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 (54) Title: CONVECTION COOLING OF DATA CENTER USING CHIMNEY

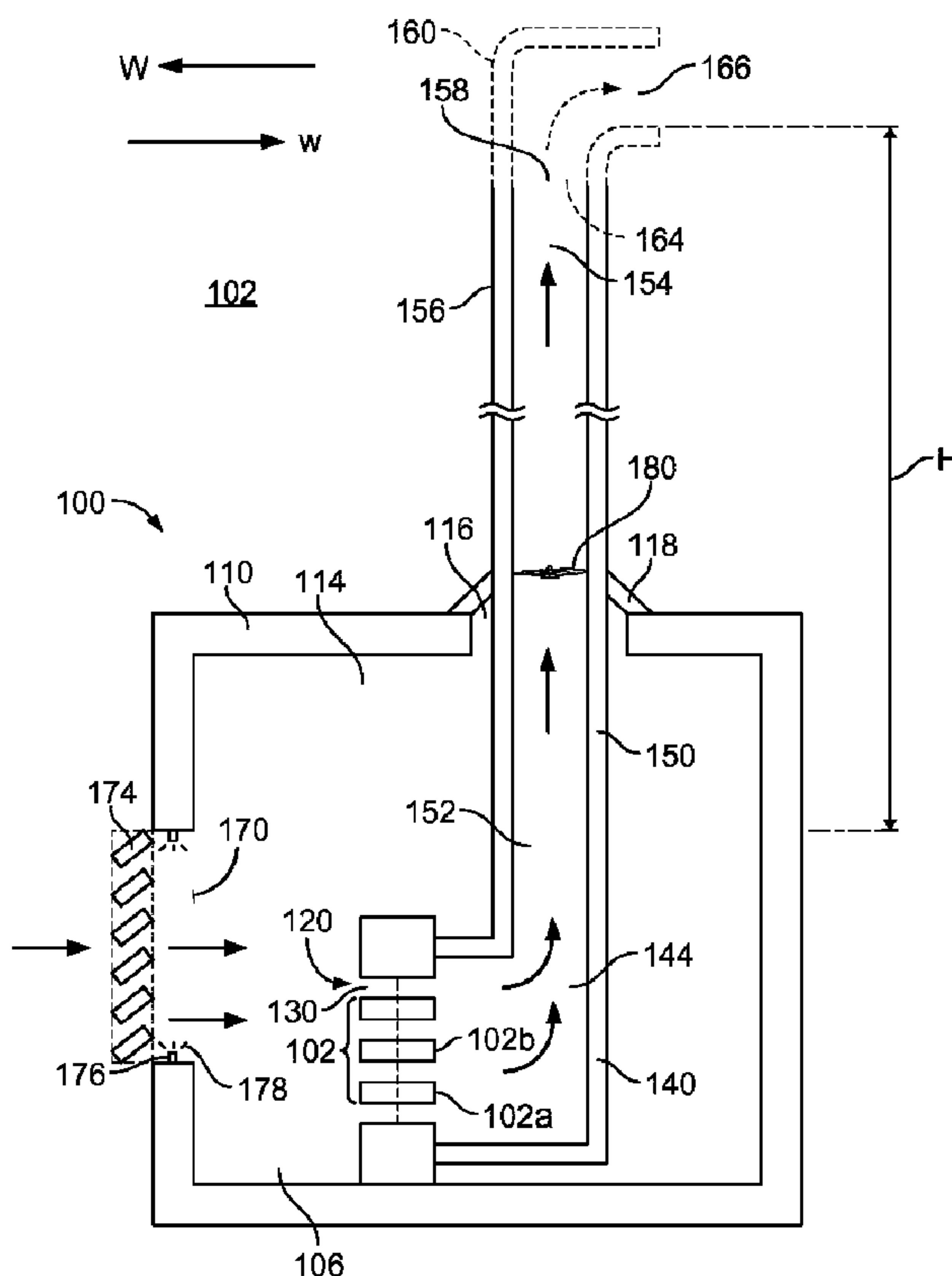


FIG. 1

(57) **Abrégé/Abstract:**

A data center includes a bank of computers, a plenum in fluid communication with the bank of computers, and a chimney in fluid communication with the plenum. The chimney is configured to use heat from the bank of computers to sufficiently lower an air pressure in the plenum to cause an air flow across the bank of computers sufficient to cool the bank of computers for normal operation.



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(54) Title: CONVECTION COOLING OF DATA CENTER USING CHIMNEY

(57) Abstract: A data center includes a bank of computers, a plenum in fluid communication with the bank of computers, and a chimney in fluid communication with the plenum. The chimney is configured to use heat from the bank of computers to sufficiently lower an air pressure in the plenum to cause an air flow across the bank of computers sufficient to cool the bank of computers for normal operation.

