United States Patent	12396138
Kind Code	B2
Date of Patent	August 19, 2025
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Heat removal systems and methods with automated fire suppression for data centers

Abstract

In an open-loop heat removal system for a building such as a data center or a home, cool air is supplied to the building by a chilling unit and hot air is expelled from the building without recycling, recirculating, or re-cooling the hot air. For fire suppression, the system receives temperature reading(s) from temperature sensor(s) and determines whether any temperature reading reaches or exceeds a temperature that indicates presence of a fire. If so, a louver positioned over an inlet module is automatically or programmatically closed, shutting off air supply to the building. The system determines whether the building is under a negative pressure internally. If not, an exhaust fan at the outlet of the building is turned on to create a negative pressure internally. The system determines whether an oxygen level of the building indicates that the fire has been contained. If not, a sprinkler system is activated.

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Family ID: **1000008766164**

Appl. No.: **17/892683**

Filed: **August 22, 2022**

Prior Publication Data

Document Identifier	Publication Date
US 20220408605 A1	Dec. 22, 2022

Related U.S. Application Data

continuation parent-doc US 15678961 20170816 US 10212855 20190219 child-doc US 16230799
continuation parent-doc US 14984149 20151230 US 9769960 20170919 child-doc US 15678961
continuation-in-part parent-doc US 16850869 20200416 US 11659693 child-doc US 17892683

continuation-in-part parent-doc US 16230799 20181221 US 10667436 20200526 child-doc US 16850869
us-provisional-application US 62098176 20141230

Publication Classification

Int. Cl.: **H05K7/20** (20060101)

U.S. Cl.:

CPC   **H05K7/20745** (20130101); **H05K7/20827** (20130101); **H05K7/20836** (20130101);

Field of Classification Search

CPC: H05K (7/20745); H05K (7/20827); H05K (7/20836)

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This is a continuation-in-part of, and claims a benefit of priority from, U.S. patent application Ser. No. 16/850,869, filed Apr. 16, 2020, issued as U.S. Pat. No. 11,659,693, entitled "HEAT REMOVAL SYSTEMS AND METHODS," which is a continuation-in-part of, and claims a benefit of priority from, U.S. patent application Ser. No. 16/230,799, filed Dec. 21, 2018, issued as U.S. Pat. No. 10,667,436, entitled "HEAT REMOVAL SYSTEMS AND METHODS," which is a continuation of, and claims a benefit of priority from, U.S. patent application Ser. No. 15/678,961, filed Aug. 16, 2017, issued as U.S. Pat. No. 10,212,855, entitled "DATA CENTER HEAT REMOVAL SYSTEMS AND METHODS," which is a continuation of, and claims a benefit of priority from, U.S. patent application Ser. No. 14/984,149, filed Dec. 30, 2015, issued as U.S. Pat. No. 9,769,960, entitled "DATA CENTER HEAT REMOVAL SYSTEMS AND METHODS," which claims a benefit of priority under 35 U.S.C. § 119(e) from Provisional Application No. 62/098,176, filed Dec. 30, 2014 entitled "DATA CENTER HEAT REMOVAL SYSTEMS AND METHODS." All applications listed in this paragraph are hereby fully incorporated by reference in their entireties.

TECHNICAL FIELD
(1) This disclosure relates generally to data centers. More particularly, this disclosure relates to a new approach to removing heat from industrial buildings such as data centers. Even more particularly, this disclosure relates to heat removal systems, methods, and computer program products with automated fire suppression for data centers.

BACKGROUND
(2) A data center is an example of an industrial facility and can be used to house computer systems and associated cooling equipment such as air conditioning systems. Large scale data centers can

include hundreds or thousands of server machines and can require as much energy as a small town to power the data center computer equipment and cooling equipment.

(3) As such, energy usage consumed by data centers is a major cost consideration for all involved. Energy costs in data centers arise from computing, networking activities, and power transformations that use energy and, as a byproduct, generate heat. However, a majority of energy costs is associated with the removal of heat from the data center. Active heat management equipment (i.e., air conditioning systems) is substantially less than 100% efficient, which means heat monitoring and management equipment adds to the data center heat removal problems because they generate heat through their own operation.

(4) In a conventional data center environment, desired temperatures are maintained using heating, ventilation, air conditioning (HVAC). Indeed, HVAC systems are an integral part of just about every data center. They are essential to maintaining the temperature, humidity, and air quality of a data center.

(5) An HVAC system usually includes a furnace, an evaporator coil, a condensing unit, vents, and refrigerant lines. Typically, the ambient temperature is monitored by the thermostat, which turns the heat or air conditioning on and off to maintain the temperature set by the thermostat.

(6) For heating, the air is heated by the furnace and then distributed throughout a data center through ductwork or piping. The furnace can be huge and is the largest component of all HVAC components. With hundreds or thousands of server machines constantly running at the same time in a data center environment, utilizing the furnace to maintain a minimum temperature is less of a problem than utilizing the remaining HVAC components to keep the data center cool and not to exceed a certain acceptable temperature.

(7) For cooling, the condensing unit is installed on the outside of the data center and filled with a refrigerant gas. When the refrigerant gas is cooled into a liquid form, the condensing unit can include a compressor to pump the liquid refrigerant to the evaporator coil. The indoor air is cooled with the liquid refrigerant in the evaporator coil as heat from indoor air is absorbed into the refrigerant. This process transforms the refrigerant from liquid to gas again. The gas is cycled back through refrigerant lines to the condensing unit as the cooled air is distributed inside the data center. Heat is released outside through the outdoor unit as the refrigerant turns back to a liquid and a fan blows air over the condenser to dissipate the heat outside.

(8) While an HVAC system regulates the heat and conditions air inside a building, an air conditioner, also referred to as an AC unit, is primarily used in air conditioning. HVAC systems and AC units are not designed to bring in fresh air from the outside for cooling purposes. Generally, outside air is brought into an HVAC system from an intake which is generally located by the furnace. Through this intake, air is drawn in from the outside and cooled for indoor distribution. Similarly, air is sucked into an AC unit initially. The air that is sucked in passes through coils. When the refrigerant passes back into the building, it passes through a narrow valve into the evaporator. When the refrigerant flows into the evaporator, the valve quickly expands. This expansion causes the refrigerant to become very cold. A fan blows air on the very cold evaporator. The coils of the evaporator are what ultimately cools the air. The cooled air is distributed via ductwork throughout the building. As the cooled air is distributed, air blown onto the evaporator from the return ducts again transfers heat into the refrigerant. The refrigerant is then pumped back to the condenser, beginning the cycle again. This results in recycled air. That is, HVAC systems and AC units recycle indoor air and do not continuously bring in fresh outdoor air.

SUMMARY OF THE DISCLOSURE

(9) Embodiments disclosed herein provide a fire suppression method for an open-loop heat removal system in which a fire can be suppressed as hot air is expelled from a building, such as a data center or a home, without recycling, recirculating, or re-cooling the hot air. Although an open-loop heat removal system is disclosed herein, those skilled in the art will appreciate that the principals of heat, oxygen, and airflow monitoring and control (e.g., through a louvre, vent, or other means) may

apply for fire suppression/protection in a closed loop environment as well.

(10) As a non-limiting example, a heat removal system may comprise: a chilling unit for supplying cool air to the building through an inlet of the building; an inlet module at the inlet of the building, the building having an outlet through which hot air is expelled from the building without recycling, recirculating, or re-cooling the hot air; an outlet module at the outlet of the building; a louver at the inlet module; an exhaust fan at the outlet module; a temperature sensor located inside the building for sensing an internal temperature of the building; an oxygen sensor for sensing an internal oxygen level of the building; a pressure sensor for sensing an internal pressure of the building; a smoke detector for detecting smoke in the building; a controller; a non-transitory computer-readable medium; and instructions stored on the non-transitory computer-readable medium and translatable by the controller for implementing a fire suppression method for the heat removal system.

(11) In some embodiments, the fire suppression method may comprise: receiving an indication from a smoke detector that smoke has been detected in the building; responsive to the indication from the smoke detector, closing the louver at the inlet module to shut off supply of the cool air through the inlet of the building; determining, utilizing a pressure sensor, whether the building is under a negative pressure internally; responsive to the building not being under a negative pressure internally, operating the exhaust fan to create a negative pressure internally; determining, utilizing an oxygen sensor, whether an internal oxygen level of the building has decreased to a point that indicates that the fire has been contained; determining whether smoke can still be detected in the building and responsive to the fire not having been contained or the smoke can still be detected in the building, activating a sprinkler system in the building.

