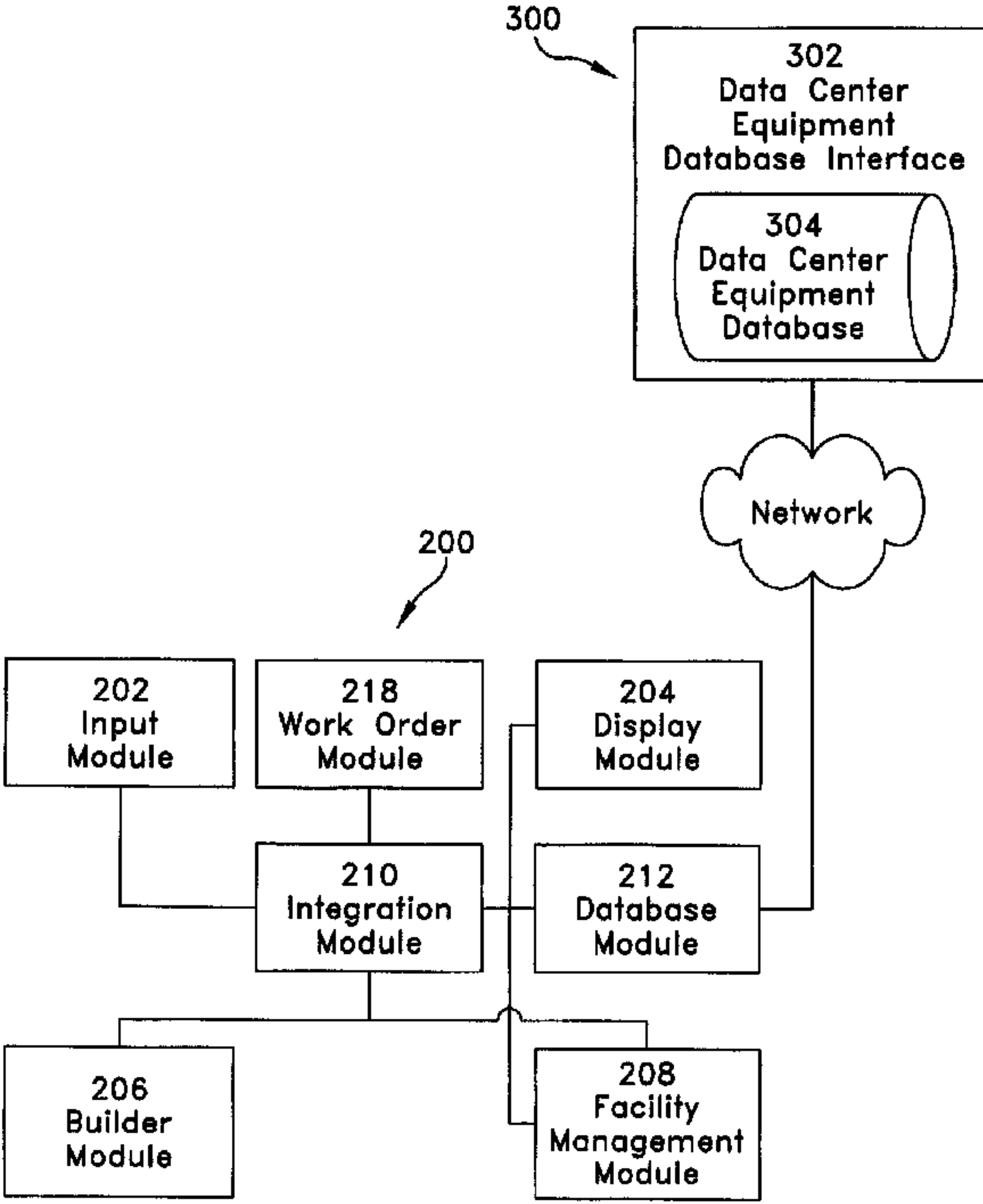

300
302
Data Center
Equipment
Database Interface
304
Data Center
Equipment
Database
Network
200
202
Input
Module
218
Work Order
Module
204
Display
Module
210
Integration
Module
212
Database
Module
206
Builder
Module
208
Facility
Management
Module

FIG. 3