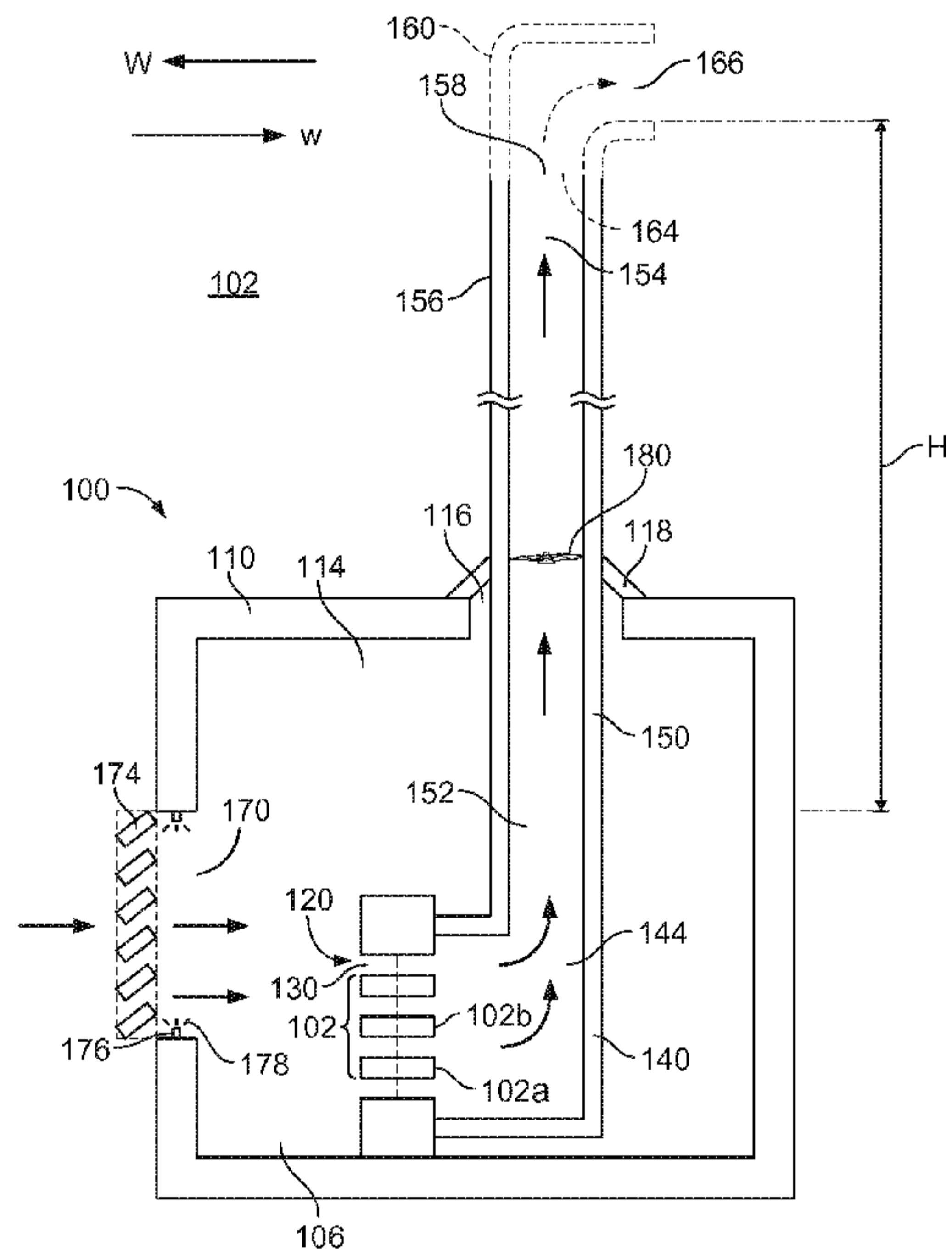


FIG. 1

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Convection Cooling of Data Center Using Chimney

TECHNICAL FIELD

This description relates to cooling computers in a data center.

BACKGROUND

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Computer data centers are commercial buildings that house a large number of computers, such as thousands or tens of thousands of rack-mounted computer servers and other computing equipment (e.g., storage devices, power supplies, and networking equipment). Typically, computer data centers provide computing services, such as web page hosting, search, e-mail, video, and other services, to a number of distributed remote users.

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Because internet-connected users have grown enormously in numbers, and the types of services they demand have grown enormously in complexity, data centers must now provide a quickly increasing amount of computing resources. As a result, the size of data centers has increased, the number of data centers has increased, and because data centers require the use of electronic equipment, the electrical demands of data centers have increased. Because a substantial portion of the electrical power used by data centers is turned into heat, cooling demands of data centers have increased significantly.

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SUMMARY

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In one aspect, a data center includes a bank of computers, a plenum in fluid communication with the bank of computers, and a chimney in fluid communication with the plenum and configured to use heat from the bank of computers to sufficiently lower an air pressure in the plenum to cause an air flow across the bank of computers sufficient to cool the bank of computers for normal operation.

25

Implementations can include one or more of the following features. A boost fan may be configured to assist a flow of air from the plenum through the chimney. The boost fan might not be capable of causing a sufficient pressure drop in the plenum to flow sufficient air to cool the bank of computers in an absence of the chimney. The chimney may be insulated to reduce dissipation of heat from a flow of air inside the chimney to a

surrounding environment. The chimney may be configured to absorb heat from a surrounding environment. The chimney may extend at least 50 feet above a bottom of the plenum. The plenum may include baffles configured to separate air within the plenum from air outside of the plenum. A movable cowl may be attached to an upper end
5 of the chimney and configured to direct a chimney opening away from a wind direction. An enclosure may surround the bank of computers and may have formed therein an air inlet and an opening for the chimney. A liquid injector may be configured to apply a liquid, e.g., water, to an inlet flow of air that flows through the bank of computers and into the plenum. A heat exchanger, e.g., an evaporative cooler, may be configured to cool
10 an inlet flow of air that flows through the bank of computers and into the plenum. The bank of computers may include a rack of computers, e.g., at least twenty-two computers. A heat source may be configured to heat an inlet flow of air that flows through the bank of computers and into the plenum. The heat source may be hot air extracted from the plenum or chimney.

15 In another aspect, a method of providing cooling for a data center includes flowing a flow of air through a bank of computers and into a plenum, flowing the flow of air into a lower portion of a chimney configured to use heat from the bank of computers to lower an air pressure in the plenum, the chimney being configured to use heat from the bank of computers to sufficiently lower the air pressure in the plenum such that the flow
20 of air across the bank of computers is sufficient to cool the bank of computers for normal operation, and flowing the flow of air out of an upper portion of the chimney.

Implementations can include one or more of the following features. The flow of air into the chimney may be boosted with a boost fan configured to flow air from the plenum through the chimney. The boost fan might not be capable of causing a sufficient
25 pressure drop in the plenum to sufficiently cool the bank of computers in an absence of the chimney. The chimney may be insulated to reduce dissipation of heat from the flow of air inside the chimney to a surrounding environment. The chimney may absorb heat from a surrounding environment. The chimney may extend at least 50 feet above a bottom of the plenum. Air within the plenum may be separated from air outside of the
30 plenum by baffles. The bank of computers may be surrounded by an enclosure having formed therein an air inlet and an opening for the chimney. A movable cowl attached to

the upper chimney end may be adjusted to direct a chimney opening away from a wind direction. An inlet flow of air that flows through the bank of computers and into the plenum may be cooled. The cooling may include applying liquid, e.g., water, to the inlet flow of air, or flowing the inlet flow of air through a heat exchanger, e.g., an evaporative cooler. The bank of computers may include a rack of computers, e.g., at least twenty-two computers. An inlet flow of air that flows through the bank of computers and into the plenum may be heated. Heating may include extracting hot air from the plenum or chimney.

Implementations can include one or more of the following advantages.

Computers in a data center can be cooled using fewer components, and thus at lower facility construction cost, and using less energy, and thus at lower facility operation cost. For example, by reducing use of fans and heat pumps as compared to conventional data center cooling systems, data center energy efficiency can be increased and data center power consumption can be reduced. Also, reducing an amount of components necessary for cooling the data center can improve reliability of the data center, can reduce costs and time necessary for constructing the data center, can reduce data center maintenance costs, and can reduce an amount of time necessary for bringing the data center online.

DESCRIPTION OF DRAWINGS

FIG. 1 is a cross-sectional side-view schematic representation of a data center.

FIG. 2 is a cross-sectional plan-view schematic representation of the data center of FIG. 1.

FIG. 3 is a cross-sectional plan-view schematic representation of an alternative implementation of a data center.

FIG. 4 is a flow diagram of an implementation of cooling a bank of computers.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

Data center cooling can be implemented with convection cooling, such as natural convection cooling, which can include use of a chimney. It can be desirable to cool computers in a data center using an apparatus, system, or method that uses as few

components as feasible and that consumes as little energy as feasible. Convection can be used to cause air flow across a bank of computers in a data center to cool the computers. Convection cooling of computers can be implemented with a plenum configured to direct hot air from the bank of computers to a chimney. The chimney can be open to a surrounding environment outside of the data center and can be configured to use convection to cause a flow of air across the bank of computers and up and out of the chimney. A data center cooling system that utilizes convection can reduce power consumption, improve efficiency, and reduce time and expense required for constructing a data center.

FIG. 1 is a cross-sectional side-view schematic representation of a data center 100. FIG. 2 is a cross-sectional plan-view schematic representation of the data center of FIG. 1. Referring to FIGS. 1 and 2, the data center 100 includes an enclosure 110, e.g., a room or a building, that houses a large number of computers or similar heat-generating electronic components. The computers can be arranged in a number of parallel rows and mounted on horizontal trays in vertical racks 102, such as racks 102a, 102b (of course, the computers can be placed in other orientations, e.g., vertical trays). About twenty-two computers can fill a standard 78" high rack. Air may circulate from workspace 106 across the trays. The work space 106 on one side of the racks 102 may, in certain circumstances, be referenced as a "cold aisle," and the plenum space 144 on the other side of the rack 102 may be considered a "warm aisle." Together, the collection of racks of computers can provide a bank of computers 120. The enclosure 110 can enclose or house other hardware (not shown) and personnel (not shown) associated with, for example, operation and maintenance of the data center 100. The bank of computers 120 can include servers configured to provide computing services, such as web page hosting, search, e-mail, video, and other services, to a number of distributed remote users.