(12) In some embodiments, closing the louver at the inlet module to shut off supply of the cool air through the inlet of the building can be triggered when a temperature reading from a temperature sensor located inside the building indicates that the temperature reading has reached or exceeded a default or user-set temperature that indicates presence of a fire in the building.

(13) In some embodiments, the fire suppression method for the heat removal system may further include setting a temperature at which the sprinkler system is activated to be higher than the default or user-set temperature that triggers closure of the louver at the inlet module. In some embodiments, the fire suppression method may further comprise setting a temperature at which the sprinkler system is activated to be higher than the default or user-set temperature. This allows the heat removal system to take appropriate actions step by step. First, the system closes the louver at the inlet of the building completely to cut off the supply of the cool air. Next, the system checks to see whether the exhaust fan(s) at outlet module(s) work. If not, the system closes the outlet module(s) and checks to see if, by closing both the inlet and the outlet, the fire is now contained.

(14) If the exhaust fan(s) work, the system checks the internal pressure and the oxygen level. Reducing the oxygen level can help to put out the fire and a negative pressure can help reduce the oxygen level in the building. Thus, in some embodiments, the system is operable to determine whether the building is under a negative pressure of 1 KPa or greater internally. In some embodiments, the system is operable to determine whether the internal oxygen level of the building is at 15% or less. If so, the fire is considered as having been contained and the process ends. If smoke is still detected after the decrease of oxygen, a sprinkler system can be programmed to come on. The above-described fire suppression method can be particularly useful for buildings that do not have windows. For example, for security reasons, a data center typically does not have windows.

(15) These, and other, aspects of the disclosure will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following description, while indicating various embodiments of the disclosure and numerous specific details thereof, is given by way of illustration and not of limitation. Many substitutions, modifications, additions and/or rearrangements may be made within

the scope of the disclosure without departing from the spirit thereof, and the disclosure includes all such substitutions, modifications, additions and/or rearrangements.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) The drawings accompanying and forming part of this specification are included to depict certain aspects of the disclosure. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale. A more complete understanding of the disclosure and the advantages thereof may be acquired by referring to the following description, taken in conjunction with the accompanying drawings in which like reference numbers indicate like features.

(2) FIG. **1** depicts a diagram illustrating an exemplary data center heat removal system configured for a data center and having a chilling unit according to some embodiments.

(3) FIG. **2** is a perspective view of an exemplary server pod of a data center implementing an exemplary data center heat removal system disclosed herein.

(4) FIG. **3** is a block diagram of an exemplary arrangement of a chilling unit according to some embodiments.

(5) FIGS. **4-7** are views of an exemplary chilling unit according to some embodiments.

(6) FIG. **8** is a block diagram illustrating an exemplary data center heat removal system configured to maintain a desired temperature in a data center according to some embodiments.

(7) FIG. **9** is a logical control diagram for an exemplary data center heat removal system according to some embodiments.

(8) FIG. **10**A depicts a building installed with an example of a heat removal system disclosed herein according to some embodiments.

(9) FIG. **10**B depicts a building installed with another example of a heat removal system disclosed herein according to some embodiments.

(10) FIG. **11** is a flow chart illustrating an example of a method of removing heat from and cooling air in a building according to some embodiments.

(11) FIG. **12** depicts a diagrammatical representation of a closed-loop heat removal system that utilizes an HVAC system to regulate the indoor temperature of a building.

(12) FIG. **13** depicts a diagrammatical representation of an open-loop heat removal system that utilizes a chilling unit to supply cool air to a building according to some embodiments.

(13) FIGS. **14**A-**14**D depict a diagrammatical representation of a closed-loop heat removal system with an inlet module, an outlet module, and heat-sensing louvers according to some embodiments.

(14) FIG. **15** is a flow diagram that illustrates an example of a fire suppression method for an open-loop heat removal system according to some embodiments.

(15) FIG. **16** is a flow diagram that illustrates another example of a fire suppression method for an open-loop heat removal system according to some embodiments.

DETAILED DESCRIPTION

(16) The invention and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments that are illustrated in the accompanying drawings and detailed in the following description. Descriptions of well-known starting materials, processing techniques, components and equipment are omitted so as not to unnecessarily obscure the invention in detail. It should be understood, however, that the detailed description and the specific examples, while indicating some embodiments of the invention, are given by way of illustration only and not by way of limitation. Various substitutions, modifications, additions and/or rearrangements within the spirit and/or scope of the underlying inventive concept will become apparent to those skilled in the art from this disclosure.

(17) Embodiments disclosed herein provide systems, methods, and computer program products that

allow a combination of active and passive thermal processes for removing heat and/or reducing oxygen levels (for fire suppression reasons) from industrial buildings having computing equipment, networking equipment, and/or power distribution systems. For the purpose of illustration, examples provided in this disclosure are described in the context of data centers. However, some embodiments disclosed herein can be adapted or otherwise implemented for different types of industrial buildings, environments, circumstances, etc. Some embodiments may automatically utilize convection for cooling. Some embodiments are designed to allow multi-stage cooling. Some embodiments utilize pressure to expel hot air and draw in cool air. Some embodiments can be built into a new building. Some embodiments can be retrofitted to remove heat from and provide cool air to an existing building or environment. Some embodiments can be particularly useful for high volume applications. Although an open-loop heat removal system is described as an example, those skilled in the art will appreciate that a closed-loop heat removal system may also implement the fire suppression method disclosed herein. Numerous additional embodiments are also possible.

(18) In some embodiments, a data center heat removal system may include an adjustable thermal feed cold air intake system, a distribution system for cold and warm air including one or more hot aisles and one or more cold aisles, and a convection system to draw cool air through data center equipment using naturally-occurring convection processes to expel hot air. That is, some embodiments utilize passive pressure differences to expel hot air and bring in cool air, either alone or in combination with active use of fans or other air circulation devices. In addition, some embodiments may use heat exchangers.

(19) In some embodiments, these components are interchangeable and modular and are the basis of a novel solution that provides an efficient method of removing heat from a data center.

(20) Embodiments utilize natural convection for heat removal from a data center including using the pressure differential between a hot aisle and a cold aisle. Embodiments may also use cold air from misters and/or freezer boxes for the intake of cold air. Some embodiments may use a natural process to form two distinct pressure regions in the data center. Some embodiments may use natural processes to maximize the air pressure differential between the cold aisle input of an individual server and its output to the warm aisle. Some embodiments allow natural process-driven multi-stage air cooling.

(21) Advantageously, embodiments efficiently manage the climate (which can include temperature, humidity, air flow, and air quality, etc.) within a data center and minimize the use for energy for air distribution. Some embodiments minimize the use of active heat management equipment that generates heat through their own operation. Some embodiments minimize and eliminate the use of moving cooling parts. Some embodiments minimize maintenance costs associated with server heating and cooling. Some embodiments manage the costs of computing services.

(22) In some embodiments, a system for removing heat from and cooling air in a building can include a chilling unit for supplying cooled air to the building at a constant rate, the building having a heat containment for capturing or receiving hot air inside the building, the building further having an exhaust structure for expelling the hot air from the building such that the hot air thus captured or received is not recycled, recirculated, or re-cooled. The chilling unit can comprise a housing having an intake end and an exhaust end and at least one fan positioned in the housing and set to operate at a constant speed to draw ambient air from the intake end of the housing, cool the ambient air, and direct the cooled air to an opening of the building.

(23) In some embodiments, a system for data center heat removal includes an adjustable pressure feed cold air intake system; one or more heat exchangers; a distribution system for cold and warm air (cool aisles and warm aisles); and a convection system to draw cool air through data center equipment along with embedded server fans. The system further may make use of naturally-occurring convection processes to expel hot air, thus creating a relative vacuum to draw in cool air (and may optimally use an adjustable fan for disposing of warm air). Thus, embodiments may include a sealed warm low pressure area and a cold pressure area.

(24) In some embodiments, a method for removing heat from and cooling air in a building (e.g., a data center or any industrial building that generates heat) can include positioning an exhaust end of a chilling unit in an opening of the building (e.g., in a wall, roof, or ceiling of the building), the chilling unit having a housing having the intake end and the exhaust end and at least one fan positioned in the housing and set to operate at a constant speed (whether the at least one fan is a fixed speed fan or a variable speed fan) to draw ambient air from the intake end of the housing, cool the ambient air, and direct the cooled air to the opening of the building. The method can further include capturing or receiving hot air inside the building through a heat containment inside the building; setting an air conditioning unit inside the building to maintain a target temperature; and expelling the hot air from the building through an exhaust structure of the building. In some embodiments, the target temperature can be a minimum service temperature required by an owner or operator of the building. The air conditioning unit can be part of any existing or commercially available HVAC system.