Computing devices in the racks 102 typically consume electrical power and generate heat, and these computing devices can include heat sinks and heat pipes to dissipate the heat from these computing devices to the air flowing across the trays. A group of racks can be part of a module that includes heat transport structures or mechanisms (not shown) configured to facilitate transfer of heat from the air to coolant

fluid flowing through the bank of computers 120, e.g., water flowing through pipes near the racks 102.

The bank of computers 120 can include vents 130, e.g., spaces between adjacent trays in a rack, fluidically connecting the bank of computers 120 and a plenum space 144 of a plenum. The vents 130 can permit fluid, e.g., air, to flow around and through computing devices or between adjacent computing devices that are part of the rack 102 of computers. The rack 102 of computers can form part of the plenum wall 140, e.g., a side of the plenum. In some implementations, racks of computers form multiple, e.g., opposite, sides of the plenum 140. The plenum space 144 can be a space enclosed by the plenum walls 140 and the bank of computers 120. The plenum walls 140 can separate air in the plenum space 144 from air in an enclosure space 114 that is within the enclosure 110 but outside of the plenum space 144. In some implementations, the plenum walls 140 can include a door (not shown) to facilitate access to the plenum space 144, such as for maintenance of equipment located within the plenum space 144 or of components of the bank of computers 120 accessible from the plenum space 144.

The plenum space 144 of the plenum can be fluidically connected to a chimney 150. In some implementations, the chimney 150 can be fluidically isolated from the enclosure space 114 except through the plenum space 144. The chimney 150 can protrude from the data center 100 through a chimney opening 116 formed in the enclosure 110. In some implementations, chimney flashing 118 can protect an interior of the data center from a surrounding environment 102 that surrounds the data center 100. The chimney 150 can extend a chimney height H above the bank of computers 120, above the bottom of the plenum 140, or above some other suitable reference point. For example, the chimney height H can be more than 50 feet, such as more than 100 feet. Such a chimney can fit substantially within the architectural shell of a multi-story building. In this case, the data center can be located on a bottom floor of a multi-story building and take advantage of the chimney effect with little or no visual impact from the outside. Alternately, a tall chimney of a decommissioned industrial facility could be converted to this use. Taller chimneys, such as up to 350 feet, could extend above the roof or be incorporated into tall structures such as the tower of a wind turbine. The chimney height H can be made sufficiently large so that adequate air flow through the

bank of computers 120, plenum space 144, and chimney 150 can occur primarily be natural convection. That is, it may be desirable to make the chimney height H great enough that natural convection through the chimney 150 can cause sufficient air flow through the computers to adequately cool the computers during certain conditions, such as normal operating conditions.

The chimney 150 can have a lower chimney portion 152 within the enclosure 110 and an upper chimney portion 154 above the enclosure 110. In some implementations, an outer surface of the chimney 156 can be insulated with an insulation (not shown), which may be desirable to prevent dissipation of heat of air within the chimney 150, as discussed further below. The chimney 150 can include a chimney outlet 158 through which air in the chimney can exit the chimney 150 and enter the surrounding environment 102. Air exiting the chimney 150 may be referred to as exhaust air.

Optionally, a cowl 160 can be attached to the chimney 150 at the chimney outlet 158. The cowl 160 can be formed to direct exhaust air to flow out of a cowl outlet 166. In some implementations, the cowl 160 can be movable, such as rotatable, so that a direction of the cowl outlet 166 can be adjustable.

The data center 100 can include an enclosure inlet 170 formed in the enclosure 110. In some implementations, it can be desirable to position the enclosure inlet 170 sufficiently far from the chimney 150 to mitigate or prevent a flow of air from the chimney outlet 158 to the enclosure inlet 170. Such flow of air can be undesirable because exhaust air exiting the chimney outlet 158 may be at a higher temperature than the surrounding environment 102. Flow of exhaust air into the enclosure inlet 170 may thus reduce a cooling effectiveness of air flowing through the bank of computers. Further, such flow of exhaust air into the enclosure inlet 170 may decrease convection, which may reduce a flow rate of air through the bank of computers, which may further reduce a cooling effectiveness of air flowing through the bank of computers 120. Such recirculation of exhaust air can halt convection if a temperature difference between air in the chimney 150 and air flowing into the bank of computers becomes too small to sustain convection through the chimney 150. Such a failure to sustain convection can interrupt cooling of the computers. In some implementations, increasing the height H of the chimney 150 can reduce a possibility of such flow of exhaust air into the enclosure inlet

170. Alternatively or additionally, the enclosure inlet 170 can be moved farther away from the chimney 150 in a horizontal direction, e.g., a direction perpendicular to a length direction of the chimney 150.

In some implementations, the enclosure inlet 170 can include a heat exchanger 174 configured to cool a flow of air entering the data center 100. The heat exchanger 174 can include, for example, an evaporative cooler. The enclosure inlet 170 can also include injectors 176 configured to apply liquid 178, such as water, to the flow of air entering the data center 100, which may be referred to as an inlet flow of air. Evaporation of the liquid 178 may cool the inlet flow of air, as discussed further below. Alternatively, the injectors 176 can inject some other cooling fluid, such as a gas, into the inlet flow of air. Cooling the flow of air through the enclosure inlet 170 can improve efficacy of cooling of the bank of computers such as by improving convection through the chimney 150, as discussed further below.

Optionally, the plenum 140 or the chimney 150 can include an optional boost fan 180, as discussed further below. The boost fan 180 can be positioned, for example, in the lower chimney portion 152, in the upper chimney portion 156, in a top of the plenum 140 where the plenum 140 joins the chimney 150, or in some other suitable location. The vents 130, plenum 140, chimney 150, optional cowl 160, enclosure inlet 170, and related components, can be collectively referred to as parts of a cooling system of the data center 100.

FIG. 3 is a cross-sectional plan-view schematic representation of an alternative implementation of a data center 100. A plenum space 144' is at least partially enclosed by a plenum 140' and the bank of computers 120. The plenum space 144' is further enclosed by baffles 320 such that a portion of the plenum space 144 is fluidically connected to the enclosure space 114 through baffle spaces 324. The baffles 324 can be configured to restrict flow of air through the baffles 324, thereby at least partially separating air within the plenum space 144' from air in the enclosure space 114. In some implementations, the baffles 324 can be sufficiently large to allow access to the plenum space 144' by a human being, such as for maintenance of equipment located within the plenum space 144' or of components of the bank of computers 120 accessible from the

plenum space 144'. In some other implementations, the plenum 140 can include a door (not shown) to facilitate access to the plenum space 144'.

FIG. 4 is a flow diagram of an implementation of cooling a bank of computers 100. Directions of flows of air are indicated by arrows in FIGS. 1-3. Air can enter the data center 100 through the enclosure inlet 170. In some implementations, the inlet flow of air flowing through the enclosure inlet 170 can be cooled (step 410). For example, a cooling fluid (not shown) can flow through the heat exchanger 174 to cool the inlet flow of air. The cooling fluid can be cooled, for example, by a chiller (not shown) located outside of the data center 100. In some other implementations, the inlet flow of air can flow through passages (not shown) and a liquid, such as water, can be applied to the passages to evaporatively cool the passages, which can thereby cool the inlet flow of air. In some implementations, the injectors 176 can apply liquid 178 to air flowing through the enclosure inlet 170, and the liquid 178 can be, for example, water. Application of the liquid 178 by the injectors 176 can be performed, for example, by spraying the liquid 178 into the inlet flow of air. For example, the liquid 178 can be applied or sprayed in droplet, nebulized, or atomized form. Evaporation of the liquid 178 in the inlet flow of air may cool the inlet flow of air. Also, in some implementations, the inlet flow of air flowing through the enclosure inlet 170 can be heated (step 410). For example, warm water can be circulated through the heat exchanger 174, or some of the warm air from the plenum 144 or stack 154 can be recirculated, to provide heating.

Air can be flowed through the bank of computers 120, through the plenum 140, and into the chimney 150 (step 420). Air entering the plenum 140 and the chimney 150, having absorbed heat from the bank of computers 120, can have a relatively higher temperature with respect to the surrounding environment 102. Relatively hot air in the chimney 150 may therefore have buoyancy with respect to the surrounding environment 102. This buoyancy may reduce an air pressure in the plenum space 144 relative to the enclosure space 114, and this effect can be referred to as a stack effect. The reduction of air pressure in the plenum space 144 relative to the enclosure space 114 may be referred to as an air pressure drop.

The stack effect can facilitate natural convection of air through the data center 100. The cooling system can be designed such that the stack effect is sufficient to cause a

sufficient air pressure drop in the plenum space 144 to effect a sufficient flow of air through the enclosure inlet 170, through the bank of computers 120, through the plenum 140, and through and out of the chimney 150 to facilitate normal operation of the bank of computers 120. In particular, the height H of the chimney 150 can be designed to cause a sufficient air pressure drop in the plenum space 144. As an example, in some implementations, sufficient cooling of the data bank 120 may be achieved where a air pressure in the plenum space 144 is 0.1 bar less than an air pressure in the enclosure space 114. In general, the pressure difference can be at least about 0.5 milli-bar (0.2 in-wg), which is representative of the pressure drop through server trays or across fin-tube heat exchanger coils. In some implementations, an air pressure drop caused by the stack effect can be calculated using the following relationship:

$$\Delta P = C \cdot a \cdot h \cdot \left(\frac{1}{T_o} - \frac{1}{T_i} \right), \text{ where:}$$

ΔP = pressure difference, in Pascals (Pa);

15 $C = 0.0342$, a constant;

a = atmospheric pressure, in Pa;

h = height of chimney, in meters (m);

T_o = absolute temperature outside of the chimney, in degrees Kelvin (K); and

T_i = absolute average temperature inside of the chimney, in K.

20 The temperature T_o can be a temperature of the surrounding environment 102, which temperature may be less than, greater than, or equal to a temperature of air in the enclosure space 114.

In some implementations, a flow rate of air caused by the stack effect can be calculated using the following relationship:

$$25 \quad Q = C \cdot A \sqrt{2 \cdot g \cdot h \cdot \frac{T_i - T_o}{T_i}}, \text{ where:}$$

Q = flue gas flow rate, in square meters per second (m^3/s);

A = cross-sectional area of chimney, in m^2 (assuming it has a constant cross-section);

C = discharge coefficient (usually taken to be from 0.65 to 0.70);

g = gravitational acceleration at sea level, which is typically 9.807 meters per second squared (m/s^2);

H = height of chimney, in m;

T_i = absolute average temperature inside of the chimney, in K; and

5 T_o = absolute outside air temperature, in K.

In general, the term 'stack effect', refers to flows induced by buoyancy effects due to temperature differences between separate columns of air inside and outside the stack.

For example, where a temperature of a surrounding environment is 50 degrees Fahrenheit and a temperature of air in the plenum 144 and the chimney 150 is 140
10 degrees Fahrenheit, the chimney can have a height H of 55 feet (or more) to induce a 0.5 millibar pressure difference. Using the equation for induced draft, this chimney could exhaust $4.4 m^3/s$ of air for each 1 square meter cross section area. The pressure difference and rate of induced flow is degraded during hot summer days but is enhanced during operation on cold winter days. Selection of the actual chimney height depends on
15 the prevailing weather conditions at the desired site as well as such factors as an economic tradeoff such as a total cost of ownership (TCO) to balance the cost of the stack structure against the savings in fan power and energy consumption.

Increasing a height H of the chimney 150 may increase the air pressure drop in the plenum space 144, which may improve cooling effectiveness of the cooling system.
20 However, it may be desirable to minimize chimney height H to minimize construction costs, to minimize a visual impact of the chimney 150 on a surrounding landscape, or for other purposes. It may therefore be desirable to design the cooling system with a chimney height H that is a minimum necessary to achieve sufficient cooling of the bank of computers 120.

25 As discussed above, the stack effect may be a result of buoyancy of air in the chimney 150, which may in turn be caused by an elevated temperature of air in the chimney 150 as compared to the surrounding environment 102, the enclosure space 114, or both. Therefore, dissipation of heat of air within the chimney 150 to the surrounding environment 150 or to the enclosure space 114 may decrease the air pressure drop in the
30 plenum space 144. That is, in the mathematical relationships described above, decreasing T_i may decrease ΔP . Increasing insulation of the chimney 150 can reduce loss of heat

from air in the chimney 150 to the surrounding environment 102 or to the enclosure space 114. However, insulation may increase a size of the chimney 150, and it may also be desirable to minimize chimney size to minimize construction costs, to minimize a visual impact of the chimney 150 on a surrounding landscape, or for other purposes. In some implementations, the stack effect may be improved by painting or coating the chimney 150 with a heat absorbing paint or coating. For example, the chimney 150 may absorb heat from sunlight (not shown), and such absorption may be facilitated by a paint or coating. Absorption of heat from sunlight by the chimney 150 can increase a temperature of air in the chimney 150 and thereby improve the stack effect.

Design of the chimney 150 and other cooling system components may also account for varying conditions of the bank of computers 120, the surrounding environment 102, and other components of cooling system and the data center 100. For instance, heat generated by the bank of computers 120 may vary with a degree of use of the bank of computers 120. As an example, decreasing heat generated by the bank of computers 120 may result in a relatively decreased temperature of air in the plenum space 144 and the chimney 150, which may reduce the stack effect. That is, as a temperature of air in the chimney 150 becomes closer to a temperature of the surrounding environment 102, the stack effect may be reduced and therefore the air pressure drop in the plenum space 144 may be reduced. This reduction in the stack effect may be acceptable in some implementations where a need for cooling is reduced when heat generation by the bank of computers 120 is reduced. However, the cooling system may need to be designed such that reduction in heat generation by the bank of computers 120 does not result in a large enough reduction of the stack effect to halt flow of air through the chimney 150 and thereby interrupt cooling of the bank of computers 120. Conversely, increasing heat generated by the bank of computers 120 may increase the stack effect, but in some implementations, this increase in the stack effect may be insufficient to adequately cool the bank of computers 120 for normal operation. To facilitate adequate cooling of the bank of computers 120, heat generation of the bank of computers 120 may be limited, or the cooling system may be designed to adequately cool the bank of computers 120 within a foreseeable range of heat generation by the bank of computers 120. As another example, increasing a temperature of the surrounding environment 102 may bring the

temperature of the surrounding environment 102 closer to the temperature of air in the chimney 150, which may reduce the stack effect and thereby reduce the air pressure drop in the plenum space 144. To account for changes in heat generation by the bank of computers 120, temperatures of the surrounding environment 102 or the enclosure space 114, or other system variables, the chimney 150 and other cooling system components can be designed to sufficiently cool the bank of computers 120 within a desired range of foreseeable operating conditions.