(25) As alluded to above, conventional HVAC systems and AC units do not continuously bring in fresh outdoor air. Instead, they recycle indoor air. Such HVAC systems and AC units can be considered as taking a closed-loop heat removal approach. Embodiments disclosed herein take a different heat removal approach in which hot air is expelled from a building and not recycled, recirculated, or re-cooled.

(26) Expelling the hot air from the building without recycling, recirculating, or re-cooling the hot air creates a pressure differential in which an air pressure at a hot side of the building is lower than an air pressure at a cool side of the building. This pressure differential draws the cooled air supplied by the chilling unit through the opening of the building from the hot side of the building to the cool side of the building. The building can utilize an air conditioning unit that is set to maintain a target temperature. Responsive to a temperature in the building rising above the target temperature, the air conditioning unit is operable to run until the temperature in the building drops down at or below the target temperature with the chilling unit supplying the cooled air to the building at the constant rate and without having to recycle, recirculate, or re-cool air heated in the building. In this way, the chilling unit can significantly reduce the energy consumption of the air conditioning unit.

(27) In some embodiments, the heat containment can be implemented in a server pod enclosing one or more banks of servers. The server pod can have openings for drawing in the cooled air and a vent for directing air heated by the one or more banks of servers to the exhaust structure. In some embodiments, the heat containment can further include a sealed hood, enclosure, ductwork, or pipe.

(28) In some embodiments, the chilling unit can further include at least a filter, an evaporative cooler, an evaporative cooling element, a freezer coil, or a chiller to further cool the air drawn in from the intake end of the housing.

(29) Below provides a non-limiting example of a data center environment in which a heat removal system may be implemented according to some embodiments. FIG. **1** depicts a diagram schematically illustrating a layout of a data center heat removal system according to some embodiments. In the example of FIG. **1**, a data center heat removal system for a data center **100** includes a chilling unit **102**. As will be described in greater detail below, the chilling unit **102** may include a housing, one or more fans or similar devices configured for drawing in air from outside the data center, one or more misters for cooling the air, and one or more chiller units for further reducing the air temperature.

(30) The data center **100** may include one or more server pods **106***a* and **106***b*. The server pods **106***a* and **106***b* may be embodied as self-contained rooms or enclosures that have walls **107**, doors **116***a*, **116***b*, **116***c*, **116***d*, and ceilings (not shown). The server pods **106***a* and **106***b* are configured to house one or more banks of servers **108***a*, **108***b* and **108***c*, and **108***d*, respectively. The server banks **108***a*, **108***b* and **108***c*, and **108***d* may comprise racks of servers mounted on above each other. It is noted that while two server pods are illustrated, in practice, a data center may employ many more.

Thus, the figures are by way of example only.

(31) The server pods **106***a* and **106***b* include openings **112** for drawing in cool air from the chilling unit **102** via one or more "cold aisles" **115**. Additional cold aisles may be formed between other server pods, in the example where the data center includes numerous server pods. The server pods **106***a* and **106***b* may further be configured such that banks of servers **108***a* and **108***b* (and similarly, server banks **108***c* and **108***d*) are separated by a "hot aisle" **110***a* and **110***b*, respectively. In operation, cold air is drawn in from the cold aisle(s) **115** and flows across the server banks **108***a* and **108***b* (and similarly, server banks **108***c* and **108***d*), where the air is heated by the servers. The heated air, isolated in the hot aisles **110***a* and **110***b*, is then drawn up and out through vents **117***a* and **117***b* in the ceiling of the respective pods **106***a* and **106***b*. The heated air escaping from the hot aisles **110***a* and **110***b* will yield lower pressure in the hot aisles **110***a* and **110***b*, causing cool air to be drawn from the cold aisle(s) **115**. The air circulation can be controlled by varying the volume of air allowed through the supply side or through the exhaust side or both (described in detail below).

(32) Accordingly, air heated by the server banks **108***a*, **108***b* and **108***c*, and **108***d* will rise to the top of the pods **106***a* and **106***b* via natural convection and be vented through vents **117***a* and **117***b*. Some embodiments provide a sealed hood for the hot air flows (see e.g., the hood **211** shown in FIG. **2**). In some embodiments, additional fans may be provided in or in conjunction with the vents **117***a* and **117***b* to assist in drawing out the heated air and/or to maintain a desired pressure differential.

(33) As illustrated by the exemplary flow lines in FIG. **1** (represented by lines **114***a* and **114***b*), air flows from the chilling unit **102** into one or more cold aisles **115**, from which they are drawn into the server pods **106***a* and **106***b* via openings **112**. Inside the server pods **106***a* and **106***b*, internal fans of the servers (not shown) may draw the air across the servers and out into the hot aisles **110***a* and **110***b*. From the hot aisles **110***a* and **110***b*, the heated air is vented through the vents **117***a* and **117***b*.

(34) In some embodiments, the vents **117***a* and **117***b* may be provided with or associated with fans that draw air up into them. In some embodiments, the fans are coupled to or controlled by one or more pressure sensors, which can be utilized to ensure that the pressure in the hot aisles **110***a* and **110***b* is lower than the pressure in the cold aisles **115**. For example, if the pressure in the hot aisle **110***a* or **110***b* is detected as being the same or higher than the pressure in the cold aisle **115**, the respective fans may be operated at a higher speed to draw more air in the hot aisles **110***a* and **110***b* up for venting through the vents **117***a* and **117***b*. This ensures that a desired pressure differential, and/or a desired air flow rate, can be maintained or otherwise controlled.

(35) FIG. **2** is a perspective view illustrating an exemplary server pod of a data center that houses a plurality of server banks (now shown). For clarity, only one server pod is shown. The data center of FIG. **2** may be an embodiment of the data center **100** shown in FIG. **1**. In this example, a server pod **206***a* and an adjacent server pod (not shown) are separated by cold aisle **215**. The sides of the server pod **206***a* include screened openings **212** for admitting cool air into the server pods **206***a*. As illustrated, the server pod **206***a* includes an access door **216***a* defining an opening to the hot aisle (not shown) inside the server pod **206***a*. In the example illustrated, the server pod hot aisle (inside the server pod **206***a*) extends from the ceiling of the server pod **206***a* to the ceiling of the data center via an enclosure or hood **211**. The cold aisle **215** is pressurized with cool air which is then drawn through the racks of the server pod **206***a*, as illustrated by arrows **214**. The air is then drawn out the top of the server pod **206***a* via the enclosed or sealed hood **211**.

(36) As described above with respect to FIG. **1**, a data center heat removal system may include one or more chilling units, such as the chilling unit **102**. FIG. **3** is a block diagram of one exemplary arrangement of a chilling unit **300**, which may be used in a data center according to some embodiments. The chilling unit **300** may include a structure or housing for housing the various components of the chilling unit, described below. In one example, a housing may comprise a shipping container housing, being approximately 20 feet long, 7′10″ tall, and 7′8″ wide according

to one non-limiting example. Other types and sizes are may also be used.

(37) In the exemplary chilling unit **300** shown in FIG. **3**, the direction of air flow through the chilling unit **300** is shown by the arrows at each end of the chilling unit **300**. Ambient air enters the chilling unit **300** at a first end **301** (as shown by the arrow **303**) and exits at a second end **305** into the data center (as shown by the arrow **307**). In the example illustrated in FIG. **3**, the chilling unit **300** includes a first fan unit **314**, a first filter **312**, a second fan unit **310**, a mister **308**, a chiller unit **306**, a third fan unit **304**, and a second mister **302**. In some embodiments, each of the components may be configured to extend across a cross section of the container. Further, in some embodiments, one or more of the components may not be necessary. For example, in some embodiments, the chiller unit **306** may not be required by a data center heat removal system disclosed herein (e.g., the data center **100** shown in FIG. **1**) where the air outside a data center configured with the data center heat removal system is usually at a sufficiently cool temperature (e.g., depending upon the climate, location, and/or altitude at which the data center is located) that artificial cooling may not be necessary. Furthermore, in some embodiments, the humidity of the air may be such that only one mister is needed.