In some implementations, capabilities of the cooling system can be supplemented or augmented to extend a range of operating conditions in which the cooling system can sufficiently cool the bank of computers 120. As an example, cooling the flow of air through the enclosure inlet 170 can improve convection by reducing a temperature of air flowing through the bank of computers 120 and into the plenum space 144. Cooling the flow of air through the enclosure inlet 170 can thus, for example, enable convection and sufficient cooling to be sustained in relatively greater temperatures of the surrounding environment 102 for a given chimney height H. Alternatively or in addition, the necessary chimney height H for a given set of environmental conditions may be reduced. Further, the optional boost fan 180 can supplement the air pressure drop in the plenum space 144, such as during extreme operating conditions, as discussed further below.

Flow of air from the plenum 140 through the chimney 150 can be increased or boosted by the boost fan 180, which can increase the air pressure drop in the plenum space 144 (step 430). In some implementations, the boost fan 180 increases a flow of air through the chimney 150, which can increase flow of air through the vents 130 and may thereby improve cooling of the bank of computers 120. Boosting of air flow into the chimney 150 can include increasing a flow rate of air through the chimney 150. For example, the boost fan 180 can be sufficiently powerful to facilitate adequate cooling of the bank of computers 120 when the boost fan 180 is implemented in conjunction with the chimney 150. That is, in some implementations, the boost fan 180 may lack sufficient power to adequately cool the bank of computers 120 in an absence of the chimney 150. In some implementations, the boost fan 180 is configured to initiate a flow of air through the chimney 150, and after such initiation, the boost fan 180 can be switched off, bypassed, or both. Such an initiation boost can, in some implementations,

be useful to initiate convection flow of air through the chimney 150. In extreme operating conditions, such as relatively high temperature of the surrounding environment 102 or relatively great heat generation by the bank of computers 120, the boost fan 180 can increase the air pressure drop in the plenum space 144 and may thereby enhance cooling capacity of the cooling system.

In some implementations, the chimney height H could be selected to generate sufficient flow of air for cooling the bank of computers 120, without use of the boost fan 180, on all but some number of days in an average year, based on, for example, average yearly temperature records for a particular surrounding environment 102. For example, the chimney height H can be selected to provide sufficient natural convection cooling of the bank of computers 120 up to a certain threshold temperature of the surrounding environment 102, the threshold temperature being less than anticipated peak temperatures of the surrounding environment 102. On days when the temperature of the surrounding environment 102 exceeds the threshold temperature, the boost fan 180 may be activated to supplement the flow of air through the chimney 150 so as to sufficiently cool the bank of computers 120. As an example, the chimney height H can be selected so as to sufficiently cool the surrounding environment without using of the boost fan 180 during more than 50% of the days of an average year, such as during 90% or more of the days of an average year. Metrics other than days can be used. For example, the chimney height H can be selected to sufficiently cool the bank of computers 150, without use of the boost fan 180, during some number of hours or minutes of an average year. Temperature data for an average expected year can be based on records of temperatures at or near a data center location. Also, on days when the boost fan 180 must be used to achieve sufficient cooling, the boost fan 180 may not provide flow of air sufficient to cool the bank of computers 120 without the chimney 150. Instead, the data center 100 may be configured such that use of both the chimney 150 and the boost fan 180 may be necessary to achieve sufficient cooling.

Air can be flowed out of the chimney 150 through the chimney outlet 158 (step 440). Optionally, air can flow from the chimney outlet 158 into a cowl inlet 164 of the optional cowl 160. In implementations that include a cowl 160 that is adjustable, the cowl 160 can be adjusted to direct air out of the cowl outlet 166 in a particular direction.

For example, the cowl 160 can be adjusted to direct air exiting the chimney 150 in a direction at an angle of least 90° from a wind direction W (see FIG. 1, the wind is following with a wind velocity w opposite the wind direction W) (step 450). That is, it can be desirable to direct air exiting the chimney 150 in a direction away from, e.g.,
5 opposite, the wind direction W from which a wind is flowing (see FIG. 1). In some implementations, directing air in a direction opposite the wind direction W can increase the flow of air through the chimney 150. Without being limited to any particular theory, the increase in air flow may be a result of a Bernoulli effect that occurs as wind flows around and past the cowl 160. That is, flow of wind around and past the cowl 160 may
10 decrease an air pressure at the cowl outlet 166, which may increase a flow rate of air through the chimney 150 and increase the air pressure drop in the plenum space 144. In some implementations, the cowl 160 can be designed to maximize a pressure drop at the cowl outlet 166 caused by the Bernoulli effect by, for example, maximizing a wind velocity w past the cowl outlet 166.

15 The above-described implementations can provide none, some, or all of the following advantages. By reducing use of fans and heat pumps as compared to conventional data center cooling systems, data center energy efficiency can be increased and data center power consumption can be reduced. Also, reducing an amount of components necessary for cooling the data center can improve reliability of the data
20 center, can reduce costs and time necessary for constructing the data center, can reduce data center maintenance costs, and can reduce an amount of time necessary for bringing the data center online.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the
25 spirit and scope of the invention. For example, the chimney can be oriented other than vertical, such as angled on or along a side of a hill. As another example, the chimney can be substantially contained within the enclosure, and the enclosure may be an atrium or some other structure with a relatively high ceiling, which may be open to the surrounding environment. In some implementations, the enclosure can be omitted and the data center
30 can be open to the surrounding environment. As an additional example, the chimney can be in fluid communication with heat-generating equipment other than a bank of

computers. Heat may be added to the chimney to enhance the stack effect. Accordingly, other embodiments are within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A data center, comprising:
 - a bank of computers;
 - a plenum in fluid communication with the bank of computers; and
 - a chimney in fluid communication with the plenum and configured to use heat from the bank of computers to sufficiently lower an air pressure in the plenum to cause an air flow across the bank of computers sufficient to cool the bank of computers for normal operation.
2. The system of claim 1, further comprising:
 - a boost fan configured to assist a flow of air from the plenum through the chimney.
3. The system of claim 2, wherein the boost fan is not capable of causing a sufficient pressure drop in the plenum to flow sufficient air to cool the bank of computers in an absence of the chimney.
4. The system of claim 1, wherein the chimney is insulated to reduce dissipation of heat from a flow of air inside the chimney to a surrounding environment.
5. The system of claim 1, wherein the chimney is configured to absorb heat from a surrounding environment.
6. The system of claim 1, wherein the chimney extends at least 50 feet above a bottom of the plenum.
7. The system of claim 1, wherein the plenum includes baffles configured to separate air within the plenum from air outside of the plenum.
8. The system of claim 1, further comprising:
 - a movable cowl attached to an upper end of the chimney and configured to direct a chimney opening away from a wind direction.