(38) In some embodiments, the number and configuration of fan units in the chilling unit **300** may be chosen based on air flow requirements, as desired. In some embodiments, the fan units **314**, **310**, and **304** may each include four 44″ drum fans capable of moving approximately 72,000 CFM of air. The control of the fan units is described in detail below. The filter units **312** may be implemented as four-stage Hepa filters in some embodiments.

(39) In some embodiments, the chiller unit **306** may be configured to include chillers on both sides of the chilling unit **300**, with coils that extend to meet each other at 45 degrees from the sides. In some embodiments, the coil units may be hinged such that, when not in use, they can swing to the sides of the chilling unit using motors.

(40) In some embodiments of a data center heat removal system, various types of sensors can be placed in a data center to sense various conditions in the data center. In some embodiments, the sensed conditions are stored in a database and are used by a control system to control the operation of the components of the chilling unit and associated fans, vents, etc. (described below). The control system may be associated with the chilling unit **300** or the data center itself, or both. The sensors may include temperature sensors, humidity sensors, air flow sensors, pressure sensors, and/or other types of environmental sensors. In some embodiments, each chilling unit **300** may provide up to 60,000 CFM of air to the data center at or under 78 degrees. In other embodiments, each chill unit **300** may provide more or less capacity, as desired.

(41) While the chilling unit **300** is pressurizing the data center, the variable speed ceiling fans (e.g., for the vents **117***a* and **117***b* of FIG. **1** or the hood **211** of FIG. **2**) of the data center may be adjusted to keep the pressure in the hot aisles at lower than the cool side of the system. When the temperature is below a threshold value (e.g., 65 degrees), one of the fans may be slowed or shut off to decrease the pressure and the ceiling fan will slow to reduce amount of air that is being released.

(42) FIGS. **4**-**7** are views of an exemplary chilling unit according to some embodiments. Other configurations and layouts are also possible. In FIGS. **4**-**7**, the housing walls are hidden to show the chilling unit components inside the housing. FIG. **4** is an isometric view of a chilling unit. Each of FIG. **5**A, FIG. **5**B, and FIG. **5**C is a top view of the chilling unit shown in FIG. **4**. FIG. **6** is a side view of the chilling unit shown in FIG. **4**. FIG. **7** is an end view of the chilling unit shown in FIG. **4**.

(43) As mentioned above, in some embodiments, a chilling unit can be housed using a standard shipping container. A typical shipping container is comprised of a steel box having doors at one end. Although a standard shipping container works well as a chilling unit housing, a customized housing can also be used. In one example, a standard 20 foot freezer shipping container is used. In this example, an intake area (described below) is formed at one end of the container.

(44) As shown in FIGS. **4**-**7**, a chilling unit **400** includes a housing **410** having doors **412** at one

end. During use of the chilling unit **400**, the doors **412** are opened, or completely removed. In FIGS. **4-6**, the direction of air flow through the chilling unit **400** is from right to left.

(45) At the right end of the chilling unit **400** are a plurality of vents **414** that form openings in the housing **410** to allow air to be drawn into the chilling unit **400** from outside. In the example shown in FIG. **4**, the vents **414** are formed on the end, and on 3 sides of the housing **410**. Downstream from the vents **414** are one or more fans **416**. In the example shown in FIGS. **4-7**, four fans are arranged to substantially cover the cross-sectional area of the housing **410**. More or fewer fans could be used. As described in more detail below, the fans **416** may be single or variable speed, and may be controlled together or independently. The fans **416** draw air into the chilling unit **400** via the vents **414**, and force the air through filter(s) **418**. In one example, the fans **416** are 42 inch drum fans, each capable of moving 18,200 cubic feet per minute (CFM) of air. In the example of FIGS. **4-7**, four fans are placed in the intake side. In other examples (e.g., FIG. **3**), four more fans are placed on the exhaust end of the housing **410**. In one example, the filters are 3-stage heap filters angled at 45 degrees from both sides to provide more surface area.

(46) Downstream from the filters **418** is a mister **420**. In the example shown, the mister **420** comprises a series of mister nozzles **421** near the top of the housing **410** pointing downward. When the mister **420** is activated, a fine mist **422** of water is sprayed downward as the air flows through the chilling unit **400**. Depending on the temperature and relative humidity, the mister **420** can lower the temperature of the air by approximately 10 degrees.

(47) Downstream from the mister **420** are mister cooling elements **424**. For clarity, the mister cooling elements **424** are not shown in FIG. **4**, but are shown in FIGS. **5**A-**6**. The mister cooling elements **424** are made of a metal material and help to cool the air even further by providing a surface for mist condensation. As the air flows through the mister cooling elements **424**, the air is not only cooled by evaporating mist, but also by passing through the mister cooling elements **424**. The mister cooling elements **424** can be any configuration that allows air to flow through, while providing a surface (e.g., a metal surface) for mist condensation. Examples of the mister cooling elements **424** can include coils, a metal grate or mesh, etc., as one skilled in the art would understand.

(48) Downstream from the mister **420** and the mister cooling elements **424** are a pair of chillers **426** mounted on opposite walls of the housing **410**. The chillers **426** can be conventional off-the-shelf air-conditioning or freezer units configured to chill the air. If the air needs to be further cooled, one or more of the chillers **426** can be turned on. FIGS. **5**A-**6** also show freezer elements such as freezer coils **428** disposed within the housing **410** between the chillers **426**. The freezer elements **428** are extensions of piping from the chillers **426** extending into the chiller unit **400** to improve heat transfer with the air. In one example, the freezer elements **428** are configured to extend out at a 45 degree angle from the sides of the housing **410**. In one example, the freezer elements **428** are movable to automatically swing back against the interior wall of the housing **410** when not in use.

(49) Note that the configuration of a chilling unit can take on many configurations, as desired. For example, the chilling unit **300** shown in FIG. **3** has three sets of fans and two sets of misters. Depending on various factors, such as local climate, data center size, cost limitations, etc., a chilling unit can be configured in such a way as to balance desired performance and cost.

(50) As mentioned above, the temperature of a data center can be controlled and maintained by sensing various conditions in the data center and controlling various components of a system accordingly. FIG. **8** is a block diagram illustrating a system **800** that is configured to maintain a desired data center temperature in the most energy efficient manner possible. The system **800** has a controller **810** capable of interfacing and controlling the various components of the system **800**. The controller **810** may be comprised of a single device that interfaces with the components of the system **800**, or may include multiple devices working together. For example, a data center may have separate fan controllers, chiller controllers, etc. In one example, a web-based application runs on a server **812** and controls the operation of the controller **810**. One or more client devices **814** can

be used by a technician to configure and monitor the controller via the web-based application.

(51) The system **800** uses a plurality of sensors **816** to sense various conditions in the data center. The sensors may include temperature sensors, humidity sensors, air flow sensors, smoke detectors, and/or pressure sensors, and any other desired sensors. The temperature sensors may sense the temperature in the hot aisles, cold aisles, server pods, chilling units, exhaust vents, individual servers, etc. The ambient temperature can also be sensed outdoors or at the intake portion of the chilling unit. Similarly, humidity sensors can also sense the humidity anywhere in the data center, as desired. The smoke detectors can be installed at various placed to detect smoke in the data center. A smoke detector is installed near the exhaust vent. Signals from this smoke detector can indicate to the controller **810** whether smoke can still be detected in the exhaust after the oxygen level in the building has been decreased to suppress fire. Pressure sensors sense air pressure at various places in the data center. By monitoring the air pressure throughout the data center, a desired air flow through the system can be maintained. In one example, the air pressure is sensed in the cold aisles, hot aisles, and exhaust vents. The system **800** may also use any other type of sensor desired.

(52) The system **800** controls the operation of the fans **818** of the system to maintain a desired air flow throughout the system. For example, a data center may have fans in the chilling units (e.g., fans **416** in FIG. **4**) and in the exhaust vents (e.g., vents **117***a* and **117***b* in FIG. **1**). The controller **810** controls whether the fans are on or off, as well as controlling their speed, when variable speed fans are used. The controller **810** is capable of determining how to most efficiently use the fans to maintain a desired air flow, and thus temperature. For example, if a given amount of air flow is needed to maintain a target temperature, the controller can selectively activate individual fans, and control them at desired speed(s) to achieve a desired airflow using the least amount of electricity possible.

(53) The system **800** can also control the opening and closing of vents **820** in the system, if the system is equipped with closable vents. For example, the intake vents of the chilling units may include louvers that can be opened and closed by the controller **810**. Similarly, the exhaust vents can be opened and closed by the controller **810**. The vents **820** can not only be opened and closed, but can be opened a desired amount, to further control the amount of air flow through the vents **820**.