9. The system of claim 1, further comprising:
an enclosure surrounding the bank of computers and having formed therein an air inlet and an opening for the chimney.
10. The system of claim 1, further comprising:
a liquid injector configured to apply a liquid to an inlet flow of air that flows through the bank of computers and into the plenum
11. The system of claim 10, wherein the liquid includes water..
12. The system of claim 1, further comprising:
a heat exchanger configured to cool an inlet flow of air that flows through the bank of computers and into the plenum.
13. The system of claim 12, wherein the heat exchanger includes an evaporative cooler.
14. The system of claim 1, wherein the bank of computers comprises a rack of computers.
15. The system of claim 14, wherein the bank of computers comprises at least twenty-two computers.
16. The system of claim 1, further comprising a heat source configured to heat an inlet flow of air that flows through the bank of computers and into the plenum.
17. The system of claim 16, wherein the heat source is hot air extracted from the plenum or chimney.
18. A method of providing cooling for a data center, comprising:
flowing a flow of air through a bank of computers and into a plenum;
flowing the flow of air into a lower portion of a chimney configured to use heat from the bank of computers to lower an air pressure in the plenum, the chimney being configured to use heat from the bank of computers to sufficiently lower the air pressure in the plenum such that the flow of air across the bank of computers is sufficient to cool the bank of computers for normal operation;
flowing the flow of air out of an upper portion of the chimney.

19. The method of claim 18, further comprising:

boosting the flow of air into the chimney with a boost fan configured to flow air from the plenum through the chimney.

20. The method of claim 19, wherein the boost fan is not capable of causing a sufficient pressure drop in the plenum to sufficiently cool the bank of computers in an absence of the chimney.

21. The method of claim 18, wherein the chimney is insulated to reduce dissipation of heat from the flow of air inside the chimney to a surrounding environment.

22. The method of claim 18, wherein the chimney is configured to absorb heat from a surrounding environment.

23. The method of claim 18, wherein the chimney extends at least 50 feet above a bottom of the plenum.

24. The method of claim 18, wherein the plenum includes baffles configured to separate air within the plenum from air outside of the plenum.

25. The method of claim 18, wherein the bank of computers is surrounded by an enclosure having formed therein an air inlet and an opening for the chimney.

26. The method of claim 18, further comprising:

adjusting a movable cowl attached to the upper chimney end to direct a chimney opening away from a wind direction.

27. The method of claim 18, further comprising:

cooling an inlet flow of air that flows through the bank of computers and into the plenum.

28. The method of claim 27, wherein the cooling includes applying liquid to the inlet flow of air.

29. The method of claim 28, wherein the liquid includes water.

30. The method of claim 27, wherein the cooling includes flowing the inlet flow of air through a heat exchanger.

31. The method of claim 30, wherein the heat exchanger includes an evaporative cooler.

32. The method of claim 18, wherein the bank of computers comprises a rack of computers.

33. The method of claim 31, wherein the bank of computers comprises at least twenty-two computers.

34. The method of claim 18, further comprising heating an inlet flow of air that flows through the bank of computers and into the plenum.

35. The system of claim 34, wherein heating comprises extracting hot air from the plenum or chimney.

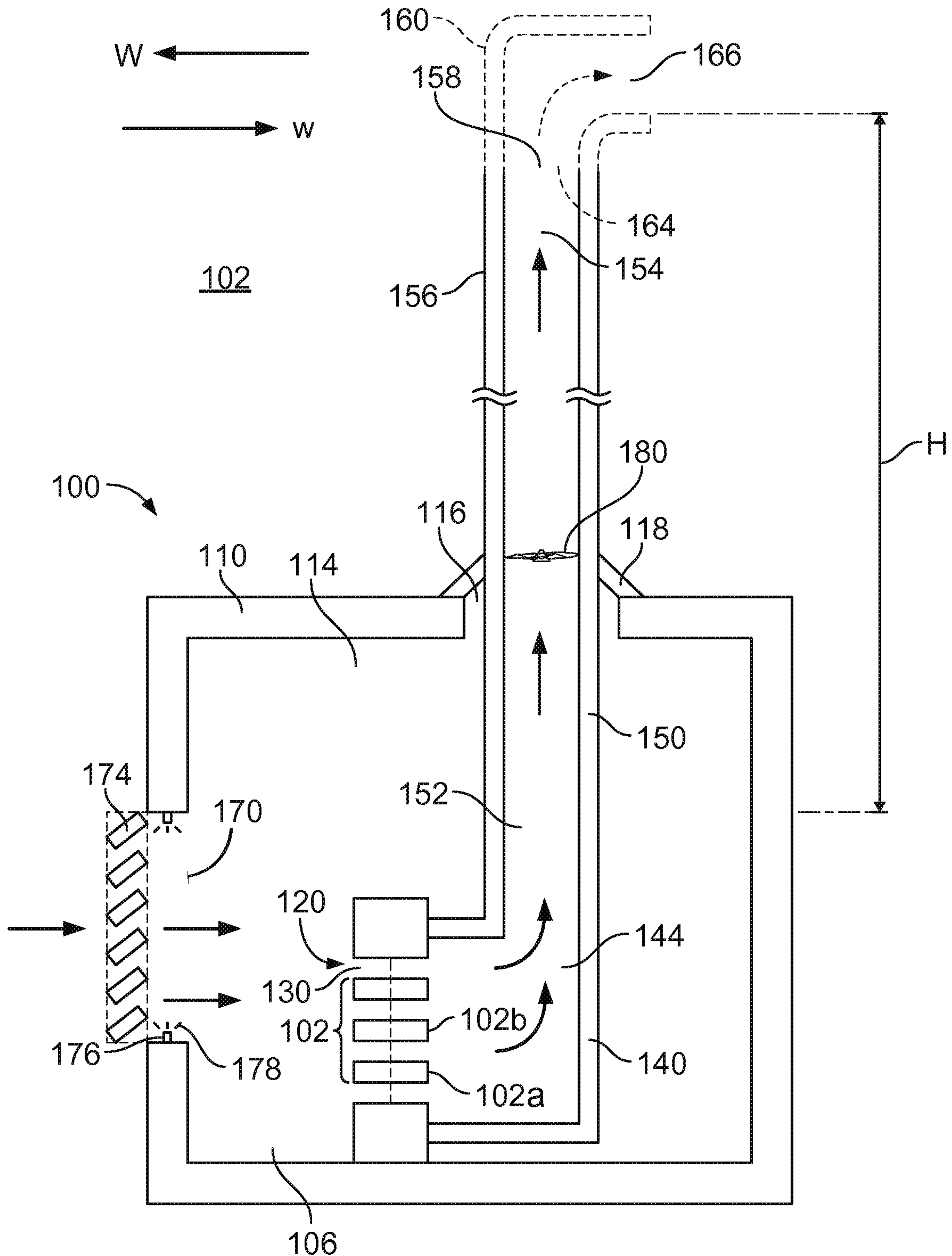


FIG. 1

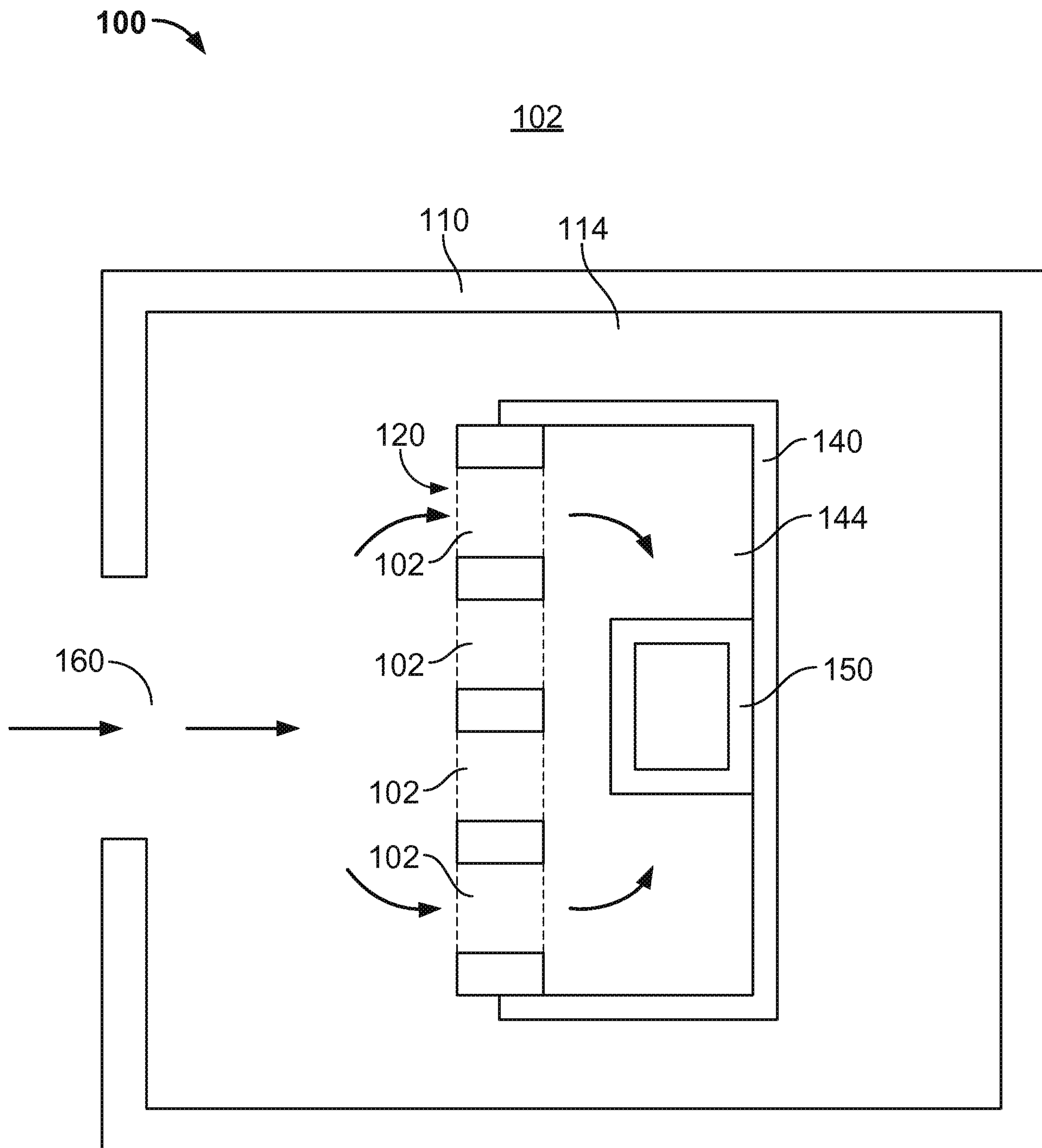