(54) The system **800** also controls the operation of the misters **822** (e.g., misters **420** in FIG. **4**) of the system to lower the air temperature in the system. As described above, activating the misters **822** can, under the right conditions, lower the air temperature by approximately 10 degrees. The misters **822** have the most effect in low-humidity conditions. By knowing the humidity of the air, the controller **810** can determine when activating the misters **822** will have a beneficial effect.

(55) The system **800** also controls the operation of the chiller units **824** (e.g., chillers **426** in FIG. **4**) of the system to lower the air temperature. By activating the chiller units **824**, the air temperature can be significantly lowered to help achieve a desired air temperature.

(56) The controller **810** may also control various other components, as desired. In addition, the controller **810** and web-based application can monitor, log, and report various aspects of the operation of the system **800**. The system **800** may include monitors, visual indicators, alarms, etc., either via client devices or standalone indicators and devices, to allow users or technicians to monitor the operation of the system **800**.

(57) The system **800** is controlled to achieve a desired target temperature in the server pods in the most efficient manner possible. The dominate factor that determines the cost of cooling a data center of electricity usage. The various components of the system **800** that contribute to lowering air temperatures each use different amounts of electricity. Therefore, the controller **810** is configured to achieve and maintain a target temperature by controlling the system components in such a way that electricity usage is minimized.

(58) A goal of the controller is to maintain a desired target temperature, using the least possible

amount of electricity. When the chiller units may use significantly more power than the fans and misters, the controller will try to maintain the desired target temperature without using the chiller units, or at least minimizing the use of the chiller units. Similarly, the controller will selectively activate and control the speed of the fans to achieve a desired airflow using the least amount of power.

(59) In one example, the controller **810** uses an algorithm to control the system. The algorithm may, when possible, maintain a desired target temperature without using the chiller units **824**. For example, under the right conditions, the desired target temperature can be maintained by controlling the activation and speed of the fans **818** alone. Under the right conditions (e.g., a relatively low humidity level), the misters **822** may be used with the fans. Use of the misters **822** may allow fans usage to be reduced, further lowering power usage.

(60) The control algorithm, via the sensors, knows the conditions (e.g., temperature, humidity, air pressure differentials) in the system, and can control the system accordingly. For example, assume that an X degree temperature drop is needed. Knowing the outside ambient air temperature, the various temperatures in the system, and the relative air pressures in the system, the controller can determine that Y cubic feet of air flow is needed to reach the desired target temperature. The controller then selectively activates and controls the speed of the fans in the system to achieve the determined air flow rate. The controller also takes into account how activation of the misters will affect the air temperature, and thus the desired air flow rate. When the sensed conditions indicate that use of the misters would be beneficial, the misters will be activated. As a result, the controller can maintain the desired target temperature using a combination of fans and the misters in the most efficient way possible, preferably without relying on the chiller units. If the outside ambient temperature is high enough (perhaps 78 degrees, in one example), the desired target temperature may not be achievable with fans and mister alone. When that is the case, the controller will turn on one or more of the chiller units to bring the air temperature down to the desired target level.

(61) FIG. **9** is a logical control diagram illustrating an example of the control of the fans (e.g., fans **416** in FIG. **4**) in a chilling unit/data center based on a sensed condition(s). In the example illustrated in FIG. **9**, the controller controls the amount of air flow through the system based on, for example, the temperature of the air at the intake of the chilling unit. In general, cooler air requires less air flow to cool the data center, while warmer air requires more air flow to cool the data center.

(62) As shown in FIG. **9**, the controller obtains a temperature reading from one or more temperature sensors. The temperature sensor(s) may be located at the intake of the chilling unit, outside of the chilling unit, or at any other suitable location. In this example, if the sensor reports an air temperature of approximately 50 degrees Fahrenheit, the controller sends a digital signal to the fans to run at 50 CFM/kW. As indicated by the air flow rate values in FIG. **9**, the desired flow rate also depends on the amount of power being consumed in the data center, in this example, 50 CFM/kW. In other words, when more power is being consumed by the data center, more heat is generated, and therefore, more air flow is needed. The desired flow rate can be achieved by selectively activating fans, as well as setting the speed of the activated fans. In some examples, the air flow rate may be fine-tuned by also controlling exhaust fans. If the sensor reports an air temperature of approximately 70 degrees Fahrenheit, the controller sends a digital signal to the chilling unit fans to run at 126 CFM/kW. If the sensor reports an air temperature of approximately 90 degrees Fahrenheit, the controller sends a digital signal to the chilling unit fans to run at 225 CFM/kW.

(63) Other components of the system (e.g., misters, coolers, etc.) can be controlled in a similar manner based on any desired sensed conditions, as one skilled in the art would understand. Also note that the activation of different components of the system may affect each other. For example, if the misters are activated, a lower air flow rate may be desired, compared to a desired air flow rate without the misters.

(64) Note that it is important to not only lower the temperature of a data center to a desired level,

but to not let the temperature drop too far below the desired level. The reliability of some server equipment relies on a relatively constant temperature. Therefore, in some conditions (e.g., winter months), the outside ambient air will be cool enough that the controller will restrict air flow to keep the air temperature up to the desired target value.

(65) The systems described above can be built into a new data center or retrofitted into an existing data center utilizing existing structures such as ducting, chimney(s), etc. In an example where a system is retrofitted into an existing data center, one or more chilling units can each be installed in an opening formed in a data center wall, as illustrated in FIG. **1**. In each hot aisle, an exhaust vent/hood (e.g., vents **117***a* and **117***b* in FIG. **1**) is created to draw hot air out of the data center. A controller and various sensors (e.g., temperature, humidity, and/or pressure, etc.) can also be installed to monitor and control the operation of the system.

(66) A distinction between the system described above and a conventional cooling system is that the system disclosed herein does not recycle or re-cool air in a building. A conventional cooling system that recycles and/or re-cools air in a building can be characterized as a "closed-loop" heat removal system in that the indoor air circulates, or mostly circulates, in a closed loop. Such a system assumes that it is more energy efficient to cool already air inside the building. A conventional cooling system such as an HVAC system may be required (depending upon the climate zone where the HVAC system is located) to use an economizer to draw outdoor air into a building and use dampers to control the amount of air pulled in, recirculated, and exhausted from the building. The use of such an economizer can reduce the time that the AC is running, which reduces the HAVC energy consumption. However, the outdoor air has to be below a set temperature and the humidity has to be lower than a set percentage. That is, economizers do not work well where the outdoor air is moist and warm. In such places, economizer cooling is not required because the potential energy savings may not be sufficient to justify the additional cost of implementing it.

(67) To this end, in some embodiments, the chilling unit described above can be modified to work in conjunction with an AC unit. However, unlike a conventional HVAC system, air heated in a building is not recycled, recirculated, or re-cooled. Rather, the hot air is expelled or otherwise exhausted from the building (which can be any industrial building such as a data center, a manufacturing plant, etc. that produces heat).

(68) In this case, the building is structured so that it has a heat containment. The structure of this heat containment can vary from implementation to implementation, depending upon building designs. In the example of FIG. **2**, the heat containment is structured as a pod (e.g., the server pod **206***a*) with a sealed hood or enclosure (e.g., hood **211**) which directs the hot air (which is heated by the server banks (e.g., the server banks **108***a*, **108***b* and **108***c*, and **108***d*) inside the pod and risen to the top of the pods **206***a* via natural convection) to flow to a vent or exhaust opening of the building. Additionally or alternative, a heat containment can include ductwork (which refers to a system of ducts) and/or pipes (e.g., for directing the hot air with or without the sealed hood to the exhaust opening). Other implementations are also possible.

(69) Exhausting the hot air from the heat containment creates a relative vacuum in the building. In some embodiments, a chilling unit disclosed herein can supply cooled air to the building as described above. However, the fan(s) and/or similar device(s) configured to draw ambient air from the intake end of the chilling unit are set to operate at a constant speed. The chilling unit may or may not include a mister or an evaporative cooler. Because the fan(s) and/or similar device(s) in the chilling unit are set to operate at a constant speed, there is no need for a controller to vary their speed. Thus, in such embodiments, the chilling unit does not need a customer controller. Rather, an AC in the building can function as a controller for the heat removal system to maintain a desired target temperature in the building. The AC unit can be set to a certain temperature so that it only operates when it senses that the temperature in the building is above that set temperature. In this way, the chilling unit can, while not replacing the AC unit, reduce the energy consumption of the

AC unit.

(70) This heat removal system, which includes a chilling unit and an AC unit, can be implemented in many ways. FIG. **10**A shows an example in which a chilling unit **1000** is positioned or installed in an opening formed in a wall of a building **1010**. As illustrated in FIG. **10**A, contained hot air is expelled from the building **1010** through a vent or exhaust structure **1030**. This creates a pressure differential between the hot side (e.g., the heat containment in the building) and the cool side (e.g., the intake side of the building) of the building. To this end, the chilling unit **1000** draws ambient air from its intake end and supplies cooled air through its exhaust end to the intake of the building **1010**. The building **1010** has an HVAC system **1020** which is set to maintain a minimum service temperature of the building. The fan(s) and/or similar device(s) in the chilling unit **1000** are set to operate at a set speed so that the HVAC system **1020** will only come on when the ambient air is at a temperature that is above the minimum service temperature of the building. In this example, both the HVAC system **1020** and the vent or exhaust structure **1030** are installed on the top of the building **1010**. However, the HVAC system **1020** can be located on the side or on the ground near the building **1010** and the exhaust structure **1030** can be located on the side of the building **1010**. Further, the chilling unit **1000** can be installed on top of the building **1010**, as illustrated in FIG. **10**B. Other implementations are also possible.

(71) Accordingly, referring to FIG. **11**, in some embodiments, a method of removing heat from and cooling air in a building can include installing or positioning an exhaust end of a chilling unit to an opening formed on a wall or roof of the building (**1101**). If needed, the building can be outfitted with a heat containment and/or an AC unit, if the building does not already have a heat containment and/or an AC unit (**1103**). The heat containment can be structured to confine and/or direct heat produced inside the building to a vent, exhaust structure, or opening (e.g., a pipe) of the building, as described above. The AC unit can be an existing HVAC unit of the building or any commercially available AC unit.

(72) The AC unit is set to maintain a target temperature (e.g., the minimum service temperature required by an owner or operator of the building) (**1105**). As the air inside the building becomes heated, it rises and is received or captured by the heat containment and is then expelled from the building (**1110**). Hot air being expelled from the building creates a pressure differential in which the pressure at the hot side of the building (where the heat containment is located) is lower than the cool side of the building. Accordingly, the method further comprises supplying the building with cooled air from the chilling unit at a constant rate (**1115**). The chilling unit supplies cooled air (which, in some embodiments, can be achieved with one or more fan(s) and/or similar device(s)) to the building at a constant rate because the one or more fan(s) and/or similar device(s) are set to operate at a constant speed. Thus, no controller is needed to vary the speed of the fan(s) and/or similar device(s) in the chilling unit and, consequently, no additional temperature sensors are needed. Instead, the AC unit acts as an external controller that will kick in and start cooling the air inside the building when the AC unit itself senses that the temperature inside the building is above the target temperature and that will stop running once the temperature inside the building is back down to or below the target temperature.

(73) In some embodiments, the minimum requirement for the chilling unit is that the one or more fan(s) and/or similar device(s)) are set to operate at a constant speed, with or without filters. In some embodiments, the chilling unit can additionally include the evaporative cooler (e.g., the mister **420** and/or the evaporative cooling element (e.g., the mist cooling element **424**). In some embodiments, the chilling unit can include one or more freezer coils and/or chiller(s). Other implementations may also be possible.

(74) FIG. **12** depicts a diagrammatical representation of a closed-loop heat removal system **1200** that utilizes an HVAC system to regulate the indoor temperature of a data center. In a typical closed-loop heat removal system, a damper may close when a rise in temperature occurs. The closing action of the damper is usually activated by a thermal element which melts at a temperature

that is higher than the ambient temperature, but that is low enough to indicate the presence of a fire, allowing springs to close the damper blade. Generally, in the event of a fire, sprinklers, halon, or other fire retardants are activated and the air conditioners are turned off automatically or manually by personnel. Even so, smoke is recirculated because of the closed-loop configuration. Unfortunately, this recirculation provides more oxygen which serves as fuel to the fire and adds danger to firefighters. The fire creates noxious fumes which, in turn, can be trapped in the closed-loop heat removal system. Noxious fumes are the number one killer in fires.

(75) FIG. **13** depicts a diagrammatical representation of an open-loop heat removal system **1300** that utilizes a chilling unit (not shown) to supply cool air to a data center. In an open-loop heat removal system, additional issues must be considered in view of potential fire hazards. For instance, on the one hand, given the negative pressure and large volume of outdoor air brought into an open-loop heat removal system continuously, in the event of a fire, oxygen continues to be fed in which, in turn, would sustain and spread the fire. On the other hand, the open-loop heat removal system can release noxious gas much more timely, efficiently, and effective, due to the negative pressure and the open-loop configuration.

(76) FIGS. **14**A and **14**B depict a diagrammatical representation of a closed-loop heat removal system with an inlet module, an outlet module, and heat-sensing louvers according to some embodiments. More specifically, FIG. **14**A depicts a diagrammatical representation of an open-loop heat removal system **1400** that has an inlet module **1410** for receiving cool air from a chilling unit **1450** and an outlet module **1420** for expelling hot air according to some embodiments. Although not shown in FIG. **14**, a louver is positioned above the inlet module **1410**.

(77) The open-loop heat removal system can have a temperature sensor configured for notifying a central controller where the fire is in a building. In some embodiments, the louver is kept in tension via a spring mechanism to stay in an open position. In the example of FIG. **14**, a fire has occurred between server pods in the building, near the inlet module **1410**. When activated by heat, the spring mechanism releases the tension, allowing the louver to automatically close, creating containment and preventing external air intake through the inlet module **1410**.

(78) The outlet module **1420** remains open, exhausting the fire from above. Moreover, the central controller, with artificial intelligence (AI) software enabled, is operable to instruct a sprinkler system in the building to active the sprinklers only where the contained fire is so that other equipment is not affected by the fire/water, preserving the life of the equipment.

(79) To suppress fire, at the minimum, both the inlet module and the outlet module should be closed. As illustrated in FIG. **14**B, in some embodiments, both can be closed purely on heat. In this case, each of the louver at the inlet module and the vent at the outlet module can have a component that melts when it reaches a certain temperature. The melting of the component can close a louver or vent with 99.99% up time.

(80) In some embodiments, a first heat-sensing louver is positioned on the exhaust side of the open-loop heat removal system and a second heat-sensing louver is positioned on the intake side. There are different types of louvers. Some louvers are triggered by heat. For instance, a heat-sensing louver would close once an aisle reaches 135° F. This kind of heat-sensing louver is made of a material that melts when the room temperature reaches or exceeds a default or user-set temperature. The melting closes the heat-sensing louver.

(81) In some embodiments, the maximum operating temperature for a data center is 78° F. However, setting the temperature for melting and closing a heat-sensing louver at 78° F. could cause false alarms. This is because the average temperature at which a fire could ignite and burn is between 424 and 475 degrees Fahrenheit (or between 218 and 246 degrees Celsius), while room temperatures in a fire can be 100° F. at floor level and rise to 600° F. at eye level. At 78° F., the maximum operating temperature for a data center may not necessarily indicate the presence of a fire. Accordingly, in some embodiments, the default temperature can be preset at 97° F. In some embodiments, the preset temperature can be user-adjustable.

(82) When used in conjunction with a fire sprinkler system, the default or user-set temperature for closing a louver should be set lower than the temperature required to activate a sprinkler system. This is because, in an open-loop heat removal system, in the event of a fire, the fire suppression begins with shutting off supply of cool air through the inlet of the building. This can be achieved with melting and closing a heat-sensing louver at the inlet module when a controller of the open-loop heat removal system receives or otherwise detects the presence of an abnormally high temperature that reaches or exceeds the default or user-set temperature. Additionally or alternatively, the open-loop heat removal system may include an electronic louver positioned over an inlet module and/or an outlet module. Upon the temperature reaches or exceeds the default or user-adjusted value, and in lieu of or in addition to closing the heat-sensing louver, the controller may programmatically instruct the electronic louver to close, so as to shut off supply of cool air.