FIG. 2

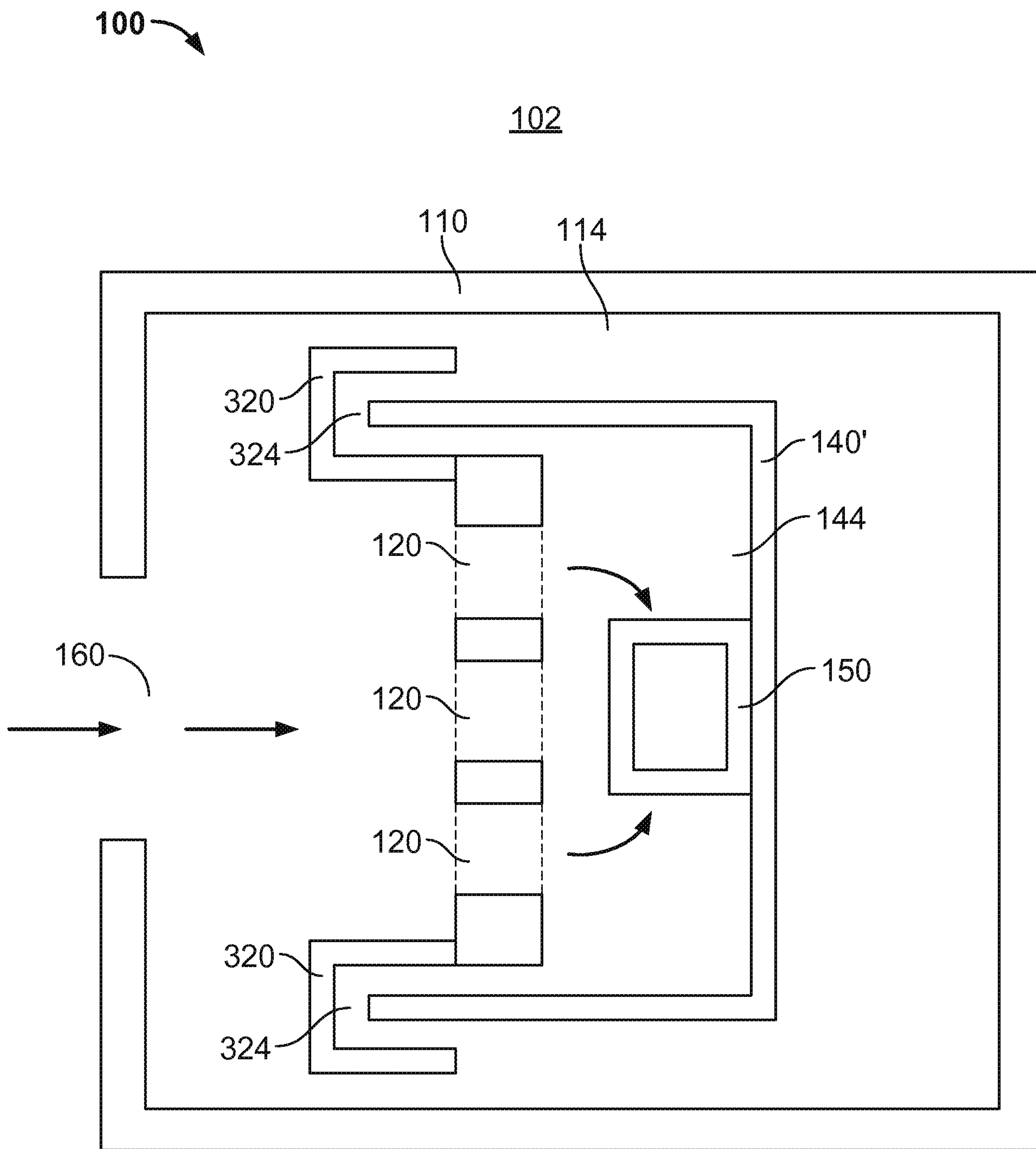


FIG. 3

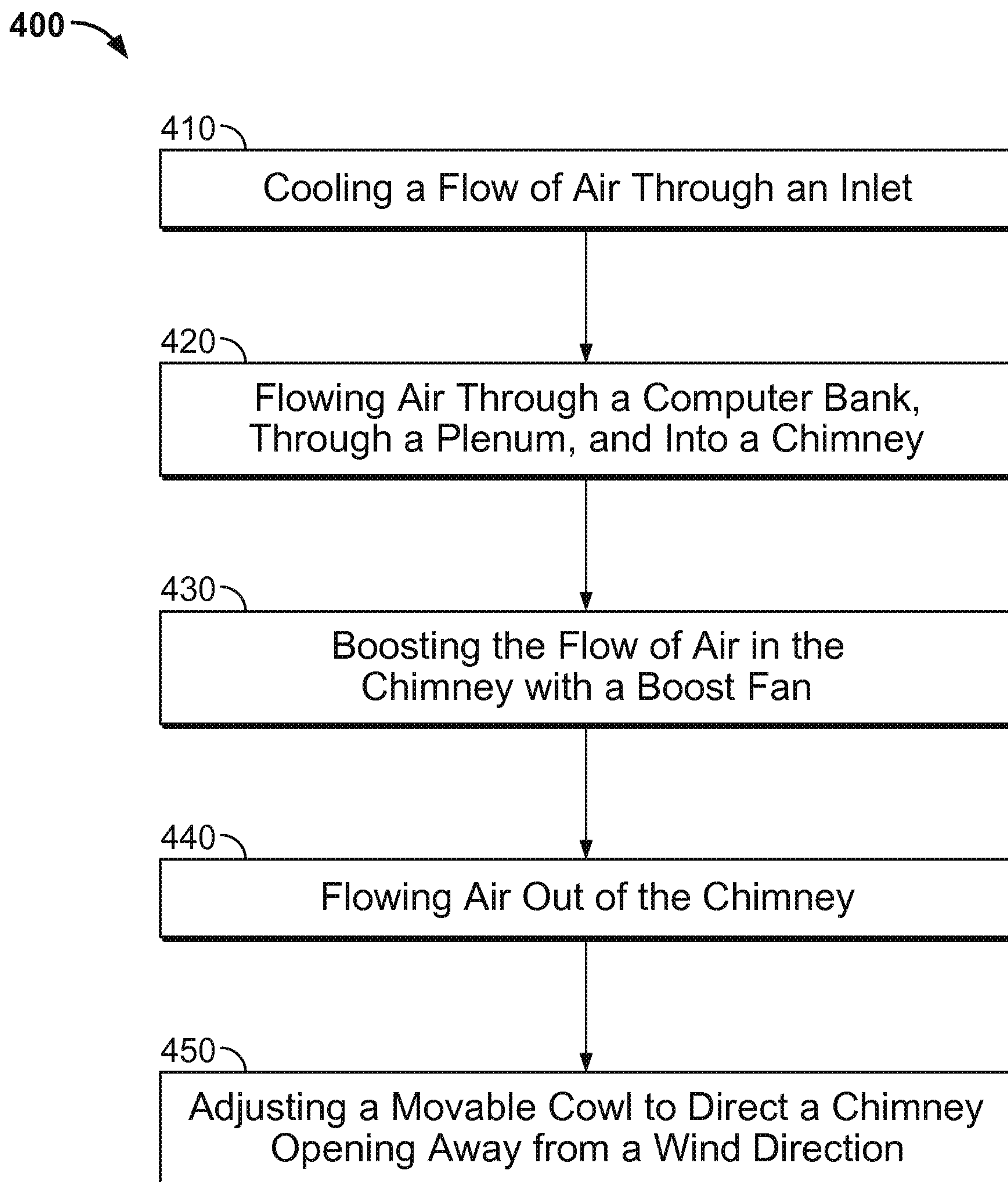


FIG. 4

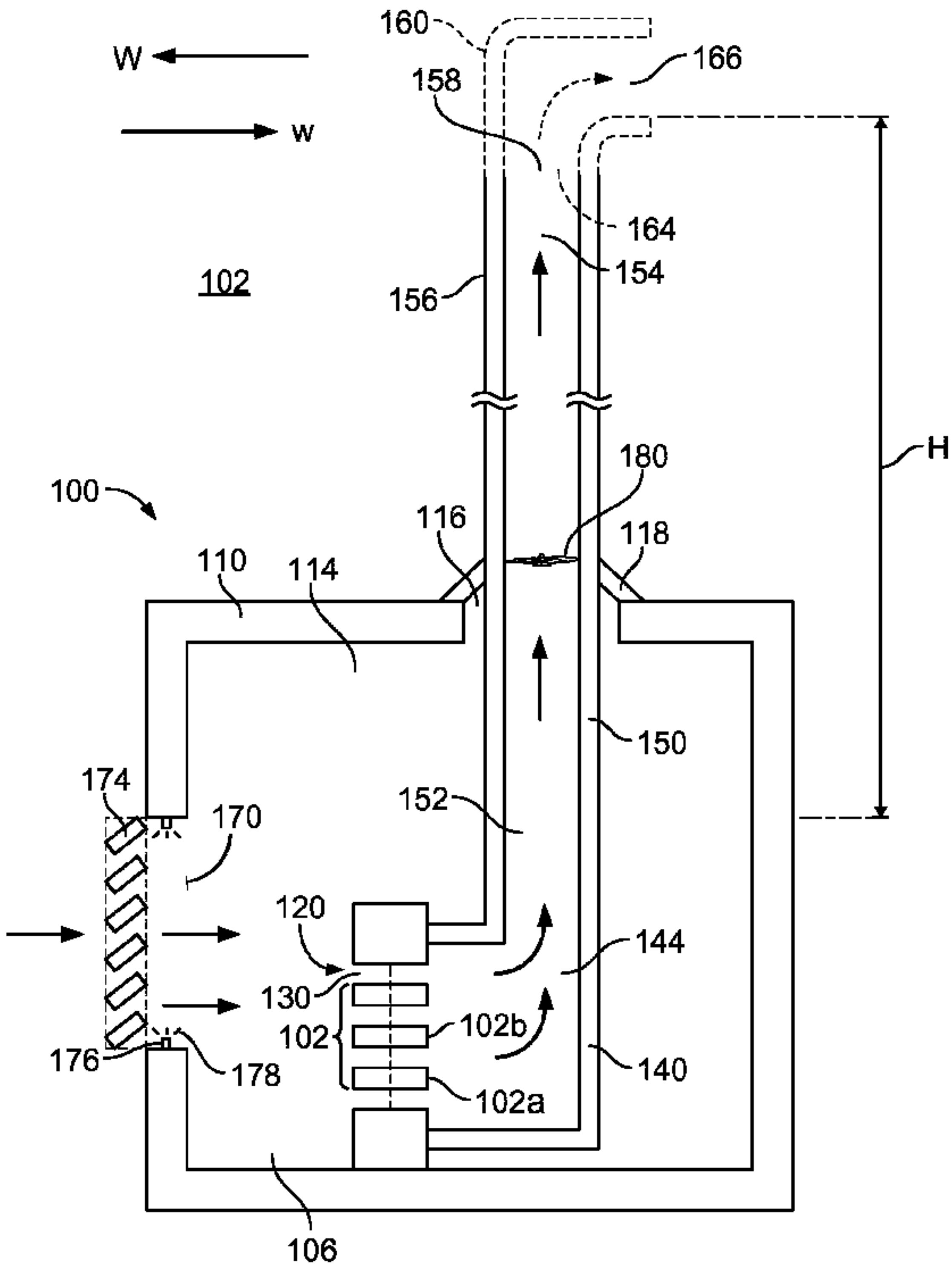


FIG. 1