(83) As those skilled in the art can appreciate, fire sprinkler systems are usually heat-activated, one sprinkler at a time. Each sprinkler has a component that melts when reaching a certain temperature. The melting of the component can open a valve on the sprinkler, allowing water to disperse from the valve. Such a sprinkler could be activated when the temperature rises to a fire-induced temperature, usually between 155° F. and 165° F. (i.e., between 57° C. and 74° C.). In some embodiments, the temperature required to activate a sprinkler system should be set at a temperature (e.g., 155° F.) that is higher than the default or user-set temperature (e.g., 97° F., 100° F., 135° F., etc.) at which louver(s) will be activated by heat or electronically. The temperature required to activate a sprinkler system may vary from implementation to implementation.

(84) With a heat-sensing louver, once the material melts, the inlet module closes. Likewise, as shown in FIG. **14**B, the outlet module closes once the material of a heat-sensing louver positioned over the outlet module melts. This kind of heat-sensing louvers must be replaced after use. In some embodiments, HVAC control dampers, model VCD 23-V available from Dodge Engineering & Controls, Inc. at Massachusetts, USA, can be used. Some louvers can be controlled by a controller electronically. An electronically-controlled louver can be opened and closed by an operator or programmatically by the controller via a preset setting. This decentralized fire suppression for an open-loop heat removal system also has the advantage of allowing disaggregation by aisle or pod fire suppression versus sprinklers or other fire suppression at the room level.

(85) As shown in FIG. **14**C and FIG. **14**D, in some cases, it may be desirable to leave the outlet module open as long as an exhaust fan is running at a volume significant enough to create a vacuum/negative pressure of 1 bar or greater internally. This would not only reduce the oxygen that fuels the fire, but it would remove the toxic byproducts of combustion and incomplete combustion like CO. Most deaths from fires are not from burns they are from the toxic byproducts of combustion. The central controller is operable to close the exhaust vent or louver only when the fan fails, for instance, when there is no signal received from the fan operation controller, when the fan is out and there is sufficient heat/pressure, or when the oxygen level falls below 15%. In the example of FIG. **14**D, the louvres are positioned at the top and bottom of each aisle on the upper and lower vents.

(86) FIG. **15** is a flow diagram that illustrates an example of a fire suppression method **1500** for an open-loop heat removal system. In some embodiments, a central controller is configured for receiving temperature readings from temperature sensor(s) located throughout a building such as a data center. In some embodiments, the central controller may be configured for proactively programmatically checking with the temperature sensor(s) on temperature readings across the data center. In some embodiments, the central controller may determine whether a temperature reading is above a default or user-set temperature (**1501**). If not, the inlet module(s) will remain open (**1503**). Otherwise, the central controller is operable to close the louver(s) at the appropriate inlet module(s) at or near where the temperature reading was sensed (**1505**). After closing the louver(s), the central controller is operable to determine whether the fire has been contained (**1507**). If so, the process ends. Otherwise, sprinklers are activated (**1509**).

(87) FIG. **16** is a flow diagram that illustrates another example of a fire suppression method **1600** for an open-loop heat removal system. In this case, the open-loop heat removal and fire suppression system has a temperature sensor, an oxygen sensor, a central controller, an electronic closing default, and a pressure sensor.

(88) In some embodiments, a central controller is configured for receiving temperature readings from temperature sensor(s) located throughout a building such as a data center. In some embodiments, the central controller may be configured for proactively programmatically checking with the temperature sensor(s) on temperature readings across the data center. In some embodiments, the central controller may determine whether a temperature reading is above a default or user-set temperature (**1601**). If not, the inlet module(s) will remain open (**1603**). Otherwise, the central controller is operable to close the louver(s) at the appropriate inlet module(s) at or near where the temperature reading is sensed (**1605**). After closing the louver(s), the central controller is operable to determine whether the fire has been contained (**1607**). If so, the process ends. If not, the central controller is operable to determine whether the exhaust fan is working (**1611**).

(89) The exhaust fan may or may not be running at the time. In the event of a fire, the central controller may check, through pressure sensor(s), whether the building has a negative pressure of 1 bar or greater internally (**1621**). If so, the central controller may check to see if the fire has been contained (**1607**). If so, the process ends. If the building does not have a negative pressure or 1 bar or greater internally, the central controller is operable to turn the exhaust fan on to create a negative pressure or 1 bar or greater internally (**1623**). The central controller then checks the oxygen level via oxygen sensor(s) and determines whether the oxygen level is less than 15% (**1625**). If so, the central controller is operable to determine whether the fire has been contained (**1615**). At less than 15% of oxygen in the air, the fire cannot burn (e.g., unable to light a cigarette lighter) in the containment aisle without full intake air and with exhaust at 10 KPa. Thus, if the oxygen level is less than 15%, the fire is considered as having been contained and the process ends. Otherwise, sprinklers are activated (**1609**). If the oxygen level is not less than 15%, the fire is not contained and sprinklers are activated (**1609**).

(90) If the exhaust fan is not working, the central controller is operable to instruct the respective louver(s) to close the appropriate outlet module(s) (**1613**). Subsequently, the central controller is operable to determine whether the fire has been contained (**1615**). If so, the process ends. Otherwise, sprinklers are activated (**1609**). If the exhaust fan is working, the central controller is operable to instruct the exhaust fan to start running to expel air/smoke (**1623**).

(91) Some embodiments described herein can be implemented in the form of control logic in software or hardware or a combination of both. The control logic may be stored in an information storage medium, such as a computer-readable medium, as a plurality of instructions adapted to direct an information processing device to perform a set of steps disclosed in the various embodiments. Based on the disclosure and teachings provided herein, a person of ordinary skill in the art will appreciate other ways and/or methods to implement the invention.

(92) It is also within the spirit and scope of the invention to implement in software programming or code the steps, operations, methods, routines or portions thereof described herein, where such software programming or code can be stored in a computer-readable medium and can be operated on by a processor to permit a computer to perform any of the steps, operations, methods, routines or portions thereof described herein. The invention may be implemented by using software programming or code in one or more control systems, by using application specific integrated circuits, programmable logic devices, field programmable gate arrays, optical, chemical, biological, quantum or nanoengineered systems, components and mechanisms, various types of sensors including temperature, humidity, and/or pressure sensors may be used. The functions of the invention can be achieved by various means including distributed, or networked systems, hardware components, and/or circuits. In another example, communication or transfer (or otherwise moving

from one place to another) of data may be wired, wireless, or by any other means.

(93) A "computer-readable medium" may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, system or device. The computer readable medium can be, by way of example only but not by limitation, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, system, device, propagation medium, or computer memory. Such computer-readable medium shall be machine readable and include software programming or code that can be human readable (e.g., source code) or machine readable (e.g., object code). Examples of non-transitory computer-readable media can include random access memories, read-only memories, hard drives, data cartridges, magnetic tapes, floppy diskettes, flash memory drives, optical data storage devices, compact-disc read-only memories, and other appropriate computer memories and data storage devices. In an illustrative embodiment, some or all of the software components may reside on a single server computer or on any combination of separate server computers. As one skilled in the art can appreciate, a computer program product implementing an embodiment disclosed herein may comprise one or more non-transitory computer readable media storing computer instructions translatable by one or more processors in a computing environment.

(94) A "processor" includes any, hardware system, mechanism or component that processes data, signals or other information. A processor can include a system with a central processing unit, multiple processing units, dedicated circuitry for achieving functionality, or other systems. Processing need not be limited to a geographic location, or have temporal limitations. For example, a processor can perform its functions in "real-time," "offline," in a "batch mode," etc. Portions of processing can be performed at different times and at different locations, by different (or the same) processing systems.

(95) Those skilled in the art will appreciate that a suitable control system can include a central processing unit ("CPU"), at least one read-only memory ("ROM"), at least one random access memory ("RAM"), at least one hard drive ("HD"), and one or more input/output ("I/O") device(s). The I/O devices can include a keyboard, monitor, printer, electronic pointing device (for example, mouse, trackball, stylus, touch pad, etc.), or the like. In embodiments of the invention, the control system can have access to at least one database over a network connection.

(96) ROM, RAM, and HD are computer memories for storing computer-executable instructions executable by the CPU or capable of being compiled or interpreted to be executable by the CPU. Suitable computer-executable instructions may reside on a computer readable medium (e.g., ROM, RAM, and/or HD), hardware circuitry or the like, or any combination thereof. Within this disclosure, the term "computer readable medium" is not limited to ROM, RAM, and HD and can include any type of data storage medium that can be read by a processor. Examples of computer-readable storage media can include, but are not limited to, volatile and non-volatile computer memories and storage devices such as random access memories, read-only memories, hard drives, data cartridges, direct access storage device arrays, magnetic tapes, floppy diskettes, flash memory drives, optical data storage devices, compact-disc read-only memories, and other appropriate computer memories and data storage devices. Thus, a computer-readable medium may refer to a data cartridge, a data backup magnetic tape, a floppy diskette, a flash memory drive, an optical data storage drive, a CD-ROM, ROM, RAM, HD, or the like.

(97) As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having," or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, product, article, or apparatus that comprises a list of elements is not necessarily limited only those elements but may include other elements not expressly listed or inherent to such process, product, article, or apparatus.

(98) Furthermore, the term "or" as used herein is generally intended to mean "and/or" unless otherwise indicated. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present),

and both A and B are true (or present). As used herein, including the accompanying appendices, a term preceded by "a" or "an" (and "the" when antecedent basis is "a" or "an") includes both singular and plural of such term, unless clearly indicated otherwise (i.e., that the reference "a" or "an" clearly indicates only the singular or only the plural). Also, as used in the description herein and in the accompanying appendices, the meaning of "in" includes "in" and "on" unless the context clearly dictates otherwise.

(99) Additionally, any examples or illustrations given herein are not to be regarded in any way as restrictions on, limits to, or express definitions of, any term or terms with which they are utilized. Instead these examples or illustrations are to be regarded as being described with respect to one particular embodiment and as illustrative only. Those of ordinary skill in the art will appreciate that any term or terms with which these examples or illustrations are utilized encompass other embodiments as well as implementations and adaptations thereof which may or may not be given therewith or elsewhere in the specification and all such embodiments are intended to be included within the scope of that term or terms. Language designating such non-limiting examples and illustrations includes, but is not limited to: "for example," "for instance," "e.g.," "in one embodiment," and the like.

(100) Those skilled in the art of the invention will recognize that the disclosed embodiments have relevance to a wide variety of areas in addition to the specific examples described above. For example, although the examples above are described in the context of data centers, some embodiments disclosed herein can be adapted or otherwise implemented to work in other types of environments, circumstances, etc. In this context, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of this disclosure. Accordingly, the scope of the present disclosure should be determined by the following claims and their legal equivalents.

Claims

1. A fire suppression method for a heat removal system, the fire suppression method comprising: receiving, by a controller of the heat removal system, a temperature reading from a temperature sensor located inside a building having an inlet through which cool air is supplied to the building and an outlet through which hot air is expelled from the building without recycling, recirculating, or re-cooling the hot air, the heat removal system further having a first inlet module at the inlet of the building, an outlet module at the outlet of the building, a first louver at the first inlet module, and an exhaust fan at the outlet module; determining, by the controller, whether the temperature reading reaches or exceeds a default or user-set temperature, indicating presence of a fire in the building; responsive to the temperature reading reaches or exceeds the default or user-set temperature, closing the first louver at the first inlet module to shut off supply of the cool air through the inlet of the building; determining, by the controller utilizing a pressure sensor, whether the building is under a negative pressure internally; responsive to the building not being under a negative pressure internally, operating, by the controller, the exhaust fan to create a negative pressure internally; determining, by the controller utilizing an oxygen sensor, whether an internal oxygen level of the building indicates that the fire has been contained; and responsive to the fire not having been contained, activating, by the controller, a sprinkler system in the building.

2. The fire suppression method according to claim 1, wherein the heat removal system further comprises a chilling unit for supplying the cool air to the building without recycling, recirculating, or re-cooling indoor air.

3. The fire suppression method according to claim 1, further comprising: setting a temperature at which the sprinkler system is activated to be higher than the default or user-set temperature for closing the louver.

4. The fire suppression method according to claim 1, wherein determining whether the building is

under the negative pressure internally comprises determining whether the building is under the negative pressure of 1 KPa or greater.

5. The fire suppression method according to claim 1, further comprising: determining whether the internal oxygen level of the building is at 15% or less.

6. The fire suppression method according to claim 1, further comprising: determining whether the exhaust fan is working; and responsive to the exhaust fan not working, closing a vent or louver at the outlet module.

7. The fire suppression method according to claim 1, further comprising: determining, from a plurality of second inlet modules positioned over a corresponding plurality of inlets of the building, an inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed; and electronically closing a second louver positioned over the inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed.

8. A heat removal system, comprising: a chilling unit for supplying cool air to a building through an inlet of the building; a first module at the inlet of the building, the building having an outlet through which hot air is expelled from the building without recycling, recirculating, or re-cooling the hot air; an outlet module at the outlet of the building; a first louver at the first inlet module; an exhaust fan at the outlet module; a temperature sensor located inside the building for sensing an internal temperature of the building; an oxygen sensor for sensing an internal oxygen level of the building; a pressure sensor for sensing an internal pressure of the building; a controller; a non-transitory computer-readable medium; and instructions stored on the non-transitory computer-readable medium and translatable by the controller for: receiving a temperature reading from the temperature sensor; determining whether the temperature reading reaches or exceeds a default or user-set temperature, indicating presence of a fire in the building; responsive to the temperature reading reaches or exceeds the default or user-set temperature, closing the first louver at the first inlet module to shut off supply of the cool air through the inlet of the building; determining, utilizing the pressure sensor, whether the building is under a negative pressure internally; responsive to the building not being under a negative pressure internally, operating, by the controller, the exhaust fan to create a negative pressure internally; determining, utilizing the oxygen sensor, whether an internal oxygen level of the building indicates that the fire has been contained; and responsive to the fire not having been contained, activating a sprinkler system in the building.

9. The heat removal system of claim 8, further comprising: a heat-sensing louver or an electronic louver positioned over the outlet module.

10. The heat removal system of claim 8, wherein a temperature at which the sprinkler system is activated is set to be higher than the default or user-set temperature for closing the louver.

11. The heat removal system of claim 8, wherein determining whether the building is under the negative pressure internally comprises determining whether the building is under the negative pressure of 1 KPa or greater.

12. The heat removal system of claim 8, wherein the instructions are further translatable by the controller for: determining whether the internal oxygen level of the building is at 15% or less.

13. The heat removal system of claim 8, wherein the instructions are further translatable by the controller for: determining whether the exhaust fan is working; and responsive to the exhaust fan not working, closing a vent or louver at the outlet module.

14. The heat removal system of claim 8, wherein the instructions are further translatable by the controller for: determining, from a plurality of second inlet modules positioned over a corresponding plurality of inlets of the building, an inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed; and electronically closing a second louver positioned over the inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed.

15. A computer program product for file suppression in a heat removal system, the computer program product comprising a non-transitory computer-readable medium storing instructions

translatable by a controller for: receiving a temperature reading from a temperature sensor located inside a building having an inlet through which cool air is supplied to the building and an outlet through which hot air is expelled from the building without recycling, recirculating, or re-cooling the hot air, the heat removal system further having a first inlet module at the inlet of the building, an outlet module at the outlet of the building, a first louver at the first inlet module, and an exhaust fan at the outlet module; determining whether the temperature reading reaches or exceeds a default or user-set temperature, indicating presence of a fire in the building; responsive to the temperature reading reaches or exceeds the default or user-set temperature, closing first the louver at the first inlet module to shut off supply of the cool air through the inlet of the building; determining, utilizing a pressure sensor, whether the building is under a negative pressure internally; responsive to the building not being under a negative pressure internally, operating the exhaust fan to create a negative pressure internally; determining, utilizing an oxygen sensor, whether an internal oxygen level of the building indicates that the fire has been contained; and responsive to the fire not having been contained, activating a sprinkler system in the building.

16. The computer program product of claim 15, wherein a temperature at which the sprinkler system is activated is set to be higher than the default or user-set temperature for closing the louver.

17. The computer program product of claim 15, wherein determining whether the building is under the negative pressure internally comprises determining whether the building is under the negative pressure of 1 KPa or greater.

18. The computer program product of claim 15, wherein the instructions are further translatable by the controller for: determining whether the internal oxygen level of the building is at 15% or less.

19. The computer program product of claim 15, wherein the instructions are further translatable by the controller for: determining whether the exhaust fan is working; and responsive to the exhaust fan not working, closing a vent or louver at the outlet module.

20. The computer program product of claim 15, wherein the instructions are further translatable by the controller for: determining, from a plurality of second inlet modules positioned over a corresponding plurality of inlets of the building, an inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed; and electronically closing a second louver positioned over the inlet module of the plurality of second inlet modules that is at or near where the temperature reading was sensed.